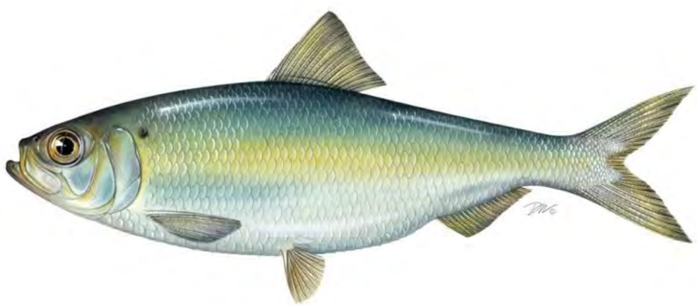
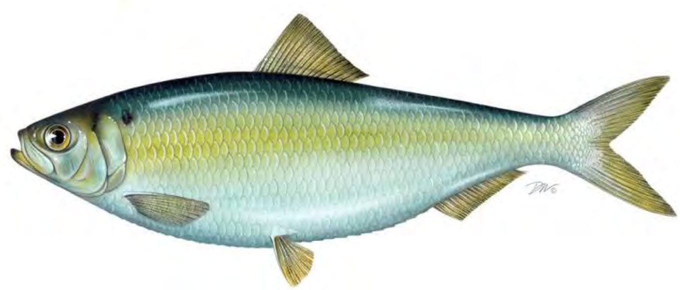
Atlantic States Marine Fisheries Commission

River Herring Stock Assessment Update
Volume II: State-Specific Reports





Vision: Sustainably Managing Atlantic Coastal Fisheries

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5 Status of River Herring in Maine

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Executive Summary

New England has a rich history of fishing and fishermen that capitalized on the abundant fisheries resources available to harvest in the Gulf of Maine. Anadromous fish were among the first species utilized as they ascended rivers and streams on spring spawning migrations. John Pory provided the first written accounts of river herring (alewife and blueback herring) abundance in New England in 1622 (Watts 2003). John Josellyn (1674) further documented accounts of river herring in Maine, then still part of Massachusetts, when describing harvest by two fishermen using stone weirs. Watts (2003) provides verbatim copies of historical documents regarding the importance of river herring in New England back to the 17th century. These texts provide a rich history of the utilization of river herring throughout New England. These historical accounts provide a background for many of the management and social issues related to managing river herring in New England today.

Maine retains some of the last healthy runs of river herring in New England. Maine's directed commercial fisheries are self-sustaining and all operate under sustainable fisheries management plans cooperatively developed between the municipalities that own rights to harvest the river herring resource and the State of Maine. While reported landings of Maine river herring have declined from historical levels in the 1950s. The State of Maine has made significant progress in increasing run size and populations numbers at several locations. Newly established runs in the Kennebec, Sebasticook and Penobscot rivers and Chemo, Pushaw and Webber ponds return an estimated 5.0 million fish that were not in existence during the last coast wide river herring assessment.

5.1 INTRODUCTION

Alewife and blueback herring, collectively known as river herring, are two of eleven species of anadromous fish found in Maine. Anadromous fish spend most of their life at sea and return to freshwater to spawn. River herring historically occurred in all major and minor coastal watersheds in the state (Watts 2003). The majority of adults return as first-time spawners at ages four and five. Spawning can commence as early as mid-April and typically ends by late July. Blueback herring spawn later than alewives and spawning dates are successively later as you move from west to east along Maine's coast.

Watts attributes the earliest declines in these populations to dam construction and industrial pollution, which rendered many waters unsuitable for river herring migration into freshwater spawning and nursery habitats. Protection of spawning populations of alewives began as early as the 1700s. Fish passage requirements at hydroelectric dams, a fishway construction program by the state, and restoration efforts in Maine over the past 30 years have significantly increased the amount of available spawning habitat.

River herring have supported important municipal commercial fisheries since colonial times. Prior to dam construction on the larger river systems, inland towns such as Clinton and Newport on the Sebasticook River, 80 miles inland, had exclusive rights to harvest river herring. Currently, 38 municipalities maintain exclusive rights to harvest river herring. At the January 2017 Board meeting the Atlantic States Marine Fisheries Commission approved sustainable fisheries management plans for 22 municipalities that will continue to fish in 2017. The majority of the harvest is sold as lobster bait, though a small percentage of the landings are smoked and utilized for human consumption.

5.2 MANAGEMENT UNIT DEFINITION

Municipal boundaries are the units used to manage Maine's river herring resources in inland waters. River herring resources that migrate inland, beyond the immediate coastal waters of the state, are property of the municipality. The Maine Department of Marine Resources (DMR) and respective municipality cooperatively manage river herring resource within the management unit. The coastal area outside municipal boundaries is closed to all commercial fishing for river herring by state law.

5.3 REGULATORY HISTORY

5.3.1 Regulation History

As early as 1706, the Town of Middleborough, Massachusetts, passed laws restricting the harvest to those planting corn (Watts 2003). The number of fish allotted for harvest was in direct proportion to the amount of corn a person planted for the season. Those not planting corn were not allotted fish for that year. These early conservations measures indicate the important role river herring held during the colonial period. Through the years several laws were passed, the most significant were those related to upstream passage at the numerous mill dams that existed during that time. In Massachusetts, upstream fish passage laws began as early as 1735. From this point forward, many of the regulations dealt with partitioning the resource among user groups and fishing methods used to harvest fish. Many of these regulations and traditional uses of the resource continue today.

Beginning in 1960 and running through 1987 the State of Maine recommended a one day closed period per week to allow river herring escapement to spawning grounds. Most municipalities, though not all, instituted the one closed day per week. From 1988-1994 the state required that all municipalities have two closed days or a conservation equivalent to ensure spawning escapement. In 1995, the state required three closed days or a conservation equivalent.

5.3.2 Current Regulations

The Department of Marine Resources, along with municipalities granted the exclusive rights to harvest river herring resources, cooperatively manage the municipal fisheries. Each town must submit an annual harvesting plan to DMR for approval that includes a three-day per week escapement period or biological equivalent to insure conservation of the resource. In some instances, an escapement number is calculated and the harvester passes a specific number upstream to meet escapement goals. River herring runs not controlled by a municipality and not approved as sustainable by the ASMFC River Herring and American Shad Management Board are closed to commercial harvest.

Each run and harvest location is unique, either in seasonality, fish composition, or harvesting limitations. Some run specific management plans require continuous escapement and are more restrictive than the three day closed period. Others have closed periods shorter than the three-day requirement, but require an escapement number, irrespective of the number harvested during the season. Maine increased the weekly fishing closure from a 24-hour closure in the 1960s to 48-hour closure beginning in 1988. The closed period increased to 72-hours beginning in 1995 to protect spawning fish (Figure 5.1). Most towns operate a weir at one location on each stream and law prohibits fishing at any other location on the stream. The state landings program compiles in-river landings of river herring from mandatory reports provided by the municipality under each municipal harvest plan or they lose exclusive fishing rights.

The state will permit twenty-two municipalities to fish for river herring in 2017. The river specific management plans require the remaining municipalities to close their runs for conservation and not harvest. There are several reasons for the state/municipal restrictions imposed on these fisheries. Many municipalities voluntarily restrict harvest to increase the numbers of fish that return in subsequent years. Some of these runs are large, but have the potential to become even larger and some suffer from lack of good upstream or downstream fish passage. The commercial fishery does not exploit the estimated 1.5 – 2.0 million river herring that return to the East Machias River or the millions of fish in the main stem of Maine's nine largest rivers.

Recreational fishermen are allowed to fish for river herring year-round but are restricted to four fishing days a week to allow river herring an opportunity to reach spawning habitats. Access to river herring populations for recreational anglers is poor and as a result, landings are low. The three day closed period required for commercial fishermen is also required for recreational anglers. The limit is 25 fish per day and gear is restricted to dip net and hook-and-line. Recreational fishermen may not fish in waters, or in waters upstream, of a municipality that owns fishing rights. Recreational fishermen are not required to report their catch. The MRIP program does sample some of these fishermen based on results queried from the database.

5.3.3 Alewife Fishing Rights (Alewife and Blueback Herring)

The commissioner is authorized to develop, manage, or lease alewife fishing rights as follows.

1) River herring rights: The commissioner shall grant the right, exclusive or otherwise, to take river herring to any municipality entitled to those rights on January 1, 1974 and may grant the right to take river herring to any other municipality provided:

   A. Any municipality that has had the right to take river herring, exclusive or otherwise, or is granted that right by the commissioner, shall take action through its legislative body and file a copy of this action with the commissioner prior to April 20th or lose that right for the remaining part of that year.

   B. Municipal rights in existence on January 1, 1974 which are not exercised for three consecutive years shall lapse.

   C. At its annual meeting the municipality may determine by vote:

(1) Whether river herring fishing will be operated by the municipality through the municipal officers or a committee.

(2) Whether the municipal rights to take river herring will be sold by the municipal officers or committee.

D. Harvesting plans shall be developed as follows.

(1) Any municipality engaged in harvesting river herring shall submit a written harvesting plan to the commissioner prior to April 20th of each calendar year. All harvesting plans shall set forth in detail the exact conditions under which alewives may be taken, all in accordance with good conservation practices.

(2) The commissioner, after consultation with the appropriate municipal officers, shall approve or modify the harvesting plan as he deems necessary for the conservation of river herring and other anadromous fish, and shall file a copy of the approved plan with the clerk of the municipality.

Limitations. The following limitations apply to any grant:

A. It shall be unlawful to take river herring from 6 a.m. each Saturday morning until 6 a.m. Sunday morning. Municipalities which make other provisions for escape of spawning river herring, which are approved by the commissioner, shall be exempt from this limit.

B. It shall be unlawful for any municipality or purchaser or lessee of the municipal right to take river herring in any manner except as provided in the approved river herring harvesting plan.

Closed period in rivers and streams not under lease agreement. In any river or stream not managed under a lease agreement, there is a 72-hour closed period on the taking of river herring and obstruction of the watercourse to allow the free passage of fish from 6 a.m. on Thursday to 6 a.m. the following Sunday.

5.4 ASSESSMENT HISTORY

Maine has not conducted a formal coast wide assessment of its river herring resources. The length of Maine's coastline and number of watersheds that support river herring make a coast wide assessment difficult. Each water body supporting a river herring run is a separate spawning stock with adults homing to natal spawning and rearing locations. Current river herring assessments focus on individual spawning runs and river specific populations and take into account species composition, run timing, and genetic differences among stocks.

River herring assessment data and analysis include annual mortality estimates, passage counts, landings, age at length, repeat spawning and juvenile abundance. Ratios of escapement to returns 4-5 years later provided data to justify an increase or decrease harvest rates and monitor spawning success. Crecco (1990) conducted the most recent ASMFC assessment for the Damariscotta fishery. Crecco determined that the Damariscotta River alewife fishery was severely over fished. Commercial exploitation rates for the fishery ranged from 90 to 98 percent. After this assessment, the Town of Damariscotta closed the fishery for 8 years to rebuild the run. It is unclear what impact the poor condition of the fishway had on escapement and harvest.

The Damariscotta river herring run is the most studied run in Maine. Its proximity to the coast and size of the run provide large numbers of study fish for researchers. Historically the commercial catches of alewives were large compared to most Maine alewife runs. Numerous studies investigated the sex ratio of river herring returns to the fishway, parent-progeny relationships, and efficiency of the fishway for male and female alewives.

Walton's (1987) research investigating the parent-progeny relationship of alewives entering the lake to spawn. His research indicates that the number of spawning females and numbers juvenile emigrants are asymptotically related. Despite the annual variability in estimated egg deposition the numbers of juveniles produced remained relatively constant throughout the eight year study. His conclusion is that the ability of Maine's lakes to produce alewives is finite and that year class strength is established prior to juvenile emigration from spawning habitats

5.5 STOCK SPECIFIC LIFE HISTORY

5.5.1 Alewife

Adults typically enter rivers from early May to early June and swim upstream into lakes, ponds, and dead water habitats to spawn. The temperature range for spawning is 12.8-15.5 °C. Each female produces 60,000-100,000 eggs, depending upon the size of the individual fish. The majority of the surviving spent adults then make their way downstream shortly after spawning. Early spawners can be seen migrating seaward and passing later run spawners that are still migrating upriver. Eggs, which are about 1.3 mm in diameter, hatch in about three days at 22 °C and six days at 15.5 °C. The seaward migration of young generally occurs from mid July through early December at a size range of 32-152 mm. Size at emigration depends upon the availability of feed in the lakes, the total numbers of young produced in a particular watershed, and the length of time the fish remain in the freshwater environment.

There are populations of dwarf anadromous alewives found in eastern Maine. These runs were located in ponds in the Bagaduce River. Two of these runs no longer exist. Walker Pond still has a population of dwarf alewives and their life history does vary from those of typical anadromous alewives in that the juveniles remain in nursery habitat for 16 months compare to the typical 4 months (Walton & Smith 1974).

Little is known about the life history of either alewife or blueback herring after they migrate to sea. Trawl survey data indicate that one and two year olds inhabit the coastal waters of Maine in the spring and fall. Abundance, species composition, and number at length change annually. Survey trawls at most of the 90 survey locations capture one or both of these species (Sherman 2001).

5.5.2 Blueback Herring

Blueback herring spawning requirements differ slightly from those of the alewife. Blueback herring spawn from Nova Scotia to northern Florida, but are most numerous in warmer waters from

Chesapeake Bay south. Females usually reach 100% maturity by age 5 and produce 60,000-103,000 eggs, whereas males generally mature at an earlier age (ages 3-4) and smaller size than females. Once the young-of the-year leave the rivers they over winter near the coast. After the first winter, little information about their migratory or feeding behavior is available.

There is little stock specific life history data available for individual stocks of blueback herring. In Maine, stocks of blueback herring spawn in the main stem rivers and larger tributaries. Spawning occurs in late May through July dependent on water temperature. The commercial alewife fishery does capture some blueback herring during the first week of June but the numbers are low. The occurrence of blueback herring does increase toward the end of the alewife-fishing season and continues to increase after commercial fishermen remove gear from the river. The reopening of the Sebasticook River allowed recolonization of the river in 2008 from the main stem Kennebec River. The Sebasticook River now has a blueback run of over 1-million fish. The East Machias, Orland and St. George rivers have significant blueback populations that are protected under Maines' commercial harvest regulations.

Blueback herring populations in Maine appear to be increasing in the upper regions of Maines watersheds because of fish passage and restoration efforts. The main stem Kennebec and Sebasticook rivers support estimated populations of several million fish. The Department expects this number to grow after upstream passage is installed on the Kennebec River at three additional main stem dams.

5.5.3 Growth

The growth of juvenile alewives is dependent on the nursery and rearing habitat they occupy. Juveniles resulting from stocking pre-spawn alewives, during the same day but at different locations, exhibit different growth rates. This depends largely on the trophic level of the pond and other environmental factors. Juveniles from eutrophic or mesotrophic lakes grow larger than those from oligotrophic lakes within the same watershed. Migration from oligotrophic lakes appears to occur earlier in the season than from mesotrophic or eutrophic lakes.

Dow (1973) indicated growth of adult alewives from cold water estuaries were smaller that those found on warmer water estuaries. Investigations by Roundsefell & Stringer (1943) reported considerable inter-site variation in the size of adult anadromous alewives from different locations in Maine. This is not substantiated by research conducted by Walton & Smith (1974) who reported similar growth parameters and no significant differences in length at age for 21 coastal watersheds in Maine.

The total lengths of adult alewives returning to spawn in the Androscoggin and Sebasticook rivers range from 260 to 330 millimeters. Based on an analysis of scale ages these returns are 3 to 8 year old, though alewives in the statewide commercial fishery are as old as 9-years. The Maine – New Hampshire Trawl Survey captures alewives much smaller than the adults captured during the annual spawning runs. The majority of these alewives are young-of-the-year and consistent with length frequencies of juvenile river herring leaving nursery habitats in the spring. The trawl survey captures a small number of alewives in the 150 to 200 mm range. These fish are assumed 2-year-olds, but this has not been confirmed through scale aging techniques (Figure 5.2).

There is little data on the growth of blueback herring in Maine. Field staff samples few adults during the annual spawning run. The few samples that do occur are limited to individuals captured at the fishway on the Sebasticook River or while sampling commercial alewife runs. The Maine – New Hampshire trawl survey does capture blueback herring during the spring and fall inshore trawl surveys (Figure 5.3)

During the past several years, data collected at the Brunswick Fishway indicate that the mean total lengths of alewives ascending the show no trends (Figure 5.4). Today alewives are as large as alewives captured in non-commercial catches of years past, but year class strength can influence trends in mean length. The Sebasticook alewives show no trend for the same period (Figure 5.5). The downward trends in mean lengths observed in some states are not apparent in Maine data for these two rivers for the past several years.

5.5.4 Fecundity

For both species, age at sexual maturity is primarily ages 4-5 in the northern portion of their ranges. Blueback herring and alewife do show up in spawning runs as young as three years old. Fecundity of individual fish correlates positively to length and age. Alewife produce 60,000-103,000 eggs per season and blueback herring produce a similar amount, 60,000 to 100,000 eggs per season. Older fish are more fecund than younger fish.

5.6 HABITAT DESCRIPTIONS

Habitat requirements for spawning populations of river herring in Maine are specific to each species. Overlap observed in spawning populations of river herring in states to the south do not appear to occur in Maine. Alewife spawning occurs in ponded habitats or slow sections of river systems. Shallow eutrophic and mesotrophic lakes appear to be the best lakes and ponds for alewife spawning. Maine does have a number of oligotrophic lakes that return alewives but the size of the juveniles emigrating from the lake tend to be small and migrations begin early in July.

In contrast, blueback herring spawn in the main channels of tidal fresh water rivers and inland streams and rivers. Typically, blueback herring spawn in fast water below locations where commercial alewife fisheries occur. There are only a few locations in Maine where blueback herring are enumerated upstream of alewife fisheries. The St. George, Kennebec, Sebasticook, East Machias and Orland rivers all support runs of blueback herring.

Access to specific habitat types, flows, or substrate, do not appear more important than access to the suite of habitat types generally found in typical coastal rivers for blueback herring or lakes and ponds for alewife. For several years, the Department documented the effects of habitat loss on the St. Croix River in eastern Maine (Figure 5.6). In 1995, the Maine Legislature passed a law resulting in a unilateral closure of the Woodland Dam and Grand Falls fishways to upstream passage of prespawn alewives into spawning habitat. The Department and Canadian fishery agencies opposed the closure of the St. Croix River based on the existing evidence that alewife caused the collapse of smallmouth bass in Spednec Lake a headpond on the river. The alewife run in the St. Croix River declined significantly and eventually collapsed. In 2000, slightly more than 5,000 fish returned to the river. Canadian fisheries agencies did stock 2,000 fish annually but the return rate was only 0.26 percent of historic levels.

5.7 RESTORATION PROGRAMS

The goal of Maine's river herring restoration activities is to provide access to all habitats that supported river herring historically. Many of these habitats are well inland of the coastal rivers that support the current river herring runs. Access to much of this habitat is still blocked by dams without upstream fish passage and other impediments. The resource agencies are making progress by installing upstream and downstream fish passage facilities, especially in the Sebasticook River watershed and smaller coastal watersheds. A significant restoration project is underway on Outlet Stream in the town of Vassalboro which will restore a run of more than one-million returns. Fish passage or dam removals at five sites on Outlet Stream will provide passage into China Lake a 3,845-acre lake that are expected to add to the growing number of fish in the Sebasticook watershed.

A recent agreement between the Department of Inland Fisheries and Wildlife and the DMR will reopen the fishway into Sheepscot Pond and increase returns to this river by sixty percent. The Sheepscot River restoration project includes one dam removal on the east branch, modification of a dam at head-of-tide to provide passage as well as a fishway into Branch Lake on the west branch.

Starting in 2010 the DMR began restoring river herring to the Penobscot River, Maine's largest river. The trap and transfer program introduced 21,556 pre-spawn river herring from the Kennebec River into three habitats (Chemo, Perch, and Mattamiscontis Ponds) in the Penobscot drainage. This trap and transfer program will continue until sufficient returns to the Penobscot permit transfers of fish from sources within the Penobscot basin. Since the 2010, the Department made significant progress in recolonizing Chemo, Perch, Mattamiscontis and several other lakes and ponds. Pushaw Lake and additional waters are currently under restoration with the goal of initiating a commercial harvest.

In 1965 Maine initiated the restoration of alewives in the St. Croix River when Denil fishways were installed at the Woodland dam (2nd dam) and the Grand Falls dam (3rd dam) on the mainstem river. A fishway previously installed in the Vanceboro dam at the outlet of Spednic Lake in 1963 on the New Brunswick side of the river worked well. However, the poorly functioning fishway on the New Brunswick shore that was operational at the Milltown dam (1st dam) in the 1960's and 1970's was replaced in 1981 with a more efficient Pool and Chute fishway. The alewife run increased dramatically four years after the Milltown fishway became fully functional in 1982 and peaked at 2.6 million fish in 1987. Coincident with the increase in the alewife population, the smallmouth bass fishery in Spednic Lake declined. Following complaints of poor smallmouth bass fishing from local guides and sporting camps at Spednic Lake in Washington County, the Department of Inland Fisheries &Wildlife undertook a cooperative study with the New Brunswick Department of Natural Resources to determine the cause for the decline in the smallmouth bass population. Although it was not possible to establish that the increase in the alewife run affected the smallmouth bass fishery, it was postulated that the large influx of alewives through the Vanceboro Dam, coupled with a lake drawdown of 9-14 feet, may have resulted in loss of young fry bass habitat (Maine Rivers 2006). This also may have increased competition for food and habitat which lead to poor bass fry survival over several successive years (Maine Rivers 2006). In response to the smallmouth bass decline, the St. Croix River Fisheries Steering Committee agreed to block the Vanceboro fishway during the alewife run and requested that Georgia Pacific Company revise its water management plan on the St. Croix watershed in order to minimize the impacts of water drawdown on young bass. Georgia Pacific agreed and closed the Vanceboro fishway beginning in 1988, which has resulted in the collapse of the alewife run in the St. Croix River.

In an effort to reach a compromise, the St. Croix River Fisheries Steering Committee drafted a Memorandum of Understanding that would allow for the controlled escapement of up to 90,000 alewives through the Grand Falls fishway into the waters below West Grand Lake and Spednic Lake. A bill was introduced in the Maine Legislature in 2001 (L.D. 365) that would allow the Woodland and Grand Falls fishways to reopen but the bill was defeated. The Maine signatories did not sign or implement the Memorandum of Understanding. The alewife run in the St. Croix River reached a new low in 2002. Canadian fisheries staff counted only 900 alewives at the Milltown fishway. The Canadian Department of Fisheries and Oceans transported 807 of the 900 alewives to the Woodland headpond in an effort to save the run from extinction.

St Croix Update: In 2013 the Maine Legislature reversed its decision and allowed river herring to pass into a larger portion of the watershed beginning in 2014. The DMR anticipates a positive response in run size within the next decade. The DMR is working with state, federal resource agencies and NGOs to assess the aging fish passage facilities at the Milltowm, Woodland and Grand Falls dams to maximize access to historic spawning habitats on the St. Croix River.

A well-established trap and truck program maintains historic runs that do not have upstream passage until resource agencies achieve permanent passage. The number of river alewife stocked varies based on available habitat and access to broodstock. The annual stocking goal of the restoration projects range from a few hundred fish to 200,000 fish, with most stocked in the Androscoggin and Kennebec watersheds. These locations do not have upstream passage and require transport of spawning fish around existing barriers. The stocking program on the Sebasticook changed in 2009 with the removal of an existing hydropower dam and upstream passage on all dams on the main stem of the Sebasticook. In 2009 stocking numbers dropped by 150,000 fish. During the 2010 stocking season Maine fisheries staff targeted 63 spawning habitats into which 323,180 pre-spawn river herring would be released. The number of stocking programs continues to decline as the number of permanent fish passages increase throughout Maine.

5.7.1 Restoration Objective(s) and/or Targets

Dam construction during the last century isolated many of the inland waters currently stocked with alewives. The historical significance of anadromous fish to these waters was eventually lost, and freshwater fish communities, especially recreationally important game fish, began dominating these habitats. The goal of the DMR restoration program is to recolonize habitat historically available to river herring within the state of Maine and maintain a sustainable commercial and recreational river herring harvest.

The interim restoration-stocking target for inland spawning habitats is six fish per surface acre for inland lakes and ponds locations stocked by truck. The State of Maine established this stocking rate during a 10-year study conducted by MDMR, Maine Department of Environmental Protection and Maine Inland

Fisheries and Wildlife (Kircheis 2002). The goal of the study was to quantify the effects of a spawning population of alewife on the resident fish species and zooplankton community within inland waters. A stocking rate of six fish per surface acre of lake or pond habitat showed no negative effects for growth rates of resident fresh water fish species. The DMR observes this stocking rate for all truck-stocked locations. It is important to note that the initial stocking rate for this study was arbitrary and the stocking density could be higher and still not demonstrate significant negative impacts to resident fish species.

The state manages coastal runs for free passage and does not restrict these waters to the six fish per acre limit. All fishways that provide upstream passage for alewives are free passage, even those that provide access to habitats once stocked by truck. The management threshold for these locations is a return rate of 235 fish per acre with 35 fish per acre escapement into spawning habitat.

The DMR management program for alewives initially focused on providing, or improving, fish passage on smaller coastal drainages. Since 1969, DMR has installed 17 fishways and maintains 19 others from Cumberland to Washington County. It also assists in the operation and maintenance of 12 non-hydro dams owned by other public entities. With the advent of better water quality in the larger river systems, DMR has actively sought installation of fish passage in hydroelectric dams licensed by the Federal Energy Regulatory Commission.

The DMR is actively involved in the restoration of anadromous fish to the Androscoggin and Kennebec rivers. Since 1983 the DMR has operated the vertical slot fishway in the Brunswick dam located at the head-of-tide on the Androscoggin River. The construction of fish lifts at the next two up-stream dams, Pejepscot and Worumbo, allows passage of anadromous fish to Lewiston Falls. The majority of alewife habitat is located in the lakes and ponds in the Sabattus and Little Androscoggin rivers. These ponds are not currently accessible due to FERC licensed hydropower dams without upstream fish passage. The DMR has transported alewives to ponds in these two drainages annually since 1983. The number stocked fluctuates widely over the years and relates to the amount and location of habitat stocked in previous years (Figure 5.7).

The DMR implemented a restoration plan for alewives in the Kennebec River watershed above Augusta in 1986 through an agreement with the majority of hydroelectric dam owners in the watershed. The agreement called for the stocking of alewives in the program’s initial years to build up the population size, with eventual fish passage later. The original agreement was modified in 1998 and incorporated into the Kennebec River Settlement Accord which resulted in the removal of the Edwards Dam in 1999. The new agreement continued funding for the anadromous fish restoration program and established new dates for fish passage. The alewife restoration program in the Kennebec River focused on stocking lakes and ponds in the Sebasticook River watershed and Seven Mile Stream drainage. Many of these habitats now have permanent fish passage and contribute significantly to the river herring runs on the Kennebec and Sebasticook rivers.

Fish passage on the Saco River became available in 1993 when Central Maine Power built fish passage facilities at the Cataract dam located at head-of-tide (dam and passage facilities now owned and operated by Florida Power and Light). The amount of habitat for alewives is limited in the Saco River drainage, but a remnant of the former run continues as the result of a trap and truck effort to the Skelton Dam headpond by the dam's owners. Passage became available at Skelton in 2002 with the installation of an inclined fish lift by Florida Power and Light.

5.7.2 Hatchery Evaluation

There are no hatcheries in Maine raising juvenile river herring for current restoration programs. The high costs of developing and supporting a long-term hatchery program prevent the state from exploring a hatchery program as an option for restoring river herring runs in Maine.

5.7.3 Fish Passage efficiency

The goal for fish passage efficiency at hydropower dams is 100 percent depending on environmental conditions. In reality, many of the upstream fish passage facilities are well below this goal. Upstream efficiency studies are routinely part of FERC licensing requirements and conducted with oversight from the state resource agencies. River herring passage efficiency at state or town owned coastal fishways or those leading into lakes and ponds are not routinely assessed. Run counts and biological data are collected at these sites to assure that these facilities are passing fish and meeting passage goals. In recent years rock-ramp or nature-like fishways have become increasingly popular for passing river herring. Their ability to maintain water levels, aesthetic features and excellent upstream passage make these fishway types a good fit for a number of passage locations.

5.7.4 Trap and transport

State resource agencies use trap and transport to maintain or rebuild extirpated runs along the Maine coast. Trap and transport also provides passage around dams without fishways and enhances runs with poor upstream passage. The trap and transfer programs stock 100,000 to 200,000 fish annually into spawning habitats that do not have upstream fish passage. As the number of upstream fish passages increase the need to truck fish decreases, allowing more time for biological assessment.

5.8 AGE

The maximum age for alewife and blueback herring in Maine is nine years (Libby 1980, Walton 1983). These ages are from river herring captured in commercial fisheries conducted in the 1970s and 1980s and still occur in the commercial fisheries conducted in 2016. Walton and Libby used ageing techniques developed by Marcy 1969, Rothschild 1963, and Norden 1967. As of 2000 in addition to Marcy, Rothschild and Norden fisheries staff also refer to Cating (1950), Marcy (1969), and Rothschild (1963) to determine the age of returning river herring. The method developed by Cating for American shad, may not be suitable for river herring and staff use caution when using the methodology developed by Cating. Maine does not have a reference set of known age fish used to validate scale ages using Cating's method.

5.9 FISHERY DESCRIPTIONS

The predominant Maine river herring fisheries are directed fisheries located at head-of-tide or above. The municipality that owns the fishing rights and the State of Maine manage these fisheries cooperatively. Traditionally the town owning the rights leases the rights to an individual fisherman or hires a fisherman to harvest the run for the town. These fisheries operate under a population and site-specific management plans that maintain and conserve spawning stock biomass.

Commercial fisherman are prohibited from targeting river herring in coastal waters using seines, weirs, gill nets or fish traps. The coastal fisheries for lobster bait ended in 2012 with the AMSFC moratorium on directed fisheries that could not meet sustainability guidelines. Our current knowledge of mixed stocks in coastal waters makes an assessment of the fishery and subsequent determination of sustainability impossible.

There are few recreational anglers fishing for river herring in the state of Maine. Access to most fishable locations are within municipalities that hold exclusive harvest rights. Where recreational anglers have access to river herring the daily limit is 25 fish taken by dip net or rod and reel.

5.9.1 Commercial fisheries

The municipal river herring fisheries conducted in Maine rivers are site specific and all commercial runs are unique in terms of species composition, run size, and harvest location. The harvest methods and local control of these fisheries make comparing the runs difficult. Four municipal commercial runs dominate the commercial landings for the State of Maine. These fisheries occur on small coastal river systems, some with limited spawning and nursery habitat. Despite the unique character of the runs in Maine, commercial catches have declined compared to historic levels of harvest (Figure 5.8)

The commercial harvesters are required to collect biological data from commercial catches. In addition, there is mandatory reporting of annual landings for each commercial fishery operated by a municipality. Funding and personnel limitations do not allow state resource management agencies an opportunity to collect this information. In 2008, MDMR asked all commercial fishermen to voluntarily collect scale samples from the commercial catches to determine the age structure and repeat spawning of fish returning to natal streams. The majority of commercial fishermen did collect samples, but there were some fishermen who did not participate. These data are in the Maine Sustainable Harvest Plan provided to the American shad and River Herring Technical Committee. During the preparation of this plan, additional age data from the 1942 report “Restoration and Management of the New England Alewife Fisheries with Special Reference to Maine” by Rounsfell and Stringer (1943) were discovered.

Libby (1982) sampled the commercial alewife fishery at Damariscotta Lake in 1980 and found that the mean total lengths of alewives during that year for both sexes were larger than those observed today at the Brunswick and Sebasticook river fishways (Table 5.1, 3.2, and 3.3).

Damariscotta Lake

The Damariscotta fishery is one of the most studied in Maine. Local residents built the fishway in 1803 and modified several times over the last 200 years. Modifications to the free stone masonry structure were to repair damage or improve passage and modify holding pools. Still the efficiency of this fishway varied and its ability to pass larger female river herring was studied by Libby (1981). He concluded the male to female ratio of the commercial catch at the base of the fishway, compared to the ratio of alewives entering the lake favored males and directly relates to the efficiency of the fishway and its length. The ratios of males to females entering the lake were as high a 4:1 during the run.

In the early 2000s an assessment of the fishway by the U.S. Fish & Wildlife Service indicated the need to modify and/or repair four sections of the fishway. The 150-meter stone pool and chute fishway that historically passed river herring into spawning habitat at Damariscotta Lake was replaced with a concrete pool and weir fishway. The elevation of the 1,781-hectare lake is 16 meters above mean high tide. A multi-year project commenced to completely rebuild the fishway. The fishway rebuild occurred over four years and the Department observed an immediate improvement in passage efficiency. Since the completion of the project annual runs as high as 1-million fish have ascended the fishway.

Harvesters trap fish in a side channel at the base of the fishway that provides supplemental attraction water. The commercial fishery operates four days a week during the duration of the run and unobstructed upstream passage is available all season. The towns of Newcastle and Nobleboro monitor the numbers of fish entering the lake. The number of fish entering the lake are counted during a ten minute period each hour and expanded to the hours of operation (Figure 5.9).

St. George River

The St. George River fishery is located at head-of-tide in the St. George River. An extensive weir system closes the river to all upstream passage. The weir is not placed in the river until May 15th and after a significant number of fish have passed upstream. The weir operates five days a week and is open 2 days a week to allow upstream passage for spawning fish. Spawning escapement is not monitored, but assumed to be two fifths of the annual run. Due to the expanse of the weir, environmental conditions, especially river flows during the spring, affect the harvest. The weir frequently lifts off bottom and breaches due to accumulated debris on the weir mesh.

Harvesters hold live river herring in a trap at the head of the weir prior to sale. Fish that are not sold can be released alive to continue their migration upstream to spawn. The St. George fishery is one of three fisheries that also include blueback herring. Alewives as old as nine and blueback herring as old as eight were sampled from this fishery in 2016 and regularly produces some of the oldest fish found in any of Maine's river herring runs.

The St. George run remains one of the most intensively fished runs in Maine (Figure 5.10). Seven ponds within the watershed provide spawning and nursery habitat. The amount of habitat available to alewife increased in 2003 with the construction of a rock ramp fishway at Sennebec Lake. Restoration efforts in the watershed continue. The DMR plans to construct upstream passage into several lakes and ponds in the watershed in the future.

Union River

The Town of Ellsworth maintains the Union River fishery by stocking adult alewives above the hydropower dam at head-of-tide. There is no free passage or upstream fish passage facility required at the hydropower station. The FERC license requires transporting river herring around the dam by

Brookfield Renewable, LLC the dam owners. The annual stocking rate (from 2015 forward) is 315,000 fish from the commercial run during the harvest. The Union River is one of three commercially harvested resources with known escapement numbers.

The fishery on the Union River is relatively new and provides a large number of alewives for commercial use, primarily lobster bait (Figure 5.11). The Union River fishery is unique because of known escapement rates. The resource agencies can manipulate these rates and correlated them directly to harvest.to determine the effects of escapement on returns. As with most other directed alewife fisheries in Maine, water flows influence the number of fish that are available to commercial harvesters. This was evident in 2005 when extreme high flows prevented alewives from reaching commercial fishing locations and destroyed commercial fishing gear.

Orland River

The Orland River fishery operates four days a week, allowing a three-day escapement period per week (Figure 5.12). Two Alaska Step Pass fishways provide upstream fish passage into a series of lakes that support spawning. In addition to the alewife run there is a significant blueback herring run that occurs on the Orland River. The commercial harvest ends prior to the majority of these fish reaching spawning locations and escapes the fishery. The fishery occurs at head of tide and like most river herring fisheries, high water and fluctuations in flows affect run timing and strength.

Ocean, Coastal, and In-river Fisheries

For decades, pressure has increased in the coastal zone to catch pelagic fish species as bait for the Maine lobster fishery. Most of the fisheries focused on Atlantic herring or menhaden that could be caught in large numbers with mobile gear. There are no directed river herring fisheries in main stem rivers below head of tide. The same is true in the coastal and ocean regions under the jurisdiction of the State of Maine. There is a strict 5% river herring bycatch tolerance for all vessel participating in these coastal and ocean fisheries and landing in Maine. All fishermen are required to report landings if they have a permit to harvest Atlantic herring and after January 1, 2011 fishermen must purchase a Pelagic License and meet mandatory reporting requirements. For many years the NMFS and State of Maine landings program attempted to record commercial river herring landings in the Atlantic herring fishery and bait gillnet fishery. However, the State of Maine did not require mandatory reporting for these fisheries prior to 2002 (Table 5.4, 3Table 5.5, Table 5.6).

5.9.2 Bycatch Losses

The data collected to determine bycatch losses come from Vessel Trip Reports (VTR) required for all federally permitted fishing vessels. The weight of bycatch is often estimated by fishermen and not an accurate weight or number. There is no means to verify these catch weights or determine the amount of under-reporting or misidentification of species reported.

River herring bycatch occurs in all small mesh fisheries conducted along Maine's coast. Bycatch by weight inside Maine territorial waters among the small mesh otter trawl fisheries is low, based on sea-sample data collected from these fisheries in past years and time of year when these fisheries occur

(Table 5.7 and Table 5.8). The small mesh fisheries with the highest bycatch target whiting and had targeted northern shrimp during the fall and winter respectively. Bycatch is limited to juvenile fish and is small compared to the catch numbers of the target species. The mid-water trawls do catch river herring, though there is not enough observer coverage to determine how much, or where, this bycatch occurs. This is a current concern to many researchers trying to rebuild stocks of Alosines.

5.9.3 Recreational Fisheries

There are not a large number of recreational anglers pursuing river herring in Maine. In Maine there is no survey or mandatory reporting required of recreation fishermen. The MRIP survey does indicate that recreational fishermen fishing for river herring were interviewed while fishing for river herring in Maine. Based on MRIP recreational catches are low with high PSE values.

5.10 FISHERY-INDEPENDENT SURVEYS

5.10.1 Adult Catch Data

Fishery independent adult catch data is limited to biological data collected at three state operated fishways, volunteer efforts to collect biological information because of Amendment 2 and the Maine-New Hampshire Inshore Trawl Survey. State fisheries personnel collect biological samples throughout the run on the Androscoggin, Kennebec and Sebasticook rivers. Data include weight-length, species composition, scale samples, and intermittent gonad weights. In addition to biological data, staff collects run counts, trap and transfer numbers, and species community data. When several species of anadromous fish are present samplers will separate species of river herring and collect sample information.

An increasing number of volunteers and conservation groups are collecting limited data on several non-commercial river herring runs. These data are collected at additional locations to assess changes made to upstream passage facilities, collect biological data to start a commercial fishery, or monitor run size. These changes typically occur at fishways that lead to upstream spawning and nursery habitats. Data collection occurs for one or more years depending on historic data and the need to acquire additional data to assess any changes in these populations.

The Maine-New Hampshire Inshore Trawl Survey provides data from the near shore coastal areas of Maine and New Hampshire to the Massachusetts boarder. The trawl survey occurs semi-annually in the spring and in the fall. The survey samples 90 stations randomized over towable bottom within five survey strata. The time series for the trawl survey is extensive and becomes more valuable as the number of sample points increase. The trawl survey data has supported the last two river herring assessment updates.

5.10.2 Age Composition

Collection of age data occurs at fish passage facilities on the Androscoggin, Kennebec and Sebasticook rivers. Data collection started at the newly constructed Lockwood fishway on the main stem Kennebec River in 2005. Staff collects a limited number of samples annually throughout the duration of these river herring runs. Since 2008, all directed commercial fisheries are required to collect scale samples that provide age and repeat spawning data for each run respectively. In addition, a number of volunteer and conservation groups are collecting scale data on non-commercial runs in hope of restoring these runs.

Age composition for alewives in the commercial catches run from 3 years to 9 years. The majority of the first time spawning fish are 4 to 5 years old and typically make up the majority of the annual run. Blueback herring ages range from 2 years to 8 years old with the majority being 4 to 5 years old fish. Because so few bluebacks are harvested there may be older fish that are not being sampled.

5.10.3 Androscoggin River

Androscoggin River alewife age data exists for most years from 1983 through 2016. The anadromous fish restoration program on the Androscoggin River began in 1983 when Central Maine Power Company constructed upstream fish passage at the head-of-tide. The age structure of returning adult alewives does not appear to change significantly between years. Data collected during the early years of the restoration project are similar to data collected for the past three-year period (Table 5.9).

There is no commercial fishery conducted on the Androscoggin River. However, there are a number of hydropower dams between head-of-tide and spawning and nursery habitat. Three hydropower dams exist on the main stem Androscoggin River and four on the Little Androscoggin River. The role these hydropower stations have on the age structure is unknown, though assumed to significantly impact survival of downstream adult migration.

5.10.4 Sebasticook River

The Sebasticook River is a major tributary to the Kennebec River that historically produced large runs of anadromous fish. Removal of Edwards' Dam at the head-of-tide in Augusta, Maine, in 1999, opened several miles of river to free passage for all anadromous fish species. After removal of Edwards, the Ft. Halifax Dam, located on the Sebasticook River, became an obstacle to upstream passage. Trap and transfer operations moved from Edwards Dam to Ft. Halifax. For a short period, an intense river herring fishery existed below the Ft. Halifax Dam. The fishery peaked in 2005 with several thousand fish harvested, but much of this harvest was unrecorded. The affect of this harvest is apparent in the ages of alewife sampled in 2003 (Table 5.10)

Biological sampling began at Ft. Halifax in 2000. Like the Androscoggin biological data collection, these biological data are a mix of several different stocks of alewives that use the Sebasticook River to access spawning habitat upstream. When fisheries staff collects biological samples, the stock of origin is unknown. These data do provide a reasonable estimate of some biological parameters but may not be representative of a particular run or stock. The dam owner removed Fort Halifax dam in 2008 instead of building a fishway. The Benton Falls hydropower dam located 6 miles upstream of the Fort Halifax site is now the first barrier on the river. There is fish passage at Benton and Burnham that provide upstream passage into a number of spawning habitats upstream. Since 2008 a significant increase in blueback herring and alewife have occurred in the Sebasticook River. Counts in 2016 indicate more than 1-million blueback herring passed upstream.

5.10.5 Juvenile Catch Data

The State of Maine conducts an annual juvenile alosine survey for six Maine rivers including Merrymeeting Bay. This survey samples for all juvenile alosines managed by the state resource agencies. The survey began in 1979, covering 17 fixed stations as well as data from a separate juvenile striped bass survey designed to assess the numbers of juvenile striped bass in the lower Kennebec River. The Juvenile Alosine Survey for the Kennebec/Androscoggin estuary monitors the abundance of juvenile alosines at 14 permanent sampling sites. Four sites are on the upper Kennebec River, three on the Androscoggin River, four on Merrymeeting Bay, one each on the Cathance, Abadagasset, and Eastern rivers. These sites are in the tidal freshwater portion of the estuary. Since 1994, MDMR added six additional sites in the lower salinity-stratified portion of the Kennebec River.

The sampling protocol for all stations is similar to that used in the juvenile shad-sampling program on the Connecticut River. Field staff samples each site once every other week from July to the end of September. The goal is to sample each site six times during the season. Field staff collects samples with a beach seine within three hours of high slack water. The seine is made of 6.35 mm stretch mesh nylon, measures 17 m long and 1.8m deep with a 1.8 m x 1.8 m bag at its center. One person holds an end of the seine stationary at the land/water interface, and the boat operator tows the opposite end perpendicular to shore. After the net fully extends, the boat operator tows the seine in an upriver arc and pulls the net ashore. The net samples an area of approximately 220 m^2. Staff sort and process the catch in the field.

The number of adult blueback herring spawning in Maine rivers is difficult to assess. These fish are limited to the main stems of rivers below the first upstream obstruction, typically a dam. Although some dams do have upstream passage facilities, blueback herring are reluctant to use these passages. Blueback herring rarely use the Brunswick fishway, though fishway staff observes large numbers of blueback herring spawning directly below the fishway in the tailrace.

The survey does not do as good a job of indicting the spawning success of alewife. Little if any spawning occurs in Merrymeeting Bay or the lower portion of Maine tidal rivers. Alewives are likely captured in the bay as they rest and feed along their downstream migration routes. A number of environmental factors may influence number of alewives in the bay at a given time. High water levels that facilitate downstream passage and colder water temperatures, believed to trigger downstream migration, may increase the number of juveniles in the bay at a given time.

5.11 ASSESSMENT APPROACH(S) AND RESULTS

Little formal assessment of any of Maine's river herring resources have occurred during the past several decades. Crecco and Gibson (1990) did conduct a formal assessment of the Damariscotta Lake run and indicated that the run was severely over fished. Crecco used the Shepherd Stock Recruitment model to estimate maximum sustainable yield, annual fishing rate at MSY, and project harvest levels that would cause collapse of the fishery. Crecco concluded that the Damariscotta run was harvested at levels that indicated stock recruitment failure was apparent.

Maine and ASMFC fisheries staff completed a comprehensive, though less detailed, assessment of several Maine river herring runs in 2010 and 2015 to meet the Amendment 2 to the American Shad and River Herring Plan. These analyzes used a number of biological datasets, harvest rates, and escapement rates to estimate population size and composition for each commercial and some non-commercial river herring runs in Maine. For most commercial fisheries the biological datasets are short, beginning in 2008 through the present. Reported harvest and estimated escapement provide a longer time series of data, many runs having data through the 1950s.

5.11.1 Spawning Stock

Data from adult fisheries independent surveys indicate that the number and weights of alewife are trending upward or are stable for the past several years (Figure 5.13 and 3Figure 5.14). The trends of blueback herring in the survey indicate variable catch numbers and catch weights during the past several years with no apparent trend (Figure 5.15 andFigure 5.16).

5.11.2 Trends in Age

Analysis of alewife scale samples collected from the Androscoggin and Sebasticook rivers indicates that returning fish are most often 4-5 years old. Blueback herring are predominately 3 to 5 years old. The numbers of river herring older than six years represent a small proportion of the adults sampled. This is an apparent shift in the age structure for all Maine river herring runs, commercial and non-commercial from the mid 1980s, but similar to length data collected in the 1940s. Scale samples collected from 15 commercial fisheries in 2008 had few river herring over 6 years of age. While commercial catches in the 1980s commonly had fish as old as 8 years of age. Since 2010 larger number of older fish do appear in the samples collected, but still remain a small percentage of the fish sampled.

5.11.3 Juvenile Stock

Results of the annual juvenile alosine survey indicate that annual production of alewife and blueback herring within the sample area and migration timing through the sites vary widely year-to-year (Table 5.11 and Table 5.12; Figure 5.17 andFigure 5.18). Prior to 1992, the number of blueback herring captured were low and sporadic, occurring only occasionally during the sample season. The survey time series for both species does indicate a stable or slightly increasing population. The juvenile survey results are a better indication of annual blueback herring spawning success.

5.12 BENCHMARKS

There are no previous benchmarks established for the Maine river herring fisheries other than Crecco's estimation of Z (3.22), u (0.891), and F (2.20) for the Damariscotta fishery in the 1970s. Estimates of Z for most of the river herring fisheries are not as high as the value Crecco observed in the 1970s.

5.12.1 Total Mortality

Prior to 2008, limited biological data were collected from the Maine municipal river herring fisheries. However, researchers did collect data during studies conducted at Damariscotta Lake in the late 1970s. Currently DMR staff collects age data on the Androscoggin, Kennebec and Sebasticook rivers while monitoring upstream fish passage. These data are used to calculate the total mortality (Z) for alewife runs from these rivers, with total mortality calculated separately by sex for each year and river system.

Since the inception of Amendment 2 in 2008, DMR has requested that commercial harvesters, volunteer and conservation groups collect scale samples from commercial and non-commercial river herring runs along the Maine coast. In 2016 harvesters and conservation groups collected scale samples from 33 runs. Commercial fishing occurs on some runs while others remain closed for conservation or were not fished within the past five years.

The DMR asked harvesters and others to collect samples from 25 fish every week during the duration of the run. Most harvesters fishing commercial runs were able to provide the number of scale samples requested. Commercial harvesters also volunteered to provide coverage at locations that are temporarily closed or have been closed for several years. The number of scale samples collected from runs that are temporarily closed, or closed for more than five years, were typically less than the number requested (Table 5.13).

Commercial river herring fisherman began collecting scale samples from catches of river herring returning to natal rivers to spawn. These samples provide a basis to estimate total mortality for all the runs fished in Maine. Fisherman continue to collect scale samples under the direction of the DMR and as part of the municipal harvest plans. In addition, a number of volunteer and conservation groups have collected data from non-commercial streams.

Calculation of total mortality estimates occurred for all runs regardless of the number of samples collected. All sample locations that had corresponding sex data are included in the combined Z-estimates in each figure. Heinke and Chapman-Robson methods were used to obtain Z-estimates. We used these methods because of the limitations of the number of age data classes that the Catch-Curve method requires for the analysis (Figure 5.25, Figure 5.26, Figure 5.27, and Figure 5.28).

The Department explored several methods to estimate Z, including Catch Curve, Heinecke, and Chapman-Robson. Each of these has advantages when working with limited data sets. The Catch Curve was most restrictive, needing a number of age-classes in order to conduct the analysis. The Chapman-Robson method addresses biases present in the Catch Curve analysis and is used as a standard in the 2015 update.

Age data analyzed from scale samples collected since the inception of the Sebasticook River run reflect, in part, the high fishing pressure exerted on this population from 2002 through 2005 (Figure 5.19, Figure 5.20) Fishing regulations allowed unrestricted access to these fisheries resources during this period. DMR assumed management of this resource from the Department of Inland Fisheries and Wildlife in 2007. Limited commercial fishing started in 2009 on the Sebasticook River after fishing rights were transferred to the Town of Benton. The annual mortality estimates for males and females differ at this location. The reasons for these differences are not clear. The Sebasticook River was a source of broodstock for a number of restoration projects east of the Kennebec River, but with increased passage these fish are no longer needed as brood stock. The Sebasticook River run ranges between 2.5 and 3.5 million fish annually and comprised of both alewife and blueback herring..

The age data presented in this analysis are from scale samples collected at the Brunswick Fishway since it opened in 1983. Much of the raw data are no longer available for analysis, but all available data contributed in calculating the Z-estimates (Figure 5.21 andFigure 5.22). Trend lines fitted to the male Z-estimates were flat for the years of data that were available and the Z-estimates for females indicated a slight upward trend. The Androscoggin River alewife run is small compared to the Sebasticook run. The annual run averages 52,000 individuals. There is not a commercial fishery on the Androscoggin River.

Z-estimates calculated using the Beverton-Holt model were compared to the Catch-Curve, Heinke, and Chapman-Robson models. The Beverton-Holt trends are similar for the Androscoggin and Sebasticook rivers, and indicate decreasing Z-estimates for both sexes of alewives for the period 2010 – 2016 (Figure 5.23 andFigure 5.24).

5.13 CONCLUSIONS AND RECOMMENDATIONS

Maine commercial river herring landings are down when compared to levels of reported harvest in the 1950s though commercial river herring landings are not an accurate measure of Maine's current river herring stocks. The majority of the river herring fisheries in Maine are closed to directed commercial harvest as a conservation measure. River herring in the main stem of nine of the state's nine largest rivers are not exploited by commercial fishermen.

The directed commercial fisheries at some locations have declined but the causes for the declining landings are not clear. These declines are likely the cause of a number of factors including environmental conditions, bycatch, habitat degradation, predation, and lack of adequate upstream and downstream fish passage. The same trends appear at locations where the stock is not commercially fished. Currently all directed fisheries continue to maintain self-sustaining fisheries for river specific stocks.

Bycatch of juvenile river herring in coastal waters appears to have decreased during the past several years. This decrease in catch is a combination of eliminating directed river herring in the coastal areas and bycatch in other small mesh fisheries inside and outside three-miles of Maine's coast. Bycatch and directed river herring landings are self-reported and may not accurately reflect the number river herring captured or discarded. In 2011, a commercial fishing license is required for anyone who fishes for any pelagic species using any gear type. This license creates a database of small mesh gear fisherman for a proposed bycatch sampling program in Maine coastal waters. The bycatch sampling program will focus on Alosines, alewife, blueback herring, and American shad captured as bycatch in the Atlantic herring, Atlantic Mackerel, and Atlantic menhaden fishery.

The DMR maintains a number of non-commercial runs through stocking while the state resource agencies pursue upstream and downstream passage into historic spawning habitats. None of the directed fisheries are stocked with spawning fish and all are expected to maintain self-sustaining populations through implementation of their management plans. Management of directed river herring fisheries in Maine incorporate management actions to conserve populations of spawning fish through gear restrictions, closed seasons, and fishing area closures. These management actions are enforced though the Maine Marine Patrol and law enforcement action at the local level. Management plans exist for all municipally owned directed fisheries, each approved by DMR.

During the 2016 fishing season fisheries staff monitored the majority of the directed fisheries and collected biological data. These data provide information for a comprehensive stock assessment for runs that are actively fish and affected by directed fishing effort. Biological data collection is difficult because of the geographic area over which these fisheries occur, the number of fishing locations and limited personnel resources. Increased sampling is important to effectively manage the existing resources and assess the effectiveness of current management actions.

The limited data that are available indicate that the current population of river herring in Maine is stable at current level and in some instances increasing. Mortality estimates for the Androscoggin and Sebasticook rivers are lower than those calculated by Crecco in the 1980s. Juvenile index survey data indicate increasing populations of blueback and alewife in Merrymeeting Bay. Analysis of mean length and weight data indicate variable trends in weights and lengths at those locations where sampling does occur.

5.13.1 Recommendations

1. Increase sampling of stock specific runs that support directed commercial fisheries.
2. Increase upstream and downstream fish passage into historical spawning and nursery habitats.
3. Quantify bycatch of river herring in ocean fisheries, especially within three miles of the coast.

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Table 5.1 Mean Total Lengths of Fishery Dependent Catches at the Damariscotta Fishway

Date	Number Sampled	Mean Total Length (mm)			
		Males	SE	Females	SE
5/6/1980	50	305.5	1.7	316.2	2.2
5/8/1980	50	300.4	1.8	316.6	1.6
5/12/1980	50	305.2	1.7	310.2	2.0
5/14/1980	50	304.1	1.6	315.4	2.3
5/16/1980	37	304.4	1.6	312.9	2.2
5/18/1980	50	301.6	1.8	308.5	1.6
5/20/1980	50	299.9	1.5	311.0	1.4
5/22/1980	50	302.0	1.4	309.0	1.8
5/24/1980	50	292.7	1.8	302.0	1.7
5/26/1980	50	299.3	1.5	308.3	1.8
5/28/1980	50	296.3	1.7	305.9	2.5
5/30/1980	50	295.7	1.7	304.2	1.8
6/1/1980	45	298.0	1.9	307.7	2.2
6/3/1980	44	293.4	2.2	307.2	2.3
6/5/1980	35	299.0	2.7	305.3	2.4

Table 5.2 Mean Total Lengths of Fishery Independent Catches at the Brunswick Fishway.

Date	Number Sampled	Mean Total Length (mm)			
		Males	SE	Females	SE
5/13/2008	50	268.1		287.1	
5/17/2008	50	270.6		281.4	
5/21/2008	50	256.0		267.7	
6/4/2008	50	267.9		279.0	

Date	Number Sampled	Mean Total Length (mm)			
		Males	SE	Females	SE
5/12/82016	50	289.8		303.4	
5/18/2016	50	278.4		285.2	
5/25/2106	50	282.4		280.6	
6/1/2016	50	271.0		280.1	

Table 5.3 Mean Total Lengths of Fishery Independent Catches at the Sebasticook Fishway.

		Mean Total Length (mm)			
Date	Number Sampled	Males	SE	Females	SE
5/9/2007	100	282.1		290.2	
5/13/2007	100	267.5		280.9	
5/14/2007	100	277.2		281.5	
5/16/2007	100	278.9		282.6	
5/21/2007	100	276.6		287.4	
5/24/2007	100	273.8		278.6	
5/26/2007	100	265.3		274.4	
5/28/2007	100	271.7		277.8	
6/6/2007	98	255.3		266.2	

Table 5.4 Combined Direct and Non-Direct Ocean, Coastal, In-River Alewife Harvest.

Ocean / Coastal Commercial Harvest (Kg)

	Gill net			Weir			Pound/Trap net		
	N	Total weight	Mean weight	N	Total weight	Mean weight	N	Total weight	Mean weight
2002	22	1,887	86	1	5	10		0	
2003	22	2,754	125		0		2	23	11
2004	30	5,599	187	1	9,923	9,923	5	68	14
2005	32	1,194	37	12	1,580	132		0	
2006	20	591	30	1	9,450	9,450	30	3,771	126
2007	30	254	8	1	0	0	1	3	3
2008	56	66	1		0		20	3,464	173
2009	37	617	17		0		36	4,526	126
2010	32	986	31				18	4,382	243
2011	1	213	213	1	145,640	145,640	10	435,874	43,587
2012	0	0	0	1	126,150	126,150	10	633,692	63,369
2013	2	513	257	1	70,100	70,100	2	17,220	8,610
2014	0	0	0	1	175,840	175,840	11	440,910	40,083
2015*	1	6	6	1	44,600	44,600	2	63,998	31,999

*preliminary data

	Unknown Gear Type			Other Gear(cast net, dip net)			Total		
	N	Total weight	Mean weight	N	Total weight	Mean weight	N	Total weight	Mean weight
2002		9			0		23	1,900	83
2003		149			0		24	2,925	122
2004		106		6	250	93	42	15,945	380
2005		35			0		44	2,808	64
2006		62		14	253	40	65	14,127	217
2007		81			0		32	4,349	136
2008		0		33	5,724	173	109	9,254	85
2009		0		1	315	700	74	5,457	74
2010		0		12	358,661	29,888	62	364,084	5,872
2011		0		16	740,635	46,290	28	1,322,438	47,230
2012		0		1	6	0	12	759,848	63,321
2013		0		23	851,191	37,008	28	941,354	33,620
2014		0		17	673,433	39,614	29	1,290,183	44,489
2015*		0		10	255,934	25,593	14	445,573	31,827

*preliminary data

Table 5.5 Direct and Non-Direct Ocean / Coastal Blueback Herring Harvest.

Blueback Herring Ocean / Coastal Commercial Harvest (Kg)

	Gill net			Weir			Pound/Trap net		
	N	Total weight	Mean weight	N	Total weight	Mean weight	N	Total weight	Mean weight
2002	22	0	0	5	450	90	5	275	55
2003	22	203	9				30	1,024	34
2004	30	135	5				12	464	39
2005	32	101	3				20	662	33
2006	20	149	7				16	640	40
2007	30	596	20	6	262	44	23	3,066	133
2008	56	2,091	37	3	1,329	443	18	195	11
2009	37	435	12	2	124	62	38	6,590	173
2010	32						26	26,470	1,018
2011	0	0	0	1	36,660	36,660	5	17,983	3,597
2012	0	0	0	1	42,050	42,050	3	1,931	644
2013	0	0	0	1	73,600	73,600	1	690	690
2014	0	0	0	1	43,960	43,960	2	81	41
2015*	0	0	0	1	133,800	133,800	0	0	0

*preliminary data

	Otter Trawl			Other Gear(cast net, dip net)			Total		
	N	Total weight	Mean weight	N	Total weight	Mean weight	N	Total weight	Mean weight
2002	3	203	68		295		35	1,223	35
2003		0					52	1,226	24
2004		0					42	599	14
2005		0					52	763	15
2006	3	2,093	698		2,109		39	4,990	128
2007							59	3,924	67
2008							77	3,615	47
2009							77	7,149	93
2010							58	26,470	456
2011	0	0	0	0	0	0	6	54,643	9,107
2012	0	0	0	0	0	0	4	43,981	10,995
2013	0	0	0	4	1,899	475	6	76,189	12,698
2014	1	9	9	0	0	0	4	44,050	11,013
2015*	0	0	0	0	0	0	1	133,800	133,800

*preliminary data

Table 5.6 Bait Gill Net Permit Holders and Active Participants.

	Bait Gill Net Fishery				
	Permit Holders	Active Permits	Number of Nets	Sq. Yards of Net	Hours Fished
2002	92	22	unknown	unknown	unlimited
2003	340	22	unknown	unknown	unlimited
2004	286	30	unknown	unknown	unlimited
2005	284	32	unknown	unknown	unlimited
2006	258	20	unknown	unknown	unlimited
2007	299	30	unknown	unknown	unlimited
2008	370	56	unknown	unknown	unlimited
2009	378	37	unknown	unknown	unlimited
2010	269	-	unknown	unknown	unlimited
2011	283	1	unknown	unknown	unlimited
2012	259	-	unknown	unknown	unlimited
2013	222	2	unknown	unknown	unlimited
2014	189	-	unknown	unknown	unlimited
2015	173	1	unknown	unknown	unlimited

In 2011 the Bait Gill Net Permit was discontinued and replaced with the Pelagic Fisheries license. Any individual that catches pelagic species in state waters waters is required to purchase this license and report landings. Bait Gill Net fishermen are required to report under the new Pelagic License.

Table 5.7 Alewife Bycatch Maine Otter Trawl Fisheries.

Alewife Bycatch in Otter Trawl Fisheries (VTR data)

Year	Total Effort Effort (hours fished)	Total Catch Reported (Kg)	CPUE hours fished
2002	52	9	0.2
2003	200	150	0.7
2004	228	107	0.5
2005	195	35	0.2
2006	242	62	0.3
2007	305	0	0.0
2008	108	0	0.0
2009	165	0	0.0
2010	24	0	0.0
2011	19.16	0	0.0
2012	11.74	0	0.0
2013	23.97	0	0.0
2014	0	0	0.0
2015*	0	0	0.0

* Preliminary data

Table 5.8 Blueback Herring Bycatch Maine Otter Trawl Fisheries.

Blueback Herring Bycatch in Otter Trawl Fisheries (VTR data)

Year	Total Effort (hours fished)	Total Catch Reported (Kg)	CPUE (hours fished)
2002	3	293	250.0
2003	0	0	0
2004	0	0	0
2005	3	1	0.8
2006	6	2,093	775.0
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0
2012	0	0	0
2013	0	0	0
2014	0	0	0
2015*	0	0	0

*Preliminary data

Table 5.9 Alewife Age Structure from Samples Collected at the Brunswick Fishway.

Androscoggin River - Brunswick Fishway

	2016		2015		2014		1995		1994		1993	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
Age 3	13	12			4	2	3	2	0	0	33	6
Age 4	66	47			23	9	36	38	48	45	19	12
Age 5	30	20			2	8	6	26	25	20	14	7
Age 6	9	2			0	2	0	11	1	2	4	7
Age 7	1	2			0	0	0	0	0	1	1	1

Table 5.10 Alewife Age Structure from Samples Collected at the Ft. Halifax and Benton Fishways.

Sebasticook River - Ft. Halifax Fishway

	2016		2015		2014		2003		2002		2001	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
Age 3			8	1	0	2	42	34	21	15	6	0
Age 4			23	20	8	14	20	26	65	53	65	44
Age 5			6	4	6	5	8	11	29	28	21	10
Age 6			0	1	3	3	0	0	6	4	3	2
Age 7			0	0	0	1	0	0	0	0	2	0

Table 5.11 Juvenile Alosine Survey - Alewife.

Alewife

			Arithmetic Mean		Geometric Mean		
Year	**Sample Size**	**Total Catch**	**Mean**	**SE**	**Mean**	**LCI**	**UCI**
1979	45	197	4.38	14.05	4.51	0.64	17.50
1980	57	338	5.93	6.56	1.64	0.48	3.70
1981	58	153	2.64	2.95	0.74	0.17	1.59
1982	59	137	2.32	5.72	0.90	0.12	2.22
1983	53	5,309	100.17	39.97	3.18	1.53	5.91
1984	45	696	15.47	5.31	0.94	0.40	1.70
1985	42	287	6.83	2.38	0.89	0.40	1.55
1986	62	404	6.52	1.52	1.43	0.84	2.21
1987	60	1,294	21.57	5.38	2.33	1.33	3.74
1988	100	2,200	22.00	8.47	2.11	1.33	3.16
1989	92	1,741	18.92	4.40	2.46	1.51	3.76
1990	98	2,047	20.89	9.07	1.57	0.90	2.49
1991	88	3,979	45.22	27.32	2.40	1.34	3.94
1992	79	3,123	39.53	15.05	2.85	1.57	4.78
1993	76	1,386	18.24	6.12	2.16	1.17	3.60
1994	93	667	7.17	1.70	1.80	1.16	2.63
1995	110	3,351	30.46	8.54	4.43	2.89	6.56
1996	89	1,150	12.92	4.37	1.38	0.75	2.22
1997	110	1,754	15.95	5.50	1.79	1.10	2.72
1998	112	1,565	13.97	9.45	1.04	0.60	1.60
1999	108	4,325	40.05	13.96	2.44	1.44	3.87
2000	111	20,885	188.15	53.83	5.64	3.30	9.25
2001	129	2,344	18.17	5.36	1.47	0.88	2.24
2002	127	1,430	11.26	2.94	1.75	1.14	2.54
2003	114	4,664	40.91	16.29	2.34	1.42	3.62
2004	105	2,769	26.37	7.71	3.45	2.18	5.22
2005	112	1,238	11.05	3.45	1.17	0.67	1.82
2006	120	3,795	31.63	11.83	1.88	1.06	3.03
2007	119	1,211	10.18	3.41	1.24	0.72	1.92
2008	104	1,267	12.18	3.97	1.02	0.55	1.62
2009	111	857	7.72	2.10	1.39	0.86	2.06
2010	114	3,889	35.04	19.77	2.03	1.23	3.11
2011	117	1,338	12.05	3.92	1.19	0.69	1.83
2012	118	2,521	22.71	14.89	1.01	0.56	1.59
2013	120	4,087	36.82	19.10	1.71	1.01	2.65
2014	120	2,055	18.51	5.77	1.47	0.85	2.28
2015	112	3,502	31.55	7.55	3.55	2.26	5.34

Table 5.12 Juvenile Alosine Survey – Blueback Herring

Blueback Herring

			Arithmetic		Geometric		
Year	**Sample Size**	**Total Catch**	**Mean**	**SE**	**Mean**	**LCI**	**UCI**
1979	45	0	0.00	0.00	0.00	0.00	0.00
1980	57	1	0.02	0.04	0.01	-0.02	0.03
1981	58	31	0.53	0.50	0.08	-0.06	0.25
1982	59	0	0.00	0.00	0.00	0.00	0.00
1983	53	0	0.00	0.00	0.00	0.00	0.00
1984	45	0	0.00	0.00	0.00	0.00	0.00
1985	42	0	0.00	0.00	0.00	0.00	0.00
1986	62	0	0.00	0.00	0.00	0.00	0.00
1987	60	25	0.42	0.26	0.05	-0.02	0.13
1988	100	13	0.13	0.10	0.03	-0.02	0.08
1989	92	9	0.10	0.07	0.03	-0.01	0.07
1990	98	4	0.04	0.03	0.02	-0.01	0.05
1991	88	0	0.00	0.00	0.00	0.00	0.00
1992	79	1,079	13.66	7.48	0.58	0.20	1.09
1993	76	47	0.62	0.62	0.05	-0.05	0.16
1994	93	289	3.11	1.32	0.38	0.15	0.66
1995	110	1,402	12.75	3.18	1.99	1.23	3.01
1996	93	620	6.67	5.93	0.30	0.09	0.55
1997	110	598	5.44	3.79	0.49	0.24	0.79
1998	112	562	5.02	2.07	0.69	0.38	1.08
1999	108	982	9.09	3.50	0.73	0.35	1.21
2000	111	1,086	9.78	9.46	0.15	-0.01	0.32
2001	129	273	2.12	0.90	0.30	0.13	0.50
2002	127	1,489	11.72	4.22	1.00	0.56	1.56
2003	114	1,697	14.89	7.79	0.90	0.47	1.44
2004	105	3,020	28.76	8.33	1.69	0.91	2.80
2005	112	1,526	13.63	5.71	0.65	0.29	1.11
2006	110	2,541	23.10	14.86	0.68	0.30	1.16
2007	113	1,218	10.78	7.80	0.48	0.21	0.82
2008	104	244	2.35	1.21	0.37	0.17	0.60
2009	111	66	0.69	0.37	0.15	0.05	0.27
2010	114	122	1.07	0.49	0.27	0.12	0.43
2011	117	184	1.57	0.60	0.29	0.12	0.49
2012	118	305	2.58	1.78	0.26	0.09	0.45
2013	120	331	2.76	1.04	0.46	0.23	0.74
2014	120	1,355	11.29	5.13	0.57	0.25	0.98
2015	112	51	0.46	0.25	0.14	0.04	0.24

Table 5.13 Alewife Run Locations Where Commercial Harvesters Collected Scales for Aging in 2008, 2010, 2016.

Run Location	**Commercial Fishery**	**2008**	**2010**	**2016**
Saco River	N		X	
Presumpscot River	N		X	X
Winnegance Lake	Y		X	X
Dresden Mills	Y	X	X	X
Sewall Pond	N	X	X	X
Nequassett Lake	y	X	X	X
Androscoggin	N	X	X	X
Vassalboro	Y		X	X
Benton	Y		X	X
Sheepscot River	Y		X	X
Dyer River	Y		X	X
Damariscotta River	Y		X	X
Medomak River	N		X	X
Warren	Y		X	X
Souadabscook River	N		X	
Chemo Pond	N		X	X
Orland	Y		X	X
Union River	Y		X	X
Wights Pond	N			X
Pierce Pond	N			X
Walker Pond	N			X
Somes Pond	N		X	X
Seal Cove Pond	N			X
Grist Mill Stream	Y	X	X	X
Flanders Stream	Y	X		X
Patten Pond	Y	X	X	X
Card Mill Stream	N	X		X
Gouldsboro	Y	X	X	X
Pembroke	Y		X	X
Cherryfield	Y		X	X
Pleasant River	N			X
East Machias	Y		X	X
Crawford Lake	N			X
Dennysville	N		X	X
Pembroke	N			X
Perry	Y		X	X
St. Croix River	N			X

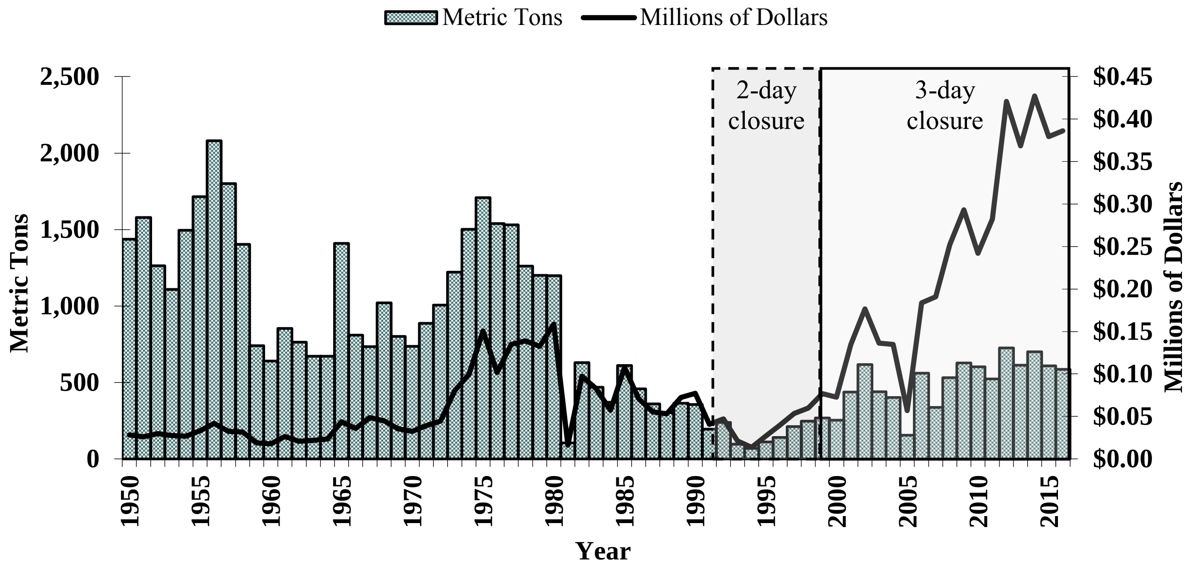

Figure 5.1 State of Maine Alewife Landings.

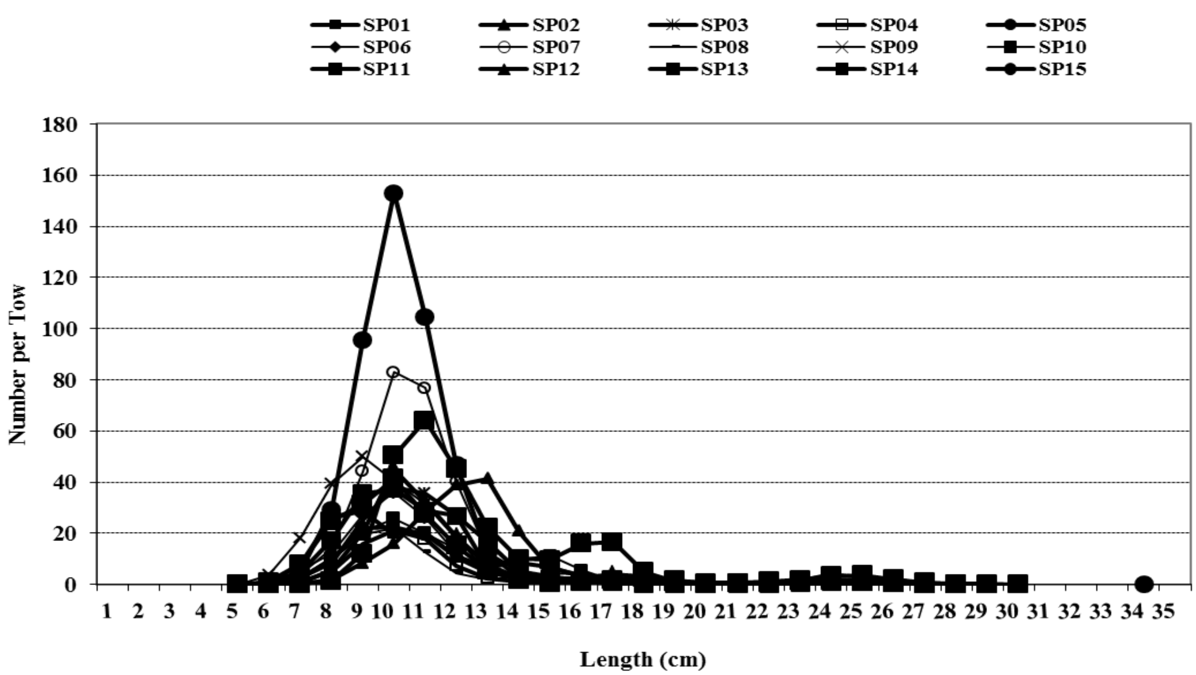

Figure 5.2 Length Frequency of Alewife Captured During the 2001 – 2015 Spring Inshore Trawl Survey.

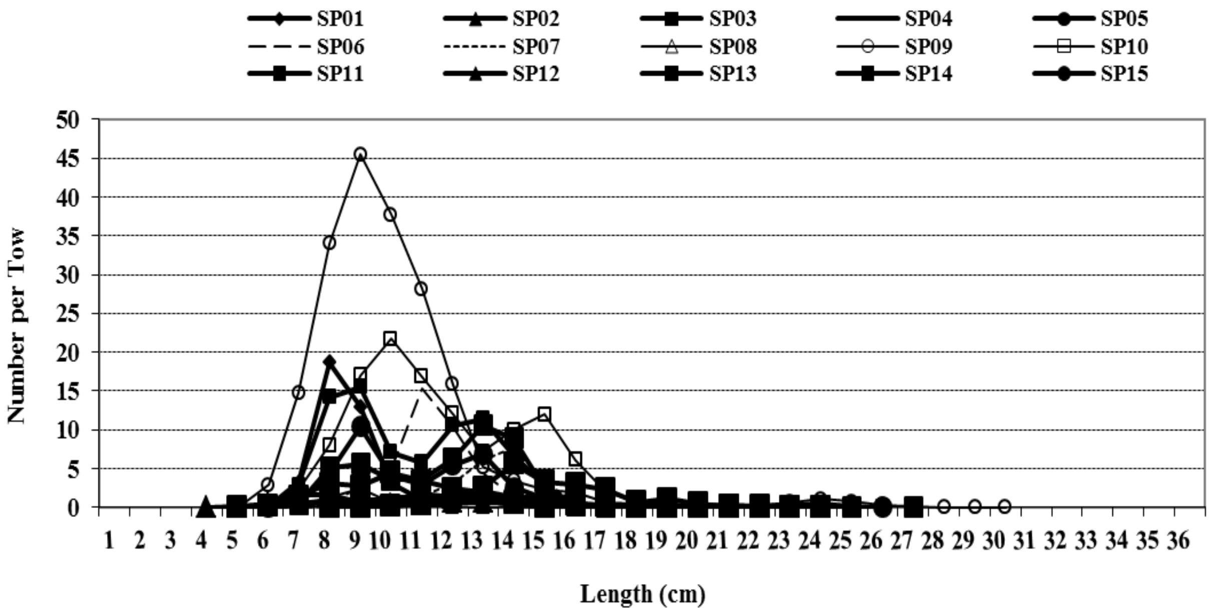

Figure 5.3 Length Frequency of Blueback Herring Captured During the 2001 – 2015 Maine-New Hampshire Spring Trawl Survey.

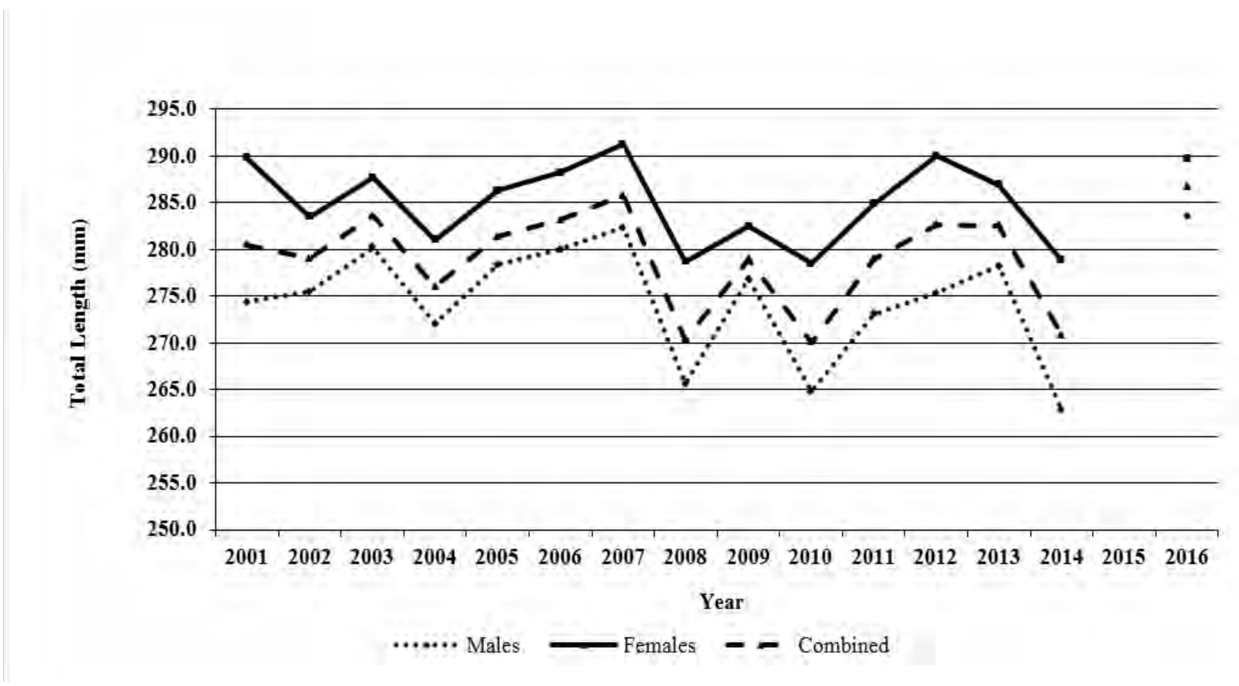

Figure 5.4 Mean Total Lengths of Alewives Sampled at the Brunswick Fishway.

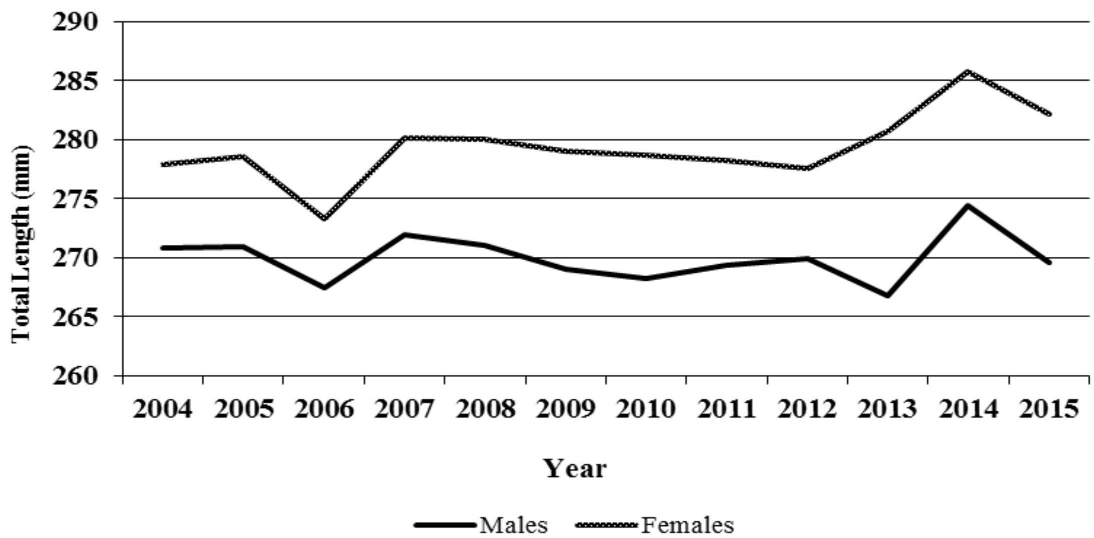

Figure 5.5 Mean Total Lengths of Alewives Sampled at the Sebasticook Fishway.

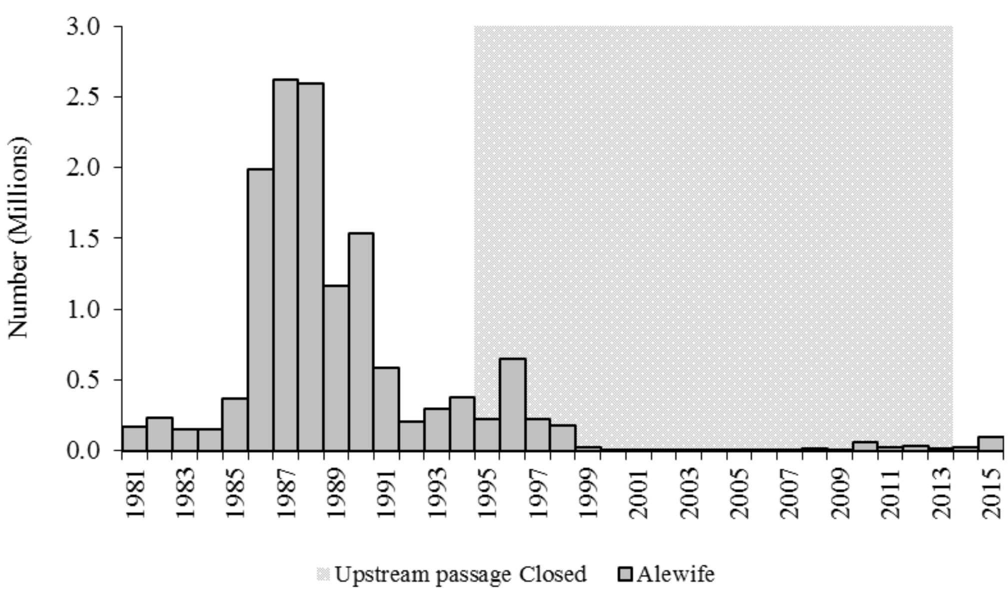

Figure 5.6 Number of river herring counted at Milltown Fishway on the St. Croix River from 1981-2015.

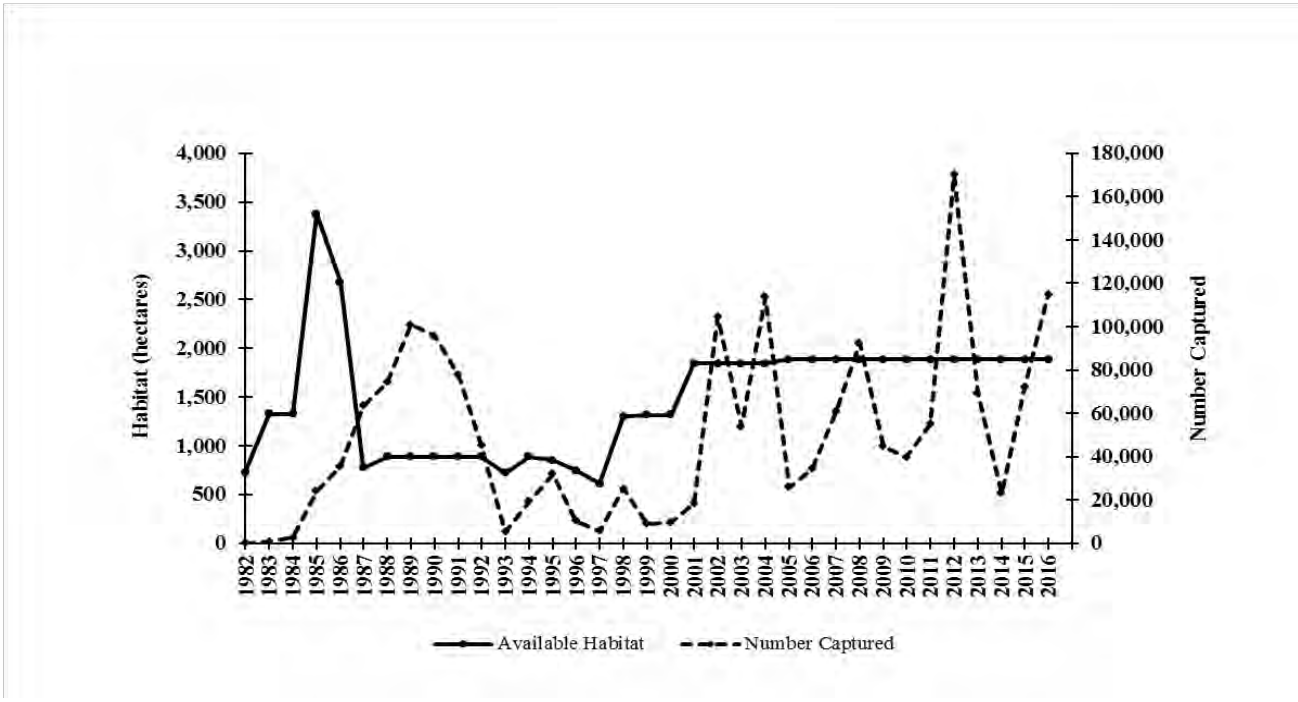

Figure 5.7 Adult River Herring Run Size and Habitat Availability - Androscoggin River Watershed, 1982-2015.

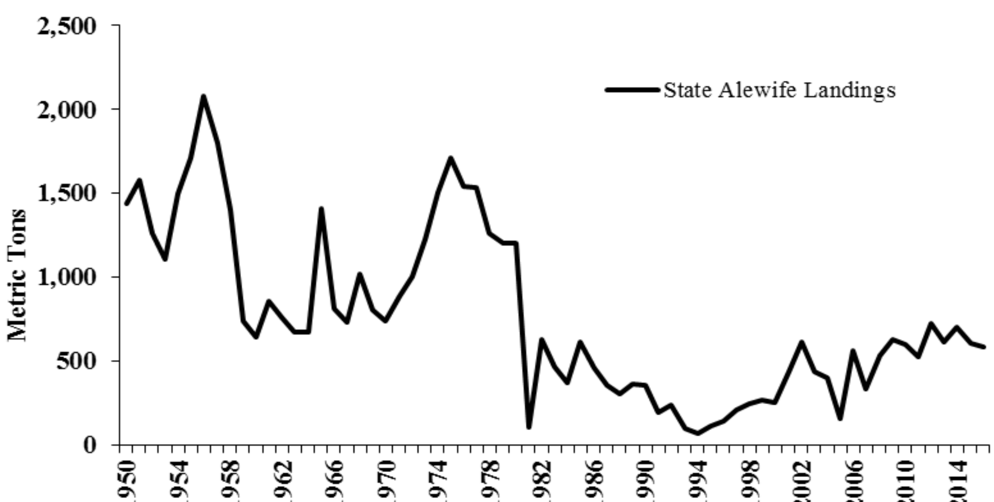

Figure 5.8 Maine Commercial Alewife Harvest.

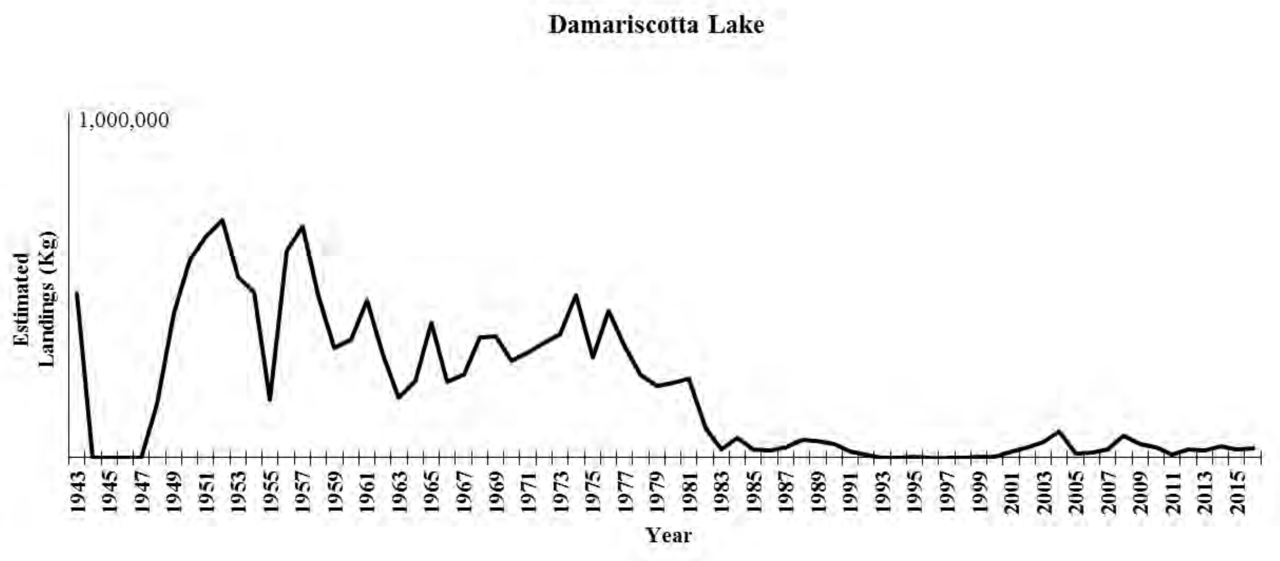

Figure 5.9 Damariscotta Lake Alewife Commercial Harvest

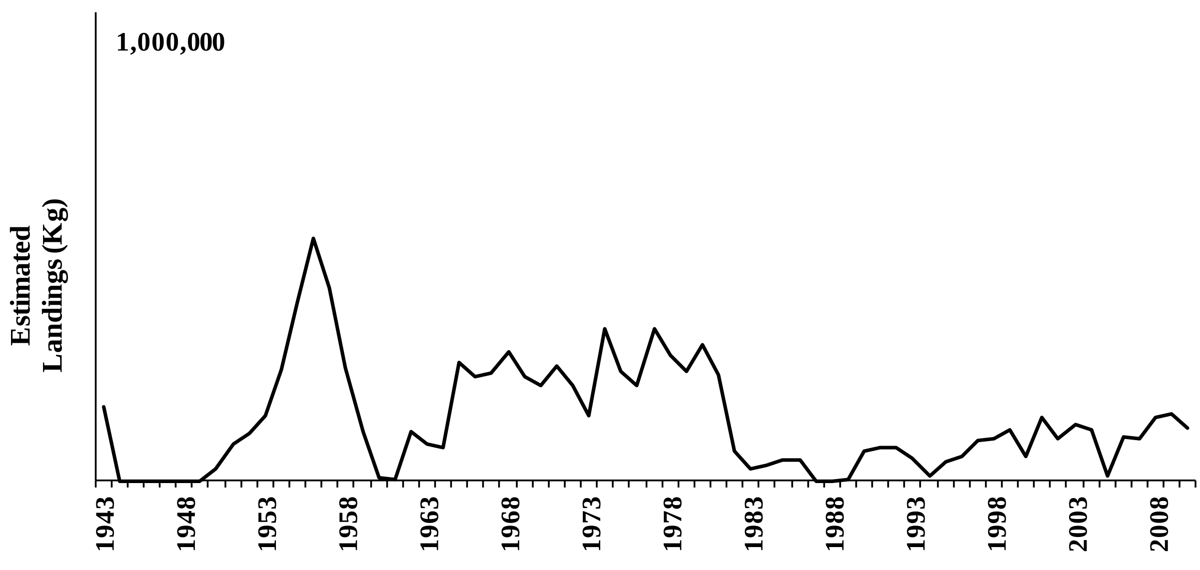

Figure 5.10 St. George Commercial River Herring Harvest

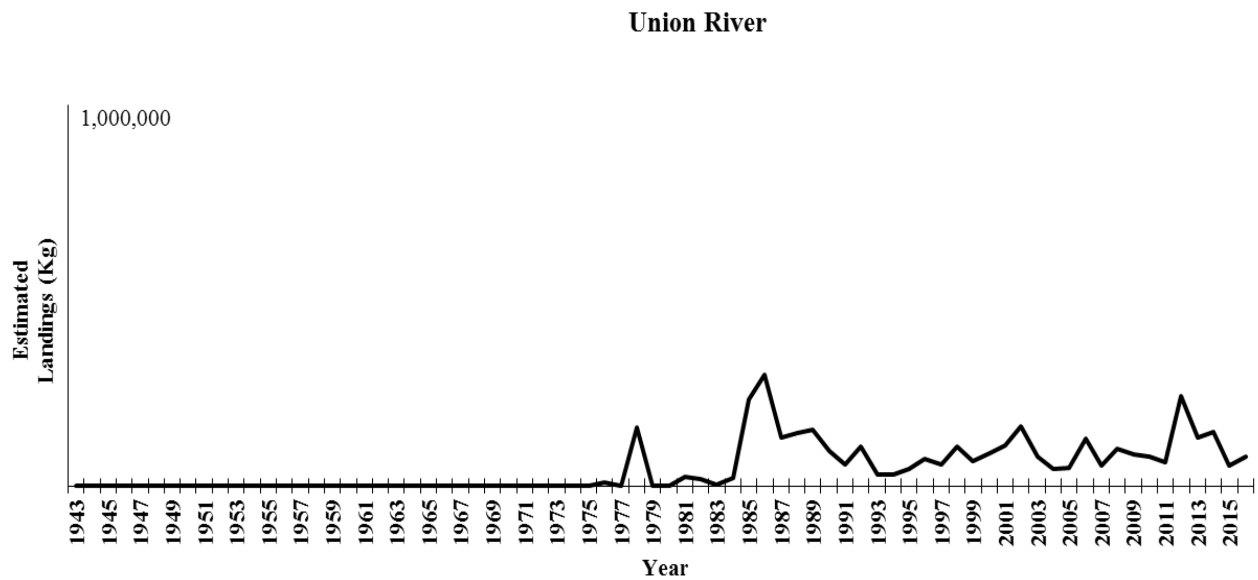

Figure 5.11 Union River Commercial Alewife Harvest

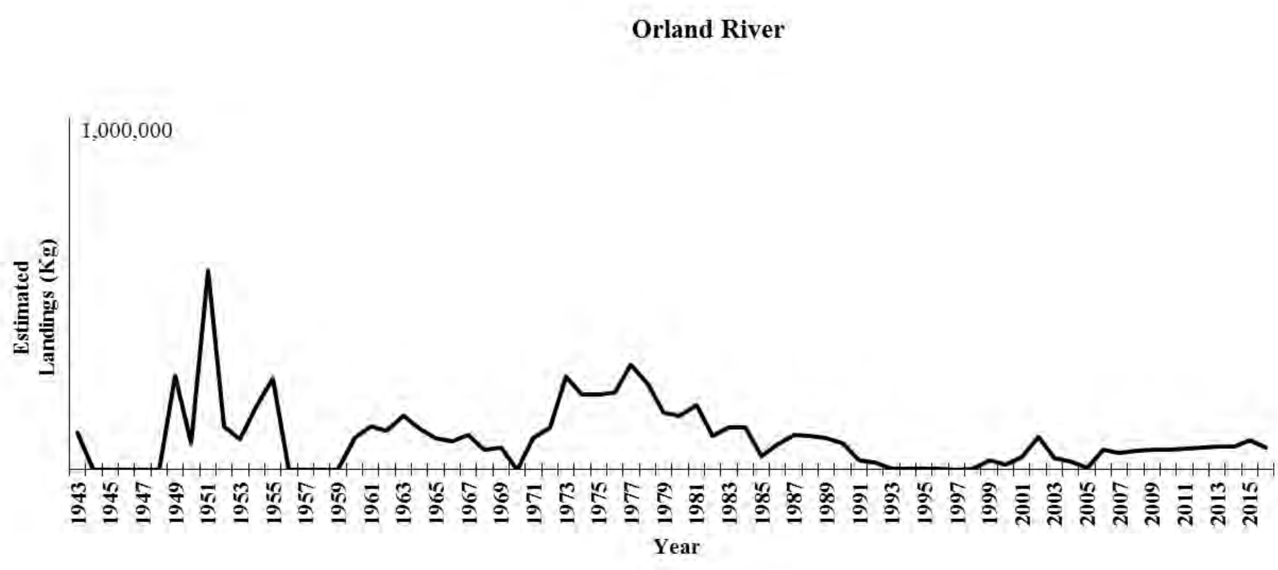

Figure 5.12 Orland Commercial River Herring Harvest

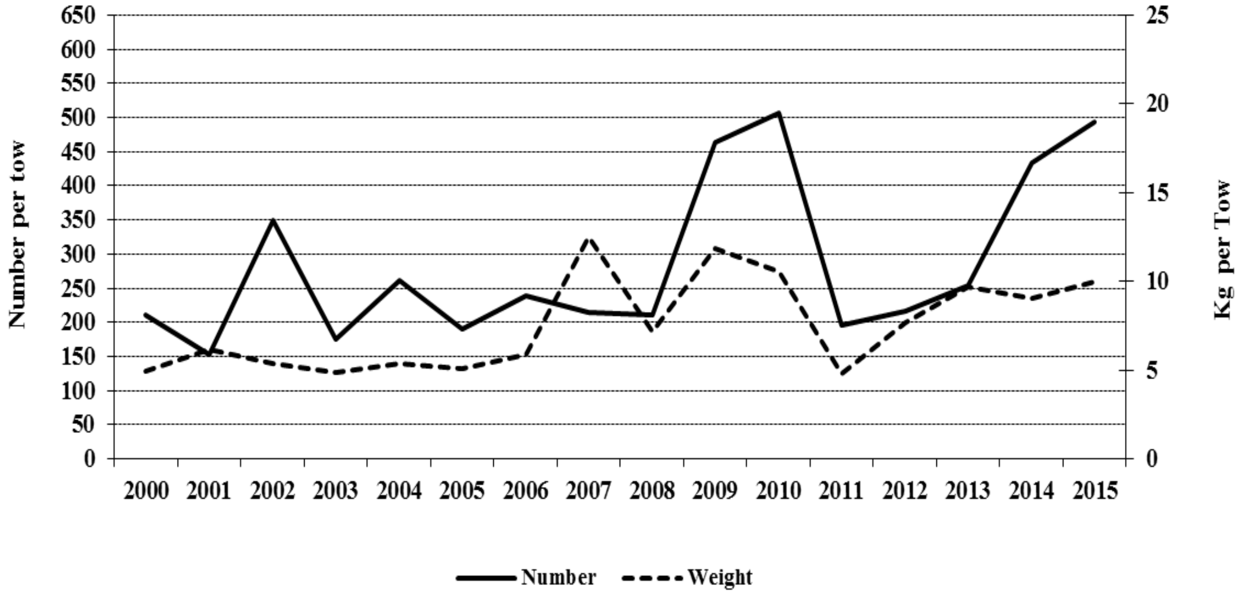

Figure 5.13 Total Number and Weight of Alewife Captured During the Fall Maine-New Hampshire Trawl Survey.

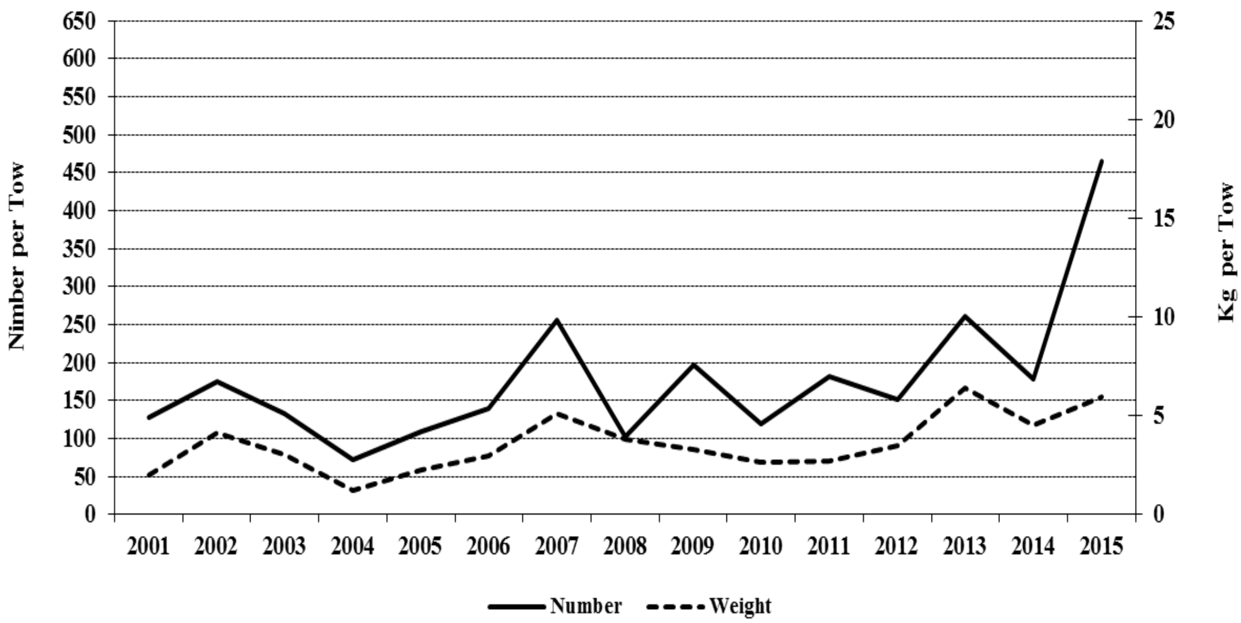

Figure 5.14 Total Number and Weight of Alewife Captured During the Spring Maine-New Hampshire Trawl Survey.

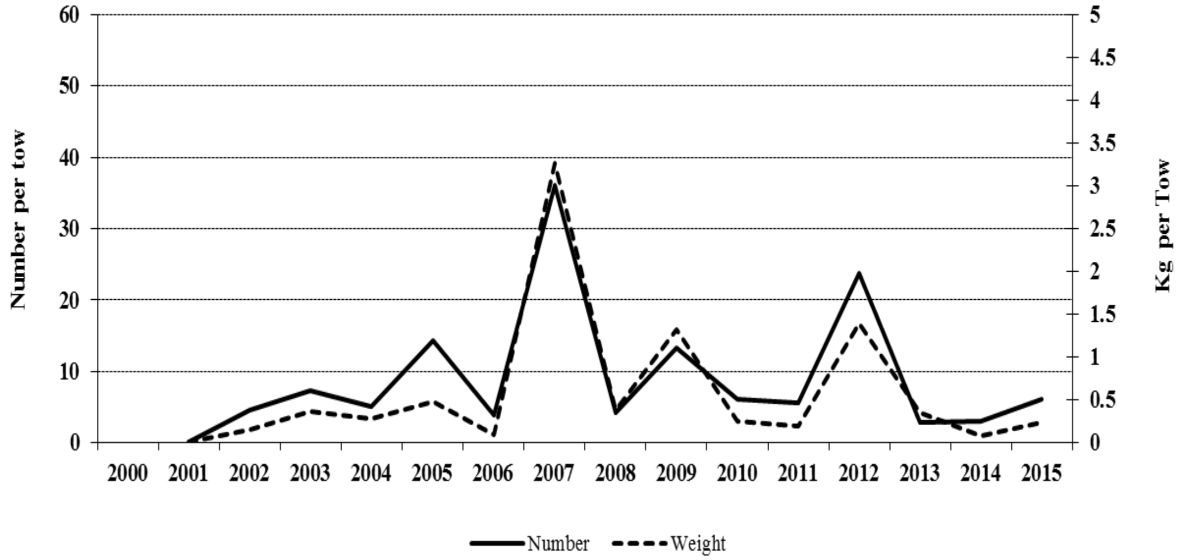

Figure 5.15 Total Number and Weight of Blueback Herring Captured During the Fall Maine-New Hampshire Trawl Survey.

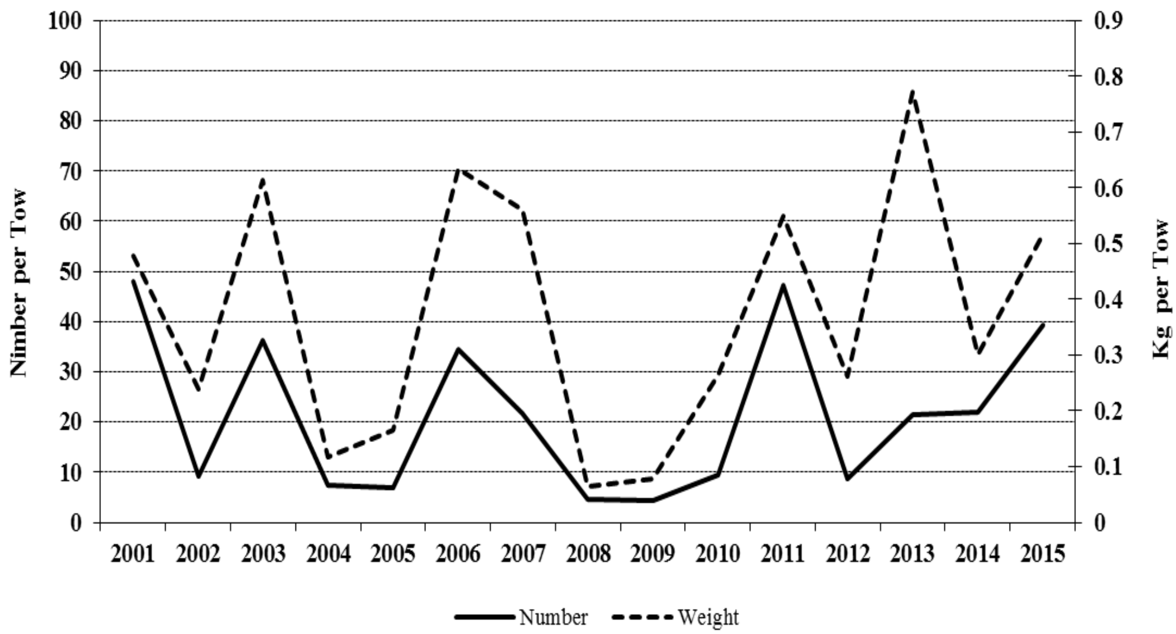

Figure 5.16 Total Number and Weight of Blueback Herring Captured During the Spring Maine-New Hampshire Trawl Survey.

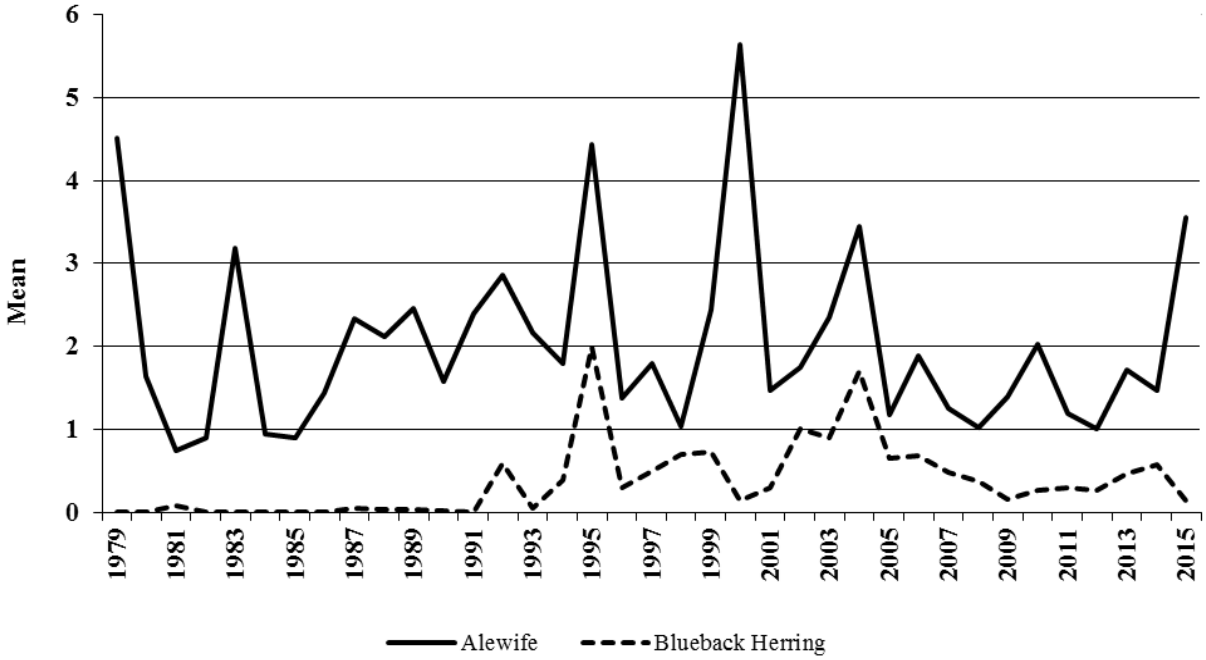

Figure 5.17 Geometric Means for Merrymeeting Bay – Alewife and Blueback Herring

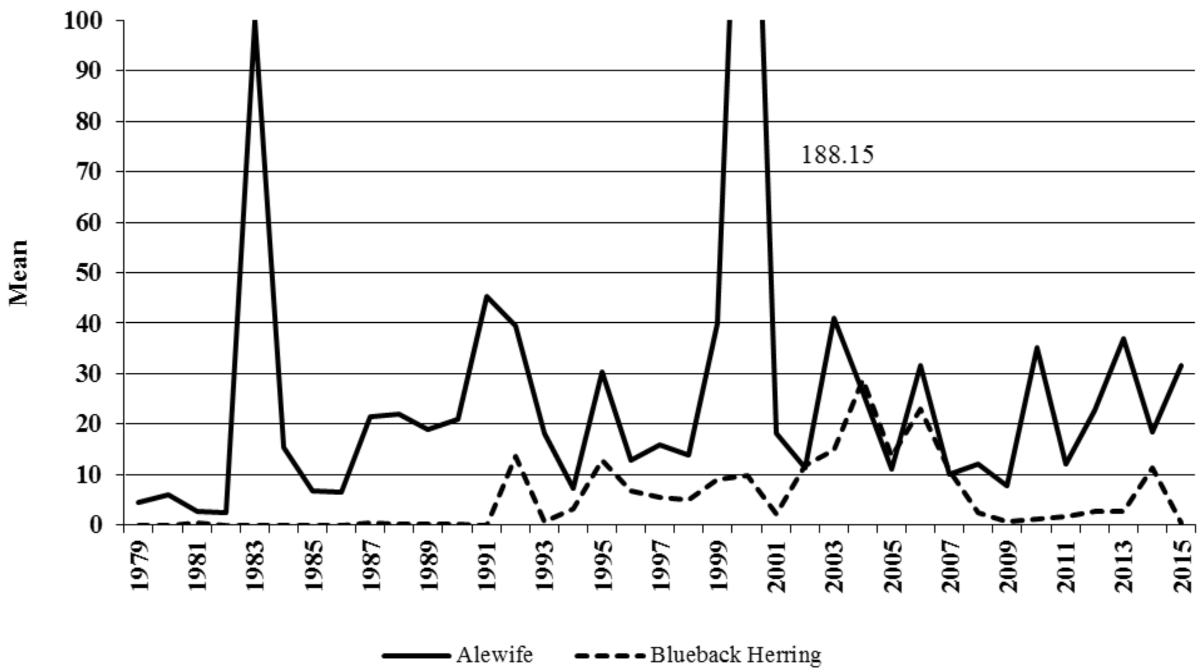

Figure 5.18 Arithmetic Means for Merrymeeting Bay – Alewife and Blueback Herring.

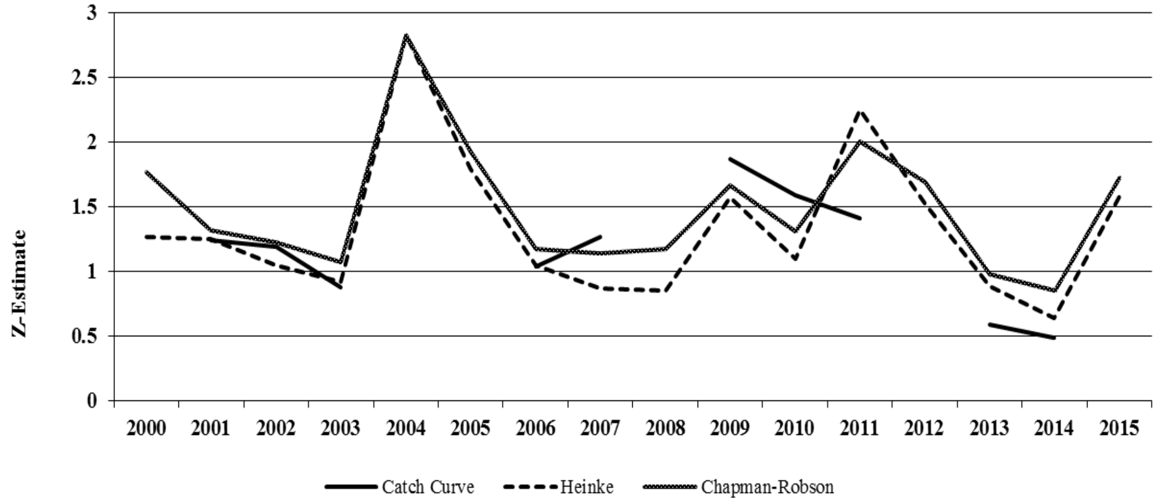

Figure 5.19 Male Alewife Z Estimates for the Sebasticook River at Ft. Halifax and Benton Falls.

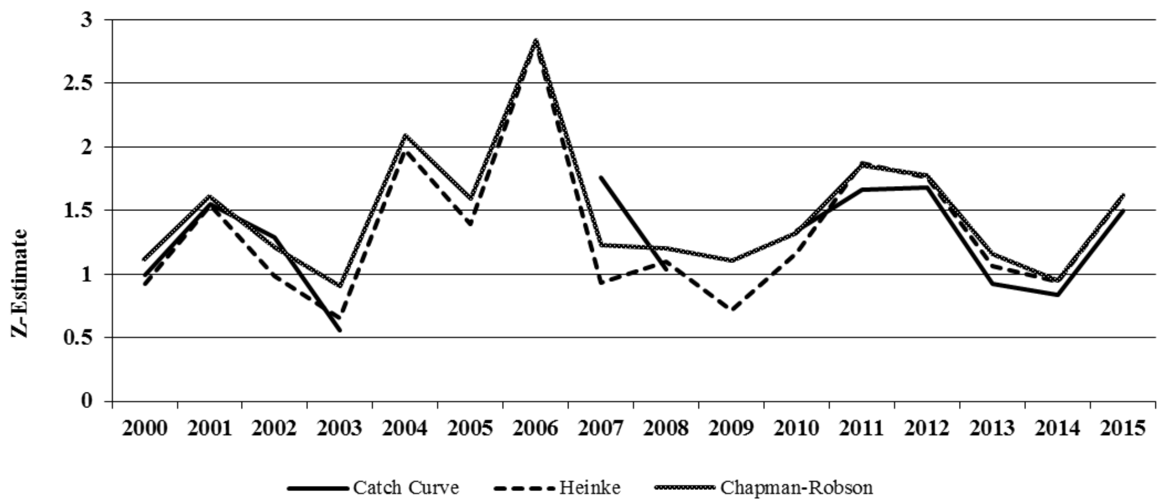

Figure 5.20 Female Alewife Z Estimates for the Sebasticook River at Ft. Halifax and Benton Falls.

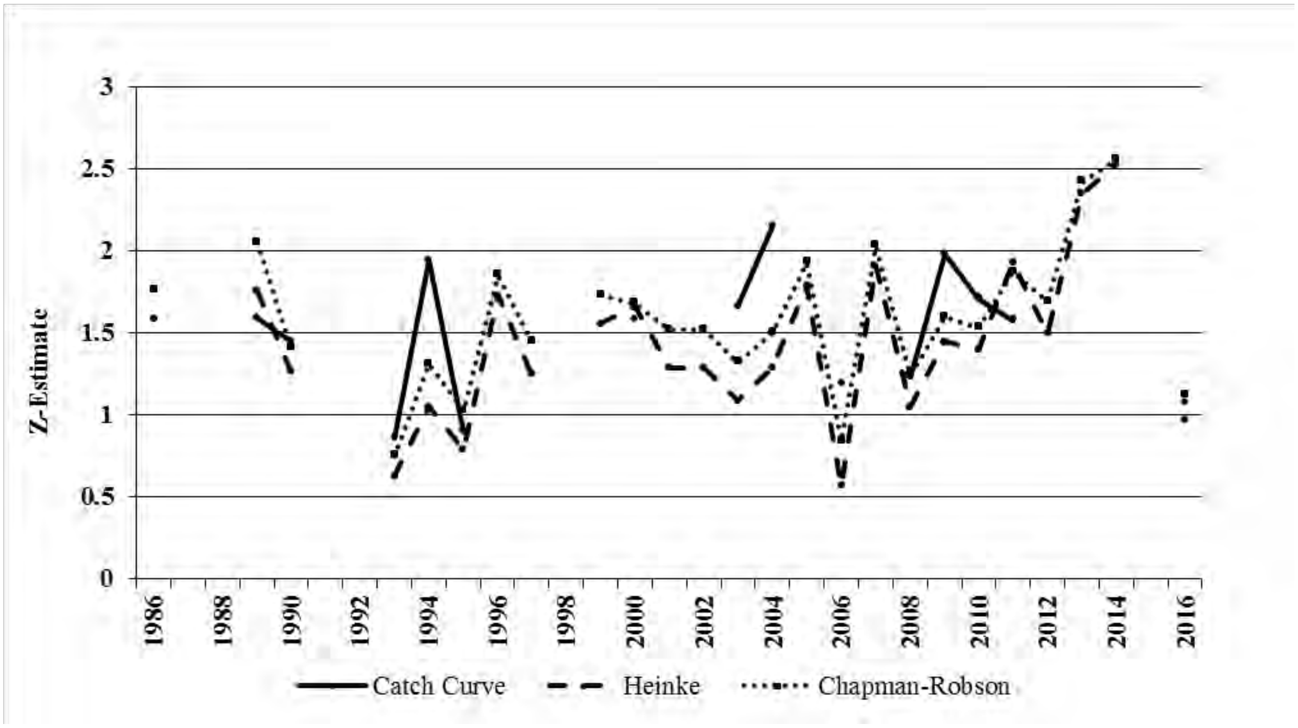

Figure 5.21 Male Alewife Z Estimates for the Androscoggin River at the Brunswick Fishway.

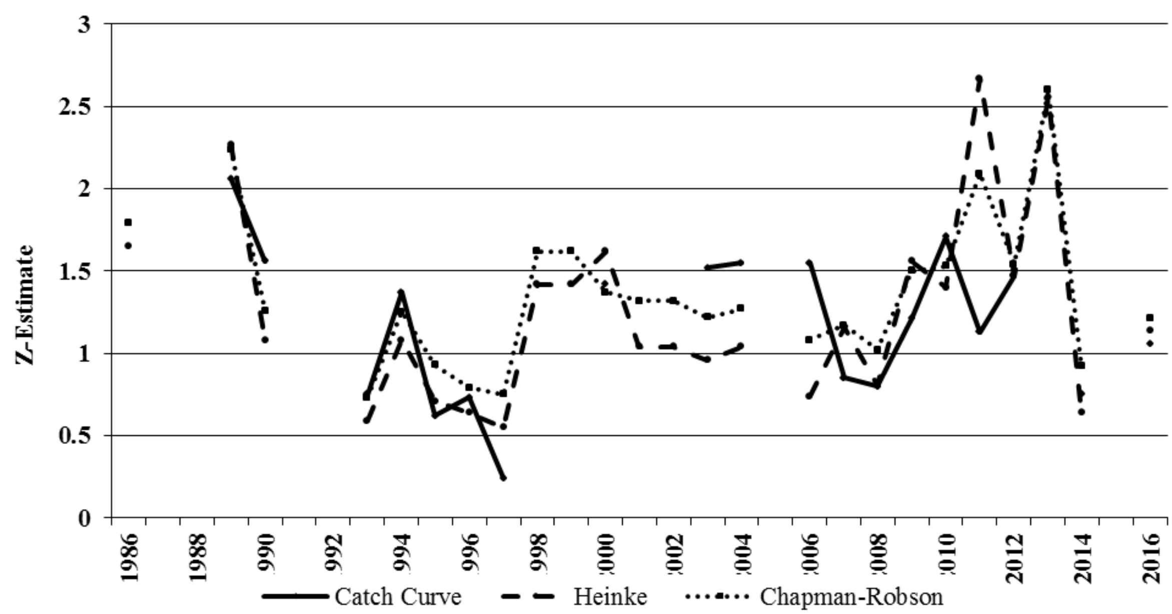

Figure 5.22 Female Alewife Z Estimates for the Androscoggin River at the Brunswick Fishway.

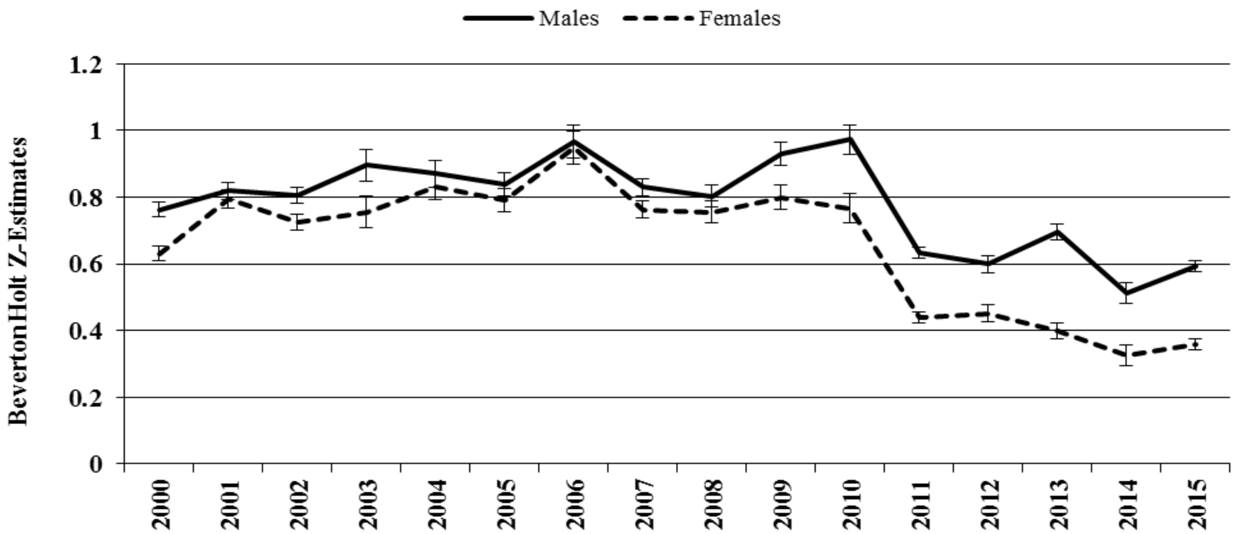

Figure 5.23 Male and Female Alewife Z Estimates for the Sebasticook River using Beverton-Holt.

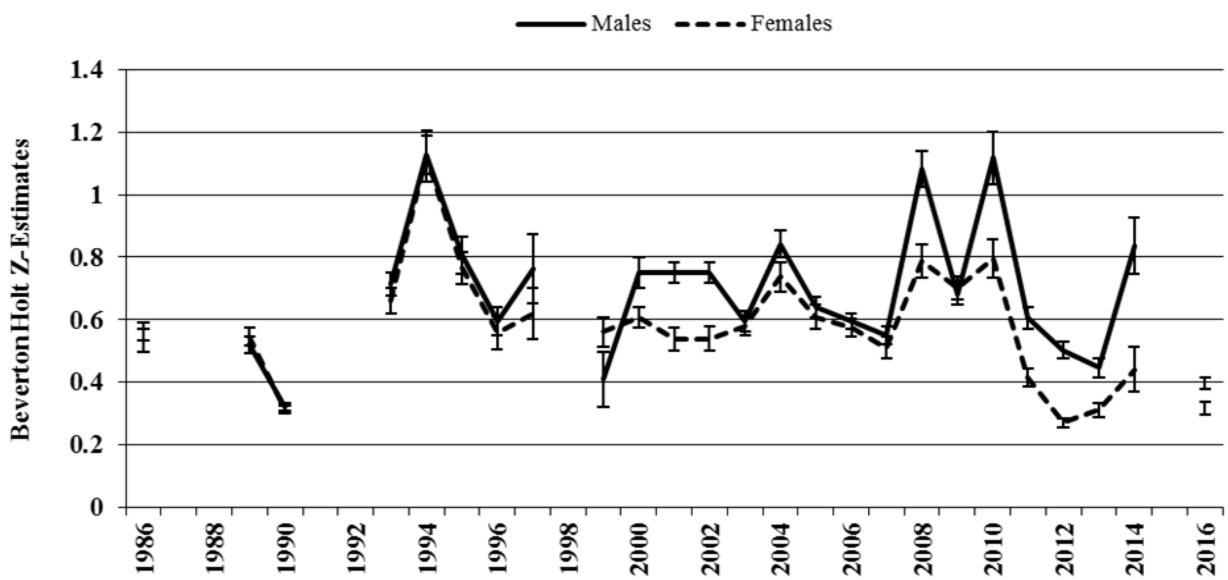

Figure 5.24 Male and Female Alewife Z-Estimates for the Androscoggin River using Beverton-Holt

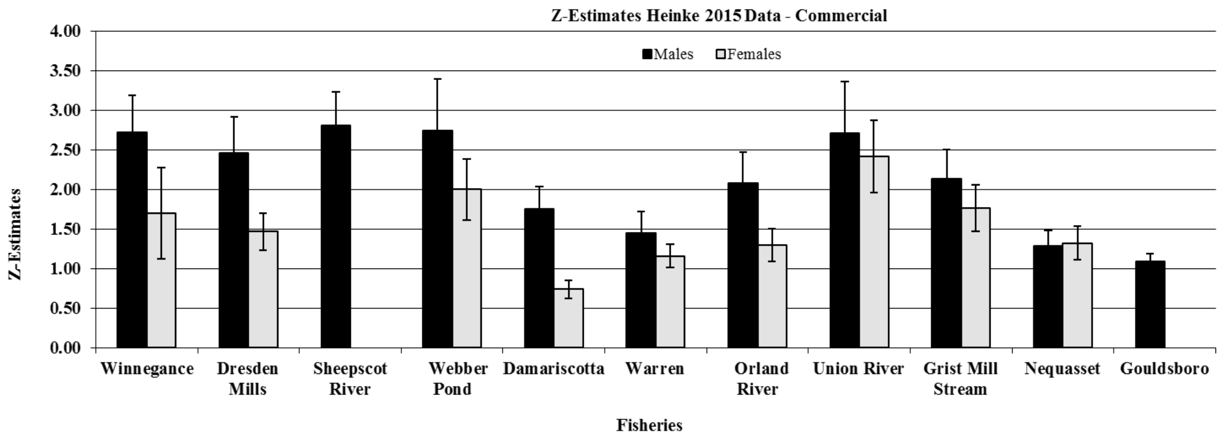

Figure 5.25 Male and female Z-estimates (Heinke) of Alewife Captured at Eleven Commercial Runs in 2015.

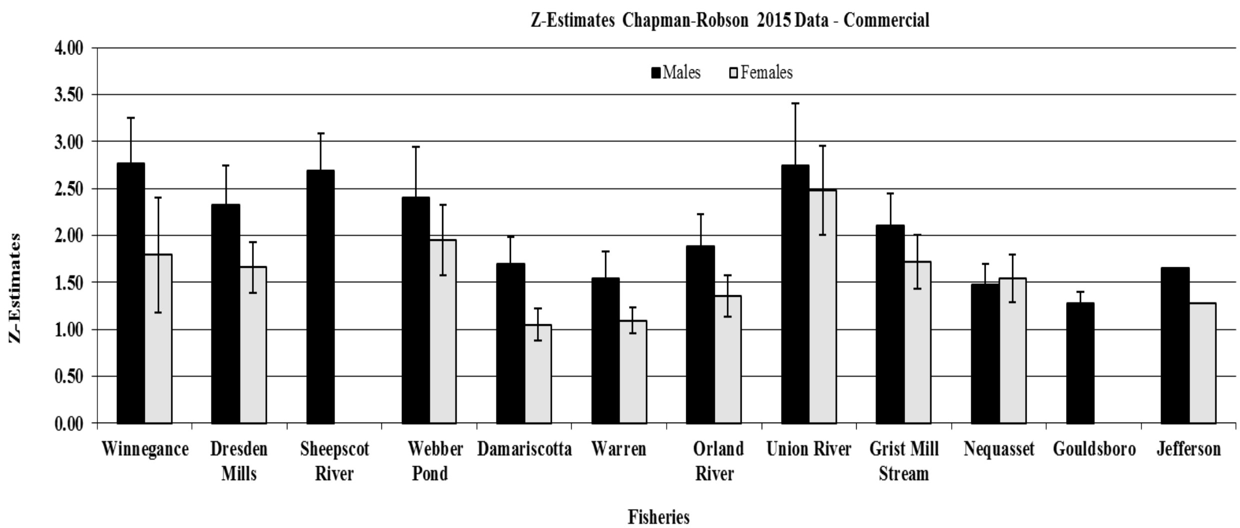

Figure 5.26 Male and female Z-estimates (Chapman-Robson) of Alewife Captured at Twelve Commercial Runs in 2015.

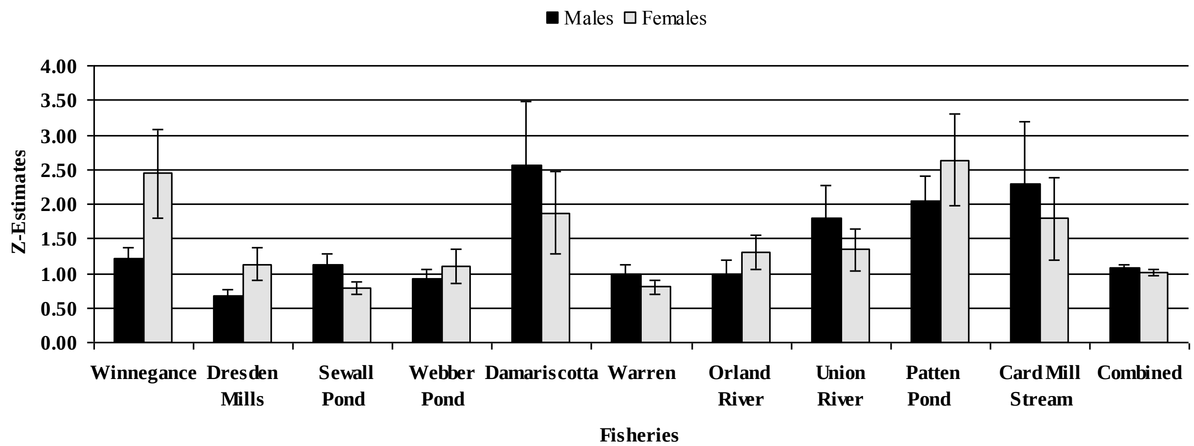

Figure 5.27 Male and female Z-estimates (Heinke) of Alewife Captured at Ten Commercial and Non-Commercial Runs in 2009.

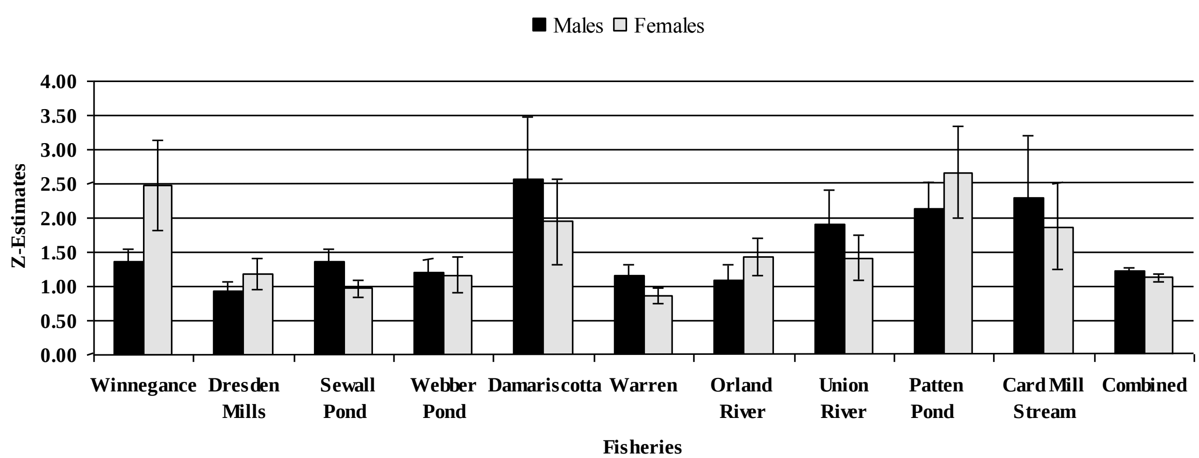

Figure 5.28 Male and female Z-estimates (Chapman-Robson) of Alewife Captured at Ten Commercial and Non-Commercial Runs in 2009.

6 Status of River Herring in New Hampshire

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6.1. INTRODUCTION

New Hampshire's coastal rivers once supported abundant runs of anadromous fish including river herring (alewife and blueback herring) (Figure 6.1), American shad, and Atlantic salmon (Jackson 1944). These and other diadromous species have been denied access to historical freshwater spawning habitat since the construction of milldams as early as the 1600s but more dramatically during the nineteenth century textile boom in most New Hampshire coastal rivers (Figure 6.2). Barriers eliminated American shad and Atlantic salmon populations, but river herring only declined in numbers because they utilized small areas of freshwater at the base of dams during spring runoffs for spawning.

Restoration of diadromous fish populations in New Hampshire began with construction of fishways in the late 1950s and continued through the early 1970s by the New Hampshire Fish and Game Department (NHFGD) in the Exeter, Lamprey, Winnicut, Oyster, and Cocheco rivers in the Great Bay Estuary (Figure 6.3, Figure 6.4, Figure 6.5, Figure 6.6, Figure 6.7) and the Taylor River in the Hampton-Seabrook Estuary (Figure 6.8). These fishways re-opened acres of freshwater spawning and nursery habitat for river herring, American shad, and other diadromous fish.

6.2. MANAGEMENT UNIT DEFINITION

NHFGD manages the river herring populations within state waters. Primarily river herring are intercepted for biological sampling and enumerated at Department owned fish ladders at the head-of-tide dams for management purposes. Individual river herring spawning runs in the Exeter (Squamscott), Lamprey, Winnicut, Oyster, Cocheco, and Taylor Rivers were evaluated independently in this report as units of the State's river herring stock.

6.2.1. Exeter/Squamscott River

The Exeter River drains an area of 326 square km in southern New Hampshire (Figure 6.3). The river flows east and north from the Town of Chester to the Town of Exeter. It empties into Great Bay northeast of Exeter. The head-of-tide occurs at the Town of Exeter and the saltwater portion of the river is called the Squamscott River.

The two lowermost dams on the main stem Exeter River are the Great Dam in Exeter at river kilometer (rkm) 10.6 and the Pickpocket Dam at rkm 22.4 (each 4.6 km high). The next barrier above Pickpocket

Dam is a set of natural falls at rkm 32.9. NHFGD constructed upstream fish passage facilities (Denil fishways) on both dams from 1969 to 1971 for anadromous fish, funded in part by the U.S. Fish and Wildlife Service (USFWS). Fish ladder improvements occurred in 1994 and 1999 and a fish trap was constructed at the upriver end of the Great Dam fish ladder. There are no downstream fish passage facilities on either dam so emigrating adults and juveniles pass over the spillway when river flows allow. There are approximately one hundred meters of fresh water that occurs between head-of-tide and the Great Dam caused by an elevated ledge that prevents saltwater incursion. River herring have been observed below the Great Dam and have the ability to spawn in this area. Most spawning and rearing habitat occurs above the dam. Periodic water quality monitoring has recorded declines in dissolved oxygen (DO) between the two dams for some years since 1995 (Smith *et al.* 2005; Langan 1995).

6.2.2. Lamprey River

The Lamprey River flows 97 km through southern New Hampshire to the Town of Newmarket where it becomes tidal and enters the Great Bay estuary just north of the mouth of the Squamscott River. The Lamprey River watershed is shown in Figure 6.4. The Macallen Dam, located at rkm 3.2 in Newmarket, is the lowermost head-of-tide dam (8.2 m high) on the Lamprey River. Fish passage is provided by a Denil fish ladder constructed from 1969 to 1970 for anadromous fish by NHFGD, funded in part by the USFWS. There are no downstream passage facilities at the Macallen Dam and emigrating juveniles and adults must pass over the spillway. Fish kills have not been observed below the first dam suggesting that adults and juveniles emigrate with limited mortality. The Wiswall Dam (3.4 m high) is located 5.6 km above the Macallen Dam and has a Denil fish ladder constructed in 2012 by the Town of Durham and operated by NHFGD. The passage at Wiswall Dam provides access to an additional 12.6 km of spawning habitat. Downstream migration at Wiswall Dam is provided by a stop log bay within the spillway that is opened during the fish migration season.

6.2.3. Winnicut River

The Winnicut River drains a watershed of 36.8 square km in southeast New Hampshire (Figure 6.5). It originates in the town of North Hampton and flows north through Greenland where it empties into Great Bay. The last remaining dam on the main stem of the river, located at the head-of-tide at approximately 3.2 rkm, was removed in 2009. A run-of-river fish passage structure was constructed in 2011 to enhance passage of river herring through the constriction of the river caused by the Route 33 Highway Bridge approximately 100 feet above the former dam.

6.2.4. Oyster River

The Oyster River drains a watershed of 27.5 km through southeast New Hampshire (Figure 6.6). It begins in Barrington and flows southeast to Lee, then flows east-southeast through Durham where it empties into Little Bay. The first dam exists at the head of tide just west of NH Route 108 at rkm 4.8. The spillway length is 42.7 m and a height of 3 m. A Denil fish ladder was constructed at this dam around 1975. The next barrier to fish passage is a dam at about rkm 7.7.

6.2.5. Cocheco River

The Cocheco River flows 48 km southeast through southern New Hampshire to Dover where it joins the Salmon Falls River to form the Piscataqua River (Figure 6.7). The lowermost dam (4.6 m high, built on a natural ledge for a total height of 8 – 10 m) on the Cocheco River is within the City of Dover at the head of tide, at rkm 5.5. A Denil fish ladder was constructed at the dam in 1969 to 1970 for anadromous fish by NHFGD, funded in part by the USFWS. The next barrier is a set of natural falls located at rkm 9.5.

The City of Dover currently owns the dam and leases the attached hydroelectric facility to Southern New Hampshire Hydroelectric Development Corporation (SNHHDC). The Federal Energy Regulatory Commission (FERC) requires SNHHDC to provide downstream fish passage and utilize a grating system to prevent small fish from passing through the turbines. The downstream passage system is a 24" PVC tube emptying in a plunge pool below the dam. This system passes emigrating diadromous species when operating efficiently. Emigrating juvenile and adult river herring must either pass over the dam if flows allow, travel through the downstream migration tube, or move through the turbines at the hydroelectric facility if they can pass through the grating system.

6.2.6. Taylor River

The Taylor River is located in southeastern New Hampshire and is about 17.1 km long (Figure 6.8). The river begins on the border between Hampton Falls and Kensington, New Hampshire. It flows north, east, then southeast through Hampton Falls where it meets tide water at Interstate 95. The lowermost 6.4 km of the river forms the boundary between Hampton and Hampton Falls. The first dam is located at rkm 5.1. There is a Denil fish ladder at this head-of-tide dam that was constructed in the late 1960s. Due to a severely diminished spawning run and lack of a sampling trap at the Taylor River the NHFG decided to discontinue daily monitoring. Beginning in 2015, the Taylor River fish ladder was opened to allow for diadromous fish passage, but was only monitored on a weekly basis. Daily monitoring activities will not be continued until further evidence of a river herring spawning run is observed. The next dam is a barrier to further fish passage and is located at rkm 6.9.

6.3. REGULATORY HISTORY

The regulatory history of river herring in New Hampshire state waters (inland and 0-3 miles) began in 1967. With the establishment of a permit and reporting requirement for residents or nonresidents utilizing a seine, net, or weir for the taking of river herring. In 1987, the taking of river herring in state waters on Wednesdays by any method was prohibited. New regulations were instituted in 2005 closing a large section of tidal waters in the Taylor River and restricting harvest days in the Squamscott River in Exeter. In 2012 the Oyster River and its tributaries were closed to the taking of river herring from the head-of-tide dam downstream to its mouth at Great Bay. The new regulations were intended to allow more river herring returns to the Exeter, Taylor, and Oyster river fishways.

The current regulations are:

Fis 603.01 River Herring.

(a) No person shall take river herring, alewives (*Alosa pseudoharengus*) and bluebacks (*Alosa aestivalis*) from the waters of the state, by any method, between sunrise Wednesday and sunrise Thursday of any week.

(b) Any trap or weir used during the period specified in paragraph (a) above, shall be constructed so as to allow total escapement of all river herring.

(c) Any river herring taken by any method during the period specified in paragraph (a) shall be immediately released back into the waters from which it was taken.

Fis 604.03 Taylor River. The Taylor River from the railroad bridge to the head of tide dam in Hampton shall be closed to the taking river herring by netting of any method.

Fis 604.04 Squamscott River.

(a) During April, May and June the taking of river herring in the Squamscott River and its tributaries from the Rt. 108 Bridge to the Great Dam in Exeter shall be subject to the following:

(1) Open to the taking of river herring by netting of any method only on Saturdays and Mondays;

(2) The daily limit shall be one tote per person. "Tote" means a fish box or container measuring 31.5"x 18" x 11.5"; and

(3) The tote shall have the harvester's coastal harvest permit number plainly visible on the outside of the tote.

Fis 604.05 Oyster River. The Oyster River and its tributaries shall be closed to the taking of river herring by any method from the head-of-tide dam at Mill Pond in Durham, 43°07'51.23"N, 70°55'08.20"W and 43°07'50.31"N, 70°55'08.04"W, downstream to the river mouth at Wagon Hill Farm and Durham Point, a line extending from 43°07'31.87"N, 70°52'17.67"W to 43°07'20.18"N, 70°52'19.16"W.

6.4. ASSESSMENT HISTORY

New Hampshire has not conducted a formal river herring stock assessment, but did provide data for the 2012 coastwide benchmark stock assessment.

6.5. GENERAL LIFE HISTORY

Both alewives and blueback herring are found in the coastal rivers and streams of New Hampshire. Alewives spawn from late-April to late-May when water temperatures have reached a minimum of 9^0 C. Blueback herring typically spawn from early-May until the end of June when temperatures have reached 16^0 C. Typically alewives spawn in the slack water areas of rivers and impoundments while blueback herring prefer faster moving water in rivers and streams. After utilizing the freshwater as nursery habitat during summer months, the juveniles typically emigrate to the ocean from late-August through October. The majority of returning adult river herring are between the ages of 3 and 5 years old.

6.5.1. Growth

From 1990 to 2015, the NHFGD has collected length, sex, species, and age data from fish ladders during the spring spawning migrations (see section 6.8) in coastal river systems. Von Bertalanffy growth curves for total length at age for male and female river herring are presented in Figure 6.10.

6.6. HABITAT DESCRIPTIONS

As stated in Atlantic States Marine Fisheries Commission's Amendment 1 of the Interstate Fishery Management Plan for Shad and River Herring (ASMFC 1999), habitats used by alosines include spawning sites and nursery areas in coastal rivers, which are primarily freshwater portions of rivers and their associated bays and estuaries. In addition to spawning and nursery areas, adult habitats also consist of the near shore ocean. These habitats are distributed along the East Coast from the Bay of Fundy, Canada to Florida. Use of these habitats by migratory alosines may increase or diminish as the size of the population changes.

New Hampshire's coastal area contains two major estuaries with the Great Bay Estuary System being the largest. The Great Bay Estuary includes seven small to moderate size rivers with most flowing into a large embayment (Great Bay and Little Bay) before draining into a narrow, 15 km long opening to the sea via the Piscataqua River. The following is a description of each river in the estuary.

Cocheco River

The Cocheco River flows 48 km southeast through southern New Hampshire to Dover where it joins the Salmon Falls River to form the Piscataqua River. The Piscataqua River flows approximately 20 km to the sea. The Cocheco River drains a watershed of 479 square km. The lowermost dam (4.6m high, built on a natural ledge for a total height of 8-10 m) on the Cocheco River is within the City of Dover, at rkm 5.5. This dam impounds an area of 20 acres. A Denil fish ladder which provides access to approximately 49 acres of potential spawning habitat was constructed at the dam in 1969 to 1970 for anadromous fish by NHFGD, the owner also maintains a downstream migration structure which was replaced for increased efficiency in 2010. The downstream passage system is a PVC tube emptying in a plunge pool below the dam. The next barrier is a set of natural falls located at rkm 9.5. During certain flow conditions there is the potential that river herring can ascend this natural falls and continue migrating upriver a distance of 1.5 km to the Watson Dam in Dover, NH. There is no fish ladder at this dam, but a downstream migration pipe is provided by the hydroelectric facility. Currently there are no concerns with the passage efficiency of the existing fish ladder or the water quality throughout the spawning and emigration season in the Cocheco River. No spawning activity has been observed below the dam.

Lamprey River

The Lamprey River flows 97 km through southern New Hampshire to the Town of Newmarket where it becomes tidal and enters the Great Bay Estuary just north of the mouth of the Exeter River. The mouth of the Lamprey River in Great Bay is approximately 27 km inland from the Atlantic coast. The Lamprey River watershed drains an area of 549 square km. It is the largest watershed that empties directly into The Great Bay. The Macallen Dam, located at rkm 3.2 in Newmarket, is the lowermost head-of-tide dam (8.2 m high) on the Lamprey River. A Denil fish ladder constructed from 1969 to 1970 for anadromous fish by NHFGD allows access to 120 acres of potential spawning habitat. The Wiswall Dam (3.4 m high) is located 5.6 km upstream of the Macallen Dam. Construction of a Denil fish ladder was completed in 2012. This fish provides access to another 12.6 km of habitat. There are no downstream passage facilities at the Macallen Dam and emigrating juveniles and adults must pass over the spillway. Fish kills have not been observed below the first dam suggesting that adults emigrate with limited mortality. Downstream passage is provided at Wiswall Dam via a stop log bay within the spillway. Stop logs are removed during the fish migration season to provide passage for both adult and juvenile river herring.

The run of river herring through the fishway each year tends to be mostly alewives. However, each spring towards the end of the annual migration a large number of blueback herring congregate just below the Macallen Dam. A small number of these blueback herring ascend the fishway, but the vast majority of them spawn below the dam. The area they spawn in is approximately 0.40 acre in size. Above the Macallen Dam there is a variety of spawning habitat available for both alewives and blueback herring with no observed water quality issues, so it is unclear why most bluebacks spawn below the fishway/dam.

Oyster River

The Oyster River begins in the town of Barrington, NH. The size of the Oyster River watershed is approximately 67 square km. The Oyster flows southeasterly approximately 27.5 km through the towns of Lee and Durham on its way to Little Bay in the Great Bay Estuary. The mouth of the Oyster River lies approximately 19 km from the Atlantic Ocean. The head-of-tide dam occurs at rkm 4.8 in Durham, NH. There is a Denil fish ladder at this dam that was constructed in 1975. This fish ladder provides access to approximately 24 acres of potential spawning habitat. The next dam on the Oyster River occurs at rkm 7.7 and is a barrier to river herring passage.

The numbers of river herring returning to the Oyster River fishway have been decreasing since the mid 1990's. One possible explanation for the decline is diminishing water quality in the Mill Pond impoundment above the head-of-tide dam. Increasing eutrophication has been observed by NHFGD staff over the past several years. Due to this eutrophication oxygen levels could be critically low while juvenile river herring are utilizing the impoundment as nursery habitat. In addition, the Oyster River is used as a municipal water supply. In years when flows are below average very little water is observed flowing over the spillway of the head-of-tide dam. River herring can only emigrate from this impoundment over the spillway and thus become "trapped" in water with diminishing quality in years with lower river discharge. In response to the diminishing river herring returns the Oyster River and its tributaries were closed to taking of all river herring in 2012.

Squamscott/Exeter River

The Exeter River drains an area of 326 square km in southern New Hampshire. The River flows east and north from the Town of Chester to the Town of Exeter. It empties into Great Bay northeast of Exeter. The head-of-tide occurs at the Town of Exeter and the saltwater portion of the river is called the Squamscott River. The two lowermost dams on the main stem Exeter River are the Great Dam in Exeter at river kilometer (rkm) 10.6 and the Pickpocket Dam at rkm 22.4 (each 4.6 km high). Both dams have a Denil fish ladder, providing access to approximately 62 acres of potential spawning habitat. The next barrier above Pickpocket Dam is a set of natural falls at rkm 32.9. The mouth of the Exeter River (Squamscott) in Great Bay lies approximately 27.4 km inland from the sea. During summer 2016 the Great Dam and associated fish ladder were removed. Beginning in spring 2017 river herring will be enumerated and sampled at the Pickpocket fish ladder.

The Exeter River is the only river monitored by the NHFGD that has available fresh water spawning habitat located below the fishway. The NHFGD constructed upstream fish passage facilities (Denil fishways) on both dams from 1969 to 1971 for anadromous fish. Fish ladder improvements occurred in 1994 and 1999 at the Great Dam fishway. A fish trap was constructed at the upriver end of the fish ladder. In addition, improvements were made in the vicinity of the ladder entrance to enhance attraction flow during normal river flow conditions. Despite the recent work to improve fish passage efficiency of the fish ladder at Great Dam, the vast majority of river herring choose to spawn below the fish ladder in an approximately 0.50 acre area of fresh water that occurs between head-of-tide and the Great Dam caused by an elevated ledge that prevents saltwater incursion. River herring gather in very large numbers below the Great Dam and spawning has been observed. These observations combined with relatively high levels of documented harvest occurring each year below the first dam and the inefficiency of the fish ladder in passing river herring indicates that spawning success in this river is much higher than indicated by fish passage numbers through the fish ladder.

There are no downstream fish passage facilities on either dam so emigrating adults and juveniles pass over the spillway when river flows allow. There are no hydroelectric operations at either fishway, however, at the Great Dam there is a condominium complex that utilizes a small amount of water from the penstock for cooling of their heating and air conditioning system. This minimal flow through the penstock does not have an impact on emigrating river herring. In addition, poor water quality has been documented in the critical nursery habitat above Great Dam. Periodic water quality monitoring has recorded low levels of dissolved oxygen (DO) between the two dams in some years since 1995 (Smith et al. 2005; Langan 1995).

Other Rivers Within the Great Bay Estuary:

There are three other major rivers in the Great Bay Estuary that are not monitored regularly by NHFGD staff. They are the Winnicut, Bellamy and Salmon Falls Rivers. The rivers range in length from 14.6 km for the Winnicut to 61 km for the Salmon Falls. Watershed sizes range from approximately 855 square km for the Salmon Falls to 45.3 square km for the Winnicut River.

The Winnicut River flows directly into Great Bay in Greenland, NH. The NHFGD operated a Canada step weir fish passage from approximately 1957 until 2009 on the Winnicut. During the summer of 2009 the fish ladder and associated NHFGD owned dam were removed to restore anadromous fish habitat. The dam removal drained a 34 acre impoundment and the Winnicut River became the only major tributary to Great Bay with no man-made barriers along its entire length.

The Bellamy River enters the Great Bay Estuary at Little Bay in Dover, NH. A partially breached timber crib dam at the head-of-tide at rkm 6.9 was removed to restore anadromous fish habitat in 2004. Since the removal NHFGD staff has observed large numbers of river herring below the next dam approximately 0.6 km upstream. Removal of the next two dams on the Bellamy River is in the planning stages currently.

The Salmon Falls River joins the Cocheco River to form the Piscataqua River within the Great Bay Estuary. The head-of-tide dam is located at approximately rkm 6.7. A Denil fish ladder has been operated at this dam since 2002. The Salmon Falls River is a border river between the states of Maine and New Hampshire and the fish ladder and associated hydroelectric facility are on the Maine side in the town of South Berwick. The hydroelectric operator is responsible for operation and maintenance of the fish ladder with technical guidance by both NHFGD and Maine Division of Marine Resources. The Denil fish ladder at the head-of-tide dam provides river herring access to a 58 acre impoundment.

6.6.1. Habitat Quality

Dams and natural barriers restrict potential available spawning and nursery habitat in New Hampshire coastal rivers for river herring. Anthropogenic changes to these river systems can further affect habitat (e.g., increased development, increased impervious surfaces, and increased water withdrawals). These may have affected all six river systems, but their effects are the most dramatic in the Exeter and Taylor Rivers. Currently, several New Hampshire state agencies are working with the Town of Exeter on instream flows and water withdrawal for water resources. These factors have affected the downstream emigration of both adult and juvenile river herring with both barrier concerns and water quality issues. These issues came to New Hampshire's attention when low DO levels were monitored in 1995 by the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) that indicated low levels of dissolved oxygen between two and five mg per liter in impoundment reaches of the Exeter River (Rich Langan, unpublished data). The 2016 removal of Great Dam in Exeter should greatly improve water quality in the Exeter River.

6.6.2. Habitat Loss

Once dams are built (with fish passage) or removed, habitat for the two species of river herring can change composition. Therefore habitat loss for one species may benefit the other depending upon whether an impoundment has been developed or a riverine system has been restored. As impoundments degrade due to anthropogenic reasons and become more eutrophic over time habitat continues to be lost.

6.6.3. Habitat Alterations

Fish passage over dams continues to be a problem in New Hampshire where 3,074 active dams have been recorded throughout the state with less than 30 known fish passage systems. New Hampshire Fish and Game has been working with the Department of Environmental Services (DES), and other state and federal agencies to address dam removal projects through the New Hampshire River Restoration Program (RRTF). To date there have been 27 dams completely removed and two partially breached under the RRTF program since 2001, several of which have benefitted diadromous species. The DES continues to work with municipalities with in-stream flow rules for water withdrawals for municipal use.

6.7. RESTORATION PROGRAMS

Restoration activities for river herring in New Hampshire river systems have included constructing and improving upstream passage facilities at dams; stocking of adult fish into historic and viable spawning reaches; removing dams; and improving water quality in spawning and rearing reaches. From 1984 to 2015 approximately 55,600 adult river herring have been stocked in coastal rivers of New Hampshire (Table 6.2). The transfers that occurred were either in-basin transfers to increase spawning habitat or out-of-basin transfers to help supplement spawning runs in rivers with lower return numbers.

Restoration of diadromous fish populations began with construction of fishways from the late 1950s to the early 1970s by the NHFGD in the Cocheco, Exeter, Oyster, Lamprey, Taylor, and Winnicut rivers. These fishways re-opened acres of freshwater spawning and nursery habitat for river herring, American shad, and other diadromous fish. Since that time, modifications have been made to the Exeter River fish ladder to improve the effectiveness at passing alosines and a holding trap was constructed to facilitate monitoring of spawning fish through enumeration and collection of biological data. The last remaining dam on the main stem of the Winnicut River was removed by the NHFGD and DES in 2009. Construction of a Denil fish ladder was completed in early 2012 on Wiswall Dam in Durham. Wiswall Dam is the second dam on the Lamprey River.

6.7.1. Restoration Objective

The restoration target for New Hampshire's river herring is to return rivers populations to levels of abundance that will enable the full utilization of available and/or historical spawning habitat.

6.7.2. Fish Passage Efficiency

New Hampshire has not conducted specific fish passage efficiency studies on the seven fish ladders in coastal rivers.

6.8. AGE

The maximum age for alewife and blueback herring in New Hampshire has been recorded at nine years. Biological samples consisting of length measurements, sex and species determination, and scale samples, used for age determination, are collected from river herring at most fishways annually. Prior to

2009, the biological sampling target for river herring was to obtain three separate samples, one sample taken at each division of the spawning run (beginning, middle, end). Each individual sample attempted to gather approximately 150 length measurements (total length in millimeters) and sex determinations. Scale samples were taken from approximately 50 fish per sample when available. Years in which the target sampling level were reached, resulted in 450 randomly selected sex/length determinations as well as 150 scales for determination of age, sex, and species for each river. Beginning in 2009, scale samples are taken by grouping river herring by species and sex into one centimeter increments (Bins). The returning river herring are sampled throughout the spawning run, in an attempt to obtain a target sampling level of five fish within each bin for each sex and each species.

All alosine scale samples are cleaned, mounted between glass slides, and aged using an overhead scale projector via methods described by Marcy (1969). Prior to 2009, scale samples were also used for species determination for river herring (i.e. alewife or blueback herring) using methods described by MacLellan et al. (1981). Two or more readers independently aged all scales. Beginning in 2009, the bin sampling method controlled the distribution of species in the scale samples; therefore a field species determination of all individuals was incorporated into the 150 random length samples taken during the beginning, middle, and end of the run to determine species distribution within each river.

6.9. FISHERY DESCRIPTIONS

Historically, river herring have been the most prevalent anadromous fishes harvested in New Hampshire and sold as food, fertilizer, bait for commercial or recreational fisheries, and even the scales were utilized for the production of artificial pearls. More recently river herring fisheries have utilized the harvest as bait for commercial and recreational fisheries solely. New Hampshire monitors in-state river herring fisheries through the Coastal Harvest Reporting Program and the National Marine Fisheries Service monitors commercial landings of river herring in New Hampshire through either vessel trip reports or dealer reports from federally permitted vessels or dealers. However, due to the large volume herring fisheries, there is likely an incomplete accounting of river herring as part of the bycatch in the herring fishery.

New Hampshire's Sustainable Fishery Management Plan (SFMP) for river herring was first approved by ASMFC in 2011. The SFMP was re-submitted in 2015 with recent data and the existing management measures—ASMFC approved the 2015 SFMP. The SFMP has two separate targets, one fishery-dependent and one fishery-independent. The fishery-dependent target will be a harvest level that results in a harvest percentage (exploitation rate) that does not exceed 20% in the 'Great Bay Indicator Stock', providing an 80% escapement level. Specifically, a three year running average of the total annual river herring harvest from throughout Great Bay Estuary will be compared to a three year running average of minimum annual counts of spawning river herring returns documented via fish ladder counts on four rivers in Great Bay Estuary plus annual harvest of river herring throughout the estuary system. The fishery-dependent target has not been exceeded since its implementation.

The New Hampshire fishery-independent target for river herring returns is 350 fish per acre of available spawning habitat. This currently equates to a return of 72,450 fish. This target is slightly above 50% of the mean annual river herring return to the Great Bay Estuary since 1990. As of 2017, the fishery-independent target has been reached each year since implementation.

6.9.1. Commercial Fisheries

In 1896 reported river herring catches totaled 293,671 pounds for New Hampshire streams (Bigelow and Schroeder 1953). Most of the current New Hampshire commercial landings of river herring are from vessels fishing in the EEZ. Landings peaked in 1977 at 210,000 pounds and have dropped ever since (Table 6.3; Figure 6.9. Commercial landings (in pounds) of river herring in New Hampshire.). The river herring caught in ocean waters were most likely of mixed stock origin. The very limited harvest of river herring in state waters is primarily for personal use such as lobster or recreational fishing bait. These landings are primarily made through netting activities of state-permitted coastal netters. All individuals participating in netting of river herring with the state are required to annually submit reports of both fishing effort and harvest weight or numbers of river herring taken. The following is a description of the river herring fishery.

Cocheco River

The river herring fishery in the Cocheco River is very sporadic with very few fish harvested over the course of the last several years. Total annual in-river harvest has ranged from zero fish to approximately 550 fish. Harvesters typically fish with cast nets, dip nets, or gill nets. The Cocheco River is closed to fishing from the fish ladder at the lowermost dam to the Washington Street Bridge approximately 200 m downstream. Most of the river herring harvest occurs from the downstream side of the Washington Street Bridge to a distance approximately 0.50 km downstream. In addition, there is a popular striped bass fishery that occurs along this stretch of river. Recreational anglers "snag" river herring to be used as live striped bass bait.

Lamprey River

The river herring harvest at the Lamprey River in recent years has been very low, usually less than 2,000 fish per year. The fishing activity is very sporadic. Landings are reported using a variety of methods including: cast net, gill net, dip net, and weir. Primarily the harvest occurs from approximately 70 m downstream of Macallen Dam to a distance of 0.50 km downstream. There is one weir fisherman that maintains his netting permit but does not consistently fish the weir. It is worth noting that each spring there is a very popular striped bass fishery that occurs within 0.33 km downstream of Macallen Dam. Striped bass anglers "snag" river herring to use as live bait.

Oyster River

There is typically very little river herring harvest that occurs in the Oyster River, usually less than 800 fish per year. The limited harvest that occurs is via dip net, cast net, or gill net. The Oyster River has very few locations where capturing river herring can be done efficiently. Due to this, harvest can occur sporadically anywhere along the tidal portion of the river. In response to diminishing returns of river herring to the Oyster River fish ladder the river was closed to the taking of river herring by any method beginning in 2012.

Squamscott/Exeter River

The river herring fishery that occurs at the Exeter River is conducted to harvest river herring for personal use as bait in fisheries for lobster and striped bass. The majority of the fishing occurs approximately 125 meters downstream of The Great Dam just to the northwest of the String Bridge. There is an elevated ledge under the String Bridge where migrating river herring gather in numbers waiting to ascend the falls. This is the area the harvesters focus their efforts. The gear types utilized by harvesters include; cast nets, gill nets, dip nets, and wire baskets. Despite being legally limited to just a two day fishery and a one tote per day per angler limit, the Exeter River can still account for as much as 90% of the total New Hampshire harvest for river herring.

In 2005, following a number of years of increased harvest in the Squamscott/Exeter River, NHFGD implemented major changes to rules for river herring and shad in this river in order to reduce the harvest levels. These changes included implementing a one tote harvest limit per day and increasing the escapement days from one day per week to 5 days per week. Harvest levels since 2005 have been reduced by at least 50% of the levels observed in 1998 and and many prior years (Table 6.3) and estimates of instantaneous mortality from 2006 to 2009 have been some of the lowest in the time series.

Other Rivers Within the Great Bay Estuary:

The Bellamy, Winnicut, and Salmon Falls Rivers have a very sporadic harvest ranging from 0 fish to as many as 2,548 fish at the Salmon Falls in 1999. The combined harvest from all three rivers ranges from as few as 111 fish in 1992 to 3,127 in 1999. Like many other New Hampshire coastal rivers it is very difficult to capture river herring efficiently at these locations so harvest can occur anywhere along the tidal portion. However, in the Bellamy River some harvest does occur within the fresh water reach of the river just above the head-of-tide. Typically gill nets, cast nets, and dip nets are used to harvest river herring at these locations.

6.9.2. Recreational Fisheries

There is a very limited recreational fishery for river herring at head-of-tide dams on some of New Hampshire's coastal rivers. This recreational fishery mainly occurs on the Squamscott, Cocheco, and Lamprey Rivers. Harvesters catch river herring with various forms of nets, traps, or snagging with hook and line for the purpose of striped bass bait.

6.9.3. Bycatch

Bycatch of river herring likely occurs in commercial fisheries targeting other species. At this time New Hampshire does not evaluate the number of river herring that are caught as bycatch from commercial fisheries within the EEZ landing in New Hampshire. Sea sampling surveys conducted by the NHFGD in the mid-1990s showed river herring bycatch comprised less than 5% of the total catch.

6.10. FISHERY-INDEPENDENT SURVEYS

Two fishery-independent surveys are conducted in New Hampshire to monitor river herring. Each spring or early summer (April through June) NHFGD operates seven fish ladders along coastal rivers to enumerate and monitor migrating diadromous species, described below. In addition to monitoring adult migration of river herring, NHFGD conducts a seine survey in the Great Bay and Hampton-Seabrook estuaries for juvenile finfish that provides an index of relative abundance for a variety of species including alewives and blueback herring.

6.10.1. Adult Catch Data

Seven fish ladders on six coastal New Hampshire rivers (Cocheco, Exeter, Lamprey, Oyster, Winnicut, and Taylor rivers) are operated from early April to mid-July, to allow for the passage of American shad, river herring, and other diadromous fish to historical spawning and nursery areas. The number of fish passing through the fishways are either enumerated by hand or estimated by the use of Smith-Root Model 1101 electronic fish counters. Counts recorded by the electronic fish counters are adjusted by daily calibration counts consisting of a minimum of ten one-minute counts. During daily visits, fish ladders and electronic counting devices are examined to assure of proper operation.

6.10.2. Juvenile Catch Data

A beach seine survey is conducted annually on a monthly basis from June to November at 15 fixed stations in New Hampshire's estuaries. Four of these stations are located in the Hampton-Seabrook Estuary and 11 are located in the Great Bay Estuary. Within the Great Bay Estuary, three stations are located in Little Harbor, three stations are located in the middle to upper Piscataqua River, and five stations are located in Little Bay/Great Bay area.

Beach seine hauls are conducted by boat using a 30.5 m long by 1.8 m high bag seine with 6.4 mm mesh deployed 10 - 15 m from the beach. A single seine haul is made at each station during the months of June through November. Seine hauls are all conducted during daylight hours and constrained to the period of approximately two hours before to two hours after low tide. Seines are set into the current and, at most stations, in water depths less than six feet to prevent the foot rope of the net from coming off the bottom. With each seine haul, surface salinity (ppt) and temperature (^{o}C) are measured and substrate type at the station is observed and recorded.

All fish captured are identified to the lowest possible taxon (species level is the target) and enumerated. All finfish captured are measured, total length to the nearest millimeter up to a maximum of 25 individuals per species per seine haul sample. The primary species of interest are winter flounder, rainbow smelt, river herring, American shad, and Atlantic silverside. In addition, if the following invertebrate species of special interest are captured, they are identified and enumerated: rock crab, Jonah crab, green crab, horseshoe crab, American lobster, and Asian shore crab.

An annual index of relative abundance is determined using the geometric mean catch-per-seine-haul. This relative annual index can be used to determine successful occurrence of river herring spawning activity between years. However, due to the estuary-wide design and limited sampling rate in close proximity to monitored rivers during times of peak juvenile river herring emigration in the late summer/fall months these indices should be used conservatively.

6.11. ASSESSMENT APPROACHES AND RESULTS

6.11.1. Trends in Run Size

New Hampshire has seen a general increase in returns to fish ladders in the last ten years. The Cocheco and Lamprey Rivers generally have the highest number of returning river herring each spring. Returns to these rivers have exceeded 40,000 fish on several occasions (Table 6.1). The Oyster River spawning population has been declining since the early 1990s. The run has decreased from 157,000 fish in 1992 to approximately 1,800 fish in 2015. The Winnicut River monitored spawning run has been generally increasing since 1998; 219 river herring in 1998 and 8,300 river herring in 2008. The Winnicut River Dam and associated fish ladder were removed in 2009. Monitoring of the spawning run in the Winnicut River was hindered in 2010, but a run-of-river fish passage structure was completed early in 2011. Unfortunately the passage structure is ineffective at passing herring and a solution is forthcoming. The Exeter and Taylor Rivers have declining river runs as well. In recent years the Taylor has had so few fish returning that the NHFGD discontinued daily monitoring in 2015. The Exeter River monitored spawning returns are typically are less than 1,000 fish each year, however a return of 5,500 occurred in 2015.

Fish ladder counts in some rivers should be classified as minimum estimates of spawning river herring. For example, large numbers of blueback herring are often observed below the ladders in the Lamprey, Cocheco, and Exeter Rivers in late May but do not ascend the ladders. Despite a recent increasing trend, returns are still lower than those experienced during the 1980’s to early 1990’s. Several factors may be contributing to this. High flows before and during the runs in some years may have influenced the decline in returns in monitored rivers. The passage inefficiency of fish ladders created by unusually high river flow levels, in turn reduces the annual return enumerations in those years. An example of strong control by environmental conditions occurred in 2005, 2006, and 2007 when New Hampshire coastal rivers experienced flood conditions that reached “100 year flood” levels in 2006 and 2007. During years where persistent high river velocity exists in all coastal rivers in the state, many river herring are unable to reach or successfully ascend the fish ladders monitored by the Department. In 2005, above average precipitation levels later in the spawning run reduced blueback returns specifically, which for runs comprised largely of bluebacks, such as the Oyster River, resulted in lowered total annual run sizes. The passage inefficiency of fish ladders created by unusually high river flow levels, in turn reduces the annual return enumerations in those years. River flows in most years since 2007 have been more favorable to fish passage. Other factors affecting returns include; poor water quality affecting survival of young-of-the-year (low DO during summer months, downstream passage problems, water withdrawals by the local municipalities, and drought conditions in some years).

6.11.2. Trends in Length

Total lengths for river herring monitored in New Hampshire coastal rivers ranged from 200 mm to 370 mm in all rivers combined (Table 6.4, Table 6.5, and Table 6.6). The mean length of males varied annually (Table 6.7, Table 6.8, and Table 6.9; Figure 6.11), ranging from 247 mm to 292 mm. Mean length of females ranged from 263 mm to 306 mm. In general, fish returning to the Oyster River had the shortest mean lengths while those returning to the Lamprey River had the longest. This is likely due to the predominance of blueback herring returning to the Oyster River while alewives dominate the monitored spawning runs in the Lamprey River. In most years there are slightly higher percentages of males returning then females.

6.11.3. Trends in Age

The river herring returning to the New Hampshire coastal fish ladders ranged in age from three to nine years old. The majority of alewife returns ranged from age four to six and blueback herring from age three to five (Table 6.10, Table 6.11, and Table 6.12; Figure 6.12). Species were not determined during ageing of scales in 1990.

6.11.4. Trends in Length at Age

Mean total length at age of river herring returning to New Hampshire coastal rivers has decreased over time since 1992 (Figure 6.13, Figure 6.14). Table 6.13, Table 6.14, and Table 6.15 show river specific river herring mean length at age information. Reasons may be degrading impoundments affecting early growth, various environmental factors such as droughts or floods that have affected either immigration or emigration pathways affecting river specific populations as a whole, selective predation, or other stressors that affect growth potential.

6.11.5. Trends in Repeat Spawning

The percentages of repeat spawning fish are determined by the presence or absence of spawning checks observed during the ageing process of collected river herring scales (Table 6.16, Table 6.17, and Table 6.18). River herring were determined to have repeated spawning up to four times in New Hampshire rivers, with the percentage of single year repeat spawning fish as high as 45% in some years.

6.11.6. Juvenile Abundance

The highest relative abundance for juvenile blueback herring as measured by the geometric mean catch per seine haul, occurred in 1999 when nearly 12,000 were captured (Table 6.19). Peaks in relative abundance for alewives occurred in 2002, 2003, and in 2006. The indices, in general, are very low for juvenile alewives. In contrast, blueback herring are one of the more commonly captured species at some stations in certain years.

6.11.7. Total Mortality

The methods used to evaluate total mortality were: Chapman-Robson, Heinecke, and Catch Curve analysis. The analysis calculated total instantaneous mortality (Z) rates and standard errors using ages from spawning river herring returning to the fishways on the Cocheco, Lamprey, Oyster, Winnicut, and Exeter rivers (Table 6.20;Figure 6.15). The catch curve analysis was the most restrictive and did not calculate mortality at times due to the small span of age classes in some rivers and/or years. However, the Chapman-Robson and Heinecke method addressed these biases if sample size included more than one age and the fish aged were greater than the determined fully recruitment age. Both the Chapman-Robson and Heinecke Z estimates essentially followed the same trend pattern over the time series for each river evaluated.

The Cocheco River has both species that utilized the fish ladder. Mortality estimates indicate peak mortality in the early 1990's then generally stabilizing from the late 1990's to the mid-2000's within ranges between 0.5 and 1.5. An increase in mortality started in 2005 for male alewives female alewives have experienced a decreasing trend since 2006. Male blueback herring mortality rates in the Cocheco River remained relatively stable since 2000 however female blueback herring mortality rates declined dramatically between 2003 and 2007 but appear to experiencing an upward trend again in 2008.

The Lamprey River primarily has alewives that negotiate the fish ladder. Very few blueback herring have been sampled from the exit of the fish ladder; they primarily spawn below the dam, therefore are not included in the analysis for the mortality rate in the Lamprey River. The mortality estimates for the alewives range from approximately 0.5 to 2.0. Both sexes follow the general mortality trend but not necessarily within the same year.

The Exeter River has both species that utilize the fish ladder however there is available spawning freshwater habitat below the dam that is utilized by river herring. Issues affecting total mortality may include downstream fish passage of juvenile and post spawned adults inhibited by water withdrawals and low flows coupled with low summer dissolved oxygen levels in impoundments above the dams. Despite the recent work to improve fish passage efficiency of the fish ladder at Great Dam, the vast majority of river herring choose to spawn below the fish ladder in an approximately 0.50 acre area of fresh water that occurs between head-of-tide and the Great Dam caused by an elevated ledge that prevents saltwater incursion. River herring gather in very large numbers below the Great Dam and spawning has been observed. These observations combined with relatively high levels of documented harvest occurring each year below the first dam and the inefficiency of the fish ladder in passing river herring indicates that escapement to spawn in this river is much higher than measured by the number of river herring passing up river through the fish ladder. This lowers the confidence of mortality rates for the Exeter River calculated using passage numbers. However, mortality estimates ranged from 0.01 to 1.7 between the two species and sexes throughout the years and appear to be on a general decline. Fishing by nets on pre-spawned adults may have contributed to a higher mortality prior to 2005 when regulations were imposed to restrict harvest.

The Winnicut River fish ladder was a Canadian step-weir design which was not effective for passing river herring however renovations in 1997 and 2002 allowed more successful passage by river herring. As a result sampling has been more consistent since 1998 but sample size has been low in some years (Table 6.1) which may affect the reliability of mortality estimates. The mortality estimates have ranged from approximately 0.2 to 2.4 since 1998, however the mortality trend is erratic for male and females between the two species. Along with the lack of confidence in mortality estimates due to low sample size, other mortality issues could be due to emigration escapement issues and fluctuations in a developing population as it reaches river carrying capacity.

The Oyster River fish ladder primarily passes blueback herring and very little alewives. The few alewives have not been included within the mortality estimates. The mortality estimates have ranged from 0.24 to greater than 2.0 between 1992 and 2008. Both sexes have experienced similar trends in mortality but not necessarily within the same years. The dissolved oxygen within the Oyster River impoundment has been recently recorded to have levels below 5 mg/l, again likely affecting adult recruitment.

Sampling has been too erratic in the Taylor River to calculate a mortality estimate with any measure of confidence due to the design of the fish ladder and level of sampling.

6.12. BENCHMARKS

6.12.1. Data and Methods

Size at age data from the river systems in general only represent mature fish. We used the length-at-age data collected by the NMFS trawl survey (1973-1986) to estimate length-at-age for immature fish and used length-weight data from ChesMMAP and the Cooperative Winter Tagging Cruise (2008-2010) to convert those lengths-at-age to weight-at-age.

The length-weight relationship developed from the ChesMMAP and Cooperative Winter Tagging Cruise data was used to convert NH's length-at-age estimates to weight-at-age for the spawning stock biomass per recruit estimates.

Repeat spawner marks were used to develop maturity schedules for each species.

Two values of natural mortality were used: 0.3 and 0.7.

Fishing mortality and natural mortality were assumed to occur consistently throughout the year, so the fraction of both that elapsed before spawning was estimated based on the month with the highest run counts (if available) or landings, and was set at 0.33 for both species.

Fishing selectivity was assumed 1 for all ages. Fishing mortality in this analysis was assumed to represent both directed in-river fishing on mature adults and incidental catch of juveniles in the ocean, as well as other sources of mortality, such as passage mortality and increased predation.

The Yield-Per-Recruit Program (v. 2.7.2) from the NMFS Toolbox was used to develop spawning stock biomass per recruit reference points. The YPR program is an implementation of the Thompson-Bell per-recruit model. The maximum age for each river was the oldest age for which biological data were available; it was assumed to represent a plus group with 11 being the oldest age in the plus group for both species.

6.12.2. Results

The SPR benchmarks were sensitive to assumptions about M, which is difficult to estimate empirically for these species.

Estimates of Z in recent years for NH rivers were at or near the Z benchmarks. Only male blueback herring in the Oyster River and male alewife and female blueback herring in the Winnicut River exceeded all Z benchmarks (Table 6.21, Table 6.21).

6.13. CONCLUSIONS AND RECOMMENDATIONS

New Hampshire rivers were severely impacted over the past several centuries, negatively affecting anadromous species. Dams, fishing, and poor water quality are among the many obstacles that river herring have faced. Restoration efforts should continue with focus on the following strategies for New Hampshire coastal rivers targeted for restoration:

1. Continue efforts to monitor and improve water quality.
2. Continue transfers of spawning adult river herring from donor rivers to increase available spawning habitat and augment declining runs in other rivers.
3. Continue work to install upstream and downstream fish passage or remove dams in coastal rivers.
4. Continue to monitor returns of spawning adult river herring to fish ladders.
5. Efforts should be made to identify and reduce all sources of mortality whether during ocean residency or in-river.

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Table 6.1 Numbers of river herring returning to fishways on coastal New Hampshire rivers.

Year	Cocheco River	Exeter River	Oyster River	Lamprey River	Taylor River	Winnicut River	Annual Total
1972				2,528		+	2,528
1973				1,380		+	1,380
1974				1,627		+	1,627
1975		2,639		2,882		+	5,521
1976	9,500		11,777	3,951	450,000	+	475,228
1977	29,500		359	11,256		2,700++	43,815
1978	1,925	205	419	20,461	168,256	3,229++	194,495
1979	586	186	496	23,747	375,302	3,410++	403,727
1980	7,713	2,516	2,921	26,512	205,420	4,393++	249,475
1981	6,559	15,626	5,099	50,226	94,060	2,316++	173,886
1982	4,129	542	6,563	66,189	126,182	2,500++	206,105
1983	968	1	8,866	54,546	151,100	+	215,481
1984	477		5,179	40,213	45,600	+	91,469
1985	974		4,116	54,365	108,201	+	167,656
1986	2,612	1,125	93,024	46,623	117,000	1,000++	261,384
1987	3,557	220	57,745	45,895	63,514	+	170,931
1988	3,915		73,866	31,897	30,297	+	139,975
1989	18,455		38,925	26,149	41,395	+	124,924
1990	31,697		154,588	25,457	27,210	+	238,952
1991	25,753	313	151,975	29,871	46,392	+	254,304
1992	72,491	537	157,024	16,511	49,108	+	295,671
1993	40,372	278	73,788	25,289	84,859	+	224,586
1994	33,140	*	91,974	14,119	42,164	+	181,397
1995	79,385	592	82,895	15,904	14,757	+	193,533
1996	32,767	248	82,362	11,200	10,113	+	136,690
1997	31,182	1,302	57,920	22,236	20,420	+	133,060
1998	25,277	392	85,116	15,947	11,979	219	138,930
1999	16,679	2,821	88,063	20,067	25,197	305	153,132
2000	30,938	533	70,873	25,678	44,010	528	172,560
2001	46,590	6,703	66,989	39,330	7,065	1,118	167,795
2002	62,472	3,341	58,179	58,065	5,829	7,041	194,927
2003	71,199	71	51,536	64,486	1,397	5,427	194,116
2004	47,934	83	52,934	66,333	1,055	8,044	176,383
2005	16,446	66	12,882	40,026	233	2,703	72,356
2006	4,318	16	6,035	23,471	147	822	34,809
2007	15,815	40	17,421	55,225	217**	7,543	96,261
2008	30,686	168	20,780	36,247	976	8,359	97,214
2009	36,165	513	11,661	42,425	*	4,974	95,737
2010	32,654	69	19,006	33,327	675	576+++	86,307
2011	43,090	256	4,755	50,447	59	72+++	99,338
2012	27,608	378	2,573	86,862	92	5+++	117,518
2013	18,337	588	7,149	79,408	128	0	105,610
2014	29,968	789	4,227	84,868	57	0	119,909
2015	64,456	5,562	1,803	69,843	*	0	141,664

* - Swim through operation.

** -Due to fish counter malfunction there was up to two weeks where passing fish were not enumerated.

+ - Fishway unable to pass fish until modifications in 1997.

++ - Fish netted below and hand passed over Winnicut River dam.

+++ - Minimum estimate based on time counts, fishway/dam removed in fall 2009.

Table 6.2 Numbers of river herring stocked in coastal New Hampshire rivers from 1984 - 2015.

Year	Cocheco River System	Winnicut River	Exeter River	Lamprey River System	Salmon Falls River
1984	5,000				
1985	500				
1986	2,000				
1987	2,125				
1988	2,000				
1989					
1990	2,000				
1991	1,700				
1992	1,300				
1993					
1994	365[a]			320[a]	220
1995	1,400[a]		125	3,230[b]	250
1996	750[a]			2,100[a]	200
1997	950[a]			2,000[a]	300
1998	1,000[a]	300		1,975[a]	240
1999	990[a]	200		2,020[a]	200
2000	1,000[a]	430		2,020[a]	320
2001	1,000[a]			2,000[a]	200
2002	1,000[a]			1,900[a]	
2003	1,100[a]			2,000[a]	
2004	1,050[a]		100	2,000[b]	
2005	1,000[a]		200	2,000[b]	
2006	1,000[a]		40	200[b]	
2007	900[a]		175	2,000[b]	
2008	1,000[a]		250	2,000[b]	
2009	500[a]		250	750[b]	
2010	1,000[a]			750[b]	
2011	2,000[a]	200	659	2,145[a]	
2012	1,000[a]			1,000[a]	
2013	480[a]				
2014					
2015	1,000[a]	250		1,500[a]	

[a] - In-river transfer.

[b] - Combination of in-river and out-of-basin transfers.

Table 6.3 Reported ocean commercial landings (kg) of river herring in New Hampshire from the NMFS, 1957-2015.

Year	Species*	Metric Tons	Pounds	$
1957	River Herring	34	75,000	750
1958	River Herring	27.2	60,000	600
1959	River Herring	36.3	80,000	800
1960	River Herring	43.1	95,000	1,000
1961	River Herring	45.4	100,000	1,000
1962	River Herring	56.7	125,000	1,250
1963	River Herring	68	150,000	1,500
1964	River Herring	34	75,000	1,125
1965	River Herring	56.7	125,000	1,875
1966	River Herring	34	75,000	1,125
1967	River Herring	29.5	65,000	1,650
1968	River Herring	18.4	40,600	1,043
1969	River Herring	17	37,500	1,081
1970	River Herring	14.1	31,000	930
1971	River Herring	11.3	25,000	750
1972	River Herring	10.9	24,000	800
1973	River Herring	9.8	21,500	944
1977	River Herring	95.3	210,000	7,518
1978	River Herring	74.8	165,000	8,200
1982	River Herring	51.9	114,500	7,400
1983	River Herring	52.3	115,216	10,730
1984	River Herring	40.8	90,000	6,300
1985	River Herring	27.8	61,300	7,128
1986	River Herring	12.2	26,990	2,275
1987	River Herring	8.9	19,550	2,346
1988	River Herring	5.5	12,087	5,440
1989	River Herring	5.1	11,200	5,478
1992	River Herring	4.4	9,802	4,900
1993	River Herring	1.2	2,676	576
1998	River Herring	11.8	25,994	3,795
2008	River Herring	3.7	8,137	1,839
2009	River Herring	4.3	9,443	1,761
2010	River Herring	3.4	7,466	*
2011	River Herring	1.9	4,094	*
2012	River Herring	1.2	2,681	*
2013	River Herring	2.0	4,420	*
2014	River Herring	2.6	5,737	*
2015	River Herring	3.4	7,566	*
GRAND TOTAL		960.9	2,118,459	93,909

*- River herring harvested by NH coastal harvesters for personnel use

Table 6.4 Length frequency of river herring returning to New Hampshire rivers, 1994-2015.

Length (cm)	Cocheco River – Combined Species																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	1	0	2	0	0	1	0	0	0	0	0	0	5	0	0	0	0	0	0	0
23	3	0	1	11	5	0	3	2	19	1	3	0	0	1	14	5	8	0	0	4	7	1
24	15	1	2	63	19	4	25	0	39	15	6	0	8	19	28	12	23	5	1	37	28	2
25	16	4	10	83	43	24	49	23	43	34	20	10	23	50	55	32	67	22	0	94	86	22
26	44	18	22	97	105	75	90	56	54	71	55	30	31	86	99	75	73	57	7	106	123	44
27	35	29	39	60	132	98	115	120	58	125	94	58	34	111	103	139	74	134	30	47	118	113
28	17	45	50	39	97	125	55	123	76	120	88	62	59	103	87	110	77	121	108	37	99	118
29	9	30	53	40	40	79	52	69	75	60	86	97	70	48	41	63	67	66	147	26	46	100
30	2	11	30	33	13	47	43	48	64	16	60	62	49	18	19	13	46	28	115	64	40	38
31	1	1	14	19	12	0	18	13	20	10	26	20	14	12	3	5	11	14	34	27	27	10
32	0	1	2	6	5	3	5	3	5	2	7	6	10	6	0	2	2	3	7	8	19	1
33	0	0	0	1	1	2	0	0	0	0	5	2	2	2	0	0	0	0	1	0	6	0
34	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1
35	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	142	140	224	452	475	458	455	458	453	454	450	347	300	457	454	456	450	450	450	450	600	450

Table 6.4 Continued.

Length (cm)	Exeter River– Combined Species																				
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	2	0	3	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
23	0	0	0	42	2	4	0	0	0	0	0	2	0	1	2	0	0	4	0	2	0	0
24	0	1	0	233	22	11	4	0	6	1	0	0	0	3	7	3	4	4	2	11	23	2
25	0	11	0	251	66	50	21	11	18	1	1	4	0	6	21	11	11	28	2	45	37	50
26	0	27	0	158	86	120	65	66	31	2	11	9	1	7	37	45	14	66	8	104	61	127
27	0	43	2	164	95	120	73	124	37	14	29	24	2	7	55	129	8	70	27	110	85	122
28	0	38	11	126	69	62	61	129	36	27	19	15	7	9	29	99	5	47	46	59	82	65
29	0	19	6	67	33	24	24	91	25	15	13	15	4	4	12	38	3	10	56	22	56	42
30	0	6	2	24	7	6	8	26	6	4	3	4	1	1	2	9	2	2	26	8	22	31
31	0	1	0	5	4	2	2	5	1	1	2	1	0	1	2	2	1	0	9	3	7	9
32	0	1	1	1	0	1	1	1	0	2	0	1	1	0	1	0	0	0	1	2	2	2
33	0	0	0	1	2	0	0	0	0	0	0	2	0	1	0	0	0	1	1	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	*	147	22	1075	386	403	259	454	160	67	78	77	16	40	168	336	48	233	179	366	375	450

**- Due to damage to fish trap, fishway became a swim through operation*

Table 6.4 Continued.

Length (cm)	Lamprey River– Combined Species																				
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
24	1	1	0	2	3	2	6	0	0	0	6	1	4	20	5	2	23	6	2	6	3	1
25	12	1	3	11	18	21	36	7	5	31	19	2	13	31	40	13	56	42	9	25	31	19
26	18	15	13	37	50	66	72	31	20	54	49	21	18	27	90	35	66	87	19	81	74	55
27	48	32	14	45	71	100	128	78	37	54	100	49	18	44	128	99	29	119	54	69	67	100
28	31	43	38	35	80	97	150	113	68	91	88	98	47	70	80	144	42	77	91	58	75	81
29	19	31	33	56	58	99	92	118	107	78	59	94	78	66	60	100	62	49	136	66	66	81
30	9	12	17	60	34	45	79	71	103	77	65	83	79	60	26	37	53	43	90	75	48	50
31	1	5	8	47	18	13	30	25	79	39	46	32	52	48	18	13	24	20	42	53	51	37
32	2	2	1	9	6	7	11	7	30	19	11	16	16	30	3	5	12	4	6	15	24	18
33	0	0	0	2	1	3	3	2	7	4	6	6	6	12	3	1	1	2	0	1	9	7
34	0	0	0	0	0	0	0	0	2	1	4	0	1	2	0	2	1	0	1	0	1	1
35	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	141	142	127	304	339	453	608	452	459	449	453	402	333	411	453	451	369	450	450	450	449	450

Table 6.4 Continued.

Length (cm)	Oyster River– Combined Species																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
22	0	0	0	0	1	1	3	0	1	0	1	7	8	1	11	0	0	3	27	0	0	0
23	7	0	3	11	15	4	4	1	15	0	5	17	49	31	98	13	8	26	43	6	4	0
24	19	0	12	72	46	20	33	6	123	42	31	40	136	98	99	91	71	84	36	49	38	3
25	28	27	29	74	91	105	78	41	86	107	85	63	106	106	83	120	171	86	83	146	78	39
26	24	43	46	113	137	147	112	116	75	136	133	90	53	126	87	46	126	92	93	128	112	139
27	23	33	24	93	109	111	111	130	96	87	110	71	49	62	49	19	60	88	81	79	106	125
28	20	16	17	62	60	52	69	98	46	40	53	44	26	20	22	7	17	43	56	33	56	82
29	13	10	1	16	38	11	30	42	29	28	28	11	19	7	2	3	3	22	16	8	34	38
30	4	14	1	4	5	2	6	12	3	6	5	0	2	2	2	0	0	5	12	1	16	16
31	0	1	0	3	3	0	0	3	0	1	1	0	0	0	0	0	1	1	1	0	5	8
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
33	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	138	150	133	448	506	453	446	449	474	447	452	343	448	453	453	299	457	450	450	450	450	450

Table 6.4 Continued.

Length (cm)	Winnicut River– Combined Species																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	2	0	0	0	0	7	2	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	2	26	0	2	1	1	26	5	7	6	3	0	0	0	0	0	0
23	0	0	0	0	3	6	87	6	25	32	13	74	30	35	29	47	0	0	0	0	0	0
24	0	0	0	0	23	36	98	50	109	138	59	65	31	75	64	91	0	0	0	0	0	0
25	0	0	0	0	26	70	107	119	145	127	116	64	16	135	98	98	0	0	0	0	0	0
26	0	0	0	0	16	64	62	126	90	99	149	46	14	106	128	88	0	0	0	0	0	0
27	0	0	0	0	6	26	43	91	49	37	80	38	11	52	75	62	0	0	0	0	0	0
28	0	0	0	0	3	9	17	57	22	7	29	19	6	18	37	42	0	0	0	0	0	0
29	0	0	0	0	1	2	7	13	7	2	5	4	7	8	15	18	0	0	0	0	0	0
30	0	0	0	0	1	2	1	2	3	1	0	0	1	7	3	0	0	0	0	0	0	0
31	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	3	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	*0	*0	*0	*0	79	218	450	464	453	444	453	343	124	443	457	452	^0	^0	^0	^0	^0	^0

**- Fishway unable to pass fish.*

^-Fishway and dam removed Summer 2009

Table 6.4 Continued.

Length (cm)	Taylor River– Combined Species																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	7	14	2	0	1	0	4	0	0	0	4	0	0	0	0	0	0	0
24	0	0	0	0	35	29	6	0	0	0	20	1	0	0	3	0	0	0	0	0	0	0
25	0	0	0	0	33	45	58	0	0	0	19	8	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	16	49	70	0	3	0	12	3	0	3	0	0	0	0	0	0	0	0
27	0	0	0	0	18	25	66	0	7	0	8	2	0	5	0	0	0	0	0	0	0	0
28	0	0	0	0	9	11	33	0	7	0	10	0	0	3	0	0	0	0	0	0	0	0
29	0	0	0	0	5	3	8	0	8	0	6	0	0	4	0	0	0	0	0	0	0	0
30	0	0	0	0	1	1	3	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0
31	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	*0	*0	*0	*0	125	181	247	0	26	0	80	14	0	18	7	0	0	0	0	0	0	^0

** -data not available for selected year*

^-No fish sampled, ASMFC removed NHFGD monitoring requirement

Table 6.5 Length frequency of alewife river herring returning to New Hampshire rivers, 1994-2015.

Length (cm)	Cocheco River - Alewife																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	7	1
24	4	1	0	3	0	0	0	0	0	0	0	0	0	1	1	3	7	5	1	34	28	2
25	8	1	3	11	0	2	1	0	1	2	0	1	3	0	3	9	20	22	0	92	85	22
26	27	2	15	9	10	4	11	3	7	4	3	6	5	2	15	14	24	57	7	106	123	44
27	37	11	22	9	27	20	25	20	10	29	14	16	5	13	26	21	18	134	30	47	117	113
28	26	34	33	8	44	29	26	30	22	36	20	27	13	27	26	18	16	121	108	37	99	118
29	10	41	47	7	15	37	18	34	21	25	28	28	22	21	17	17	7	66	147	26	46	100
30	5	17	39	11	9	10	18	19	21	8	21	24	18	12	8	5	3	28	115	64	40	38
31	2	4	25	8	5	6	7	8	7	4	13	10	8	8	2	1	0	14	34	27	27	10
32	0	1	3	2	3	2	0	3	3	3	2	7	1	4	0	0	0	3	7	8	19	1
33	0	0	1	2	2	1	0	0	1	0	0	1	2	3	0	0	0	0	1	0	6	0
34	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	1
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	119	112	190	70	115	111	106	117	93	111	102	120	77	92	98	88	96	450	450	445	598	450

Table 6.5 Continued.

Length (cm)	Exeter River - Alewife																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
23	0	0	0	1	0	3	0	0	0	0	0	1	0	1	0	0	0	4	0	2	0	0
24	0	0	0	1	1	2	0	0	0	0	0	1	0	0	1	1	2	4	1	11	7	0
25	0	0	0	7	5	3	3	0	0	0	0	2	0	4	7	3	8	28	2	45	24	17
26	0	11	0	14	8	13	9	1	6	1	0	4	1	9	27	20	5	66	8	104	59	69
27	0	27	2	19	18	41	29	6	11	7	10	14	2	7	33	73	5	70	27	110	83	98
28	0	48	8	29	33	20	29	18	19	16	15	17	1	9	43	131	3	47	46	59	82	58
29	0	24	5	21	18	15	17	20	11	20	12	16	7	6	18	58	2	10	56	22	56	41
30	0	11	3	14	5	6	6	10	5	5	3	4	4	2	3	17	0	2	26	8	22	31
31	0	5	1	3	4	2	1	1	0	3	3	2	0	1	1	4	1	0	9	3	7	9
32	0	1	1	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0	1	2	2	2
33	0	0	0	1	0	0	0	0	0	1	0	1	1	1	0	0	0	1	1	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	*	127	20	111	92	105	94	56	52	54	44	64	16	40	134	307	26	233	178	366	311	325

**- Due to damage to fish trap, fishway became a swim through operation*

Table 6.5 Continued.

Length (cm)	Lamprey River - Alewife																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
23	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
24	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	2	6	2	6	3	1
25	9	2	2	1	6	6	5	0	1	2	6	1	5	5	5	1	6	42	9	25	31	19
26	12	1	8	9	22	8	17	5	3	20	13	4	9	7	17	6	14	87	19	81	74	55
27	30	22	12	11	27	27	30	12	12	13	22	9	11	10	39	24	10	119	54	69	67	100
28	47	32	25	10	30	35	36	39	18	22	37	24	6	18	24	45	3	77	91	58	75	81
29	25	36	41	13	28	27	47	40	28	26	32	38	23	27	31	32	1	49	136	66	66	81
30	12	14	24	30	16	22	27	30	35	28	19	24	31	30	13	26	0	43	90	75	48	50
31	4	8	10	14	5	11	23	12	23	12	23	20	24	18	9	7	1	20	42	53	51	37
32	1	3	5	4	0	3	7	6	12	13	5	4	9	11	5	3	0	4	6	15	24	18
33	1	1	1	1	0	1	2	1	5	3	3	3	4	9	0	1	0	2	0	1	9	7
34	0	0	0	0	0	0	1	0	2	0	2	1	0	3	0	0	0	0	1	0	1	1
35	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	141	119	128	94	135	141	195	145	139	140	162	128	122	140	143	145	37	450	450	450	449	450

Table 6.5 Continued.

Length (cm)	Oyster River - Alewife																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	3	7	2	0
25	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	5	16	10	11	29	3	10
26	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	6	13	24	13	52	17	38
27	0	1	2	0	0	0	0	0	0	0	0	0	0	0	1	2	15	55	17	62	15	43
28	0	3	2	0	0	0	0	0	0	0	2	0	0	0	1	0	5	32	12	26	28	36
29	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	20	12	7	28	20
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	5	12	1	13	9
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	5	7
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	8	5	0	0	0	0	0	1	0	3	0	0	0	4	15	54	149	83	185	112	163

Table 6.5 Continued.

Length (cm)	Winnicut River - Alewife																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	1	8	1	1	0	1	0	0	0	0	0	0
23	0	0	0	0	0	1	1	0	0	0	0	16	5	8	3	3	0	0	0	0	0	0
24	0	0	0	0	1	4	8	8	5	11	4	21	7	19	8	15	0	0	0	0	0	0
25	0	0	0	0	0	17	4	19	21	17	11	14	5	25	14	17	0	0	0	0	0	0
26	0	0	0	0	1	21	3	25	23	24	34	16	1	40	37	18	0	0	0	0	0	0
27	0	0	0	0	2	11	3	21	17	11	29	17	3	24	37	27	0	0	0	0	0	0
28	0	0	0	0	1	10	2	11	6	6	9	5	3	9	21	14	0	0	0	0	0	0
29	0	0	0	0	0	2	0	3	5	1	4	2	3	7	9	17	0	0	0	0	0	0
30	0	0	0	0	0	1	0	0	1	0	0	0	3	3	4	2	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	2	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	*0	*0	*0	*0	5	67	21	87	79	70	92	100	32	139	134	116	^0	^0	^0	^0	^0	^0

**- Fishway unable to pass fish.*

^-Fishway and dam removed Summer 2009

Table 6.5 Continued.

Length (cm)	Taylor River - Alewife																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
29	0	0	0	0	1	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	*0	*0	*0	*0	3	0	0	0	0	0	1	0	0	19	0	0	0	0	0	0	0	^0

** data not available for selected year*

^-No fish sampled, ASMFC removed NHFGD monitoring requirement

Table 6.6 Length frequency of blueback river herring returning to New Hampshire rivers, 1994-2015.

Length (cm)	Cocheco River - Blueback																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	1	0	0	2	0	0	0	0	3	0	0	0	0	0	3	1	7	0	0	0	0	0
24	4	0	0	8	3	0	2	0	10	0	0	0	1	1	7	0	10	0	0	3	0	0
25	10	0	8	18	15	0	6	1	14	7	0	0	0	17	9	0	26	0	0	2	1	0
26	1	8	5	20	14	9	9	5	7	11	7	3	2	18	13	0	8	0	0	0	0	0
27	4	8	14	10	15	16	4	8	6	5	7	2	1	21	8	0	1	0	0	0	1	0
28	2	4	8	10	6	4	2	11	7	2	1	0	2	5	7	1	0	0	0	0	0	0
29	1	3	4	5	1	0	2	0	5	0	2	0	2	5	1	0	0	0	0	0	0	0
30	0	2	3	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	23	25	42	75	54	29	25	25	53	25	17	5	8	67	48	2	53	0	0	5	2	0

Table 6.6 Continued.

Length (cm)	Exeter River - Blueback																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
24	0	0	0	22	2	0	0	0	0	0	0	0	0	0	2	1	0	0	1	0	16	2
25	0	5	0	40	23	3	0	0	0	1	0	0	0	0	4	2	1	0	0	0	13	33
26	0	11	0	34	31	15	1	9	0	0	3	0	0	0	3	2	0	0	0	0	2	58
27	0	9	0	27	16	22	0	26	1	0	6	0	0	0	0	1	0	0	0	0	2	24
28	0	14	0	25	4	7	1	20	0	0	4	0	0	0	0	0	0	0	0	0	0	7
29	0	12	1	11	3	2	0	16	1	0	0	0	0	0	1	0	0	0	0	0	0	1
30	0	7	1	1	0	0	1	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	1	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	*0	61	2	161	80	51	3	85	2	1	13	0	0	0	12	6	1	0	1	0	33	125

**- Due to damage to fish trap, fishway became a swim through operation*

Table 6.6 Continued.

Length (cm)	Lamprey River - Blueback																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0	0	0	0
25	0	0	0	1	0	7	0	0	0	0	0	0	0	2	0	0	18	0	0	0	0	0
26	0	0	0	0	0	7	0	0	0	2	0	0	0	2	0	0	10	0	0	0	0	0
27	0	2	0	0	0	2	0	0	0	1	0	0	1	5	0	1	1	0	0	0	0	0
28	0	3	0	0	0	3	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
29	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	13	0	2	0	19	0	0	0	3	0	0	2	11	0	1	32	0	0	0	0	0

Table 6.6 Continued.

Length (cm)	Oyster River - Blueback																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0	3	27	0	0	0
23	4	0	2	2	0	1	0	0	1	0	0	1	8	3	16	0	8	26	41	5	4	0
24	15	1	5	15	8	4	5	1	11	5	5	20	23	30	43	13	66	82	33	42	36	3
25	30	10	23	24	16	13	17	6	43	23	19	11	38	35	25	33	153	76	72	117	75	29
26	28	39	37	36	34	39	30	25	21	53	30	28	25	45	29	22	112	68	80	76	95	101
27	24	32	31	35	33	44	51	48	30	32	39	22	11	37	20	10	44	33	64	17	91	82
28	18	16	25	15	35	34	21	41	21	15	23	31	19	20	9	7	12	11	44	7	28	46
29	20	10	4	15	17	8	17	14	11	15	9	9	13	8	2	1	3	2	4	1	6	18
30	8	8	0	5	6	2	2	8	2	5	3	0	2	1	0	0	0	0	0	0	3	7
31	0	3	1	1	2	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	1
32	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	147	120	128	150	151	145	143	144	141	149	128	126	141	179	145	86	398	301	367	265	338	287

Table 6.6 Continued.

Length (cm)	Winnicut River - Blueback																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	4	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
23	0	0	0	0	1	3	17	0	1	3	1	4	12	4	0	3	0	0	0	0	0	0
24	0	0	0	0	13	8	28	2	9	15	5	16	16	4	3	0	0	0	0	0	0	0
25	0	0	0	0	27	16	40	14	29	21	13	10	16	6	1	12	0	0	0	0	0	0
26	0	0	0	0	18	24	28	12	14	21	9	10	15	7	6	15	0	0	0	0	0	0
27	0	0	0	0	9	13	21	15	8	14	10	5	4	3	4	2	0	0	0	0	0	0
28	0	0	0	0	2	3	14	10	5	2	6	6	4	5	1	1	0	0	0	0	0	0
29	0	0	0	0	2	2	3	5	2	1	0	1	3	0	1	0	0	0	0	0	0	0
30	0	0	0	0	1	0	2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
31	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	*0	*0	*0	*0	74	69	157	59	68	77	44	52	73	30	16	33	^0	^0	^0	^0	^0	^0

**- Fishway unable to pass fish.*

^-Fishway and dam removed Summer 2009

Table 6.6 Continued.

Length (cm)	Taylor River - Blueback																					
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	2	3	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0
24	0	0	0	0	21	12	2	0	1	0	8	0	0	0	4	0	0	0	0	0	0	0
25	0	0	0	0	35	11	8	0	0	0	19	6	0	0	1	0	0	0	0	0	0	0
26	0	0	0	0	22	18	28	0	1	0	13	5	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	16	12	29	0	3	0	9	3	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	10	5	19	0	11	0	9	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	4	3	9	0	11	0	4	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	4	2	2	0	3	0	3	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	*0	*0	*0	*0	115	67	97	0	30	0	67	14	0	0	7	0	0	0	0	0	0	^0

** data not available for selected year*

^-No fish sampled, ASMFC removed NHFGD monitoring requirement

Table 6.7 Percent of male and female river herring, mean total length (mm), and total sampled river herring during spawning returns to the first dam on the Cocheco, Exeter, Oyster, Lamprey, Taylor, and Winnicut rivers, New Hampshire, 1994-2015.

	Cocheco River– Combined Species					Exeter River– Combined Species					Oyster River– Combined Species				
	%		Mean Length		Total	%		Mean Length		Total	%		Mean Length		Total
Year	Male	Female	Male	Female	N	Male	Female	Male	Female	N	Male	Female	Male	Female	N
1994	56.5	44.5	274	274	462	*	*	*	*	*	63.2	36.8	262	277	450
1995	48.8	51.2	279	287	450	66.5	33.5	271	284	520	53.0	47.0	264	277	450
1996	50.7	49.3	282	290	402	54.8	45.2	278	284	221	61.4	38.6	258	270	446
1997	63.7	36.3	267	278	452	59.2	40.8	262	266	1075	60.7	39.3	261	272	448
1998	52.4	47.6	271	280	475	64.5	35.5	268	278	386	48.2	51.8	261	273	506
1999	52.4	47.6	277	288	458	65.8	34.2	267	278	403	57.4	42.6	261	273	453
2000	61.5	38.5	272	285	455	66.0	34.0	273	280	259	59.0	41.0	263	277	446
2001	54.1	45.9	278	286	458	59.7	40.3	277	288	454	60.8	39.2	269	283	449
2002	59.6	40.4	273	287	453	63.1	36.9	272	282	160	69.0	31.0	259	270	474
2003	49.3	50.7	275	280	454	62.7	37.3	283	291	67	51.7	48.3	260	272	447
2004	42.4	57.6	282	288	450	57.7	42.3	277	286	78	58.0	42.0	263	275	452
2005	50.4	49.6	285	294	347	66.2	33.8	278	289	77	60.5	39.5	257	273	343
2006	60.0	40.0	281	295	300	43.8	56.2	281	295	16	79.1	20.9	251	273	448
2007	62.8	37.2	272	285	457	60.0	40.0	268	283	40	64.7	35.3	254	267	453
2008	59.0	41.0	266	279	454	58.3	41.7	268	278	168	65.8	34.2	248	263	453
2009	58.3	41.7	273	282	456	56.3	43.8	276	283	336	76.6	23.4	251	265	299
2010	66.7	33.3	275	278	450	60.4	39.6	263	277	48	66.3	33.7	256	266	457
2011	56.7	43.3	276	287	354	64.4	35.6	267	279	230	56.9	42.9	258	269	149
2012	47.8	52.2	290	299	320	40.2	58.7	283	294	328	50.4	49.6	252	273	454
2013	54.9	44.9	271	279	452	62.8	37.2	268	279	364	57.8	42.2	259	267	604
2014	55.2	44.7	272	284	587	66.1	33.9	273	285	375	49.8	50.2	263	277	337
2015	53.2	46.8	279	290	450	71.1	28.9	267	279	450	59.2	40.8	271	282	450

**-Sampling did not occur.*

Table 6.7 Continued.

	Lamprey River– Combined Species					Taylor River– Combined Species					Winnicut River– Combined Species				
	%		Mean Length		Total	%		Mean Length		Total	%		Mean Length		Total
Year	Male	Female	Male	Female	N	Male	Female	Male	Female	N	Male	Female	Male	Female	N
1994	51.9	48.1	274	281	447	*	*	*	*	*	*	*	*	*	*
1995	52.6	47.4	279	293	450	*	*	*	*	*	*	*	*	*	*
1996	51.0	49.0	281	294	398	*	*	*	*	*	*	*	*	*	*
1997	46.7	53.3	284	297	304	*	*	*	*	*	*	*	*	*	*
1998	56.3	43.7	279	289	339	70.4	29.6	253	274	125	84.8	15.2	254	271	79
1999	52.3	47.7	279	289	453	61.9	38.1	253	269	181	82.6	17.4	257	271	218
2000	52.3	47.7	279	290	608	44.9	55.1	261	274	247	79.8	20.2	248	265	450
2001	58.2	41.8	286	294	452	*	*	*	*	*	71.8	28.2	262	273	464
2002	58.2	41.8	292	306	459	38.5	61.5	269	288	26	73.7	26.3	255	265	453
2003	57.2	42.8	284	296	449	*	*	*	*	*	85.4	14.6	253	264	444
2004	53.0	47.0	285	290	453	63.8	36.2	255	275	80	79.0	21.0	260	269	453
2005	57.2	42.8	290	298	402	71.4	28.6	256	263	14	78.4	21.6	247	266	343
2006	55.3	44.7	289	303	333	*	*	*	*	*	89.5	10.5	251	264	124
2007	59.6	40.4	282	303	411	61.1	38.9	287	279	18	88.0	12.0	257	270	443
2008	47.5	52.5	274	283	453	*	*	*	*	*	81.4	18.6	259	274	457
2009	60.3	39.7	282	291	451	*	*	*	*	*	82.1	17.9	256	277	452
2010	60.7	39.3	272	296	369	*	*	*	*	*	*	*	*	*	*
2011	56.2	43.8	274	286	450	*	*	*	*	*	*	*	*	*	*
2012	55.1	44.9	287	298	470	*	*	*	*	*	*	*	*	*	*
2013	50.2	49.8	280	293	756	*	*	*	*	*	*	*	*	*	*
2014	52.3	47.7	283	292	450	*	*	*	*	*	*	*	*	*	*
2015	54.7	45.3	288	302	450	*	*	*	*	*	*	*	*	*	*

**-Sampling did not occur.*

Table 6.8 Percent of male and female alewife river herring, mean total length (mm), and total sampled river herring during spawning returns to the first dam on the Cocheco, Exeter, Oyster, Lamprey, Taylor, and Winnicut rivers, New Hampshire, 1994-2015.

	Cocheco River - Alewife					Exeter River - Alewife					Oyster River - Alewife				
	%		Mean Length		Total	%		Mean Length		Total	%		Mean Length		Total
Year	Male	Female	Male	Female	N	Male	Female	Male	Female	N	Male	Female	Male	Female	N
1994	58.0%	42.0%	268	274	119	*	*	*	*	*	+	+	+	+	0
1995	50.9%	49.1%	282	289	112	64.6%	35.4%	277	288	127	50.0%	50.0%	261	270	8
1996	52.1%	47.9%	283	293	190	60.0%	40.0%	283	296	20	80.0%	20.0%	267	283	5
1997	75.7%	24.3%	276	291	70	64.9%	35.1%	275	286	111	+	+	+	+	0
1998	53.0%	47.0%	277	287	115	58.7%	41.3%	276	279	92	+	+	+	+	0
1999	52.3%	47.7%	280	290	111	64.8%	35.2%	272	277	105	+	+	+	+	0
2000	56.6%	43.4%	279	287	106	71.3%	28.7%	275	283	94	+	+	+	+	0
2001	45.3%	54.7%	280	292	117	71.4%	28.6%	283	291	56	+	+	+	+	0
2002	61.3%	38.7%	284	293	93	63.5%	36.5%	277	284	52	100.0%	0.0%	290	0	1
2003	39.6%	60.4%	279	284	111	61.1%	38.9%	283	293	54	+	+	+	+	0
2004	44.1%	55.9%	286	292	102	63.6%	36.4%	279	293	44	33.3%	66.7%	281	284	3
2005	48.3%	51.7%	283	294	120	65.6%	34.4%	277	289	64	+	+	+	+	0
2006	64.9%	35.1%	284	296	77	43.8%	56.3%	281	295	16	+	+	+	+	0
2007	49.5%	49.5%	283	295	93	60.0%	40.0%	268	283	40	+	+	+	+	0
2008	58.2%	41.8%	273	281	98	60.4%	39.6%	269	280	134	75.0%	25.0%	271	268	4
2009	51.1%	48.9%	271	283	184	58.3%	41.7%	276	283	307	68.8%	31.3%	259	269	16
2010	48.6%	51.4%	283	294	72	50.0%	50.0%	265	280	32	72.7%	27.3%	256	282	22
2011	52.0%	48.0%	274	292	75	58.7%	41.3%	267	280	63	54.8%	45.2%	271	285	62
2012	46.0%	50.8%	287	299	63	45.8%	54.2%	279	294	59	48.0%	52.0%	268	279	50
2013	50.6%	49.4%	279	291	87	48.6%	51.4%	274	283	70	47.7%	52.3%	266	279	65
2014	48.1%	51.9%	280	291	106	51.4%	48.6%	280	288	70	46.0%	54.0%	282	296	50
2015	48.8%	51.3%	283	293	80	50.8%	50.8%	280	292	63	49.2%	50.8%	280	290	59

**-Sampling did not occur.*
+-Sampling occurred but no alewife encountered in run.

Table 6.8 Continued.

	Lamprey River - Alewife					Taylor River - Alewife					Winnicut River - Alewife				
	%		Mean Length		Total	%		Mean Length		Total	%		Mean Length		Total
Year	Male	Female	Male	Female	N	Male	Female	Male	Female	N	Male	Female	Male	Female	N
1994	55.3%	44.7%	274	284	141	*	*	*	*	*	*	*	*	*	*
1995	46.2%	53.8%	278	292	119	*	*	*	*	*	*	*	*	*	*
1996	51.6%	48.4%	283	293	128	*	*	*	*	*	*	*	*	*	*
1997	51.1%	48.9%	286	294	94	*	*	*	*	*	*	*	*	*	*
1998	58.5%	41.5%	275	285	135	66.7%	33.3%	260	286	3	80.0%	20.0%	261	267	5
1999	48.9%	51.1%	277	290	141	+	+	+	+	0	77.6%	22.4%	259	272	67
2000	52.3%	47.7%	282	291	195	+	+	+	+	0	66.7%	33.3%	245	264	21
2001	56.6%	43.4%	287	293	145	*	*	*	*	*	73.6%	26.4%	259	268	87
2002	59.7%	40.3%	290	305	139	+	+	+	+	0	83.5%	16.5%	259	276	79
2003	64.3%	35.7%	285	296	140	*	*	*	*	*	88.6%	11.4%	255	272	70
2004	53.1%	46.9%	283	292	162	100.0%	0.0%	251	0	1	77.2%	22.8%	263	269	92
2005	53.1%	46.9%	287	297	128	+	+	+	+	0	81.0%	19.0%	245	265	100
2006	50.0%	50.0%	285	301	122	*	*	*	*	*	93.8%	6.3%	254	279	32
2007	59.3%	40.7%	285	307	140	57.9%	42.1%	287	281	19	84.2%	15.8%	258	273	139
2008	42.7%	57.3%	276	285	143	+	+	+	+	0	79.9%	20.1%	264	273	134
2009	54.8%	45.2%	282	291	197	*	*	*	*	*	66.9%	33.1%	260	277	166
2010	45.7%	54.3%	279	294	81	*	*	*	*	*	*	*	*	*	*
2011	47.6%	51.2%	280	290	84	*	*	*	*	*	*	*	*	*	*
2012	48.1%	51.9%	282	290	79	*	*	*	*	*	*	*	*	*	*
2013	50.0%	50.0%	279	291	82	*	*	*	*	*	*	*	*	*	*
2014	49.5%	50.5%	285	295	101	*	*	*	*	*	*	*	*	*	*
2015	49.4%	50.6%	288	298	83	*	*	*	*	*	*	*	*	*	*

**-Sampling did not occur.*

+-Sampling occurred but no alewife encountered in run.

Table 6.9 Percent of male and female blueback river herring, mean total length (mm), and total sampled river herring during spawning returns to the first dam on the Cocheco, Exeter, Oyster, Lamprey, Taylor, and Winnicut rivers, New Hampshire, 1994-2015.

	Cocheco River - Blueback					Exeter River - Blueback					Oyster River - Blueback				
	%		Mean Length		Total	%		Mean Length		Total	%		Mean Length		Total
Year	Male	Female	Male	Female	N	Male	Female	Male	Female	N	Male	Female	Male	Female	N
1994	69.6%	30.4%	251	259	23	*	*	*	*	*	68.0%	32.0%	260	276	147
1995	24.0%	76.0%	269	274	25	67.2%	32.8%	272	292	61	52.5%	47.5%	266	277	120
1996	50.0%	50.0%	265	277	42	100.0%	0.0%	294		2	57.0%	43.0%	260	269	128
1997	58.7%	41.3%	257	268	75	85.7%	14.3%	260	272	161	66.7%	33.3%	261	275	150
1998	59.3%	40.7%	258	267	54	77.5%	22.5%	257	277	80	47.0%	53.0%	264	275	151
1999	65.5%	34.5%	265	270	29	72.5%	27.5%	263	274	51	57.2%	42.8%	263	274	145
2000	76.0%	24.0%	258	271	25	100.0%	0.0%	278		3	62.2%	37.8%	263	277	143
2001	52.0%	48.0%	267	273	25	55.3%	44.7%	272	288	85	58.3%	40.3%	268	282	144
2002	71.7%	28.3%	255	267	53	50.0%	50.0%	266	286	2	73.8%	26.2%	260	271	141
2003	52.0%	48.0%	256	265	25	100.0%	0.0%	249		1	56.4%	43.6%	261	273	149
2004	41.2%	58.8%	263	273	17	69.2%	30.8%	268	274	13	59.4%	40.6%	263	273	128
2005	80.0%	20.0%	262	263	5	+	+	+	+	0	61.9%	37.3%	255	276	126
2006	62.5%	37.5%	263	282	8	+	+	+	+	0	74.5%	24.1%	254	277	141
2007	70.1%	29.9%	260	269	67	+	+	+	+	0	59.2%	40.8%	254	267	179
2008	64.6%	35.4%	250	272	48	58.3%	41.7%	248	271	12	71.0%	29.0%	247	261	145
2009	50.0%	50.0%	234	282	2	100.0%	0.0%	255		6	66.4%	33.6%	253	267	119
2010	79.2%	20.8%	252	249	53	100.0%	0.0%	259		1	66.1%	33.9%	256	264	398
2011	+	+	+	+	0	100.0%	0.0%	268		1	46.8%	53.2%	250	266	62
2012	+	+	+	+	0	+	+	+	+	0	53.2%	46.8%	254	268	62
2013	80.0%	20.0%	247	258	5	+	+	+	+	0	41.7%	58.3%	254	266	60
2014	0.0%	100.0%		264	2	78.8%	21.2%	249	257	33	53.1%	46.9%	259	276	64
2015	+	+	+	+	0	51.2%	48.8%	265	274	41	41.5%	58.5%	273	282	53

**-Sampling did not occur.*
+-Sampling occurred but no blueback encountered in run.

Table 6.9 Continued.

	Lamprey River - Blueback					Taylor River - Blueback					Winnicut River - Blueback				
	%		Mean Length		Total	%		Mean Length		Total	%		Mean Length		Total
Year	Male	Female	Male	Female	N	Male	Female	Male	Female	N	Male	Female	Male	Female	N
1994	+	+	+	+	0	*	*	*	*	*	*	*	*	*	*
1995	38.5%	61.5%	288	292	13	*	*	*	*	*	*	*	*	*	*
1996	+	+	+	+	0	*	*	*	*	*	*	*	*	*	*
1997	0.0%	100.0%		282	2	*	*	*	*	*	*	*	*	*	*
1998	+	+	+	+	0	73.0%	27.0%	253	271	115	85.1%	14.9%	254	271	74
1999	47.4%	52.6%	253	265	19	67.2%	32.8%	253	272	67	88.4%	11.6%	256	267	69
2000	+	+	+	+	0	48.5%	51.5%	262	274	97	72.0%	28.0%	249	265	157
2001	+	+	+	+	0	*	*	*	*	*	78.0%	22.0%	262	279	59
2002	+	+	+	+	0	33.3%	66.7%	268	288	30	75.0%	25.0%	253	263	68
2003	100.0%	0.0%	264		3	*	*	*	*	*	85.7%	14.3%	254	258	77
2004	+	+	+	+	0	58.2%	41.8%	254	273	67	79.5%	20.5%	256	269	44
2005	+	+	+	+	0	71.4%	28.6%	256	263	14	80.8%	19.2%	249	267	52
2006	100.0%	0.0%	256		2	*	*	*	*	*	84.9%	15.1%	247	257	73
2007	63.6%	36.4%	262	271	11	+	+	+	+	0	83.3%	16.7%	254	266	30
2008	+	+	+	+	0	100.0%	0.0%	239		7	87.5%	12.5%	260	278	16
2009	75.0%	25.0%	255	251	4	*	*	*	*	*	65.1%	34.9%	252	265	43
2010	90.6%	9.4%	256	268	32	*	*	*	*	*	*	*	*	*	*
2011	+	+	+	+	0	*	*	*	*	*	*	*	*	*	*
2012	+	+	+	+	0	*	*	*	*	*	*	*	*	*	*
2013	+	+	+	+	0	*	*	*	*	*	*	*	*	*	*
2014	+	+	+	+	0	*	*	*	*	*	*	*	*	*	*
2015	+	+	+	+	0	*	*	*	*	*	*	*	*	*	*

**-Sampling did not occur.*

+-Sampling occurred but no blueback encountered in run.

Table 6.10 Number-at-age of river herring collected from the coastal rivers of New Hampshire, 1994-2015.

Cocheco River– Combined Species																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	69	19	45	45	29	6	61	20	17	6	1	2	0	0	6	13	5	2	1	3	1	4
4	61	74	78	49	65	62	36	61	54	89	15	29	13	31	27	75	13	16	16	38	26	24
5	10	42	63	34	50	47	27	43	45	29	69	47	21	55	57	48	28	32	19	16	36	23
6	0	2	35	14	15	20	7	9	24	7	26	46	25	54	44	42	19	19	17	13	20	18
7+	0	0	2	3	10	5	0	9	6	5	8	1	26	19	12	8	7	6	10	1	25	11
Total	140	137	223	145	169	140	131	142	146	136	119	125	85	159	146	186	72	75	63	91	108	81

Exeter River– Combined Species																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	*	70	6	82	69	23	53	8	2	2	0	2	0	3	21	3	6	6	1	5	4	1
4	*	94	11	112	44	88	37	45	15	30	6	25	1	9	62	147	17	24	13	29	44	61
5	*	17	5	52	37	38	5	47	27	14	31	26	6	15	44	119	12	27	30	19	35	28
6	*	4	0	22	16	7	2	31	10	6	18	8	4	11	16	39	3	6	12	10	15	13
7+	*	0	0	4	6	0	0	10	0	3	2	3	5	2	3	5	0	1	3	7	5	1
Total	*	185	22	272	172	156	97	141	54	55	57	64	16	40	146	313	38	64	59	70	103	104

Oyster River– Combined Species																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	65	33	32	64	36	44	61	21	12	32	20	22	6	9	46	33	29	51	12	16	4	3
4	48	68	61	50	58	84	56	48	54	62	17	38	46	71	48	64	23	43	40	70	32	46
5	23	25	37	28	44	15	25	39	37	43	69	45	46	68	38	22	32	21	38	22	60	38
6	4	2	3	7	11	2	1	24	28	7	21	20	32	22	11	13	10	6	17	13	14	21
7+	0	0	0	1	2	0	0	10	11	5	4	0	9	9	6	3	6	3	5	4	4	4
Total	140	128	133	150	151	145	143	142	142	149	131	125	139	179	149	135	100	124	112	125	114	112

Table 6.10 Continued.

Lamprey River– Combined Species																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	48	26	26	15	18	15	50	11	3	8	7	0	3	2	9	6	10	5	1	4^	4	2
4	68	74	60	18	30	44	68	49	28	53	26	25	13	21	25	44	21	25	24	28	29	27
5	19	31	35	35	46	53	44	52	39	41	63	55	42	42	52	79	27	34	30	13	27	22
6	5	1	5	24	31	35	26	26	42	17	45	44	36	54	37	60	25	15	16	24	25	15
7+	1	0	0	4	10	13	7	7	27	24	21	4	30	32	20	12	9	5	8	13	16	17
Total	141	132	126	96	135	160	195	145	139	143	162	128	124	151	143	201	92	84	79	82	101	83

Taylor River– Combined Species																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	*	*	*	*	49	48	31	*	1	*	22	1	*	0	3	*	*	*	*	*	*	*
4	*	*	*	*	33	10	47	*	1	*	19	13	*	1	4	*	*	*	*	*	*	*
5	*	*	*	*	24	4	14	*	6	*	15	0	*	10	0	*	*	*	*	*	*	*
6	*	*	*	*	6	5	5	*	16	*	7	0	*	6	0	*	*	*	*	*	*	*
7+	*	*	*	*	6	0	0	*	6	*	5	0	*	2	0	*	*	*	*	*	*	*
Total	*	*	*	*	118	67	97	*	30	*	68	14	*	19	7	*	*	*	*	*	*	*

Winnicut River– Combined Species																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	*	*	*	*	45	44	60	42	29	36	3	48	9	5	5	30	*	*	*	*	*	*
4	*	*	*	*	24	69	70	64	61	88	58	52	41	56	29	65	*	*	*	*	*	*
5	*	*	*	*	4	19	30	25	30	21	66	38	34	60	71	40	*	*	*	*	*	*
6	*	*	*	*	4	4	16	14	21	2	7	13	16	32	37	49	*	*	*	*	*	*
7+	*	*	*	*	2	0	2	1	6	0	2	1	5	16	8	25	*	*	*	*	*	*
Total	*	*	*	*	79	136	178	146	147	147	136	152	105	169	150	209	*	*	*	*	*	*

** data not available for selected year*

Table 6.11 Number-at-age of alewife river herring collected from the coastal rivers of New Hampshire, 1994-2015.

Cocheco River - Alewife																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	52	10	37	18	11	1	48	14	3	4	1	2	0	0	0	13	5	1	1	1	1	4
4	57	60	61	15	38	45	26	52	29	72	10	28	9	7	18	74	13	20	16	35	25	24
5	10	40	51	23	42	40	25	36	33	26	57	43	19	29	37	48	28	26	19	16	36	23
6	0	2	31	12	14	20	7	7	22	5	26	46	25	39	33	41	19	16	17	13	19	18
7+	0	0	1	2	10	5	0	8	6	4	8	1	24	18	10	8	7	12	10	21	25	11
Total	119	112	181	70	115	111	106	117	93	111	102	120	77	93	98	184	72	75	63	66	106	80

Exeter River – Alewife																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	*	44	5	24	20	12	52	2	2	1	0	2	0	3	17	0	4	13	1	5	0	1
4	*	68	11	55	23	51	36	16	14	30	2	25	1	9	57	146	15	21	13	29	23	34
5	*	11	4	21	30	35	4	29	26	14	23	26	6	15	44	118	11	21	30	19	28	16
6	*	1	0	7	14	7	2	8	10	6	17	8	4	11	14	39	2	8	12	10	14	11
7+	*	0	0	4	5	0	0	1	0	3	2	3	5	2	2	4	0	0	3	7	5	1
Total	*	124	20	111	92	105	94	56	52	54	44	64	16	40	134	307	32	63	59	70	70	63

Oyster River – Alewife																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	0	3	1	0	0	0	0	0	0	0	0	0	0	0	1	3	2	5	2	4	1	0
4	0	5	3	0	0	0	0	0	0	0	0	0	0	0	0	6	13	18	17	34	7	25
5	0	0	1	0	0	0	0	0	1	0	2	0	0	0	2	2	3	30	14	14	29	21
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	8	13	9	10	10
7+	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	3	2	1	4	4	3	3
Total	0	8	5	0	0	0	0	0	1	0	3	0	0	0	4	16	22	62	50	65	50	59

Table 6.11 Continued.

Lamprey River – Alewife																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	48	25	26	15	18	3	50	11	3	8	7	0	2	0	9	4	9	0	1	3	4	2
4	68	65	60	17	30	38	68	49	28	53	26	25	13	19	25	44	16	20	24	28	29	27
5	19	28	35	35	46	52	44	52	39	38	63	55	41	38	52	78	25	23	30	13	27	22
6	5	1	5	23	31	35	26	26	42	17	45	44	36	52	37	59	24	23	16	24	25	15
7+	1	0	0	4	10	13	7	7	27	24	21	4	30	31	20	12	7	18	8	13	16	17
Total	141	119	126	94	135	141	195	145	139	140	162	128	122	140	143	197	81	84	79	81	101	83

Taylor River – Alewife																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	*	*	*	*	0	0	0	*	0	*	0	0	*	0	0	*	*	*	*	*	*	*
4	*	*	*	*	2	0	0	*	0	*	0	0	*	1	0	*	*	*	*	*	*	*
5	*	*	*	*	0	0	0	*	0	*	1	0	*	10	0	*	*	*	*	*	*	*
6	*	*	*	*	0	0	0	*	0	*	0	0	*	6	0	*	*	*	*	*	*	*
7+	*	*	*	*	1	0	0	*	0	*	0	0	*	2	0	*	*	*	*	*	*	*
Total	*	*	*	*	3	0	0	*	0	*	1	0	*	19	0	*	*	*	*	*	*	*

Winnicut River – Alewife																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	*	*	*	*	1	12	9	28	18	20	2	34	4	5	3	21	*	*	*	*	*	*
4	*	*	*	*	3	38	7	41	23	40	36	31	9	45	24	35	*	*	*	*	*	*
5	*	*	*	*	0	13	2	9	18	9	47	24	9	51	66	37	*	*	*	*	*	*
6	*	*	*	*	1	4	2	9	15	1	5	10	7	24	33	49	*	*	*	*	*	*
7+	*	*	*	*	0	0	1	0	5	0	2	1	3	14	8	24	*	*	*	*	*	*
Total	*	*	*	*	5	67	21	87	79	70	92	100	32	139	134	166	*	*	*	*	*	*

** data not available for selected year*

Table 6.12 Number-at-age of blueback river herring collected from the coastal rivers of New Hampshire, 1994-2015.

Cocheco River - Blueback																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	17	9	8	27	18	5	13	6	14	2	0	0	0	0	6	0	0	0	0	2	0	0
4	4	14	17	34	27	17	10	9	25	17	5	1	4	24	9	1	0	0	0	3	1	0
5	0	2	12	11	8	7	2	7	12	3	12	4	2	27	20	0	0	0	0	0	0	0
6	0	0	4	2	1	0	0	2	2	2	0	0	0	15	11	1	0	0	0	0	1	0
7+	0	0	1	1	0	0	0	1	0	1	0	0	2	1	2	0	0	0	0	0	0	0
Total	21	25	42	75	54	29	25	25	53	25	17	5	8	67	48	2	0	0	0	5	2	0

Exeter River – Blueback																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	*	26	1	58	49	11	1	6	0	1	0	0	0	0	4	3	2	0	0	0	4	0
4	*	26	0	57	21	37	1	29	1	0	4	0	0	0	5	1	2	0	0	0	21	27
5	*	6	1	31	7	3	1	18	1	0	8	0	0	0	0	1	1	1	0	0	7	12
6	*	3	0	15	2	0	0	23	0	0	1	0	0	0	2	0	1	0	0	0	1	2
7+	*	0	0	0	1	0	0	9	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Total	*	61	2	161	80	51	3	85	2	1	13	0	0	0	12	6	6	1	0	0	33	41

Oyster River – Blueback																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	65	30	31	64	36	44	61	21	12	32	20	22	6	9	45	30	27	25	10	12	3	3
4	48	63	58	50	58	84	56	49	54	62	17	39	48	71	48	58	10	21	23	36	25	21
5	23	25	36	28	44	15	25	39	36	43	67	45	46	68	36	20	29	9	24	8	31	17
6	4	2	3	7	11	2	1	25	28	7	21	20	32	22	11	11	8	5	4	4	4	11
7+	0	0	0	1	2	0	0	10	11	5	3	0	9	9	5	0	4	2	1	0	1	1
Total	140	120	128	150	151	145	143	144	141	149	128	126	141	179	145	119	78	62	62	60	64	53

Table 6.12 Continued.

Lamprey River – Blueback																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	0	1	0	0	0	12	0	0	0	0	0	0	1	2	0	2	1	0	0	0	0	0
4	0	9	0	1	0	6	0	0	0	0	0	0	0	2	0	0	5	0	0	0	0	0
5	0	3	0	0	0	1	0	0	0	3	0	0	1	4	0	1	2	0	0	0	0	0
6	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	1	1	0	0	0	0	0
7+	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0
Total	0	13	0	2	0	19	0	0	0	3	0	0	2	11	0	4	11	0	0	0	0	0

Taylor River – Blueback																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	*	*	*	*	49	48	31	*	1	*	22	1	*	0	3	*	*	*	*	*	*	*
4	*	*	*	*	31	10	47	*	1	*	19	13	*	0	4	*	*	*	*	*	*	*
5	*	*	*	*	24	4	14	*	6	*	14	0	*	0	0	*	*	*	*	*	*	*
6	*	*	*	*	6	5	5	*	16	*	7	0	*	0	0	*	*	*	*	*	*	*
7+	*	*	*	*	5	0	0	*	6	*	5	0	*	0	0	*	*	*	*	*	*	*
Total	*	*	*	*	115	67	97	*	30	*	67	14	*	0	7	*	*	*	*	*	*	*

Winnicut River – Blueback																						
Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3	*	*	*	*	44	32	51	14	11	16	1	14	5	0	2	9	*	*	*	*	*	*
4	*	*	*	*	21	31	63	23	38	48	22	21	32	11	5	30	*	*	*	*	*	*
5	*	*	*	*	4	6	28	16	12	12	19	14	25	9	5	3	*	*	*	*	*	*
6	*	*	*	*	3	0	14	5	6	1	2	3	9	8	4	0	*	*	*	*	*	*
7+	*	*	*	*	2	0	1	1	1	0	0	0	2	2	0	1	*	*	*	*	*	*
Total	*	*	*	*	74	69	157	59	68	77	44	52	73	30	16	43	*	*	*	*	*	*

** data not available for selected year*

Table 6.13 Mean total length-at-age (TL, mm) of river herring returning to New Hampshire rivers, 1992-2015.

Cocheco River– Combined Species																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	280	249	260	268	272	253	258	258	268	271	248	262	266	258			236	249	255	246	244	245	245	266
4	284	267	273	282	282	262	269	273	277	280	266	274	274	273	265	261	257	266	273	263	284	261	255	270
5	314	284	292	290	292	286	280	284	295	288	284	285	282	284	280	268	271	281	293	273	283	285	279	281
6	322	300		307	296	305	293	294	304	292	300	294	300	300	291	285	277	292	297	301	301	303	296	302
7+	328				311	309	314	314		309	306	305	311	315	298	312	290	312	306	311	317	313	318	325

Exeter River– Combined Species																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	274		*	271	285	253	257	259	270	272	266	252		236		245	252	250	253	255	244	253	246	265
4	283	264	*	283	285	268	270	269	283	274	273	283	271	272	273	261	270	275	265	268	276	263	260	271
5	290	279	*	296	300	282	280	279	293	285	281	289	277	283	284	271	279	280	285	281	287	283	278	285
6	302	298	*	317		289	288	297	306	287	287	295	288	301	285	289	282	286	290	285	295	304	293	300
7+	292	319	*			315	312			287		314	311	322	300	306	310	291			317	309	317	328

Oyster River– Combined Species																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	267	242	253	262	257	255	254	258	261	260	250	254	249	241	235	243	238	249	250	245	238	246	249	258
4	277	264	273	270	265	267	269	269	271	271	252	261	264	256	245	250	248	255	260	263	255	261	264	272
5	288	278	288	283	269	280	278	281	280	276	268	275	270	272	258	264	262	269	269	280	274	279	279	288
6	303	289	293	308	274	292	293	296	281	281	276	286	276	280	277	271	273	275	274	293	288	294	294	290
7+	318					318	307			287	284	298	290		291	288	281	286	282	285	291	311	308	305

Table 6.13 Continued.

Lamprey River– Combined Species																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	283		269	274	278	263	261	253	273	272	262	264	259		247	247	261	250	254		256	250	252	255
4	293	274	279	285	287	274	266	268	281	282	279	276	271	273	261	268	269	272	261	258	267	263	268	271
5	302	283	292	297	296	296	281	281	295	292	294	288	284	290	285	279	277	285	288	275	285	287	285	295
6	320	301	308	314	300	305	292	296	304	299	304	298	294	301	302	299	287	295	303	294	304	301	307	302
7+	321		329			316	304	312	312	306	311	319	313	324	310	313	305	307	309	314	318	314	321	321

Taylor River– Combined Species																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	*	251	*	*	*	*	246	253	263	*	236	*	247	253	*		241	*	*	*	*	*	*	*
4	*	265	*	*	*	*	255	266	267	*	266	*	258	258	*	264	238	*	*	*	*	*	*	*
5	*	279	*	*	*	*	272	282	274	*	275	*	267		*	276		*	*	*	*	*	*	*
6	*	295	*	*	*	*	284	294	291	*	284	*	281		*	295		*	*	*	*	*	*	*
7+	*	309	*	*	*	*	296			*	291	*	296		*	308		*	*	*	*	*	*	*

Winnicut River– Combined Species																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	*	*	*	*	*	*	249	250	239	254	250	247	232	233	229	239	235	237	*	*	*	*	*	*
4	*	*	*	*	*	*	260	261	253	262	252	256	258	248	242	247	254	254	*	*	*	*	*	*
5	*	*	*	*	*	*	271	273	269	272	266	269	266	268	252	258	263	265	*	*	*	*	*	*
6	*	*	*	*	*	*	285	289	274	281	272	280	274	268	275	270	278	279	*	*	*	*	*	*
7+	*	*	*	*	*	*	303		289	268	291		277	263	281	292	287	289	*	*	*	*	*	*

**data not available for selected year*

Table 6.14 Mean total length-at-age (TL, mm) of alewife river herring returning to New Hampshire rivers, 1992-2015.

Cocheco River - Alewife																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	285	249	263	272	274	261	267	250	273	274	262	265	266	258				249	255	246	244	248	245	266
4	288	271	273	283	286	262	273	276	280	281	275	277	279	273	266	273	262	266	273	263	284	262	255	270
5	316	291	292	290	296	289	281	287	297	291	288	287	284	286	281	276	276	281	293	273	283	285	279	281
6	322	302		307	298	308	294	294	304	297	301	306	300	300	291	288	280	292	297	301	301	303	297	302
7+	328				325	305	314	314		313	306	312	311	315	299	314	294	312	306	312	317	312	318	325

Exeter River-Alewife																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	279		*	274	284	261	260	258	270	282	266	255		236		245	255		256	255	244	253		265
4	284	262	*	283	285	276	275	270	283	280	274	283	276	272	273	261	272	276	265	268	276	263	266	274
5	292	282	*	296	302	292	280	280	292	287	281	289	279	283	284	271	279	280	284	282	287	283	286	296
6	304	302	*	305		299	289	297	306	289	287	294	289	301	284	289	282	286	304	285	295	304	296	305
7+		329	*			315	307			298		314	311	322	300	306	308	297			317	309	317	328

Oyster River - Alewife																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	272			262	278												231	250	276	258	246	248	265	
4	281			268	269													255	257	267	253	261	278	273
5	298				266						290		284				274	264	258	281	283	283	288	290
6	297																	261	276	296	288	296	296	297
7+	324												281				303	286	278	281	293	311	313	307

Table 6.14 Continued.

Lamprey River - Alewife																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	283		269	274	278	263	261	249	273	272	262	264	259		250		261	252	254		256	250	252	255
4	293	274	279	284	287	275	266	268	281	282	279	276	271	273	261	269	269	272	260	258	267	263	268	271
5	302	282	292	297	296	296	281	281	295	292	294	290	284	290	286	280	277	285	290	275	285	287	285	295
6	320	301	308	314	300	305	292	296	304	299	304	298	294	301	302	300	287	295	304	294	304	301	307	302
7+	321		329			316	304	312	312	306	311	319	313	324	310	314	305	307	322	314	318	314	321	321

Taylor River - Alewife																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	*	256	*	*	*	*				*		*			*			*	*	*	*	*	*	*
4	*	260	*	*	*	*	260			*		*			*	264		*	*	*	*	*	*	*
5	*	279	*	*	*	*				*		*	251		*	276		*	*	*	*	*	*	*
6	*		*	*	*	*				*		*			*	295		*	*	*	*	*	*	*
7+	*		*	*	*	*	286			*		*			*	308		*	*	*	*	*	*	*

Winnicut River - Alewife																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	*	*	*	*	*	*	244	249	240	254	251	248	234	231	227	239	233	234	*	*	*	*	*	*
4	*	*	*	*	*	*	263	259	252	261	254	259	260	247	243	248	254	250	*	*	*	*	*	*
5	*	*	*	*	*	*		273	264	270	265	269	266	268	251	258	263	265	*	*	*	*	*	*
6	*	*	*	*	*	*	277	288	276	278	271	290	277	269	284	271	278	279	*	*	*	*	*	*
7+	*	*	*	*	*	*			282		294		276	263	281	292	286	290	*	*	*	*	*	*

**data not available for selected year*

Table 6.15 Mean total length-at-age (TL, mm) of blueback river herring returning to New Hampshire rivers, 1992-2015.

Cocheco River – Blueback																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	273		252	264	262	248	252	260	252	262	245	255					236					244		
4	277	263	268	275	266	262	264	267	268	273	256	260	264	258	262	257	247	234				253	254	
5	299	277		294	276	282	274	270	278	270	273	261	271	263	274	259	262							
6	322	292			282	288	287			277	290	266				277	268	282					273	
7+					297	318				280		277			286	292	272							

Exeter River – Blueback																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	264		*	267	292	249	255	261	255	268		249					239	250	244				246	
4	276	268	*	281		260	265	267	282	271	266		268				254	251	264				252	267
5	283	277	*	294	295	276	278	271	298	281	286		270					260	301				248	272
6	297	292	*	321		284	279			287			275				276		262				264	276
7+	292	308	*				334			286							312	270						

Oyster River – Blueback																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	267	242	253	262	256	255	254	258	261	260	250	254	249	241	234	243	238	248	248	242	237	246	243	258
4	276	264	273	270	265	267	269	269	271	270	252	261	264	256	245	250	248	255	264	260	256	261	261	271
5	287	278	288	283	269	280	278	281	280	276	268	275	269	272	258	264	261	269	270	276	269	271	271	286
6	304	290	293	308	274	292	293	296	281	281	276	286	276	280	277	271	273	277	273	288	288	290	288	284
7+	316					318	306			287	284	298	292		291	288	276		284	287	284		292	299

Table 6.15 Continued.

Lamprey River – Blueback																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3				279				254							241	247		245	257					
4	280			287		253		270								262			262					
5		288		304				250				264			271	267		258	265					
6						312										279		269	263					
7+																272			260					

Taylor River – Blueback																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	*	248	*	*	*	*	246	252	263	*	236	*	247	253	*		241	*	*	*	*	*	*	*
4	*	264	*	*	*	*	255	266	267	*	266	*	258	258	*		238	*	*	*	*	*	*	*
5	*	279	*	*	*	*	272	282	274	*	275	*	268		*			*	*	*	*	*	*	*
6	*	295	*	*	*	*	284	294	291	*	284	*	281		*			*	*	*	*	*	*	*
7+	*	309	*	*	*	*	298			*	290	*	296		*			*	*	*	*	*	*	*

Winnicut River – Blueback																								
Mean Length (mm) at Age																								
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Age																								
3	*	*	*	*	*	*	249	250	239	255	247	245	230	239	230		239	245	*	*	*	*	*	*
4	*	*	*	*	*	*	260	262	253	263	251	254	256	249	242	241	256	259	*	*	*	*	*	*
5	*	*	*	*	*	*	271	274	269	273	267	268	264	270	252	254	266	262	*	*	*	*	*	*
6	*	*	*	*	*	*	287		274	285	274	270	267	266	269	270	276		*	*	*	*	*	*
7+	*	*	*	*	*	*	303		296	268	276				281	292		287	*	*	*	*	*	*

**data not available for selected year*

Table 6.16 Distribution of repeat spawning frequency of river herring returning to New Hampshire rivers, from scale samples aged between 2000 and 2015.

	Cocheco River - Combined Species					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	66%	15%	18%	1%	0%	131
2001	57%	33%	6%	2%	1%	142
2002	63%	25%	12%	0%	0%	146
2003	71%	16%	10%	3%	0%	136
2004	34%	45%	18%	3%	0%	119
2005	47%	29%	18%	6%	0%	125
2006	53%	24%	13%	8%	2%	85
2007	69%	17%	9%	4%	1%	160
2008	68%	26%	6%	0%	0%	146
2009	78%	21%	1%	0%	0%	90
2010	35%	35%	29%	1%	0%	72
2011	64%	21%	12%	9%	0%	75
2012	41%	40%	16%	2%	2%	63
2013	53%	23%	15%	8%	0%	93
2014	44%	27%	19%	11%	0%	108
2015	62%	19%	7%	10%	1%	81

	Exeter River - Combined Species					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	90%	8%	2%	0%	0%	97
2001	48%	33%	16%	3%	0%	141
2002	80%	13%	7%	0%	0%	54
2003	62%	25%	13%	0%	0%	55
2004	58%	26%	14%	2%	0%	57
2005	78%	16%	3%	3%	0%	64
2006	63%	31%	6%	0%	0%	16
2007	83%	15%	3%	0%	0%	40
2008	90%	8%	2%	1%	0%	146
2009	88%	11%	1%	0%	0%	314
2010	76%	21%	0%	3%	0%	38
2011	89%	11%	0%	0%	0%	64
2012	66%	25%	8%	0%	0%	59
2013	71%	20%	9%	0%	0%	70
2014	64%	30%	5%	1%	0%	103
2015	66%	25%	8%	1%	0%	104

Table 6.16 Continued

	Oyster River - Combined Species					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	66%	26%	7%	2%	0%	145
2001	36%	42%	16%	5%	1%	146
2002	63%	17%	15%	4%	0%	142
2003	49%	32%	16%	3%	0%	149
2004	32%	25%	34%	8%	1%	131
2005	50%	35%	14%	1%	0%	126
2006	57%	24%	13%	6%	0%	141
2007	62%	28%	7%	3%	0%	179
2008	72%	17%	7%	3%	0%	149
2009	59%	35%	6%	0%	0%	101
2010	53%	24%	18%	5%	0%	100
2011	73%	38%	9%	4%	0%	124
2012	60%	31%	17%	3%	1%	112
2013	81%	12%	6%	0%	0%	126
2014	33%	60%	6%	1%	0%	114
2015	47%	29%	18%	4%	1%	112

	Lamprey River - Combined Species					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	54%	26%	17%	3%	1%	195
2001	41%	45%	10%	3%	0%	145
2002	37%	29%	29%	5%	0%	139
2003	48%	27%	20%	6%	0%	143
2004	45%	27%	20%	7%	1%	162
2005	48%	36%	14%	2%	0%	128
2006	41%	34%	19%	6%	0%	124
2007	43%	27%	22%	6%	2%	151
2008	67%	20%	8%	3%	1%	143
2009	50%	40%	9%	1%	0%	146
2010	36%	39%	20%	5%	0%	92
2011	52%	21%	15%	11%	0%	84
2012	54%	33%	10%	3%	0%	79
2013	46%	30%	18%	5%	0%	82
2014	43%	40%	13%	4%	1%	101
2015	42%	25%	22%	11%	0%	83

Table 6.16 Continued

	Taylor River - Combined Species					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	69%	28%	2%	1%	0%	97
2001	*	*	*	*	*	*
2002	7%	40%	47%	7%	0%	30
2003	*	*	*	*	*	*
2004	71%	15%	10%	4%	0%	68
2005	93%	7%	0%	0%	0%	14
2006	*	*	*	*	*	*
2007	68%	26%	5%	0%	0%	19
2008	100%	0%	0%	0%	0%	7
2009	*	*	*	*	*	*
2010	*	*	*	*	*	*
2011	*	*	*	*	*	*
2012	*	*	*	*	*	*
2013	*	*	*	*	*	*
2014	*	*	*	*	*	*
2015	*	*	*	*	*	*

	Winnicut River - Combined Species					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	77%	11%	9%	3%	0%	179
2001	57%	33%	9%	1%	0%	146
2002	67%	12%	18%	3%	0%	147
2003	63%	34%	3%	0%	0%	147
2004	36%	44%	18%	1%	0%	136
2005	66%	24%	9%	1%	0%	152
2006	70%	24%	4%	3%	0%	105
2007	38%	40%	14%	7%	1%	169
2008	36%	33%	26%	3%	1%	150
2009	54%	23%	16%	6%	0%	149
2010	*	*	*	*	*	*
2011	*	*	*	*	*	*
2012	*	*	*	*	*	*
2013	*	*	*	*	*	*
2014	*	*	*	*	*	*
2015	*	*	*	*	*	*

**-Sampling did not occur.*
+-Sampling occurred but no alewife encountered in run.

Table 6.17 Distribution of repeat spawning frequency of alewife river herring returning to New Hampshire rivers, from scale samples aged between 2000 and 2015.

	Cocheco River - Alewife					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	68%	11%	20%	1%	0%	106
2001	56%	34%	6%	3%	1%	117
2002	54%	33%	13%	0%	0%	93
2003	69%	17%	12%	2%	0%	111
2004	30%	46%	20%	4%	0%	102
2005	46%	29%	18%	7%	0%	120
2006	49%	25%	14%	9%	3%	77
2007	69%	15%	8%	8%	1%	93
2008	70%	27%	3%	0%	0%	98
2009	78%	20%	1%	0%	0%	88
2010	35%	35%	29%	1%	0%	72
2011	57%	21%	12%	9%	0%	75
2012	41%	40%	16%	2%	2%	63
2013	51%	24%	16%	8%	0%	87
2014	43%	27%	18%	11%	0%	106
2015	63%	19%	8%	10%	1%	80

	Exeter River - Alewife					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	89%	9%	2%	0%	0%	94
2001	63%	36%	2%	0%	0%	56
2002	81%	13%	6%	0%	0%	52
2003	61%	26%	13%	0%	0%	54
2004	64%	23%	11%	2%	0%	44
2005	78%	16%	3%	3%	0%	64
2006	63%	31%	6%	0%	0%	16
2007	83%	15%	3%	0%	0%	40
2008	91%	8%	1%	0%	0%	134
2009	88%	11%	1%	0%	0%	307
2010	81%	19%	0%	0%	0%	32
2011	89%	11%	0%	0%	0%	63
2012	66%	25%	8%	0%	0%	59
2013	71%	20%	9%	0%	0%	70
2014	51%	40%	7%	1%	0%	70
2015	73%	14%	11%	2%	0%	63

Table 6.17 Continued.

	Oyster River - Alewife					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000						+
2001						+
2002	0%	100%	0%	0%	0%	1
2003						+
2004	100%	0%	0%	0%	0%	3
2005						+
2006						+
2007						+
2008	50%	25%	0%	25%	0%	4
2009	40%	33%	27%	0%	0%	15
2010	73%	14%	5%	9%	0%	22
2011	65%	26%	6%	3%	0%	62
2012	66%	16%	14%	1%	1%	50
2013	83%	11%	6%	0%	0%	65
2014	36%	56%	8%	0%	0%	50
2015	61%	29%	7%	2%	2%	59

	Lamprey River - Alewife					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	54%	26%	17%	3%	1%	195
2001	41%	45%	10%	3%	0%	145
2002	37%	29%	29%	5%	0%	139
2003	49%	26%	19%	6%	0%	140
2004	45%	27%	20%	7%	1%	162
2005	48%	36%	14%	2%	0%	128
2006	40%	34%	20%	6%	0%	122
2007	43%	26%	22%	6%	2%	140
2008	67%	20%	8%	3%	1%	143
2009	50%	41%	8%	1%	0%	145
2010	37%	38%	20%	5%	0%	81
2011	52%	21%	15%	11%	0%	84
2012	54%	33%	10%	3%	0%	79
2013	46%	30%	18%	5%	0%	82
2014	43%	40%	13%	4%	1%	101
2015	42%	25%	22%	11%	0%	83

**-Sampling did not occur.*
+-Sampling occurred but no alewife encountered in run.

Table 6.17 Continued.

	Taylor River - Alewife					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000						+
2001	*	*	*	*	*	*
2002						+
2003	*	*	*	*	*	*
2004	100%	0%	0%	0%	0%	1
2005						+
2006	*	*	*	*	*	*
2007	68%	26%	5%	0%	0%	19
2008						+
2009	*	*	*	*	*	*
2010	*	*	*	*	*	*
2011	*	*	*	*	*	*
2012	*	*	*	*	*	*
2013	*	*	*	*	*	*
2014	*	*	*	*	*	*
2015	*	*	*	*	*	*

	Winnicut River - Alewife					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	76%	0%	19%	5%	0%	21
2001	55%	36%	7%	2%	0%	87
2002	59%	13%	22%	5%	0%	79
2003	64%	31%	4%	0%	0%	70
2004	34%	45%	20%	2%	0%	92
2005	60%	28%	11%	1%	0%	100
2006	63%	31%	0%	6%	0%	32
2007	38%	40%	14%	8%	0%	139
2008	35%	34%	26%	4%	1%	134
2009	45%	27%	21%	8%	0%	116
2010	*	*	*	*	*	*
2011	*	*	*	*	*	*
2012	*	*	*	*	*	*
2013	*	*	*	*	*	*
2014	*	*	*	*	*	*
2015	*	*	*	*	*	*

**-Sampling did not occur.*

+-Sampling occurred but no alewife encountered in run.

Table 6.18 Distribution of repeat spawning frequency of blueback river herring returning to New Hampshire rivers, from scale samples aged between 2000 and 2015.

	Cocheco River - Blueback					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	56%	32%	12%	0%	0%	25
2001	60%	28%	8%	0%	4%	25
2002	79%	11%	9%	0%	0%	53
2003	76%	12%	4%	8%	0%	25
2004	59%	35%	6%	0%	0%	17
2005	80%	20%	0%	0%	0%	5
2006	88%	13%	0%	0%	0%	8
2007	69%	19%	12%	0%	0%	67
2008	63%	25%	13%	0%	0%	48
2009	50%	50%	0%	0%	0%	2
2010						+
2011						+
2012						+
2013	100%	0%	0%	0%	0%	5
2014	50%	0%	50%	0%	0%	2
2015						+

	Exeter River - Blueback					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	100%	0%	0%	0%	0%	3
2001	39%	32%	25%	5%	0%	85
2002	50%	0%	50%	0%	0%	2
2003	100%	0%	0%	0%	0%	1
2004	38%	38%	23%	0%	0%	13
2005						+
2006						+
2007						+
2008	75%	0%	17%	8%	0%	12
2009	50%	50%	0%	0%	0%	6
2010	50%	33%	0%	17%	0%	6
2011	100%	0%	0%	0%	0%	1
2012						+
2013						+
2014	91%	9%	0%	0%	0%	33
2015	56%	41%	2%	0%	0%	41

**-Sampling did not occur.*
+-Sampling occurred but no blueback encountered in run.

Table 6.18 Continued.

	Oyster River - Blueback					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	65%	26%	7%	2%	0%	143
2001	35%	43%	15%	6%	1%	144
2002	64%	16%	16%	4%	0%	141
2003	49%	32%	16%	3%	0%	149
2004	30%	26%	34%	9%	1%	128
2005	50%	35%	14%	1%	0%	126
2006	57%	24%	13%	6%	0%	141
2007	62%	28%	7%	3%	0%	179
2008	72%	17%	8%	3%	0%	145
2009	63%	35%	2%	0%	0%	86
2010	47%	27%	22%	4%	0%	78
2011	53%	35%	8%	3%	0%	62
2012	44%	37%	16%	3%	0%	62
2013	80%	13%	7%	0%	0%	60
2014	31%	63%	5%	2%	0%	64
2015	32%	30%	30%	8%	0%	53

	Lamprey River - Blueback					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000						+
2001						+
2002						+
2003	0%	33%	67%	0%	0%	3
2004						+
2005						+
2006	100%	0%	0%	0%	0%	2
2007	45%	36%	18%	0%	0%	11
2008						+
2009	0%	0%	100%	0%	0%	1
2010	27%	45%	18%	9%	0%	11
2011						+
2012						+
2013						+
2014						+
2015						+

**-Sampling did not occur.*
+-Sampling occurred but no blueback encountered in run.

Table 6.18 Continued.

	Taylor River - Blueback					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	69%	28%	2%	1%	0%	97
2001	*	*	*	*	*	*
2002	7%	40%	47%	7%	0%	30
2003	*	*	*	*	*	*
2004	70%	15%	10%	4%	0%	67
2005	93%	7%	0%	0%	0%	14
2006	*	*	*	*	*	*
2007						+
2008	100%	0%	0%	0%	0%	7
2009	*	*	*	*	*	*
2010	*	*	*	*	*	*
2011	*	*	*	*	*	*
2012	*	*	*	*	*	*
2013	*	*	*	*	*	*
2014	*	*	*	*	*	*
2015	*	*	*	*	*	*

	Winnicut River - Blueback					
Year	% r0	% r1	% r2	% r3	% r4	Total N
2000	76%	13%	8%	3%	0%	157
2001	59%	29%	12%	0%	0%	59
2002	76%	10%	13%	0%	0%	68
2003	61%	36%	3%	0%	0%	77
2004	41%	43%	16%	0%	0%	44
2005	79%	17%	4%	0%	0%	52
2006	73%	21%	5%	1%	0%	73
2007	40%	40%	13%	3%	3%	30
2008	44%	31%	25%	0%	0%	16
2009	88%	12%	0%	0%	0%	33
2010	*	*	*	*	*	*
2011	*	*	*	*	*	*
2012	*	*	*	*	*	*
2013	*	*	*	*	*	*
2014	*	*	*	*	*	*
2015	*	*	*	*	*	*

**-Sampling did not occur.*
+-Sampling occurred but no blueback encountered in run.

Table 6.19 Annual juvenile abundance index of river herring seined in Great Bay Estuary, New Hampshire, 1997-2015.

Year	Alewife Catch	Alewife Arithmetic Mean	Alewife Geometric Mean	Blueback Catch	Blueback Arithmetic Mean	Blueback Geometric Mean
1997	16	0.18	0.07	295	3.31	0.49
1998	14	0.16	0.04	1821	20.23	0.66
1999	660	7.33	0.27	11838	131.53	0.97
2000	71	0.79	0.26	5092	56.58	0.74
2001	119	1.24	0.13	1476	15.38	0.88
2002	164	1.82	0.34	261	2.90	0.26
2003	899	9.99	0.32	1812	20.13	0.76
2004	35	0.39	0.14	124	1.38	0.22
2005	29	0.32	0.11	2146	23.84	0.35
2006	1471	16.34	0.32	432	4.80	0.42
2007	203	2.26	0.21	1503	16.70	0.50
2008	39	0.43	0.15	37	0.41	0.13
2009	32	0.36	0.10	182	2.02	0.20
2010	14	0.16	0.08	79	0.88	0.17
2011	21	0.24	0.08	7	0.07	0.05
2012	6	0.07	0.02	29	0.32	0.08
2013	739	8.21	0.23	6	0.07	0.04
2014	8	0.09	0.05	46	0.51	0.14
2015	117	1.30	0.31	19	0.21	0.06

Table 6.20 Estimates of total instantaneous mortality (Z) with standard errors for river herring in coastal New Hampshire rivers, using Chapman-Robson, Heinecke, and catch curve methods based on age, separated by species and sex, 1990-2015.

Cocheco River			Chapman-Robson		Heinecke		Catch Curve	
Species	Sex	Year	Z estimate	SE	Z estimate	SE	Z estimate	SE
Alewives	Male	1992	0.84	0.138	0.57	0.093	0.44	0.184
Alewives	Male	1993	1.49	0.233	1.25	0.191	*	*
Alewives	Male	1994	2.30	0.468	2.22	0.446	*	*
Alewives	Male	1995	1.19	0.176	0.89	0.128	1.70	0.748
Alewives	Male	1996	0.84	0.103	0.63	0.075	0.39	0.019
Alewives	Male	1997	1.22	0.260	1.14	0.240	1.07	0.017
Alewives	Male	1998	1.87	0.370	2.14	0.441	1.35	0.782
Alewives	Male	1999	0.82	0.112	0.64	0.086	1.02	0.357
Alewives	Male	2000	0.84	0.111	0.76	0.101	0.73	0.138
Alewives	Male	2001	1.03	0.159	0.83	0.126	1.05	0.455
Alewives	Male	2002	0.71	0.099	0.49	0.068	0.83	0.155
Alewives	Male	2003	0.95	0.152	0.74	0.117	0.93	0.276
Alewives	Male	2004	1.28	0.217	1.05	0.174	1.11	0.146
Alewives	Male	2005	1.06	0.183	0.72	0.121	1.47	0.786
Alewives	Male	2006	1.85	0.514	1.73	0.475	*	*
Alewives	Male	2007	1.19	0.258	1.39	0.306	0.75	0.834
Alewives	Male	2008	1.82	0.402	1.69	0.364	*	*
Alewives	Male	2009	0.86	0.097	0.72	0.080	0.96	0.269
Alewives	Male	2010	1.00	0.208	0.82	0.169	1.01	0.288
Alewives	Male	2011	0.96	0.198	0.82	0.169	0.63	0.039
Alewives	Male	2012	0.9	0.195	0.65	0.138	0.65	0.259
Alewives	Male	2013	0.6	0.094	0.56	0.087	0.19	0.185
Alewives	Male	2014	0.67	0.109	0.57	0.093	0.41	0.152
Alewives	Male	2015	0.93	0.185	0.73	0.144	0.95	0.165
Alewives	Female	1992	1.95	0.520	1.85	0.486	*	*
Alewives	Female	1993	1.49	0.262	1.27	0.216	*	*
Alewives	Female	1994	1.76	0.365	1.61	0.327	*	*
Alewives	Female	1995	1.19	0.176	0.89	0.128	1.70	0.748
Alewives	Female	1996	1.24	0.196	0.97	0.151	1.67	0.639
Alewives	Female	1997	**	**	**	**	**	**
Alewives	Female	1998	0.55	0.081	0.36	0.054	0.46	0.132
Alewives	Female	1999	1.06	0.188	1.07	0.190	0.87	0.206
Alewives	Female	2000	0.62	0.093	0.43	0.064	0.40	0.201
Alewives	Female	2001	0.76	0.103	0.61	0.082	0.56	0.149
Alewives	Female	2002	0.95	0.187	0.69	0.134	0.77	0.305
Alewives	Female	2003	1.33	0.177	1.47	0.199	1.01	0.169
Alewives	Female	2004	1.02	0.150	0.94	0.136	1.11	0.166
Alewives	Female	2006	1.14	0.283	0.94	0.231	1.20	0.342
Alewives	Female	2007	1.02	0.186	1.01	0.184	0.97	0.107
Alewives	Female	2008	0.96	0.169	0.78	0.136	0.67	0.070
Alewives	Female	2009	0.65	0.071	0.44	0.048	0.49	0.224
Alewives	Female	2010	0.88	0.168	0.66	0.125	0.51	0.103
Alewives	Female	2011	0.71	0.135	0.53	0.1	0.58	0.135
Alewives	Female	2012	0.53	0.095	0.37	0.067	0.39	0.088
Alewives	Female	2013	0.57	0.088	0.5	0.078	0.16	0.259

Table 6.20   Continued.

Cocheco River			Chapman-Robson		Heinecke		Catch Curve	
Species	Sex	Year	Z estimate	Species	Sex	Year	Z estimate	Species
Alewives	Female	2014	0.72	0.115	0.62	0.099	0.46	0.067
Alewives	Female	2015	0.54	0.088	0.44	0.072	0.33	0.054
Blueback	Male	1992	1.56	0.430	1.67	0.469	1.28	0.340
Blueback	Male	1993	2.60	0.667	2.56	0.653	*	*
Blueback	Male	1994	2.01	0.634	1.95	0.606	*	*
Blueback	Male	1996	0.94	0.251	0.92	0.245	0.55	0.317
Blueback	Male	1997	1.79	0.400	1.65	0.361	*	*
Blueback	Male	1998	1.39	0.344	1.15	0.279	*	*
Blueback	Male	1999	1.56	0.430	1.39	0.375	*	*
Blueback	Male	2000	1.03	0.247	0.75	0.175	1.15	0.536
Blueback	Male	2001	0.98	0.417	1.10	0.471	0.69	0.400
Blueback	Male	2002	1.13	0.233	0.96	0.195	1.04	0.200
Blueback	Male	2003	0.98	0.308	1.30	0.420	0.62	0.360
Blueback	Male	2004	**	**	**	**	**	**
Blueback	Male	2005	**	**	**	**	**	**
Blueback	Male	2006	1.10	0.516	0.92	0.424	*	*
Blueback	Male	2007	1.34	0.255	1.16	0.217	1.55	0.376
Blueback	Male	2008	1.30	0.338	1.22	0.316	1.24	0.083
Blueback	Male	2009	**	**	**	**	**	**
Blueback	Male	2010	**	**	**	**	**	**
Blueback	Male	2011	**	**	**	**	**	**
Blueback	Male	2012	**	**	**	**	**	**
Blueback	Male	2013	**	**	**	**	**	**
Blueback	Male	2014	**	**	**	**	**	**
Blueback	Male	2015	**	**	**	**	**	**
Blueback	Female	1992	1.47	0.483	1.30	0.420	*	*
Blueback	Female	1993	1.73	0.364	1.58	0.324	*	*
Blueback	Female	1994	1.39	0.567	1.25	0.505	*	*
Blueback	Female	1995	1.87	0.623	1.79	0.589	*	*
Blueback	Female	1996	1.47	0.483	1.70	0.579	1.10	0.634
Blueback	Female	1997	0.96	0.213	0.89	0.197	0.88	0.053
Blueback	Female	1998	1.61	0.434	1.73	0.475	1.32	0.362
Blueback	Female	1999	1.20	0.452	0.98	0.361	*	*
Blueback	Female	2000	0.81	0.340	0.69	0.289	0.55	0.083
Blueback	Female	2001	1.03	0.340	0.92	0.300	0.90	0.117
Blueback	Female	2002	1.39	0.416	1.18	0.346	*	*
Blueback	Female	2003	1.32	0.410	1.39	0.433	1.10	0.234
Blueback	Female	2004	**	**	**	**	**	**
Blueback	Female	2005	**	**	**	**	**	**
Blueback	Female	2006	**	**	**	**	**	**
Blueback	Female	2007	0.75	0.172	0.60	0.136	0.20	0.222
Blueback	Female	2008	0.98	0.255	0.69	0.177	1.04	0.523
Blueback	Female	2009	**	**	**	**	**	**
Blueback	Female	2010	**	**	**	**	**	**
Blueback	Female	2011	**	**	**	**	**	**
Blueback	Female	2012	**	**	**	**	**	**
Blueback	Female	2013	**	**	**	**	**	**
Blueback	Female	2014	**	**	**	**	**	**
Blueback	Female	2015	**	**	**	**	**	**

Table 6.20 Continued.

Lamprey River			Chapman-Robson		Heinecke		Catch Curve	
Species	Sex	Year	Z estimate	SE	Z	SE	Z	SE
Alewives	Male	1990	1.61	0.596	1.50	0.550	*	*
Alewives	Male	1991	**	**	**	**	**	**
Alewives	Male	1992	1.23	0.182	1.24	0.184	1.05	0.247
Alewives	Male	1993	1.95	0.290	1.81	0.264	*	*
Alewives	Male	1994	1.74	0.284	1.67	0.271	1.83	0.143
Alewives	Male	1995	1.88	0.344	1.74	0.312	*	*
Alewives	Male	1996	1.25	0.182	1.08	0.156	1.23	0.220
Alewives	Male	1997	1.10	0.207	0.87	0.161	1.10	0.350
Alewives	Male	1998	1.05	0.156	0.85	0.125	0.86	0.174
Alewives	Male	1999	0.73	0.092	0.50	0.062	0.70	0.229
Alewives	Male	2000	0.84	0.100	0.71	0.083	0.81	0.158
Alewives	Male	2001	0.71	0.084	0.51	0.060	0.85	0.157
Alewives	Male	2002	1.41	0.248	1.15	0.198	*	*
Alewives	Male	2003	0.69	0.077	0.57	0.063	0.39	0.155
Alewives	Male	2004	0.86	0.110	0.68	0.086	0.81	0.107
Alewives	Male	2005	1.10	0.162	0.75	0.108	1.65	0.859
Alewives	Male	2006	0.83	0.121	0.65	0.094	0.92	0.164
Alewives	Male	2007	1.13	0.187	1.07	0.176	1.02	0.411
Alewives	Male	2008	1.73	0.364	1.76	0.370	1.59	0.117
Alewives	Male	2009	1.09	0.128	0.86	0.099	1.02	0.301
Alewives	Male	2010	1.05	0.219	0.73	0.150	1.28	0.644
Alewives	Male	2011	0.73	0.139	0.53	0.1	0.61	0.118
Alewives	Male	2012	1	0.208	0.92	0.19	0.66	0.147
Alewives	Male	2013	0.55	0.09	0.46	0.075	0.51	0.245
Alewives	Male	2014	0.85	0.155	0.63	0.114	0.46	0.085
Alewives	Male	2015	0.77	0.147	0.59	0.112	0.81	0.245
Alewives	Female	1990	**	**	**	**	**	**
Alewives	Female	1991	**	**	**	**	**	**
Alewives	Female	1992	1.08	0.171	0.89	0.139	0.94	0.183
Alewives	Female	1993	1.56	0.244	1.35	0.205	*	*
Alewives	Female	1994	1.10	0.172	1.03	0.161	1.11	0.070
Alewives	Female	1995	1.20	0.173	0.90	0.126	1.73	0.757
Alewives	Female	1996	1.07	0.164	0.76	0.113	1.26	0.600
Alewives	Female	1997	1.06	0.199	0.79	0.147	1.07	0.417
Alewives	Female	1998	0.86	0.144	0.64	0.106	0.82	0.189
Alewives	Female	1999	0.85	0.113	0.66	0.087	0.79	0.110
Alewives	Female	2000	0.76	0.093	0.56	0.068	0.66	0.146
Alewives	Female	2001	1.28	0.217	1.05	0.174	1.63	0.540
Alewives	Female	2002	0.71	0.103	0.48	0.068	0.90	0.430
Alewives	Female	2003	0.57	0.082	0.43	0.061	0.47	0.142
Alewives	Female	2004	0.85	0.110	0.66	0.084	0.75	0.141
Alewives	Female	2005	1.01	0.147	0.77	0.110	1.10	0.485
Alewives	Female	2006	0.87	0.142	0.64	0.104	0.50	0.112
Alewives	Female	2007	1.02	0.165	0.90	0.144	1.08	0.103
Alewives	Female	2008	0.87	0.113	0.81	0.105	0.86	0.246
Alewives	Female	2009	0.95	0.118	0.62	0.076	0.84	0.465
Alewives	Female	2010	1.39	0.344	1.15	0.279	*	*
Alewives	Female	2011	0.97	0.206	0.78	0.163	0.73	0.143
Alewives	Female	2012	0.91	0.174	0.73	0.138	0.93	0.127
Alewives	Female	2013	0.58	0.092	0.43	0.069	0.21	0.147
Alewives	Female	2014	0.52	0.074	0.35	0.049	0.38	0.115
Alewives	Female	2015	1.14	0.283	1.1	0.272	0.9	0.117

Table 6.20 Continued.

Oyster River			Chapman-Robson		Heinecke		Catch Curve	
species	sex	year	estimate	SE	estimate	SE	estimate	SE
Blueback	Male	1992	0.67	0.080	0.48	0.056	0.41	0.080
Blueback	Male	1993	2.04	0.349	1.93	0.323	*	*
Blueback	Male	1994	1.01	0.109	0.82	0.087	1.30	0.281
Blueback	Male	1995	1.51	0.242	1.29	0.201	*	*
Blueback	Male	1996	1.17	0.175	0.92	0.134	1.35	0.487
Blueback	Male	1997	0.79	0.081	0.58	0.059	0.78	0.200
Blueback	Male	1998	0.64	0.077	0.41	0.049	0.47	0.234
Blueback	Male	1999	2.11	0.351	2.01	0.327	*	*
Blueback	Male	2000	0.93	0.103	0.64	0.069	0.72	0.341
Blueback	Male	2001	0.77	0.094	0.58	0.071	0.73	0.214
Blueback	Male	2002	0.73	0.078	0.60	0.063	0.53	0.066
Blueback	Male	2003	1.14	0.149	0.92	0.118	1.34	0.260
Blueback	Male	2004	1.59	0.255	1.47	0.232	1.81	0.287
Blueback	Male	2005	0.99	0.137	0.71	0.096	0.88	0.374
Blueback	Male	2006	0.83	0.086	0.61	0.062	1.19	0.455
Blueback	Male	2007	0.89	0.093	0.70	0.073	0.93	0.165
Blueback	Male	2008	0.67	0.067	0.51	0.051	0.72	0.114
Blueback	Male	2009	1.21	0.173	1.30	0.188	0.80	0.542
Blueback	Male	2010	0.62	0.101	0.57	0.093	0.51	0.119
Blueback	Male	2011	0.91	0.174	0.8	0.153	0.9	0.12
Blueback	Male	2012	1.1	0.231	0.73	0.15	*	*
Blueback	Male	2013	2.2	0.647	2.14	0.624	*	*
Blueback	Male	2014	2.83	0.941	2.83	0.941	*	*
Blueback	Male	2015	0.72	0.156	0.53	0.113	0.13	0.162
Blueback	Female	1992	0.60	0.091	0.76	0.116	0.47	0.169
Blueback	Female	1993	1.64	0.257	1.45	0.221	*	*
Blueback	Female	1994	1.01	0.180	0.75	0.132	0.90	0.329
Blueback	Female	1995	1.29	0.210	1.12	0.180	1.34	0.263
Blueback	Female	1996	1.19	0.185	0.91	0.137	1.67	0.707
Blueback	Female	1997	0.69	0.100	0.51	0.073	0.77	0.126
Blueback	Female	1998	0.97	0.122	0.79	0.098	1.01	0.126
Blueback	Female	1999	1.61	0.256	1.59	0.252	1.49	0.057
Blueback	Female	2000	1.10	0.195	0.78	0.136	1.47	0.714
Blueback	Female	2001	0.89	0.158	0.75	0.132	0.47	0.128
Blueback	Female	2002	0.63	0.107	0.41	0.068	0.43	0.193
Blueback	Female	2003	0.79	0.113	0.58	0.082	0.66	0.171
Blueback	Female	2004	1.34	0.219	1.20	0.194	1.35	0.202
Blueback	Female	2005	1.22	0.214	0.90	0.154	*	*
Blueback	Female	2006	0.76	0.136	0.50	0.088	0.24	0.094
Blueback	Female	2007	1.22	0.181	1.22	0.182	0.90	0.283
Blueback	Female	2008	0.80	0.134	0.59	0.098	0.91	0.274
Blueback	Female	2009	1.01	0.180	0.75	0.132	0.90	0.329
Blueback	Female	2010	1.33	0.280	1.31	0.276	1.13	0.121
Blueback	Female	2011	0.79	0.166	0.78	0.163	0.58	0.095
Blueback	Female	2012	1.3	0.338	1.22	0.316	1.24	0.083
Blueback	Female	2013	1.15	0.217	1.13	0.214	0.83	0.245
Blueback	Female	2014	1.53	0.385	1.56	0.395	1.35	0.147
Blueback	Female	2015	0.8	0.155	0.56	0.107	0.85	0.209

Table 6.20 Continued.

Winnicut River			Chapman-Robson		Heinecke		Catch Curve	
species	sex	year	estimate	SE	estimate	SE	estimate	SE
Alewives	Male	1998	1.1	0.667	1.1	0.667	*	*
Alewives	Male	1999	1.47	0.25	1.41	0.239	1.37	0.009
Alewives	Male	2000	0.89	0.247	0.85	0.233	0.76	0.183
Alewives	Male	2001	1.25	0.197	1.34	0.213	0.87	0.501
Alewives	Male	2002	0.7	0.102	0.58	0.083	0.74	0.242
Alewives	Male	2003	1.95	0.346	1.82	0.316	*	*
Alewives	Male	2004	2.37	0.47	2.30	0.450	*	*
Alewives	Male	2005	0.69	0.079	0.48	0.054	0.86	0.182
Alewives	Male	2006	0.62	0.124	0.42	0.084	0.36	0.092
Alewives	Male	2007	1.00	0.123	0.94	0.115	0.90	0.013
Alewives	Male	2008	1.16	0.134	1.00	0.113	1.12	0.246
Alewives	Male	2009	1.45	0.249	1.29	0.219	1.68	0.357
Alewives	Female	1999	0.89	0.247	0.69	0.189	0.63	0.167
Alewives	Female	2000	0.61	0.251	0.69	0.289	0.33	0.190
Alewives	Female	2001	0.69	0.147	0.57	0.121	0.45	0.110
Alewives	Female	2002	0.75	0.244	0.69	0.224	0.59	0.144
Alewives	Female	2003	0.92	0.359	0.85	0.330	0.69	<0.001
Alewives	Female	2004	1.28	0.366	1.54	0.454	0.85	0.892
Alewives	Female	2005	1.16	0.355	0.88	0.261	*	*
Alewives	Female	2007	0.73	0.18	0.53	0.130	0.65	0.150
Alewives	Female	2008	0.86	0.186	0.83	0.179	0.67	0.158
Alewives	Female	2009	0.99	0.179	0.93	0.168	0.60	0.259
Blueback	Male	1998	1.12	0.149	1.05	0.139	1.03	0.164
Blueback	Male	1999	0.98	0.131	0.71	0.093	0.82	0.326
Blueback	Male	2000	1.06	0.134	1.02	0.128	1.19	0.238
Blueback	Male	2001	1.06	0.193	0.93	0.168	1.06	0.130
Blueback	Male	2002	1.22	0.196	1.22	0.195	1.14	0.024
Blueback	Male	2003	1.71	0.27	1.63	0.254	1.86	0.197
Blueback	Male	2004	1.16	0.211	0.82	0.144	*	*
Blueback	Male	2005	1.27	0.251	1.17	0.230	1.15	0.059
Blueback	Male	2006	0.87	0.118	0.66	0.088	0.90	0.160
Blueback	Male	2007	0.69	0.141	0.51	0.103	0.69	0.299
Blueback	Male	2008	1.39	0.567	1.25	0.505	*	*
Blueback	Male	2009	2.35	0.656	2.30	0.636	*	*
Blueback	Female	1998	0.63	0.226	0.69	0.250	0.35	0.268
Blueback	Female	1999	**	**	**	**	**	**
Blueback	Female	2000	0.94	0.161	0.72	0.121	0.67	0.166
Blueback	Female	2001	1.30	0.464	1.10	0.385	*	*
Blueback	Female	2002	0.85	0.242	0.77	0.220	0.42	0.245
Blueback	Female	2003	1.39	0.474	1.20	0.404	*	*
Blueback	Female	2004	1.25	0.546	1.10	0.471	*	*
Blueback	Female	2005	2.08	0.875	2.08	0.875	*	*
Blueback	Female	2006	1.25	0.546	1.10	0.471	*	*
Blueback	Female	2007	0.69	0.354	0.69	0.354	0.20	0.172
Blueback	Female	2008	**	**	**	**	**	**
Blueback	Female	2009	1.67	0.501	1.95	0.606	0.71	0.615

Table 6.20 Continued.

Exeter River***		Chapman-Robson		Heinecke		Catch Curve	
Species	Year	Z estimate	SE	Z estimate	SE	Z estimate	SE
River Herring	1991	1.02	0.113	0.92	0.100	1.05	0.066
River Herring	1992	1.01	0.091	0.85	0.076	1.19	0.223
River Herring	1993	1.37	0.162	1.24	0.145	1.35	0.152
River Herring	1994	No Sampling					
River Herring	1995	1.72	0.180	1.70	0.178	1.58	0.076
River Herring	1996	1.39	0.375	1.16	0.307	*	*
River Herring	1997	1.01	0.077	0.89	0.067	1.09	0.157
River Herring	1998	0.64	0.050	0.51	0.040	0.59	0.093
River Herring	1999	1.26	0.116	1.07	0.097	1.27	0.261
River Herring	2000	1.03	0.110	0.79	0.082	1.18	0.212
River Herring	2001	0.98	0.109	0.76	0.083	1.28	0.282
River Herring	2002	1.53	0.276	1.31	0.231	*	*
River Herring	2003	0.91	0.129	0.83	0.118	0.78	0.020
River Herring	2004	1.19	0.176	0.94	0.136	1.37	0.477
River Herring	2005	1.27	0.224	1.21	0.212	1.08	0.057
River Herring	2006	0.69	0.183	0.51	0.133	0.09	0.181
River Herring	2007	0.99	0.195	0.77	0.149	1.05	0.321
River Herring	2008	0.89	0.083	0.69	0.062	1.13	0.159
River Herring	2009	0.90	0.053	0.65	0.037	1.13	0.290
River Herring	2010	1.00	0.185	0.76	0.137	0.87	0.300
River Herring	2011	1.53	0.308	1.32	0.259	NA	NA
River Herring	2012	1.2	0.19	1.1	0.172	1.2	0.144
River Herring	2013	0.73	0.092	0.59	0.074	0.49	0.037
River Herring	2014	0.8	0.083	0.59	0.06	0.74	0.14
River Herring	2015	1.03	0.106	0.9	0.091	1.31	0.31

*- *No Z estimate due to less than three ages to assess.*

**- *No Z estimates due to extremely low sample size, no species differentiation, or ages below fully recruited age.*

Table 6.21: Spawner-per-recruit Z benchmarks for New Hampshire and 2009 estimates of Z by river system

				Benchmark			
River	**Species**	**Sex**	**Z_{2009}**	**Z40% (M=0.3)**	**Z20% (M=0.3)**	**Z40% (M=0.7)**	**Z20% (M=0.7)**
Cocheco	Alewife	Male	0.86	0.46	0.60	0.92	1.11
Cocheco	Alewife	Female	0.65	0.46	0.60	0.92	1.11
Lamprey	Alewife	Male	1.09	0.46	0.60	0.92	1.11
Oyster	Blueback	Male	1.21	0.48	0.64	0.95	1.15
Oyster	Blueback	Female	1.01	0.48	0.64	0.95	1.15
Winnicut	Alewife	Male	1.45	0.46	0.60	0.92	1.11
Winnicut	Alewife	Female	0.99	0.46	0.60	0.92	1.11
Winnicut	Blueback	Female	1.67	0.48	0.64	0.95	1.15

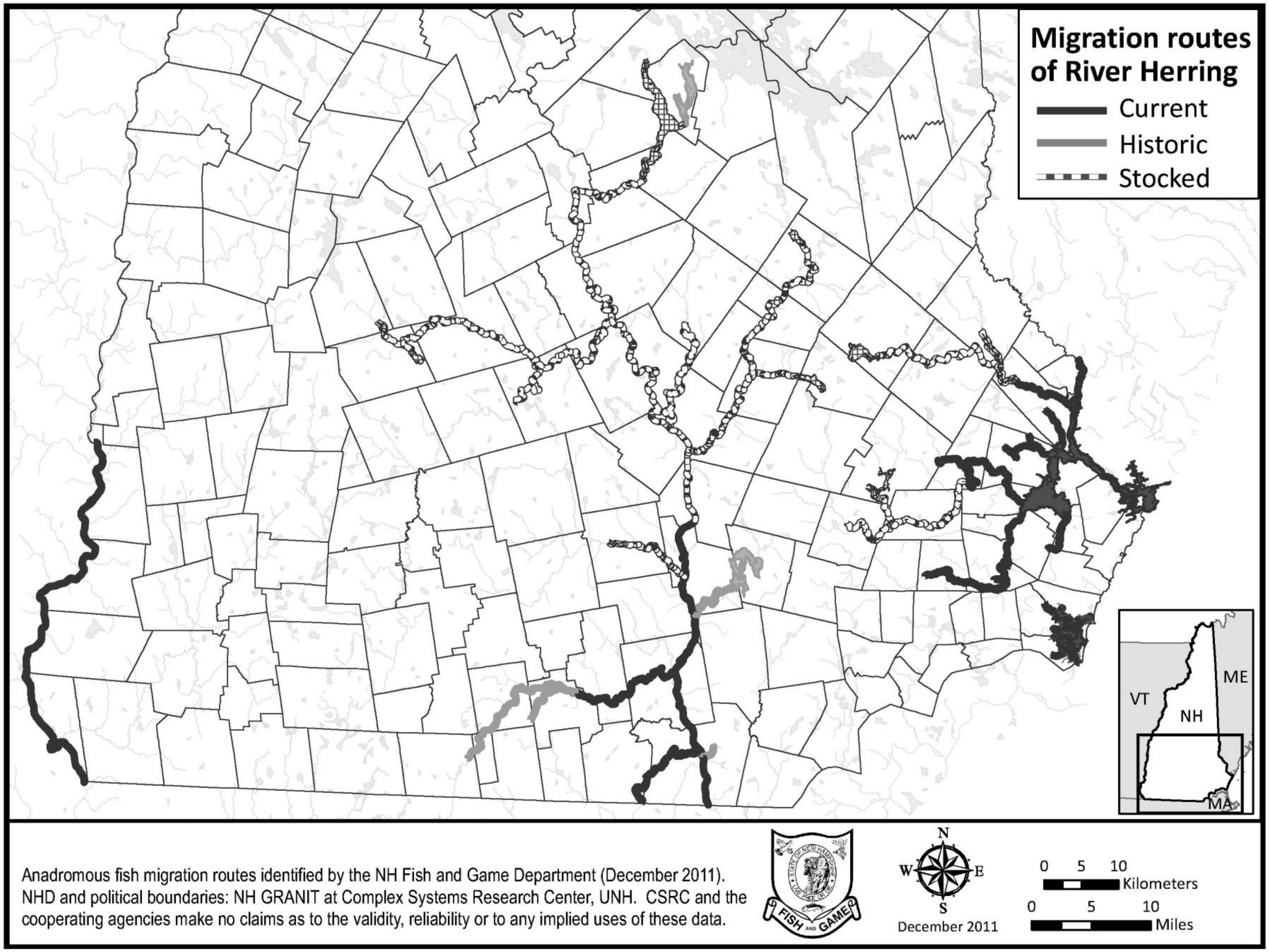


Figure 6.1 Map of New Hampshire's river herring migration routes (historic, current and stocked fish).

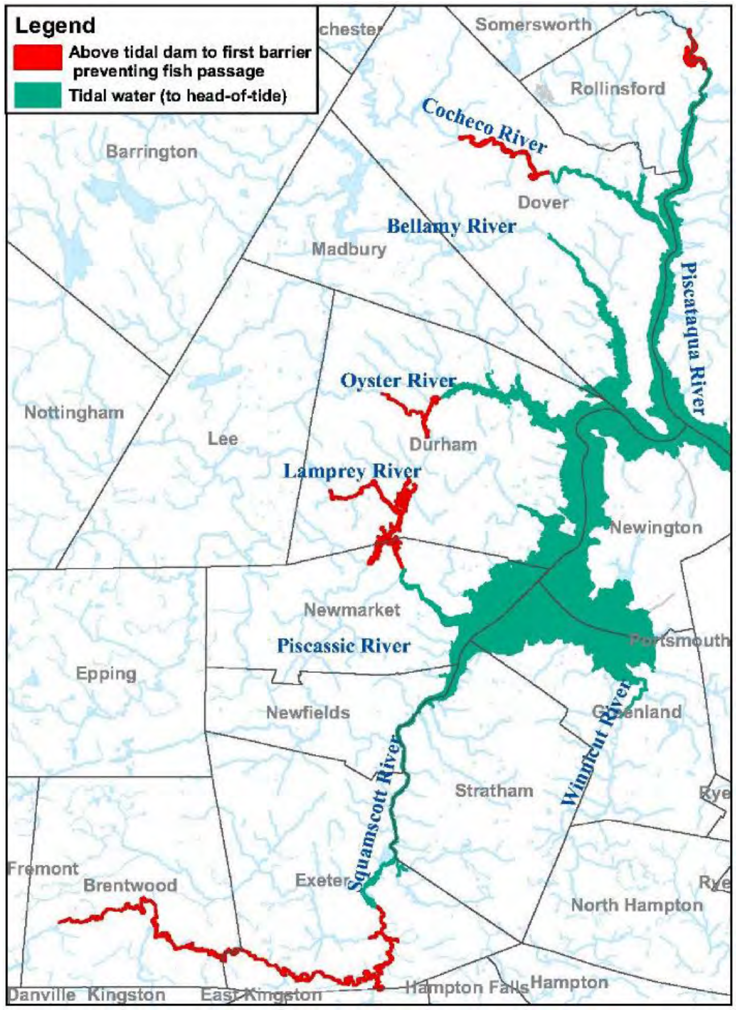


Figure 6.2 Great Bay Estuary rivers with fish passage and available anadromous spawning and rearing habitat.

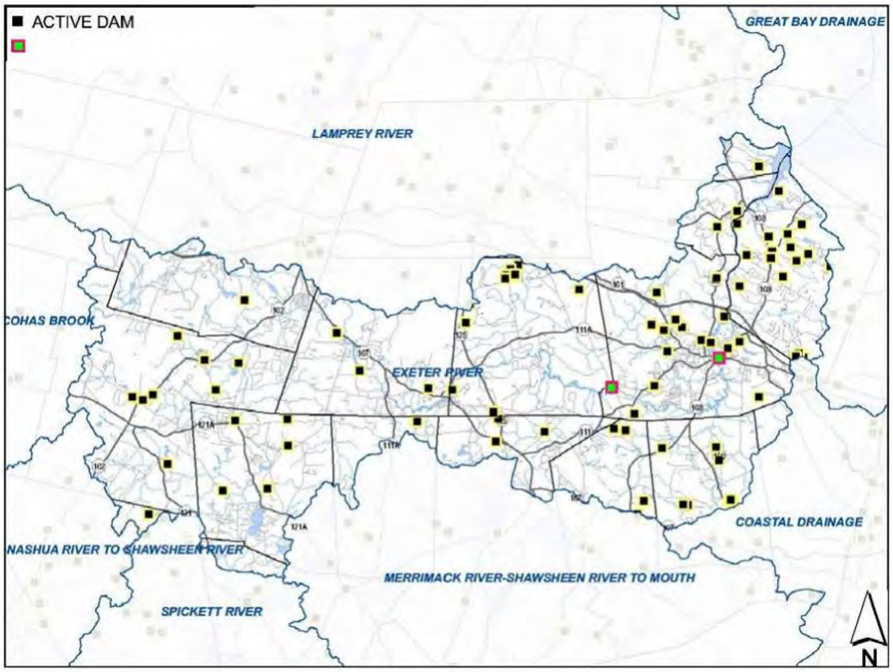


Figure 6.3 Exeter River watershed dams and fish passage, Great Bay Estuary, New Hampshire.

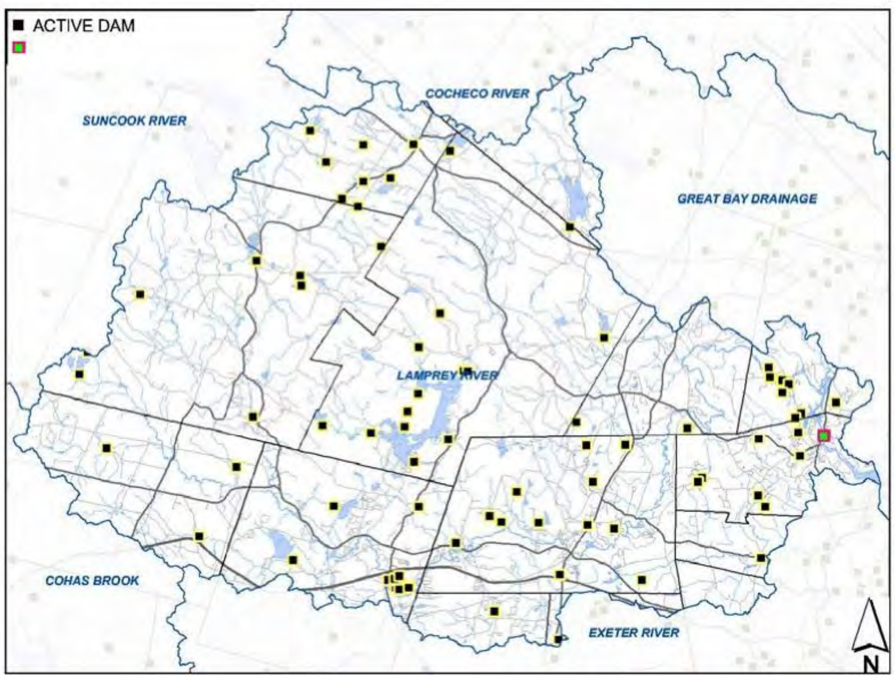


Figure 6.4 Lamprey River watershed dams and fish passage, Great Bay Estuary, New Hampshire.

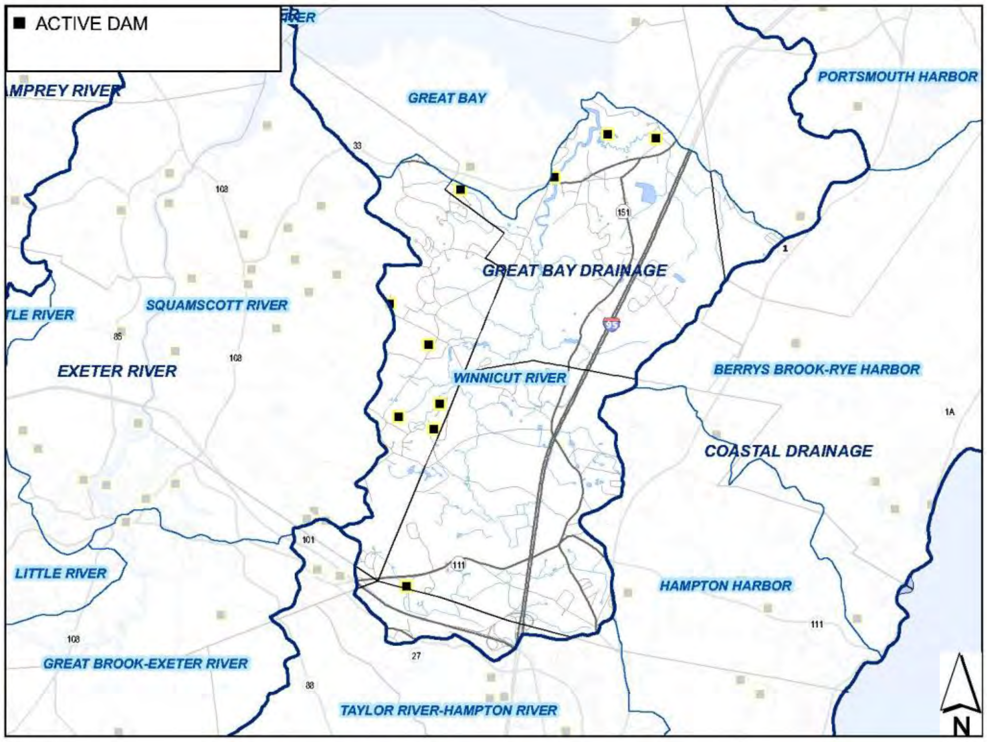


Figure 6.5 Winnicut River watershed dams and fish passage, Great Bay Estuary, New Hampshire.

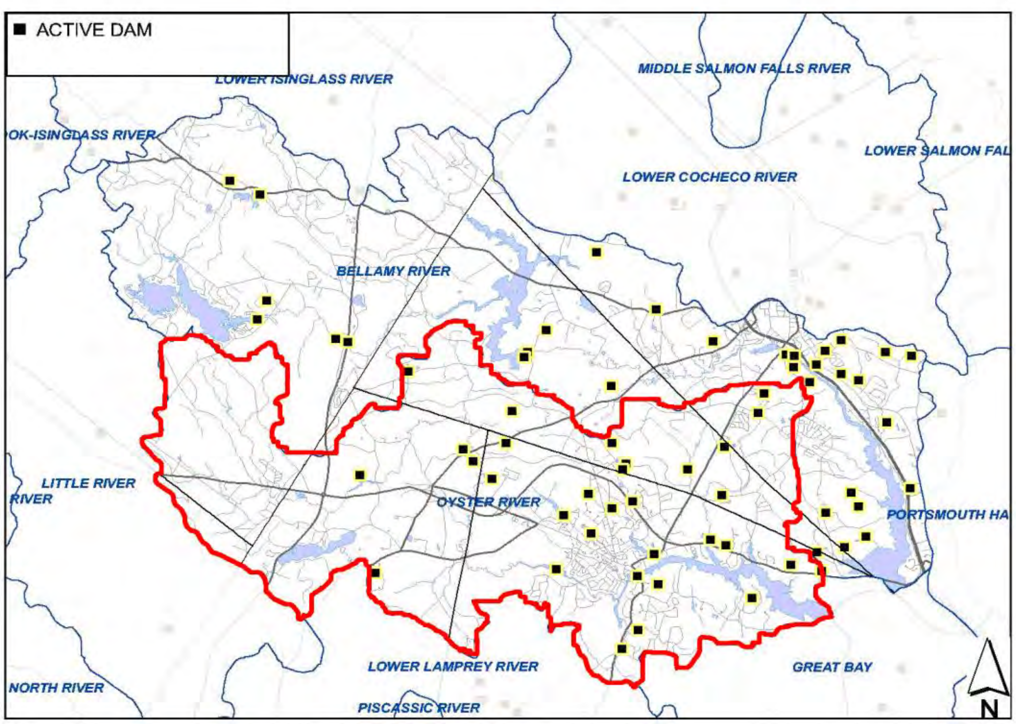


Figure 6.6 Oyster River watershed dams and fish passage, Great Bay Estuary, New Hampshire.

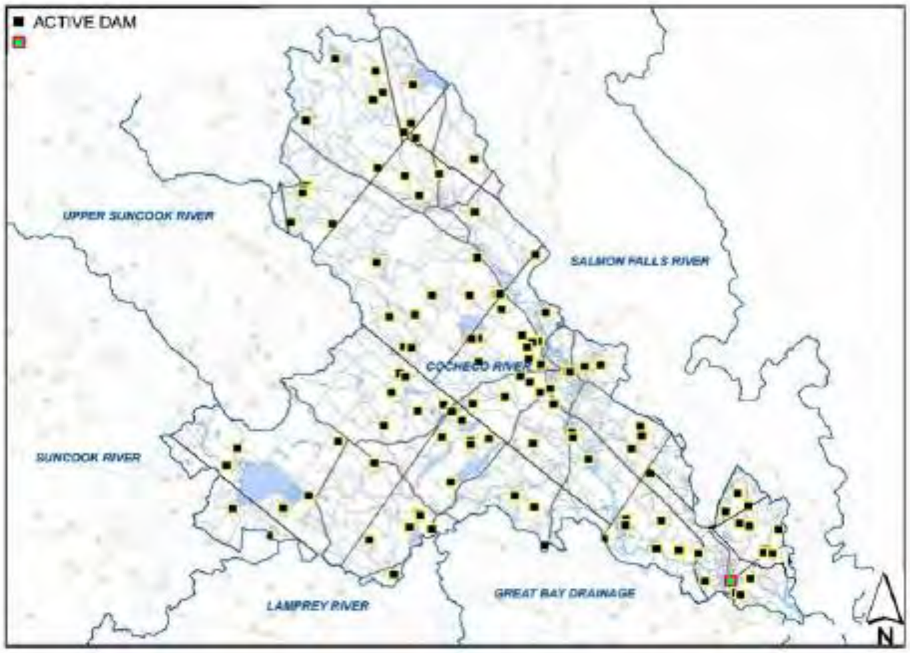


Figure 6.7 Cocheco River watershed dams and fish passage, Great Bay Estuary, New Hampshire.

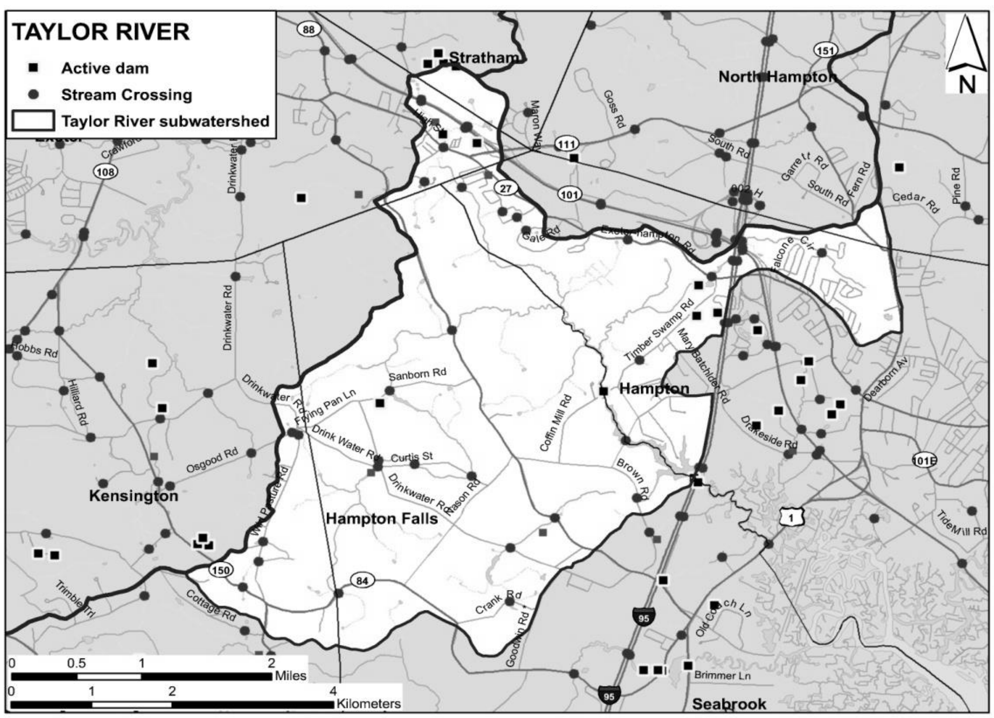


Figure 6.8 Taylor River watershed dams and fish passage, Hampton-Seabrook Estuary, New Hampshire.

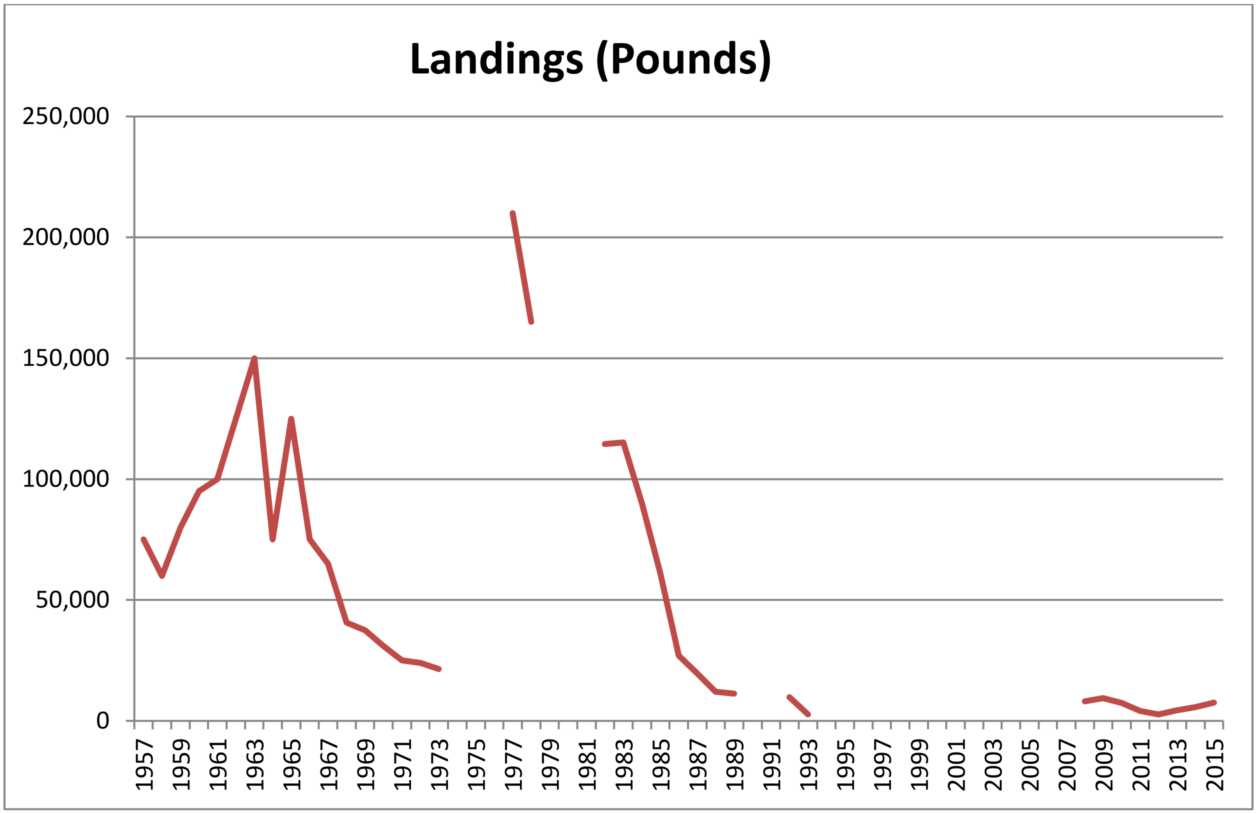


Figure 6.9. Commercial landings (in pounds) of river herring in New Hampshire.

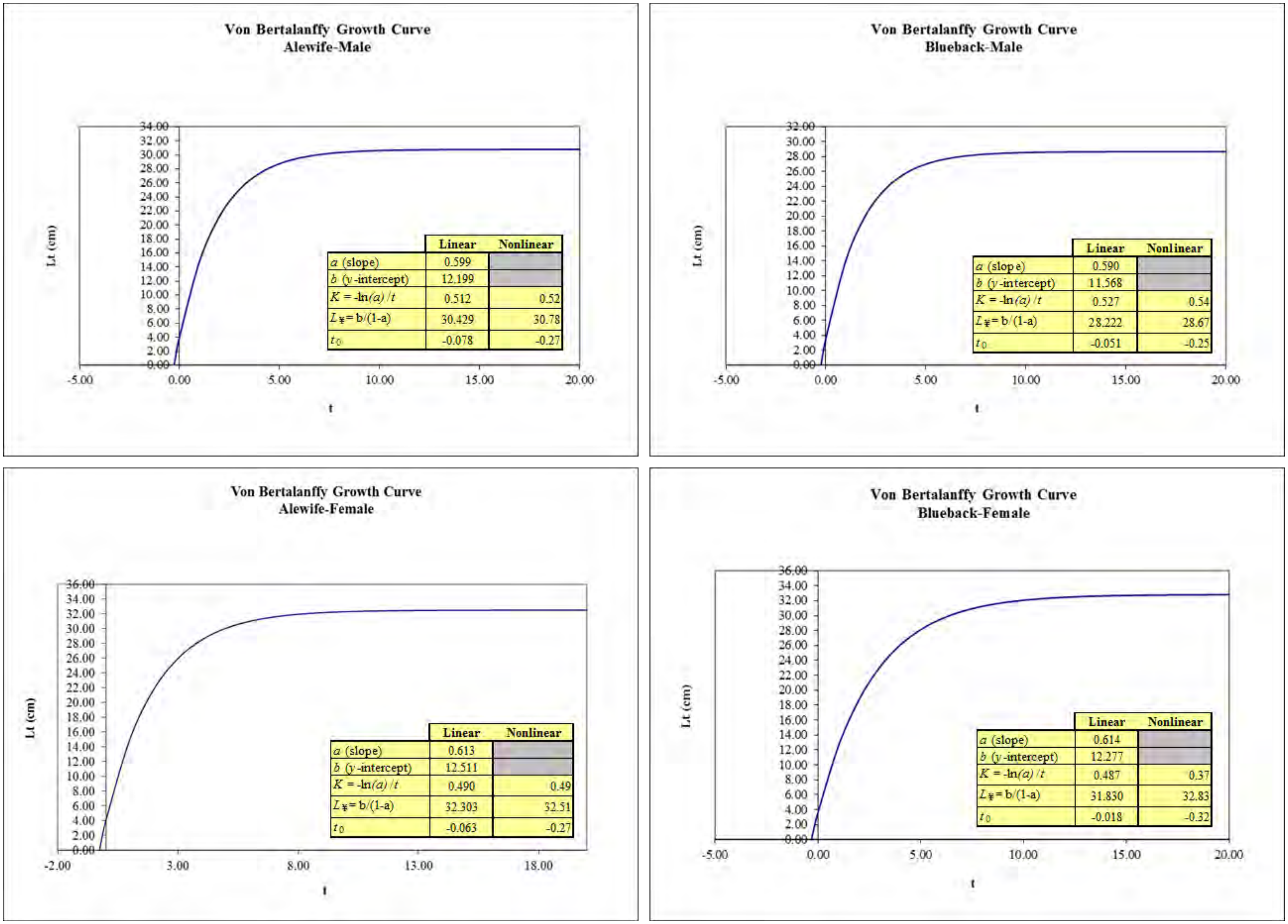
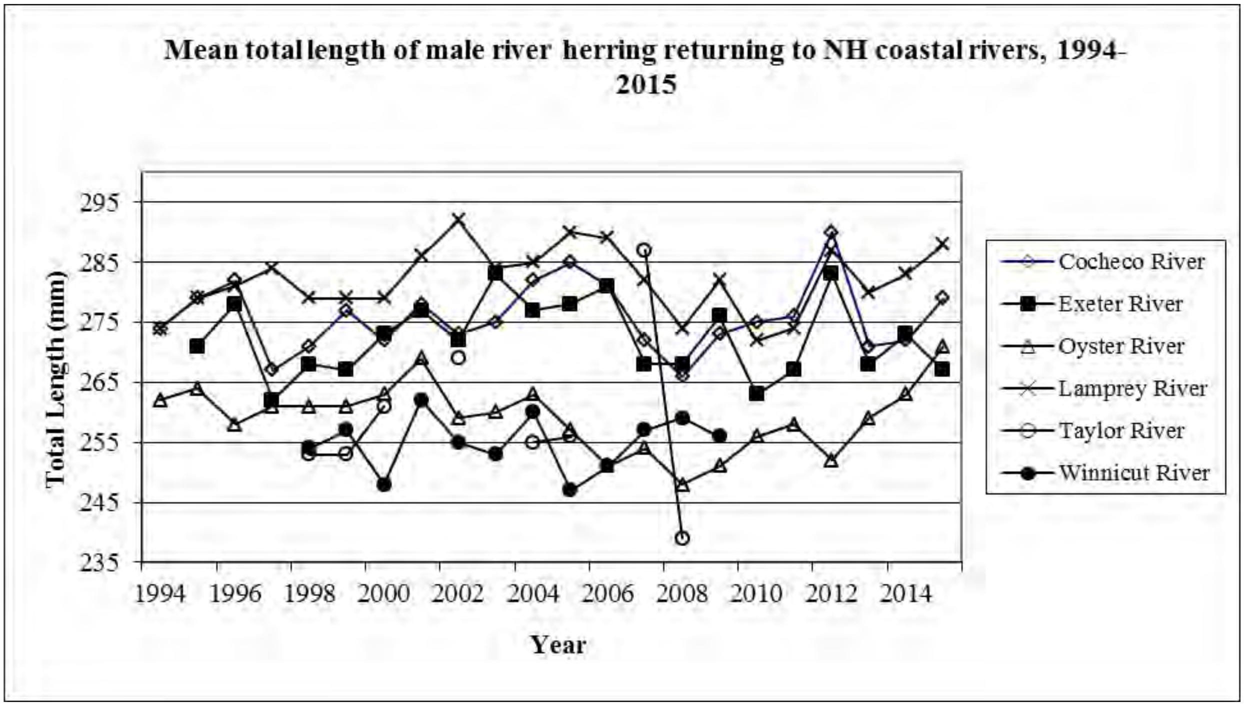


Figure 6.10 Von Bertalanffy growth curves for male and female river herring from New Hampshire rivers.



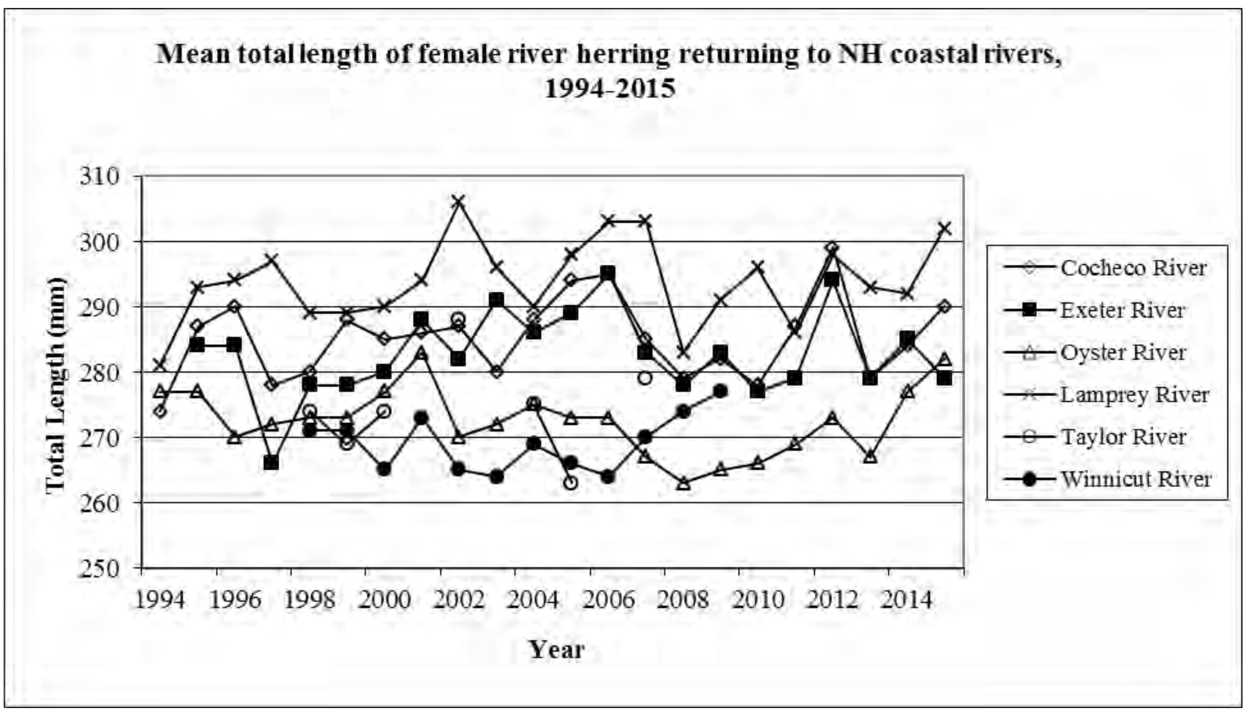


Figure 6.11 Mean total length (mm) of male and female river herring returning to the coastal rivers of New Hampshire, 1994-2015.

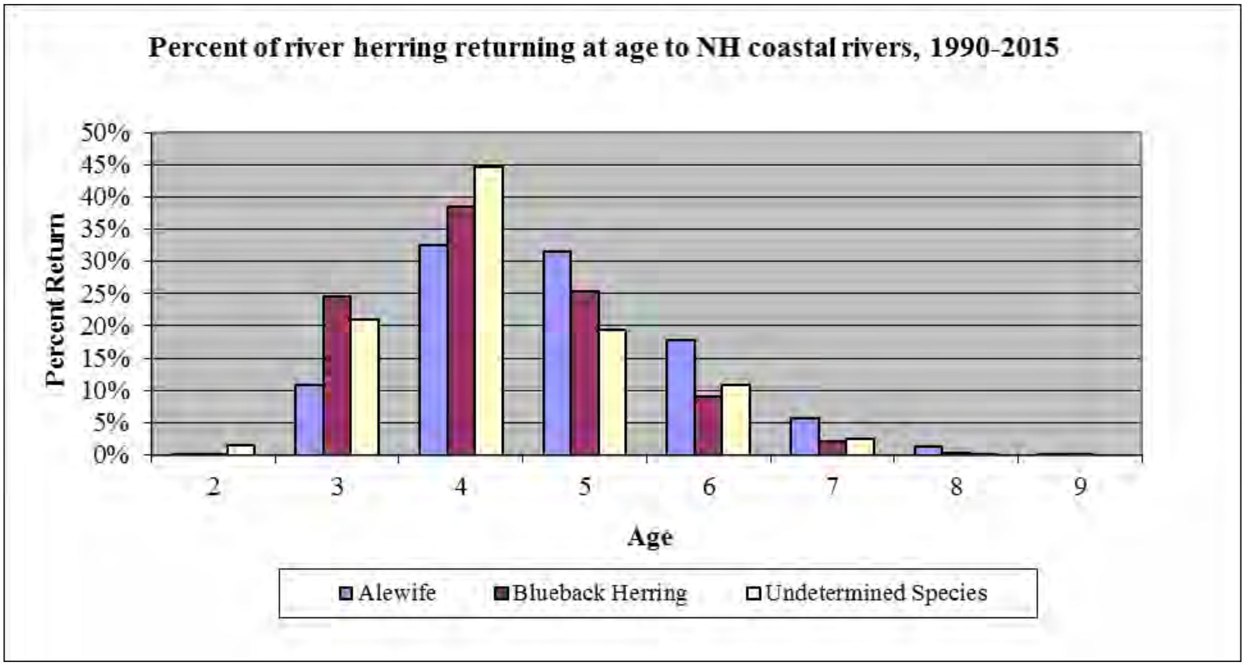


Figure 6.12 Percent of river herring returning at age to New Hampshire coastal rivers, 1990-2015.

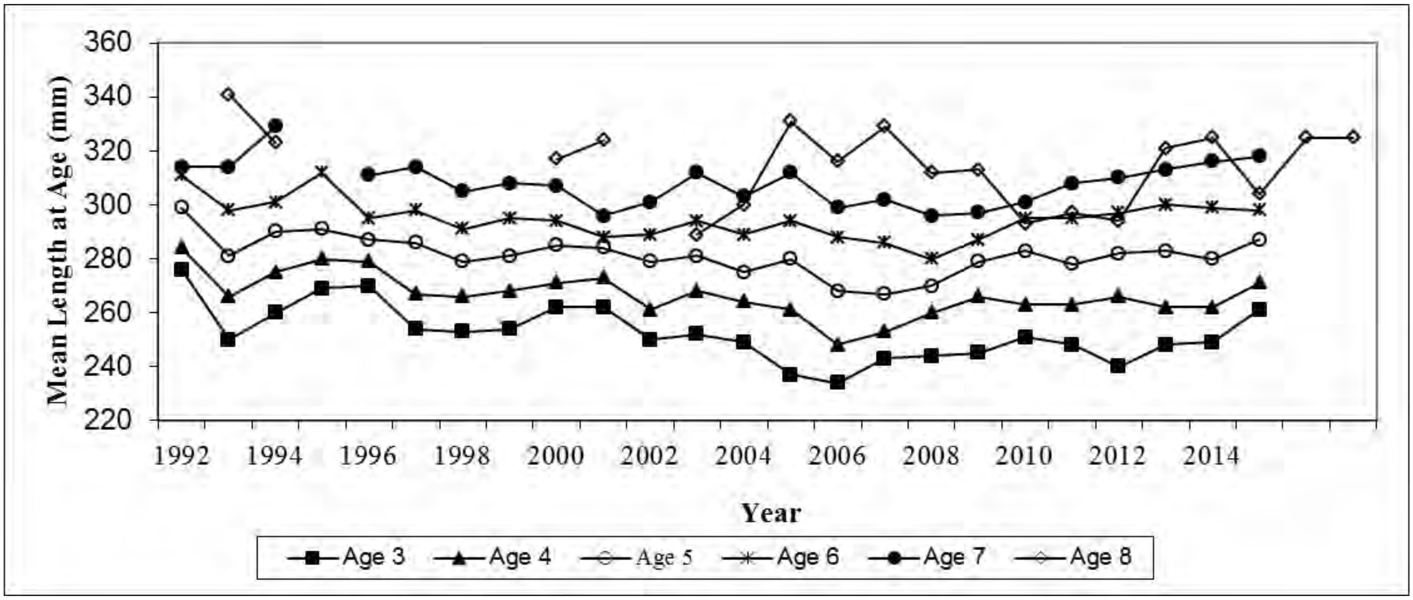


Figure 6.13 Mean length at age for river herring returns to New Hampshire coastal rivers, 1992 - 2015.

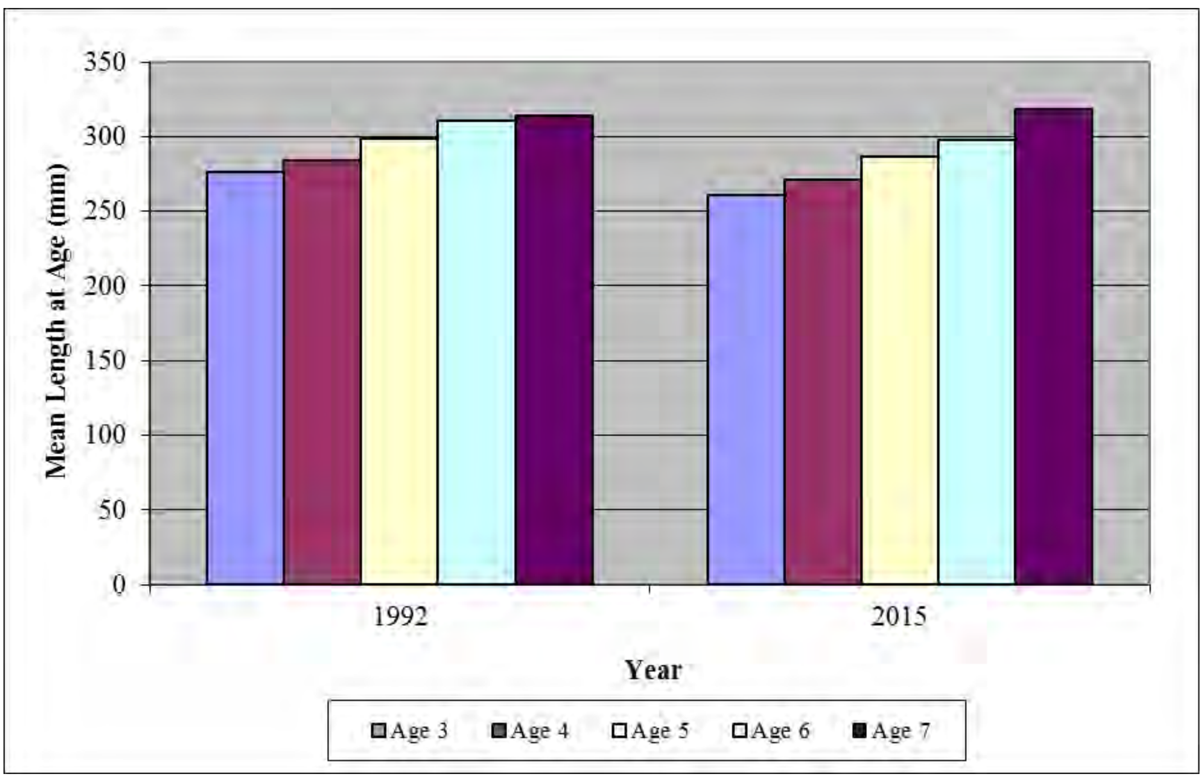


Figure 6.14 Mean length at age differences between 1992 and 2015 of river herring returning to New Hampshire coastal rivers.

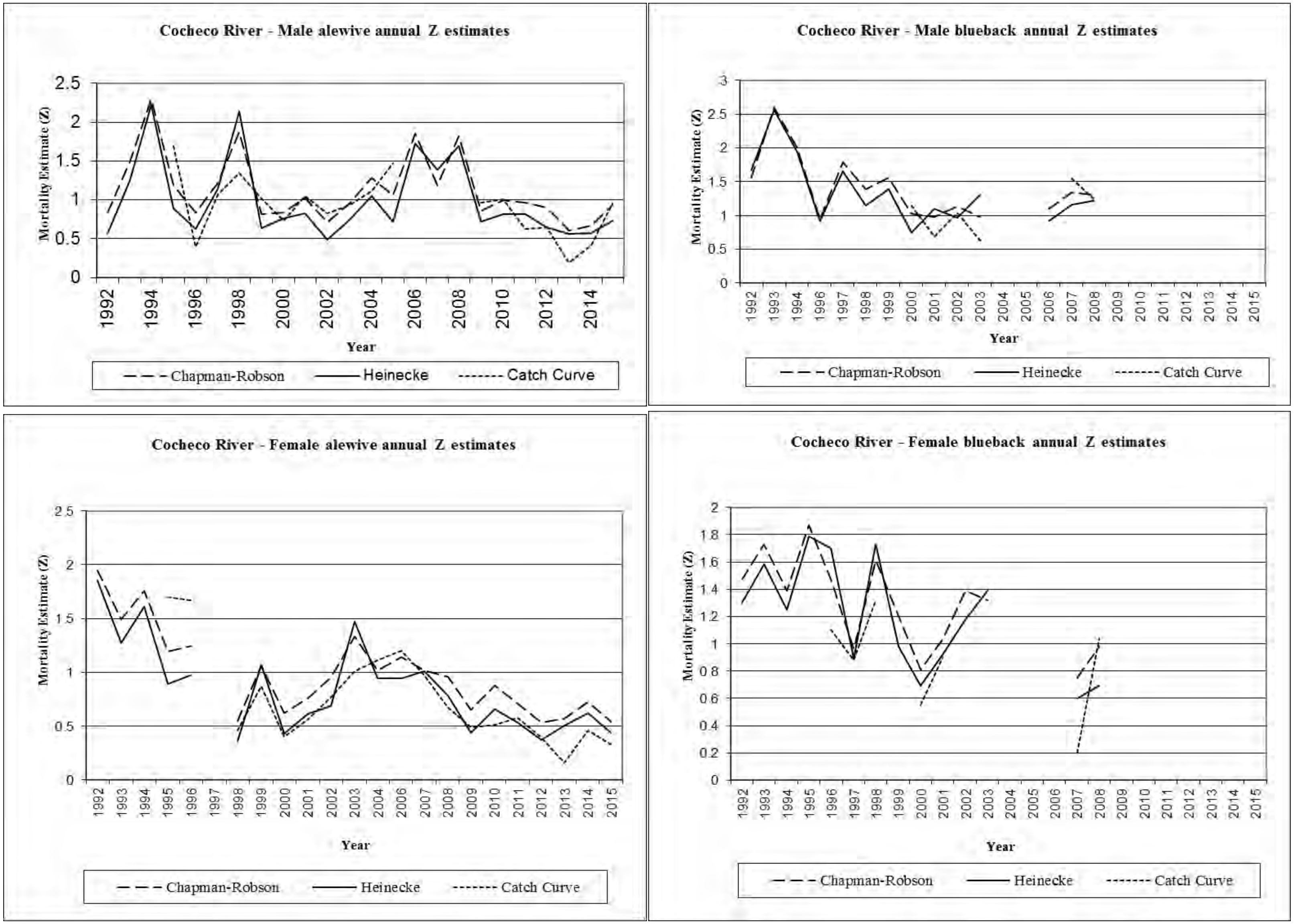


Figure 6.15 Estimates of total instantaneous mortality (Z) for river herring in coastal New Hampshire rivers, using Chapman-Robson, Heinecke, and catch curve methods based on age, separated by species and sex, 1990-2015.

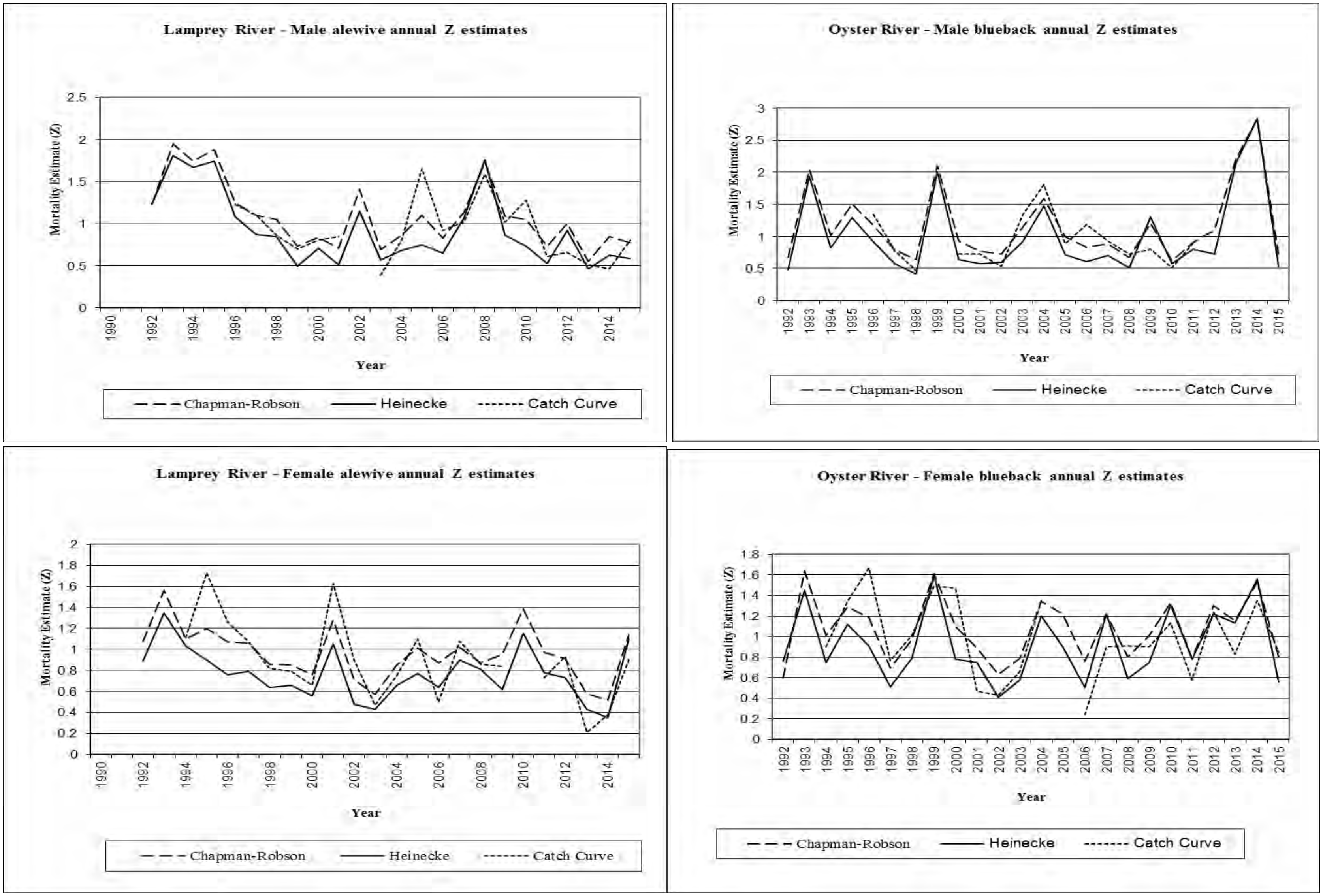


Figure 6.14 Continued.

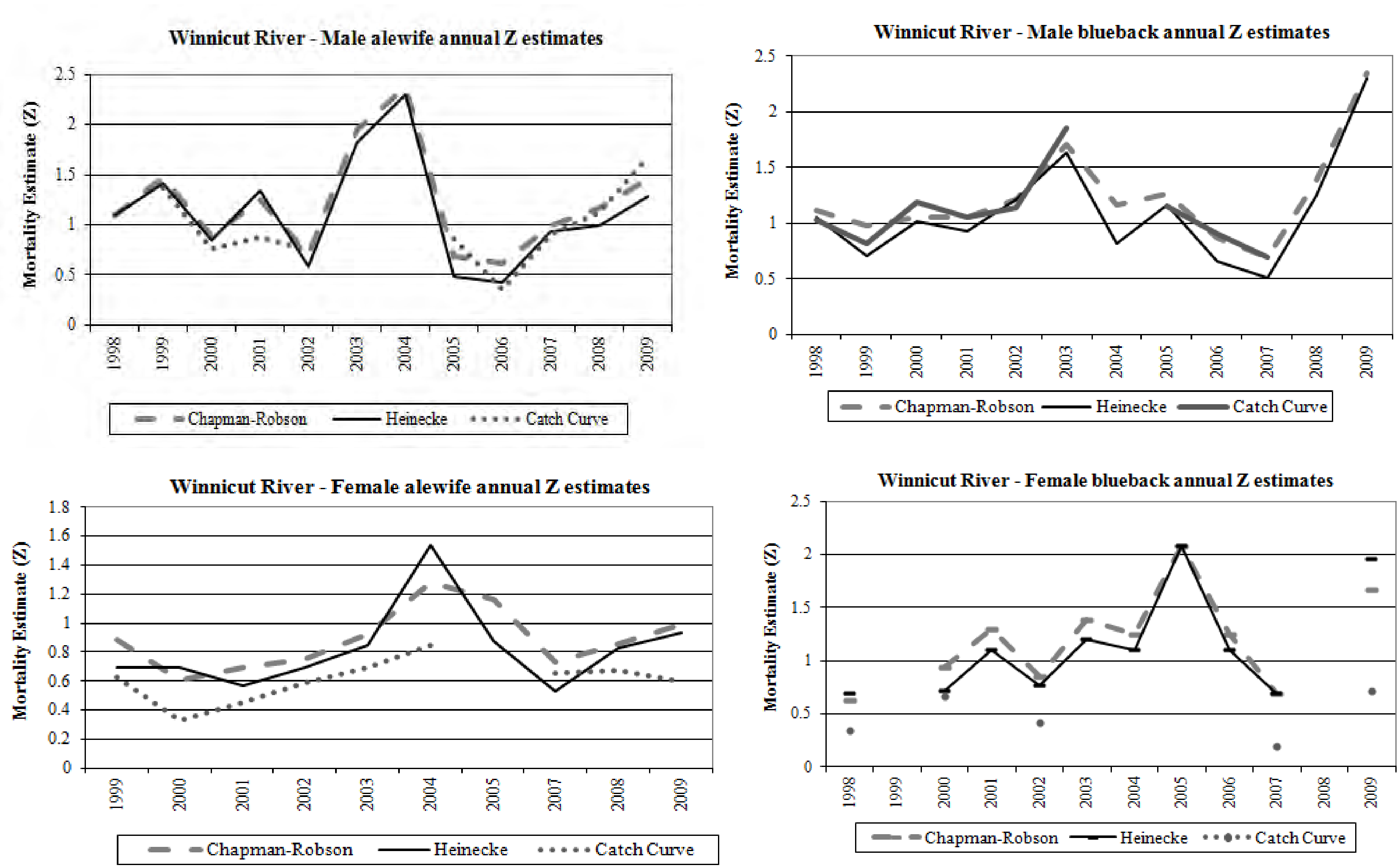
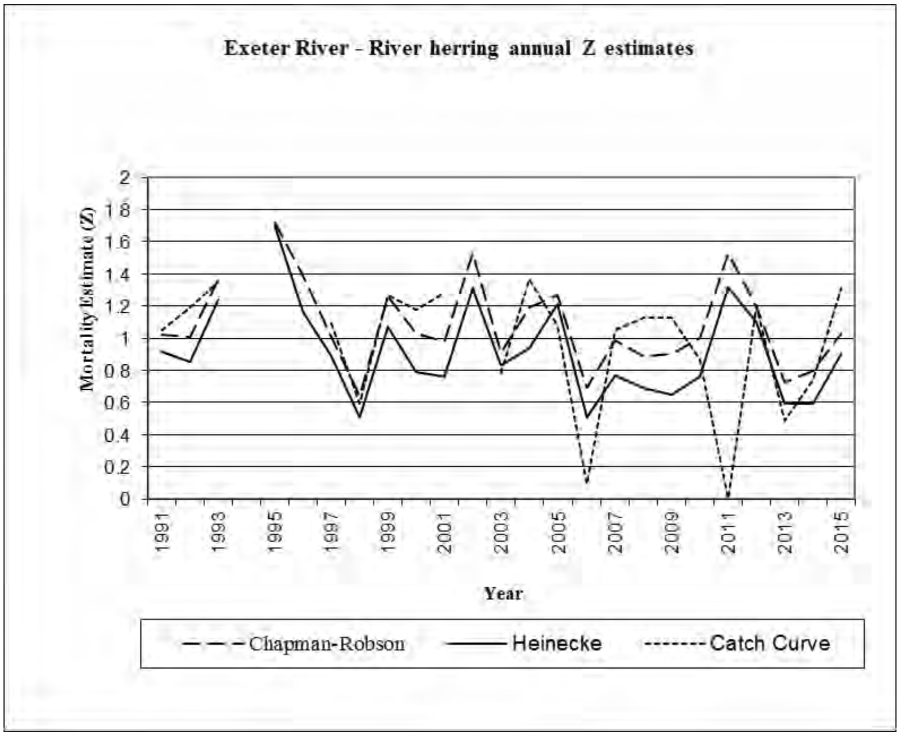


Figure 6.14 Continued.



**Due to low sample size Z estimates were not conducted between species or sex.*

Figure 6.14 Continued

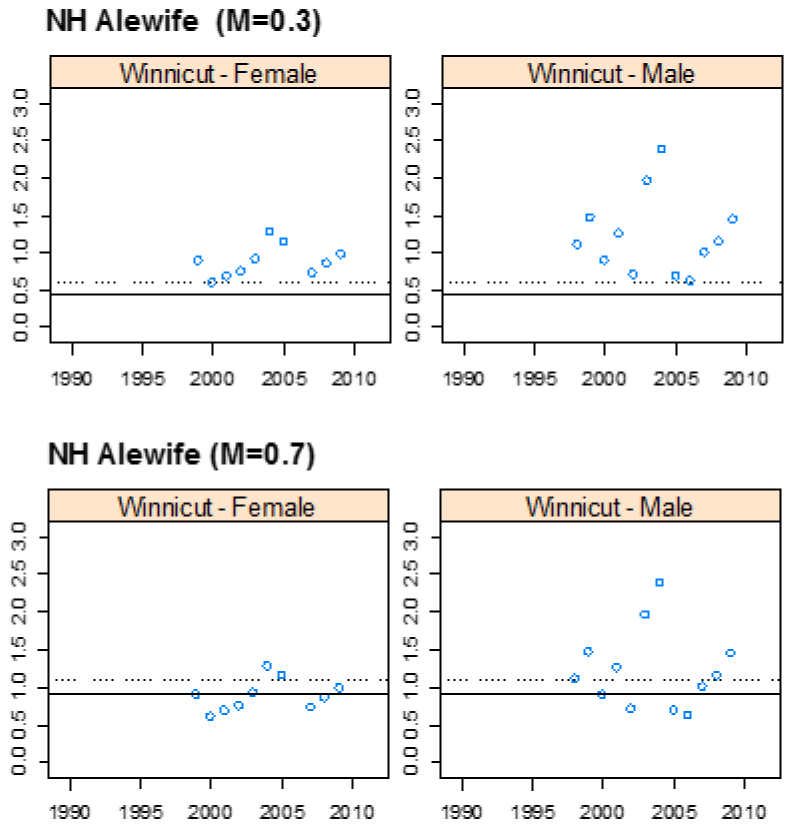


Figure 6.16: Empirical estimates of Z for NH alewife by river for different values of M. Dashed lines represent $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

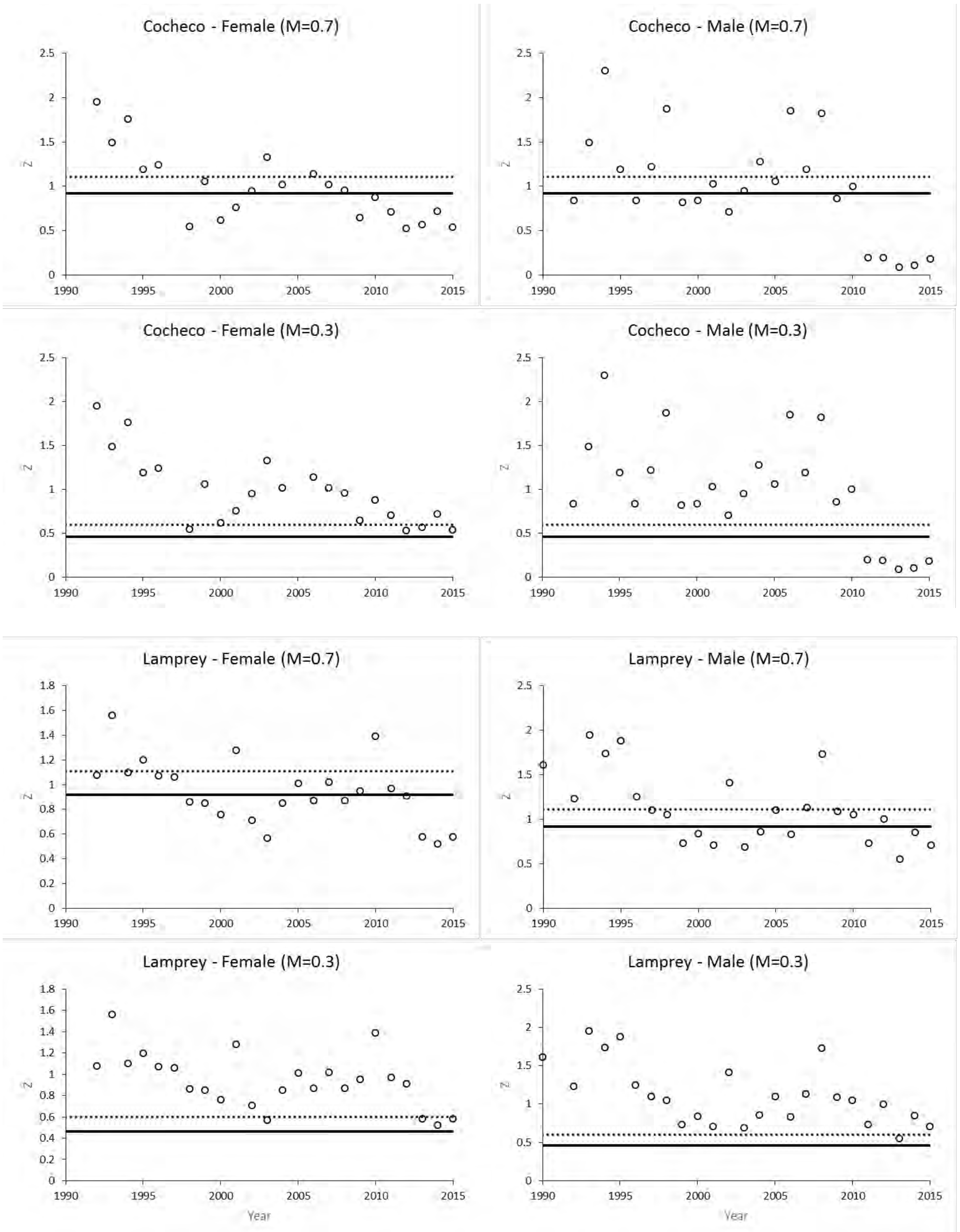
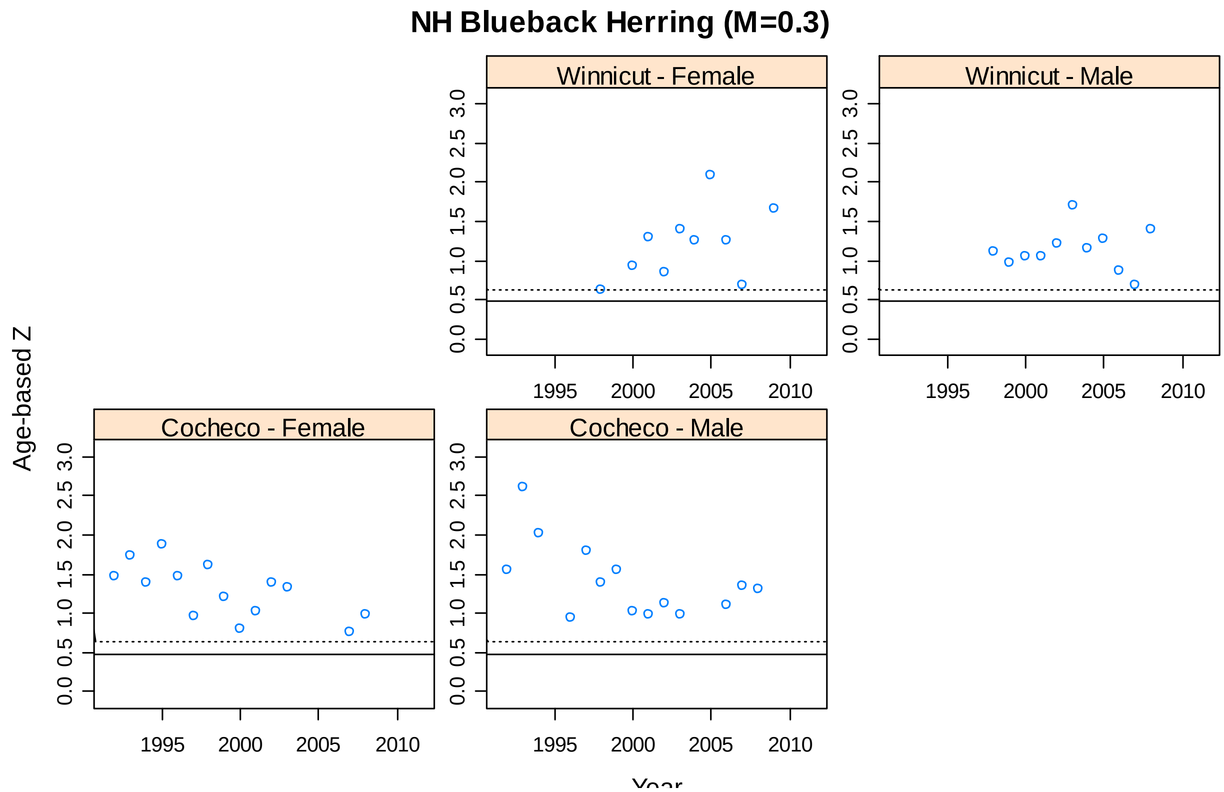


Figure 6.17 Continued



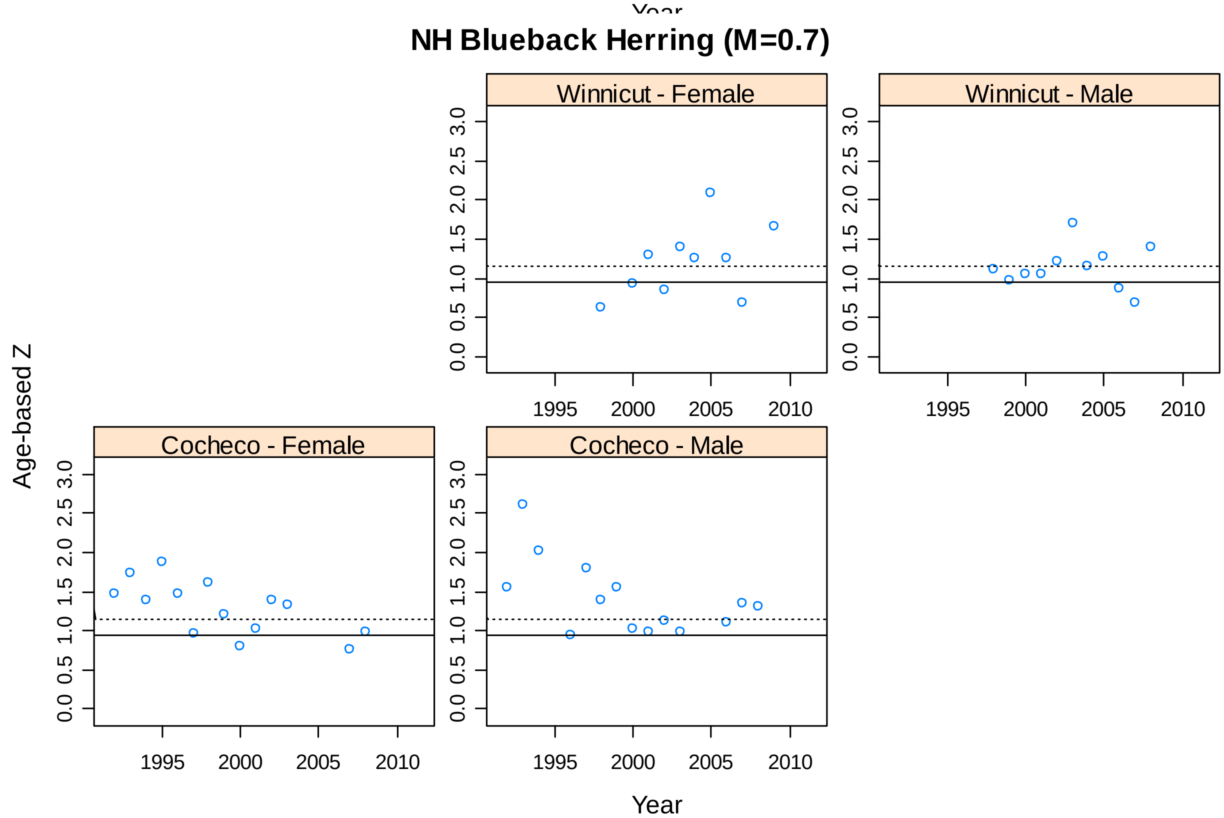


Figure 6.18: Empirical estimates of Z for NH blueback herring by river for different values of M. Dashed lines represent $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

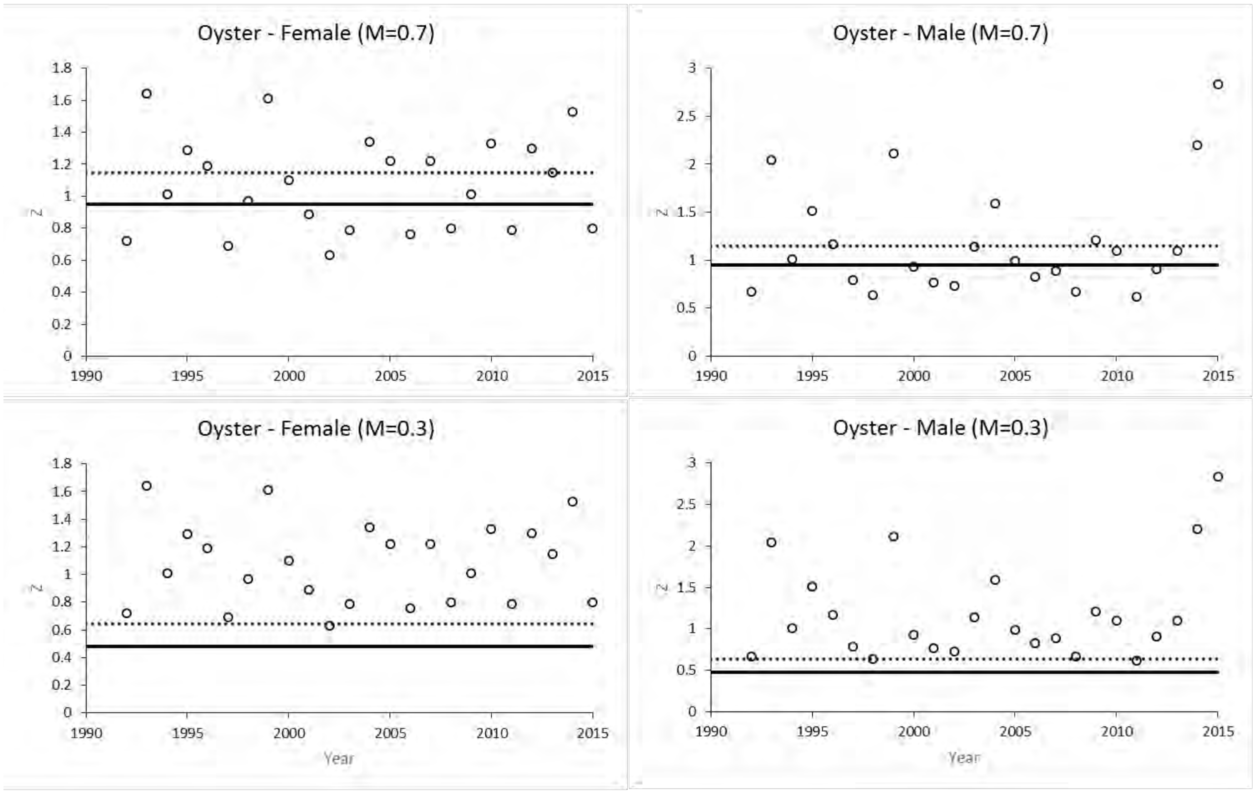


Figure 6.19 Continued

7 Status of River Herring in Massachusetts

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Executive Summary

Data on abundance, size structure and age composition were used to assess the current status of alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) in Massachusetts rivers. Count data for three rivers (Parker River, Monument River and Mattapoisett River) indicated a precipitous decline in alewife abundance after 2000. A strong decline was not observed in the Nemasket River, but average passage count after 2004 (587,000 fish) was about half of the average passage count prior to 2004 (1.04 million fish). Abundance has increased slowly in each river since about 2006-2008. A decline in the Monument River run size of blueback herring was not observed until after 2004 and total run size remains low. Size data from the Monument River and Stony Brook showed that the average total lengths of alewife and blueback herring have declined by about 20-25 mm over time. The current maximum age of both species is 1-2 years less than the maximum age observed during 1985-1987. The proportions of alewives that were repeat spawners in the Monument River declined in recent years by 64% or more compared to data from 1986-1987. In other rivers, proportions of repeated spawners as high as 0.54 (Charles River) were observed, but most estimates were below 0.30 in recent years. Similar reductions in proportions of repeat spawners were observed for blueback herring in the Monument River.

7.1. INTRODUCTION

In Massachusetts, more than 100 coastal rivers and streams are home to the anadromous alewife (*Alosa pseudoharengus*) and blueback (*Alosa aestivalis*) herring. Known colloquially as “river herring”, these fishes are ecologically-important because they are forage for many marine and freshwater fish predators such as striped bass (*Morone saxatilis*), cod (*Gadus morhua*), and yellow perch (*Perca flavescens*) as well as birds (Loesch, 1987). In addition, they are a key link in the transfer of nutrients between freshwater and marine systems (Mullen et al., 1986). River herring provide recreational and cultural benefits to citizens who value them for food and bait.

In the early to mid 2000s, river herring abundance in several runs throughout Massachusetts declined to historical low levels. The declines prompted the Massachusetts Division of Marine Fisheries (DMF) to establish in 2005 a three-year moratorium on the sale and harvest of river herring throughout the state, which has been extended to the present day. Since the harvest ban, river herring abundance has increased in many runs throughout coastal Massachusetts, but remains depressed in others. This report summarizes historical and current data on abundance, population characteristics, and mortality of river herring for the determination of the status of the stocks.

7.2. MANAGEMENT UNIT DEFINITION

River herring runs in Massachusetts are managed directly by DMF or by Town governments that have local control management plans approved by DMF.

7.3. FISHERY REGULATIONS

Currently, the Commonwealth of Massachusetts is in the 12th year of a harvest moratorium for river herring. Starting with the 2006 season,, the moratorium was scheduled to expire on January 1, 2009, but lack of recovery prompted an extension of the moratorium through 2011. The Massachusetts Marine Fisheries Advisory Commission approved in November of 2008 the following regulations on the Harvest, Possession and Sale of River Herring in the Commonwealth , 322-CMR Section 6:17:

Purpose. 322 CMR 6.00 is promulgated to establish consistent state management of river herring fisheries.

Definitions.

(a) "River Herring" means those species of fish known as alewives (*Alosa pseudoharengus*) and bluebacks (*Alosa aestivalis*).

(b) "Batch" means all fish in any separate container.

(c) "Container" means any box, tote, bag, bucket or other receptacle containing loose fish which may be separated from the entire load or shipment.

(3) 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.

Exceptions. The Director may authorize the harvest and possession of river herring from a particular spawning run for personal use based on documentation that the spawning run from which herring are harvested is not depleted.

Tolerance for bait fisheries. No person shall possess any batch of fish where more than 5% of the total is comprised of river herring species by count.

(6) Expiration. These measures shall expire on January 1, 2012. (*updated and current*)

7.4. ASSESSMENT HISTORY

No assessments of river herring populations in Massachusetts were conducted prior to the present effort that used 2004-2010 data. Three major efforts have been made by the Division of Marine Fisheries (and predecessor agency) to survey the presence and status of river herring runs and in the last century (Belding 1921; Reback et al. 1972; and Reback et al. 2004-5). These surveys provide valuable information on the presence of runs, fish passage, and fisheries, but did not attempt to quantify population abundance.

7.5. GENERAL LIFE HISTORY

Both blueback herring and alewives are found in many coastal stream systems in Massachusetts. While both species are capable of spawning in a variety of freshwater environments in Massachusetts, bluebacks typically spawn in more riverine areas, while alewives tend to spawn in more lacustrine (ponds and lakes) areas. Alewives begin to spawn in late March to mid-May when water temperatures reach about 10.5ºC , but they have been observed in Massachusetts streams as early as February and, in one instance, January. Bluebacks begin to spawn later in the spring (late April through June) when water temperatures reach about 13.9ºC. Blueback eggs are semi-buoyant and tend to drift with the current while alewife eggs will remain in contact with the substrate. After utilizing the freshwater habitat for a nursery area juvenile herring begin their migration to the ocean in late June to early July (Gahagan et al. 2010). Peak migration occurs in September on Cape Cod (Kosa and Mather, 2001; Yako et al., 2002) and it continues through December. Once in the marine environment, river herring feed on zooplankton such as microcrustaceans, fish eggs and fish larvae (Munroe, 2002). Maturity occurs between 2 to 5 years of age and the fish return to their natal streams utilizing their olfactory sense to guide them to home waters.

7.6. HABITAT DESCRIPTIONS

With over 100 river herring runs in Massachusetts there is a wide range of habitat types used by anadromous alewife and blueback herring. Many habitats have been altered from natural states by watershed development and dam construction. The typical alewife run has a corridor of migratory habitat that transitions from intertidal to freshwater river and leads to a freshwater pond used for spawning and nursery habitat. Other habitats used by alewife include man-made ponds, large reservoirs, brackish tidal ponds, and main stem rivers. Blueback herring can use the same habitat types as alewife but show a tendency to favor lotic environments. The Division of Marine Fisheries has an ongoing investigation to assess the suitability of river herring spawning and nursery habitats (Chase 2010) that will contribute additional information on water quality and habitat requirements.

7.7. RESTORATION PROGRAMS

Massachusetts' statutes direct the Division of Marine Fisheries to work with Towns to sustain river herring runs, manage fisheries and provide fish passage. The Division of Marine Fisheries has maintained a fishway crew since 1934. This ongoing program has focused on sustaining and restoring passageways for adult river herring migration and juvenile herring emigration. The present program continues this tradition with additional efforts aimed at collaborative projects, spawning and nursery habitat restoration and other diadromous fish species.

7.8. AGE

Age samples have been recorded in the Monument River since 1980. Outside of the Monument River few efforts were made to age river herring in Massachusetts until the present assessment for 2004-2015. All available river herring age data in Massachusetts are summarized in the following sections.

7.9. FISHERY DESCRIPTIONS

7.9.1. Commercial Fishery

Historically, river herring were one of the most valuable anadromous fishes harvested commercially in Massachusetts and sold as food or commercial bait (Belding, 1921). Prior to the 1950s, annual landings were 5 million pound or less (Appendix Table 1; Figure 1). Landings increased dramatically during the late 50s-early 60s (peak: 33 million pounds in 1958) as foreign fleets, using purse seines, exploited herring on Georges Bank (Appendix Table 1; Figure 1). By the early-1980s, after the establishment of the exclusive economic zone, river herring landings became a small fraction of the historical highs with most harvest occurring in spawning runs. Regulation of harvest limits in 1989 (25 fish/day) by the Commonwealth of Massachusetts restricted landings further and by 1994, there was little river herring sold commercially at fish houses (Appendix Table 1; Figure 1). Since 2005, there has been a moratorium on the possession and sale of river herring in Massachusetts.

The landings data reported by NMFS are underestimated because of poor or no record-keeping of harvest by towns with herring runs. Since the 1980s, DMF has collected annual harvest data from the towns of Middleboro, Bournedale, and Mattapoisett with herring runs on the Nemasket River, Monument River and Mattapoisett River, respectively (Figure 2).

7.9.2. Bycatch in Commercial Fisheries

The issue of river herring bycatch has received much attention recently.Bycatch of river herring does occur in commercial fisheries that are targeting other species. Quantification of this take is difficult to estimate and efforts are being made to improve monitoring and reporting of this source of mortality. The commercial mid-water trawl, pair trawls, bottom trawl and purse seine fisheries for Atlantic herring are a point of focus. Cieri et al. (2008) reported that bycatch of river herring from the Atlantic herring fishery ranged from 171,973 pounds to 1.68 million pounds during 2005-2007. Catch caps were created for mid-water trawl and bottom trawl fishermen pursuing Atlantic herring and Atlantic mackerel in 2014. Periodic reports of by-catch are also received from the long fin and short fin squid, whiting, and northern shrimp fisheries as well as menhaden bait fisheries. Reports are often anecdotal and not well documented. In addition small numbers of illegal harvest (poaching) are usually reported to the MA Environmental Police each spring. These types of losses contribute to the total mortality of alewife and blueback herring but the actual extent and amount is poorly known at this time. In the Atlantic herring fishery, only 5% of the total landings are allowed to contain river herring as bycatch. In response to these bycatch issues, in 2008, DMF initiated a comprehensive monitoring program for river herring bycatch in the Atlantic herring fishery. In 2010 DMF, SMAST, and the mid-water trawl fleet created a collaborative River Herring Bycatch Avoidance Program (RHBA), with a goal of reducing at-sea bycatch by 50%. A subsequent RHBA was created with small-mesh bottom trawl herring fishermen in late 2011. Recently, a comprehensive evaluation of the first four full years of the mid-water trawl RHBA (2011-2014) found that the RHBA program coincided with a 58% reduction in bycatch from the previous four year period (2007-2010), with the overall fishery bycatch rate being reduced by 21% (Bethoney et al. In Press).

7.9.3. Recreational Fishery

Historically, river herring were commonly harvested for food in coastal towns in Massachusetts. Recreational use in recent decades was mainly for bait in the striped bass fishery. The discontinued Marine Recreational Fisheries Statistics Survey (MRFSS) estimated of the numbers of river herring harvested and released by anglers in Massachusetts are very imprecise and show little trend (Appendix Table 2). Since spring of 2005, there has been no recreational (bait) fishery for alewife and/or blueback herring allowed in the Commonwealth of Massachusetts.

7.9.4. Subsistence Fishery

The only subsistence river herring fishery currently conducted within Massachusetts is under a Memorandum of Understanding (MOU) between the Commonwealth and the federally recognized Mashpee Wampanoag Indian Tribe on Cape Cod. This understanding recognizes the Tribe's aboriginal fishing rights and allows harvesting of river herring by Tribal members which is regulated by the Tribe pursuant to the Tribe's regulatory authority. Reported harvests were provided to DMF for 2010-2013 and ranged from about 1,200 fish to 3,500 fish per year, with removals coming from several rivers. No reporting has occurred since 2013.

7.9.5. Stocking Efforts

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. Stocking of gravid river herring where river access has been provided or improved is generally conducted for three or more consecutive years per system. Prior to the moratorium the program transported between 30,000 and 50,000 fish per year into ten to fifteen different systems. A DMF stocking protocol was developed and implemented in 2013 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. The protocol has reduced stocking activity with most recent efforts occurring with-in drainage, moving fish upstream past multiple obstructions to the headwater spawning habitat.

7.10. FISHERIES-INDEPENDENT MONITORING

Data on alewife and blueback herring in Massachusetts come from mostly historical and/or current work conducted by DMF, academic and federal scientists, and local citizen groups interested in protecting river herring resources. Figure 3 shows the rivers and locations for which fisheries-independent data are available. In this document, "passage" estimates are considered herring counts that, when added to the harvest estimates, may not produce the total amount of herring in the river system because the count location is situated above viable spawning habitat of river herring (e.g., Nemasket River). "Escapement" estimates are considered herring counts that, when added to harvest estimates, produce the total amount of river herring in the system because the harvest and count locations are situated close to the river mouth (e.g., Monument River). In 2013, DMF began using otoliths rather than scales to age river herring. All scales are now archived, with the exception of Monument alewife, which are still processed to generate repeat spawning rate estimates. The following gives a brief description of data available:

Acushnet River (New Bedford) - Since 2005, DMF has conducted a census of river herring entering the spawning ground using a fish trap. Simultaneous estimation of passage by using an electronic counter began in 2008, and video counting was attempted in 2008. DMF has also collected biological samples from dead fish, but samples were non-random and sample sizes were too small to use in this assessment. This location monitors the herring run response to fish passage restoration.

Agawam River (Wareham) - The town of Wareham has been estimating combined passage using an electronic counter since 2006. Biological data are available from only 1991.

Back River (Weymouth) - The town of Weymouth's herring warden provides a "relative" passage estimate from his daily observations of run activity. No statistically-valid design is used. In 2007, DMF characterized the alewife population under an NOAA Anadromous Fish Conservation Act grant. DMF collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations (see Monument River below). DMF resumed collecting biological data and installed a SR-1601 Electronic Resistivity Counter in 2015.

Bound Brook (Scituate) - The North and South Rivers Watershed Association began passage counts using visual estimation in 2010. No statistical design was used. There are no biological data available.

Charles River (Boston) - The University of Massachusetts with assistance of DMF conducted video counts in 2008 and 2009. DMF conducted video counts in 2013 and 2014. Biological data are available from 1985, 1993, 2013, and 2014.

Connecticut River (Holyoke) - Fishlift counts have been made at the Holyoke Dam since 1967 for blueback herring by the US Fish and Wildlife Service. The numbers are used by the State of Connecticut in their river herring assessment; therefore, the information is not discussed herein to avoid duplication of effort.

Coonamessett River (Falmouth) - Falmouth Department of Natural Resources has been estimating passage using visual estimation since 2005. There are no biological data available.

Herring Brook, First (Scituate) - The North and South Rivers Watershed Association conducted passage counts using visual estimation in 2005-2006. No statistical design was used. There are no biological data available.

Herring Brook, Second (Norwell) - The North and South Rivers Watershed Association conducted passage counts using visual estimation in 2005-2006. No statistical design was used. There are no biological data available.

Herring Brook, Third (Norwell/Hanover) - The North and South Rivers Watershed Association conducted passage counts using visual estimation in 2003, and 2005-2006. No statistical design was used. There are no biological data available.

Herring River (Wellfleet) - The Association to Preserve Cape Cod has been estimating passage numbers using visual counting since 2007. There are no biological data available.

Herring River (Harwich) - The Association to Preserve Cape Cod has been estimating passage numbers using visual counting since 2007. DMF began collecting biological data and installed a SR-1601 Electronic Resistivity Counter in 2016.

Ipswich River (Ipswich) - The Ipswich Watershed Association has been estimating passage using visual counting since 2000. They've attempted to use the statistical design of Rideout et al. (1979) but prior to 2005, effort was not sufficient to provide reliable estimates. In 2006-2008, DMF also made census counts by using a fish trap. There are no biological data available.

Jones River (Kingston) - The Jones River Watershed Association has been conducting passage counts using visual estimation since 2005. There are no biological data available. No statistically-valid design was used.

Little River (Gloucester) - Massachusetts Audubon made passage counts using visual estimation during 2000-2002, 2005, and 2009. There are no biological data available. No statistically-valid design was used.

Marston-Mills River (Marston-Mills) - Starting in 2007, a local watershed group provides visual counts of combined herring passage at Mill Pond dam in the Marston-Mills River. They use a stratified random design. There are no historical or current data on population characteristics.

Mattapoisett River (Mattapoisett) - Since 1988, Alewives Anonymous has provided passage counts of alewife using an electronic fish counter. Harvest data are also provided. In 1995, 2006 and 2007, DMF collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations (see Monument River below).

Merrimack River (Lawrence) - The number of herring lifted at the Essex and Pawtucket Dam fishlifts since 1983 are provided by the US Fish and Wildlife Service. In 2014, DMF began collecting 100 herring a week from the Essex Dam fish lift to biologically characterize this population.

Monument River (Bournedale) - DMF has been scientifically monitoring the abundance, sex composition, length structure, age composition and removals of alewife and blueback herring in the Monument River since the early 1980s (Churchill, 1981; O'Hara, 1980; Brady, 1987a, b). Prior to 1985, abundance was estimated by using visual counts following the statistical design of Rideout et al. (1979). Since 1985, escapement has been estimated by using a Smith-Root electronic fish counter that is calibrated daily. Fish entering the system are sampled weekly by using a dipnet. Ages are determined from otoliths and scales are used to identify repeat spawners and are also aged using the criteria of Rothschild (1963), Marcy (1969) and Kornegay (1977). Fish samples are used to apportion abundance into species- and sex-specific estimates (Brady, 1987). In the past, DMF often used herring from this river as donor stock to other river systems. All numbers transported are added to harvest recorded by the Bournedale fish warden to get total number of removals. Scale ages are only available for 1984-1987, 1993, and 1995-present. Since the counting location is not far above the catchment basin where herring are removed, and both are close to the river mouth, the total run size is estimated by adding escapement counts to removal numbers.

Mystic River (Boston) - DMF has collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations since 2004 (see Monument River above). Beginning in 2012, the Mystic River Watershed Association began a visual count estimate using the statistical method of Nelson (2006).

Nemasket River (Middleboro) - Since 1996, the town of Middleboro has provided visual counts of alewife passage at the fishway off Wareham Street (river mile 7.5). The statistical design of Rideout et al. (1979) is used. Since 2004, DMF has characterized the alewife and blueback populations under an NOAA Anadromous Fish Conservation Act grant. DMF has collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations (see Monument River above).*Parker River* (Newbury) - Students and researchers at the University of Massachusetts, Amherst conducted several studies during the 1970s that provide information on juvenile and adult population characteristics, abundance and migration of alewives (Beltz, 1975; Cohen, 1976; Cole et al., 1976; Cole et al., 1978; Huber, 1974; Jimenez, 1978; Libey, 1976; Mayo, 1974; Rideout et al., 1979). Since 1997, the Parker River Clean Water Association has been estimating passage numbers at the first dam using visual counting and the statistical design of Nelson (2006). In 2014, DMF installed a video system to better estimate passage at the first dam. Due to high flood waters of 2005 and 2006, a weir failed, making it difficult for alewives to pass. The weirs were repaired in the summer of 2013 and additional modifications were made to the fishway in 2014. Passage counts between 2005 and 2014 may have been biased. Since 2012, DMF has collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations (see Monument River above).

Pilgrim Lake (Orleans) - The Association to Preserve Cape Cod has provided abundance estimates of alewife passage using visual counting and a stratified random design since 2008.

Quashnet River (Falmouth/Mashpee) - In 2004, DMF characterized the alewife population under an NOAA Anadromous Fish Conservation Act grant. DMF collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations (see Monument River above). There are no estimates of passage numbers available.

Sippican River (Wareham) - Alewives Anonymous made electronic census counts of alewife passage in 1995-2002 and 2006. There are no biological data available.

South River (Marshfield) - The North and South Rivers Watershed Association conducted passage counts using visual estimation in 2006, 2008 and 2010. No statistical design was used. There are no biological data available.

Stony Brook (Brewster) - The Association to Preserve Cape Cod has provided estimates of alewife passage numbers at the lower Mill Pond dam using visual counting and a stratified random design since 2007. In 2004, DMF characterized the alewife population under an NOAA Anadromous Fish Conservation Act grant. DMF collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations (see Monument River above). Mr. George A. Kurlycheck, a Middle School teacher in Harwich, collected average size data on alewife (sexes combined) from 1978-2001.

Town Brook (Plymouth) - DMF has collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations since 2004 (see Monument River above). The town of Plymouth, University of Massachusetts, and DMF have made visual counts since 2008 and video counts were made in 2008 and 2009.

Town River (Bridgewater) - The town of Bridgewater has made combined electronic passage counts of river herring (species combined) since 2000. There are no biological data available.

Trunk River (Falmouth) - Falmouth Department of Natural Resources has been estimating passage since 2008. No statistical design is used. There are no biological data available.

Wankinco River (Wareham) - The town of Wareham has made combined electronic passage counts since 2007. There are no biological data available.

7.10.1. Trends in Run Size

The river estimates of passage counts and total run size used in this assessment came from the Mattapoisett River, Monument River, Nemasket River, Parker River, and Town River (Appendix Table 3; Figure 4). Some river estimates were deemed limited and not used for this assessment because 1) lack of statistical design (e.g., Back River), 2) non-reflectance of natural abundance trends (e.g., Merrimack River), or 3) shortness of time series (e.g., Marston-Mills River, Stony Brook, and Town Brook).

Matttapoisett River

Alewife - Passage estimates of alewife showed increasing trends in numbers from 22,000 fish in 1988 to 130,000 fish in 2000 (Appendix Table 3; Figure 4). Passage estimates dropped precipitously through 2004 to 5,385 fish. Passage size has increased gradually to 55,429 fish in 2014 (Appendix Table 3; Figure 4).

Monument River

Alewife - A fluctuating, but increasing trend in total run size was evident from 1980 to 2000, peaking at about 597,937 fish (Appendix Table 3; Figure 4). Thereafter, it dropped precipitously through 2002 to 182,031 fish, and then continued to decline through 2006 to the lowest level observed in the time series (52,472 fish). Alewife abundance has increased gradually since 2007 to an average of about 131,448 fish, with run counts exceeding 200,000 individuals in 2014 and 2015. (Appendix Table 3; Figure 4).

Blueback - Total run size was highest during 1980-1991, averaging about 64,800 fish. Abundance was lower on average (41,000 fish) during 1992-2002 and it began to decline in 2003 to 8,140 fish in 2007 (Appendix Table 3; Figure 4). Abundance increased to 18,532 and 30,356 fish in 2008 and 2009, respectively, but dropped to 9,358 fish in 2010 (Appendix Table 3; Figure 4). Since 2010, abundance has fluctuated between 13,632 (2011) and 101,863 (2013) herring.

Nemasket River

Alewife - Passage numbers of alewife have fluctuated considerably since 1996 (Appendix Table 3; Figure 4). Passage numbers averaged 720,000 fish prior to 2002, but following the peak (1.4 million fish), numbers declined through 2005 to 226,000 fish. Since 2007, numbers have increased to 565,000 fish on average (Appendix Table 3; Figure 4).

Parker River

Alewife - Passage counts of alewives and blueback herring fluctuated considerably during the 1970s, peaking at 38,163 fish in 1973 and then declining to an average of 11,256 fish between 1976-1978. Passage counts were as high as 7,894 fish in 2000, exceeding the 1977 estimate of 6,654 fish, but declined to low levels by 2005 (Appendix Table 3; Figure 4). Since 2008, passage numbers have increased. It is very likely that passage conditions obscure population trends at this site.

Town River

Alewife/Blueback - Passage numbers of alewife and blueback herring (combined) have fluctuated considerably since 2000 (Appendix Table 3; Figure 4). Passage numbers were as high 310,000 fish in 2003. In most years, however, passage numbers averaged only 32,149 fish (Appendix Table 3; Figure 4). During the period 2012-2014, passage and counts at Town River were affected by extreme low flows, dam and fishway degradation, and counter failures, making counts for those years inaccurate or non-reflective of abundance trends.

7.10.2. Trends in Size Structure

Raw length frequencies available for each river, species and sex are shown in Appendix Tables 4-5, and summary statistics for the length distributions are shown in Appendix Tables 6-7. Males of each species are smaller in length than females of the same species, and blueback herring are smaller in length than alewives. Comparison of average sizes among rivers showed that alewives collected in the Monument River, Mystic River, Quashnet River, Stony Brook, and Town Brook were about 10-30 mm smaller than alewives collected in the Back, Mattapoisett, Parker,and Nemasket rivers (Appendix Tables 6 and 7). Mean total length of both species and sexes from the Monument River declined from 1984 through the mid-1990s (Appendix Table 7; Figure 5). Female and male alewives and blueback herring sampled during 2011-2015 were about 20-25 mm smaller, on average, than alewives and blueback herring of the same sex sampled during 1984-1987 (Appendix Table 7). Mean total length of alewife (sexes combined) in Stony Brook showed a similar decline over time (Figure 5).

7.10.3 Trends in Age

Any available age data regardless of the length of the time series were used in this assessment. Raw data are presented in Appendix Tables 8 and 9. Mean age is presented in Appendix Table 10.

Agawam River

Alewife - Age samples (n=71 for females; n=86 for males) were available from 1991. The youngest and oldest alewives observed on the run were ages 3 and 7, respectively, for females and ages 3 and 6, respectively, for males (Appendix Table 8; Figure 6). Mean ages for female and male alewife in 1991 were 4.6 and 4.3 years, respectively (Appendix Table 10).

Blueback - Age samples (n=6 for females; n=7 for males) were available from 1991. These sample sizes were too small to provide accurate observation mean sizes, gender differences and the youngest and oldest ages of blueback herring in the run. (Appendix Table 10).

Back River

Alewife - Age samples (n=210 for females; n=228 for males) were available from 2007 for alewife only. The youngest and oldest alewives observed in the run were ages 3 and 8, respectively, for females and ages 3 and 7, respectively, for males (Appendix Table 8; Figure 6) . Mean ages for female and male alewife in 2007 were 4.2 and 4.0 years, respectively (Appendix Table 10).

Charles River

Alewife - Age samples were available from 2013-2014 for alewife. The youngest and oldest alewives observed in the run were ages 3 and 6, respectively, for both females and males (Appendix Table 8; Figure 6). Mean ages for female and male alewife in 2007 were 4.2 and 4.0 years, respectively (Appendix Table 10).

Blueback - Age samples were available from 1985 1993 and 2012-2014. The youngest and oldest alewives observed in the run were ages 2 and 10, respectively, for females and ages 2 and 7, respectively, for males (Appendix Table 8). Mean ages for female and male alewife were 5.2 and 4.4 years in 1985, respectively, and 4.8 and 4.0 in 1993 (Appendix Table 10).

Mattapoisett River

Alewife - Age samples were available from 1995 and 2006. The youngest and oldest alewives observed in the run were ages 3 and 7, respectively, for females and 3 and 6, respectively, for males (Appendix Table 8; Figure 6). Mean ages for female and male alewife were 4.8 and 4.4, respectively, in 1995 and 3.9 and 3.7 years, respectively, in 2006 (Appendix Table 10) indicating a possible decline between the two years.

Monument River

Alewife - The earliest time series (1985-1987) of age composition data come from Brady (1987a). The youngest and oldest individuals observed in the run during 1985-1987 were age 3 and 8 for females, and age 3 and 7 for males, respectively (Appendix Table 9). Ages 4-5 were the most abundant age-classes in the spawning run. From 1993-2015, the youngest and oldest individuals observed on the run were age 2 and 8 for both sexes, respectively, although ages older than 6 were observed infrequently (Appendix Table 9). Ages 4 and 5 were the most abundant age-classes. Comparison of the age compositions between 1984-1987 and later years indicated that the maximum age of male and female alewife has decreased by one to two years. Comparison of mean ages during 1985-1987 to mean ages during 1993-2015 indicated a decline in mean age over time (Appendix Table 10; Figure 7).

Blueback - The earliest time series (1985-1987) of age composition data come from Brady (1987b). The youngest and oldest individuals of both sexes observed in the run during 1985-1987 were age 3 and 7, respectively (Appendix Table 9). Ages 4-5 were the most abundant age-classes in the spawning run. From 1993-2015, the youngest and oldest individuals observed on the run were age 3 and 6, respectively, for both sexes, except in 1997 and 2008 (Appendix Table 9). Ages 4 and 5 were the most abundant age-classes. Comparison of the age compositions over time indicated that the maximum age of male and female alewife has decreased by one to two years. Comparison of mean ages during 1985-1987 to mean ages during 1993-2015 indicated a decline in mean age over time (Appendix Table 10; Figure 7).

Mystic River

Alewife - Age compositions of both sexes of alewife from 2004-2015 were composed of ages 2-9 with peak numbers occurring mostly at ages 4 and 5 (Appendix Table 8). Mean age ranged from 3.9 to 4.7 years for females and from 3.5 to 4.3 years for males (Appendix Table 10).

Blueback - Age samples for blueback herring were available from 2005-2015. The youngest and oldest individuals of both sexes observed in the run were age 2 and 8, respectively (Appendix Table 8). Ages 4 and 5 were the most abundant age-classes. Mean age ranged from 3.2 to 4.5 years for females and from 3.2 to 3.8 years for males (Appendix Table 10).

Nemasket River

Alewife - The youngest and oldest individuals observed in the run during 2004-2015 were age 3 and 8, respectively for females and age 2 and 8, respectively for males (Appendix Table 8). Ages 4-5 were the most abundant age-classes. Mean age ranged from 3.4 to 5.3 years for females, and from 4.9 to 3.3 years for males (Appendix Table 10).

Parker River

Alewife - The earliest time series (1971-1978) of age composition data come from studies of alewife by Cole et al. (1976), Cole et al. (1978), and Mayo (1974). In this period, the youngest and oldest alewives of both sexes observed in the run were age 3 and 9, respectively. Ages 4-6 were the most abundant age-classes in the spawning run, although ages 7-8 were common. Average age from 1971-1978 ranged from 4.3 to 6.0 years for females, and from 4.0 to 5.7 for males (Appendix Table 10). The time series begun in 2011 suggests that the age structure of alewife in the Parker River has become more truncated. The youngest and oldest female alewife observed between 2011-2015 were age 3 and 7, respectively. The youngest and oldest males were age 2 and 8, respectively. For both sexes ages 3-5 were the most abundant age-classes with few older fish (Appendix Table 8). Average age from 2011-2014 ranged from 3.6 to 4.5 for females and 3.4 to 4.3 for males(Appendix Table 10).

Blueback - Age samples for blueback herring were available from 2011-2015. The youngest and oldest females observed between 2011-2015 were age 3 and 7, respectively. The youngest and oldest males were age 2 and 6, respectively. For both sexes ages 3-5 were the most abundant age-classes with occasional older fish (Appendix Table 8). Average age from 2011-2014 ranged from 3.2 to 4.1 for females and 3.2 to 3.9 for males (Appendix Table 10).

Quashnet River

Alewife - During 2004, the youngest and oldest individuals observed in the run were age 3 and 5 for both sexes, respectively (Appendix Table 8). Age 4 was the most abundant age-class. Mean ages for female and male alewife in 2004 were 4.3 and 3.9 years, respectively (Appendix Table 10).

Blueback - No description of the age composition is made because only 8 individuals were aged (Appendix Table 8).

Stony Brook

Alewife - During 2004, the youngest and oldest individuals observed in the run were age 3 and 7 for females, and age 3 and 6 for males, respectively (Appendix Table 8). Ages 4-5 were the most abundant age-classes. Mean ages for female and male alewife in 2004 were 4.5 and 4.1, respectively (Appendix Table 10).

Town Brook

Alewife - The youngest and oldest individuals observed in the run during 2004-2015 were age 3 and 8 for females and age 2 and 7 for males, respectively (Appendix Table 9). Age 4 was the most abundant age-class for both sexes. Mean age ranged from 3.7 to 4.9 years for females and from 3.4 to 4.6 years for males (Appendix Table 10).

Blueback - No description of the age composition is made because only 10 were aged.

7.10.4. Trends in Mean Length-At-Age

Mean length-at-age data for alewife and blueback herring from the Monument River were plotted by sex and year to determine if changes in growth have occurred over time (Figure 8). Unfortunately, data from 1984-1987 were not available for historical comparison. Mean length-at-age of alewife for ages 3-5 of both sexes has gone through several declines and increases over the 23 year time series. Mean lengths plateaued during 2012-2014 and decreased in 2015 (Figure 8). Mean length-at-age for blueback herring has varied without trend (Figure 8).

7.10.5. Trends in Proportions and Repeat Spawners

The frequencies of new and repeat spawners determined by reading spawning checks on scales are listed in Appendix Table 11 and 12 by species, river, sex and year. The proportions that repeat spawners comprised the total samples are given in Table 1. After 2013, repeat spawning frequency was determined for Monument River alewife only.

Agawam River

Alewife - The proportion of repeat spawners for female and male alewife in 1991 was 0.11 and 0.10, respectively (Table 1).

Blueback - The proportions of repeat spawners for female and male blueback herring were not calculated due to small sample size (Table 1).

Back River

Alewife - The proportion of repeat spawners for both sexes was 0.11 in 2007 (Table 1).

Charles River

Blueback - The proportions of repeat spawners for female blueback herring were 0.54 in 1985,0.44 in 1993, 0.36 in 2012, and 0.14 in 2013. For males, the proportions were 0.49 in 1985, 0.25 in 1993, 0.14 in 2012, and 0.13 in 2013(Table 1). Data for both sexes indicate a possible decline in the fraction of repeat spawners.

Mattapoisett River

Alewife - The proportions of repeat spawners for female alewife were 0.33 in 1995 and 0.04 in 2007. For males, the proportions were 0.19 in 1995 and 0.03 in 2007 (Table 1). Data for both sexes indicate a possible decline in the fraction of repeat spawners.

Monument River

Alewife - The earliest time series (1986-1987) of repeat spawner data come from Brady (1987a). During 1986-1987, the estimated proportions of repeat spawners for females ranged from 0.44 to 0.45, and those for males ranged from 0.39 to 0.41 (Table 1). From 1993-2015, proportions of repeat spawners ranged from 0.01-0.41, but most were $\leq$0.29. Since 2003, the proportions of repeat spawners have been $\leq$0.19.

Blueback - The earliest time series (1986-1987) of repeat spawner data come from Brady (1987b). During 1986-1987, the estimated proportions of repeat spawners for females ranged from 0.38 to 0.39, and those for males ranged from 0.20 to 0.22 (Table 1). From 1993-2013, proportions of repeat spawners ranged from 0.00-0.27, but most were $\leq$0.20. Since 2003, the proportions of repeat spawners have been $\leq$0.14.

Mystic River

Alewife - The estimated proportions of repeat spawners for female and male alewife varied without trend (range: 0.0 in 2006 to 0.46 in 2012 for females; 0.0 in 2006 to 0.34 in 2012 for males) (Table 1).

Blueback - The estimated proportions of repeat spawners for female and male blueback herring varied without trend (range: 0.03 in 2005 to 0.52 in 2012 for females; 0.06 in 2005 to 0.49 in 2012 for males) (Table 1).

Nemasket River

Alewife - The estimated proportions of repeat spawners for females and males were high in 2004 (0.43 for females; 0.44 for males) but declined thereafter to ≤0.30 for females and ≤0.29 for males (Table 1).

Quashnet River

Alewife - The estimated proportions of repeat spawners for both sexes were ≤0.07 in 2004 (Table 1).

Blueback – No estimates of proportions of repeat spawners were produced because of low sample sizes (Table 1).

Stony Brook

Alewife - The estimated proportions of repeat spawners for both sexes were ≤0.21 in 2004 (Table 1).

Town Brook

Alewife - The estimated proportions of repeat spawners for female and male alewife were low (≤0.17) prior to 2007, but increased above 0.17 thereafter (Table 1).

Blueback - No estimates of proportions of repeat spawners were produced because of low sample sizes (Table 1).

7.10.6. Trends in Total Instantaneous Mortality Rates

The Chapman-Robson survival estimator (Chapman and Robson, 1960; Murphy, 1997) was applied to the annual age frequency data to generate estimates of survival rate (S) for each species, sex and year. Total instantaneous mortality rate (Z) was estimated by the natural-log transformation of S. For age data, the first age-at-full recruitment was the age with the highest frequency. Only Z estimates made from data with three or more age-classes (including first fully-recruited age) were deemed valid.

Estimates of Z from the age data by species and sex are given in Appendix Table 13 and are plotted in Figures 9 and 10. Although Z estimates were made for alewife and blueback herring from several rivers, long time series of Z estimates from which change could be detected were available only from the Monument River. Estimates for each river are summarized below:

Agawam River

Alewife – The Z estimates for females and males in 1991 were 0.96 and 1.18, respectively. (Appendix Table 13; Figure 9).

Blueback – The Z estimate for females in 1991 0.81. The Z estimate for males in 1991 was not valid (Appendix Table 13; Figure 10).

Back River

Alewife - The Z estimates for females and males in 2007 were 1.24 and 1.64, respectively. (Appendix Table 13; Figure 9).

Charles River

Blueback - The Z estimates for females and males in 1985 were 0.67 and 0.96, respectively. (Appendix Table 13; Figure 10). In 1993, the Z estimates were 1.19 for females and 1.05 for males (Appendix Table 13; Figure 10). From 2012-2014, Z estimates for females ranged from 0.81 (2012) to 1.31 (2014), while those for males ranged from 0.84 (2013) to 1.41 (2014) (Appendix Table 13; Figure 10).

Mattapoisett River

Alewife - Z estimates for females and males in 1995 were 0.72 and 0.94, . During 2006-2007, a Z estimate was only available for females in 2007 and was 1.1 (Appendix Table 13; Figure 10).

Monument River

Alewife - For 1985-1987, Z estimates from age frequency data ranged from 0.76 (1987) to 1.04 (1985) for females and from 0.84 (1987) to 1.03 (1986) for males (Appendix Table 13; Figure 9). For 1993-2015, Z estimates from age frequency data ranged from 0.87 (1993) to 2.4 (2014) for females and from 1.02 (1993) to 1.99 (2011) for males. Age structure was too truncated for females in 2015 and for males in 2014 and 2015 to provide valid estimates (Appendix Table 13). Comparison of Z estimates showed an increase in total mortality over the time series for both sexes (Figure 9).

Blueback - For 1985-1987, Z estimates from age frequency data ranged from 0.98 (1985) to 1.49 (1986) for females and from 1.06 (1987) to 1.27 (1985) for males (Appendix Table 13; Figure 10) For 1993-2015, Z estimates from age frequency data ranged from 0.75 (1993) to 1.93 (2015) for females and from 0.76 (2001) to 2.12 (2015) for males (Appendix Table 13; Figure 10). Comparison of Z estimates from age and repeat spawner data showed no trend in total mortality over the time series for both sexes, although the most recent two years have been among the highest values (Figure 10).

Mystic River

Alewife - Z estimates for females during 2004-2015 ranged from 0.93 (2015) to 1.58 (2004) (Appendix Table 13; Figure 9). For males, Z estimates during 2004-2015 ranged from 0.88 (2005) to 2.23 (2007)(Appendix Table 13; Figure 9).

Blueback - Z estimates for females during 2004-2015 ranged from 0.86 (2008) to 2.25 (2011) (Appendix Table 13; Figure 10). For males, Z estimates during 2004-2015 ranged from 0.83 (2012) to 1.99 (2015)(Appendix Table 13; Figure 10).

Nemasket River

Alewife - Z estimates for females during 2004-2015 ranged from 0.95 (2010) to 2.31 (2014) (Appendix Table 14; Figure 16). For males, Z estimates during 2004-2015 ranged from 0.93 (2009) to 2.13 (2015) (Appendix Table 13; Figure 9).

Stony Brook

Alewife - Z estimates for Stony Brook alewife were only available in 2004. The Z estimates were 1.96 for females (Appendix Table 13; Figure 9) and 1.3 for males (Appendix Table 13; Figure 9).

Town Brook

Alewife - Z estimates for females during 2004-2010 ranged from 0.84 (2010) to 2.16 (2015) (Appendix Table 13; Figure 9). For males, Z estimates during 2004-2015 ranged from 0.87 (2009) to 1.93 (2015)(Appendix Table 13; Figure 9).

7.10.7. Trends in Age-1 Indices of Relative Abundance

Relative indices of age-1 abundance for alewife and blueback herring from the DMF trawl survey are shown in Figure 20 for areas north and south of Cape Cod. Indices of relative abundance of alewife fluctuated without trends during 1978-2015 and were generally lower south of Cape Cod.

7.11. CONCLUSIONS AND RECOMMENDATIONS

The following is a short list of many potential causes of the changes in abundance, population characteristics and dynamics of alewife and blueback herring in Massachusetts acting singly or synergistically:

Environmental Changes - Changes in weather as a result of climate change can impact many aspects of the alewife and blueback life stages. Changes in rainfall patterns could affect the food production in the nursery areas and cause higher mortality of juveniles as competition for limited zooplankton resources is believed a major factor affecting survival and growth of juveniles (Walton 1983). Such changes can cause shifts in the carrying capacity of a nursery ground and ultimately affect recruitment. Another potential impact of changes in rainfall is on the migration patterns of juvenile herring. It is believed that drops in temperature and rainfall events cue juveniles to move out of Massachusetts river systems in fall (Kosa and Mather, 2001; Yako et al., 2002). Decreases in rainfall during their peak migration in fall may inhibit migration and increase potential mortality.

Predation - It is possible that the increase in total mortality observed after 1999 and decrease in size of herring over time are the result of selective predation by increasing populations of striped bass (*Morone saxatilis*), cormorants (*Phalacrocorax auritus*), spiny dogfish (*Squalus acanthias*), seals (*Phoca vitulina*) and other species of fish and wildlife that have apparently prospered as river herring have declined.

Bycatch in Fisheries - It is possible that bycatch in several fisheries for small pelagic fish off the Massachusetts coast may be contributing to increases in total mortality in some herring runs. More information is needed on the impact of ocean bycatch. Since 2010, DMF has sampled portside landings of small mesh fisheries in New England to better understand the potential impacts of bycatch (Bethoney et al. 2013, Bethoney et al. 2014). Assessments of stock unit catch composition and amounts indicate that bycatch is likely not uniform across the species' range, but focused on certain geographic areas (Hasselman et al. 2016).

Legal Bait Harvesting and Poaching - Although not well quantified, anecdotally, there was a tremendous increase in unreported harvest of river herring both legally and illegally from the spawning runs primarily for use as bait in the recreational striped bass fishery. This occurred 6-7 years prior to the moratorium in concurrence with the rebuilding of the striped bass stocks. Prior to that surge in use of river herring for striped bass bait, there was similar unreported harvest of river herring for lobster bait that may not have been widespread as the striped bass bait harvest but at times caused large removals from individual runs.

Watershed Alterations - Many watersheds in Massachusetts continue to be degraded by stormwater impacts, eutrophication, and water withdrawals and other hydrologic disruption related to coastal development. Such conditions may affect the passage and spawning of adults and survival of young. Since 2008, DMF has been assessing the status and impairment of individual river herring spawning and nursery habitats with standard sampling protocols (Chase 2010).

Acknowledgements

Funding for this effort was provided by the Massachusetts Division of Marine Fisheries and Sportfish Restoration Funds Grant F-57-R. Thanks are due to current and past staff of the Diadromous Fish Biology and Management Project for collecting and processing field samples and to current and past members of the MDMF Age and Growth Laboratory for ageing scales and otoliths. Our appreciation is also expressed for the dedication of Town herring wardens and the many citizen volunteers who have contributed to river herring counts and stewardship in Massachusetts.

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Alewife

Female

River	1986	1987	1991	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Agawam			0.11																						
Back																	0.11								
Mattapoisett					0.33											0.04									
Monument	0.45	0.44		0.20	0.08	0.18	0.29	0.41	0.11	0.08	0.14	0.29	0.12	0.01	0.08	0.16	0.08	0.15	0.13	0.13	0.16	0.12	0.12	0.13	0.06
Mystic														0.36	0.08	0.00	0.13	0.25	0.29	0.15	0.35	0.46	0.22		
Nemasket														0.43	0.29	0.10	0.13	0.22	0.30	0.23	0.26	0.19	0.17		
Quashnet														0.07											
Stony														0.21											
Town														0.14	0.18	0.08	0.17	0.29	0.31	0.21	0.23	0.37	0.29		

Male

River	1986	1987	1991	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Agawam			0.10																						
Back																	0.11								
Mattapoisett					0.19											0.03									
Monument	0.39	0.41		0.23	0.05	0.24	0.22	0.29	0.12	0.10	0.18	0.31	0.19	0.07	0.04	0.05	0.06	0.13	0.10	0.07	0.09	0.06	0.04	0.11	0.05
Mystic														0.32	0.30	0.00	0.07	0.16	0.21	0.14	0.22	0.34	0.16		
Nemasket														0.44	0.29	0.10	0.12	0.20	0.17	0.16	0.26	0.15	0.21		
Quashnet														0.05											
Stony														0.12											
Town														0.17	0.12	0.04	0.23	0.32	0.32	0.17	0.25	0.27	0.31		

Blueback

Female

River	1985	1986	1987	1991	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Agawam				*																						
Charles	0.54				0.44																		0.36	0.14		
Monument		0.38	0.39		0.18	0.11	0.06	0.17	0.00	0.20	0.00	0.00	0.08	0.03	0.08	0.05	0.14	0.01	0.06	0.05	0.01	0.06	0.12	0.06		
Mystic																0.03	0.16	0.15	0.36	0.12	0.15	0.21	0.52	0.18		
Quashnet															*											
Town																*										

Male

River	1985	1986	1987	1991	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Agawam				*																						
Charles	0.49				0.25																		0.14	0.13		
Monument		0.22	0.20		0.13	0.06	0.17	0.00	0.27	0.10	0.00	0.02	0.14	0.03	0.02	0.08	0.14	0.06	0.06	0.04	0.01	0.07	0.15	0.04		
Mystic																0.06	0.21	0.18	0.27	0.13	0.13	0.20	0.49	0.10		
Quashnet															*											
Town																*										

Table 7.1. Proportion of repeat spawners in alewife and blueback herring samples by sex, river and year. *=not calculated due to small sample size.

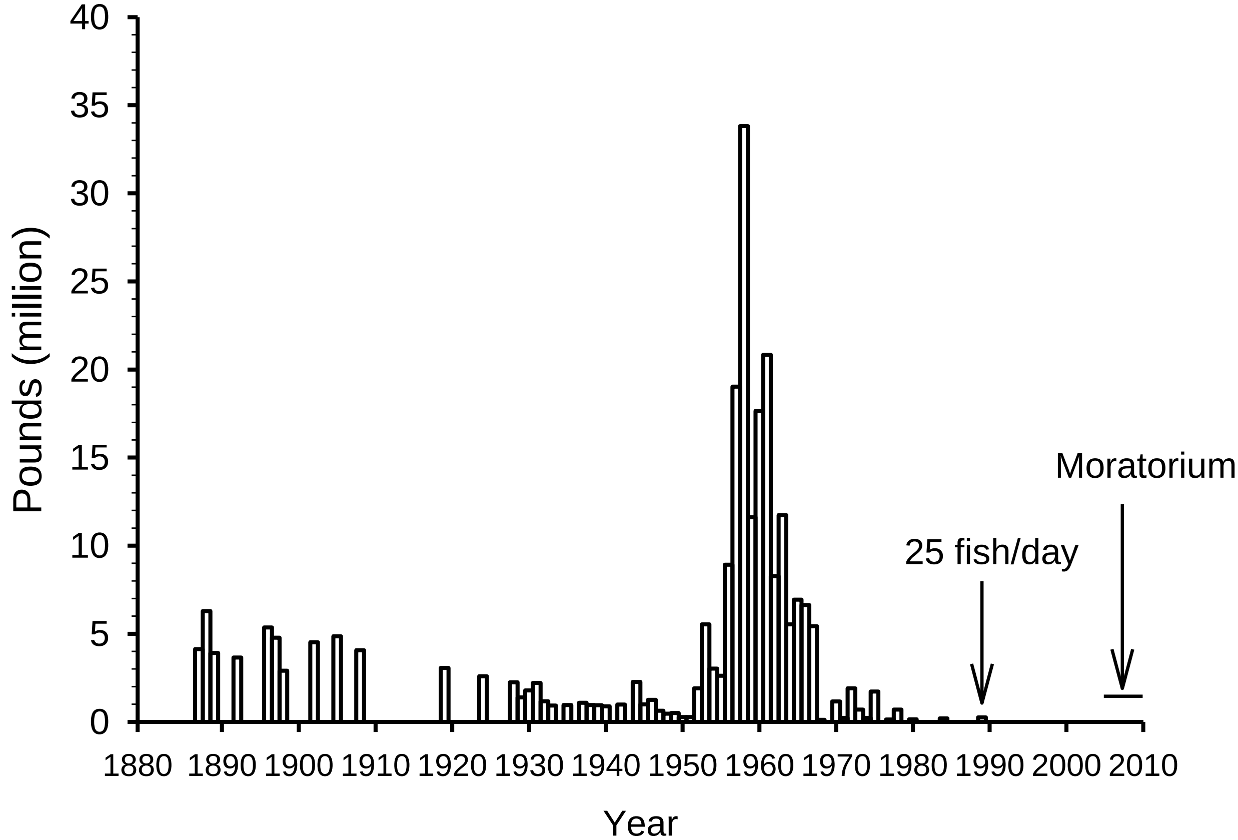


Figure7. 1. Massachusetts commercial landings of river herring, 1887-2010.

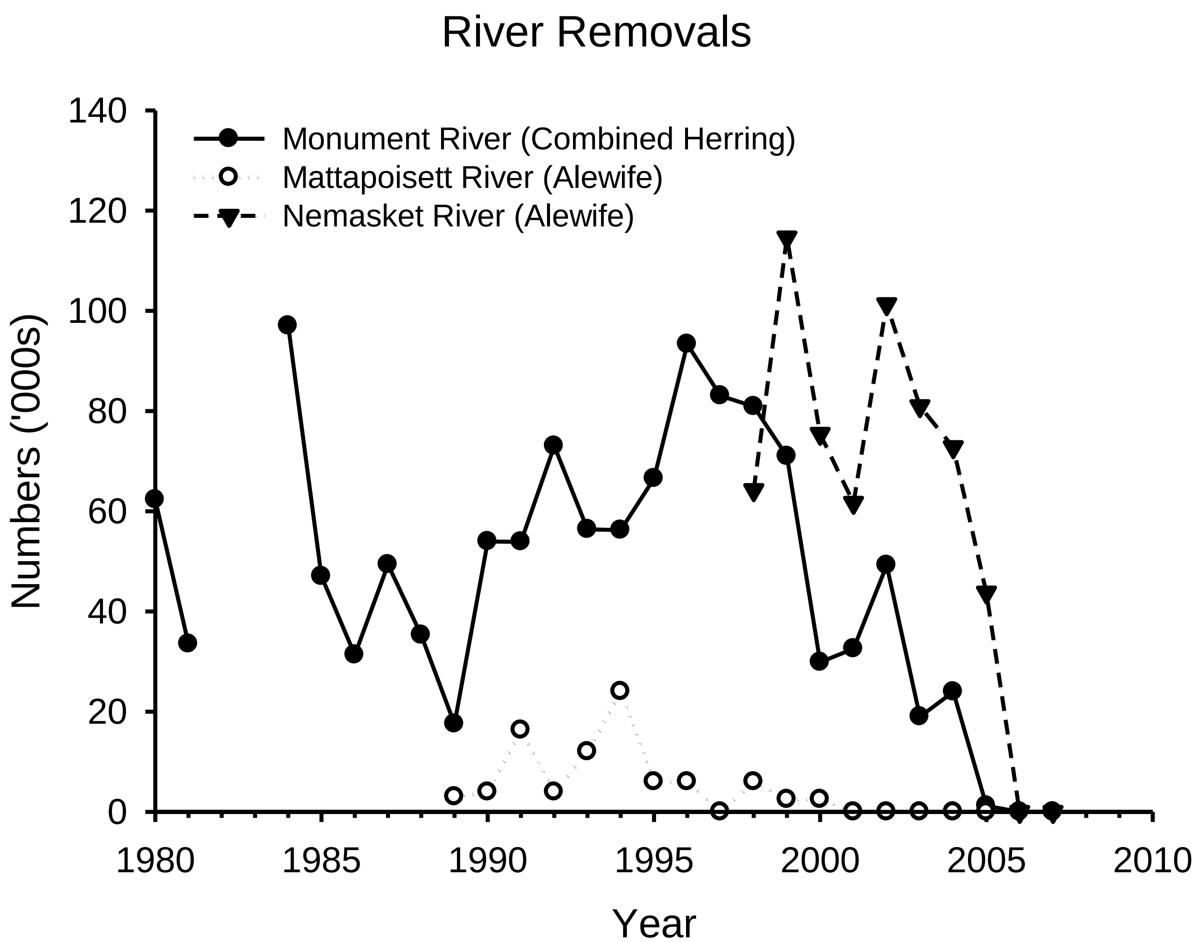


Figure 7.2. Number of fish removed (for bait, stocking, or scientific samples) from three Massachusetts rivers, 1980-2010.

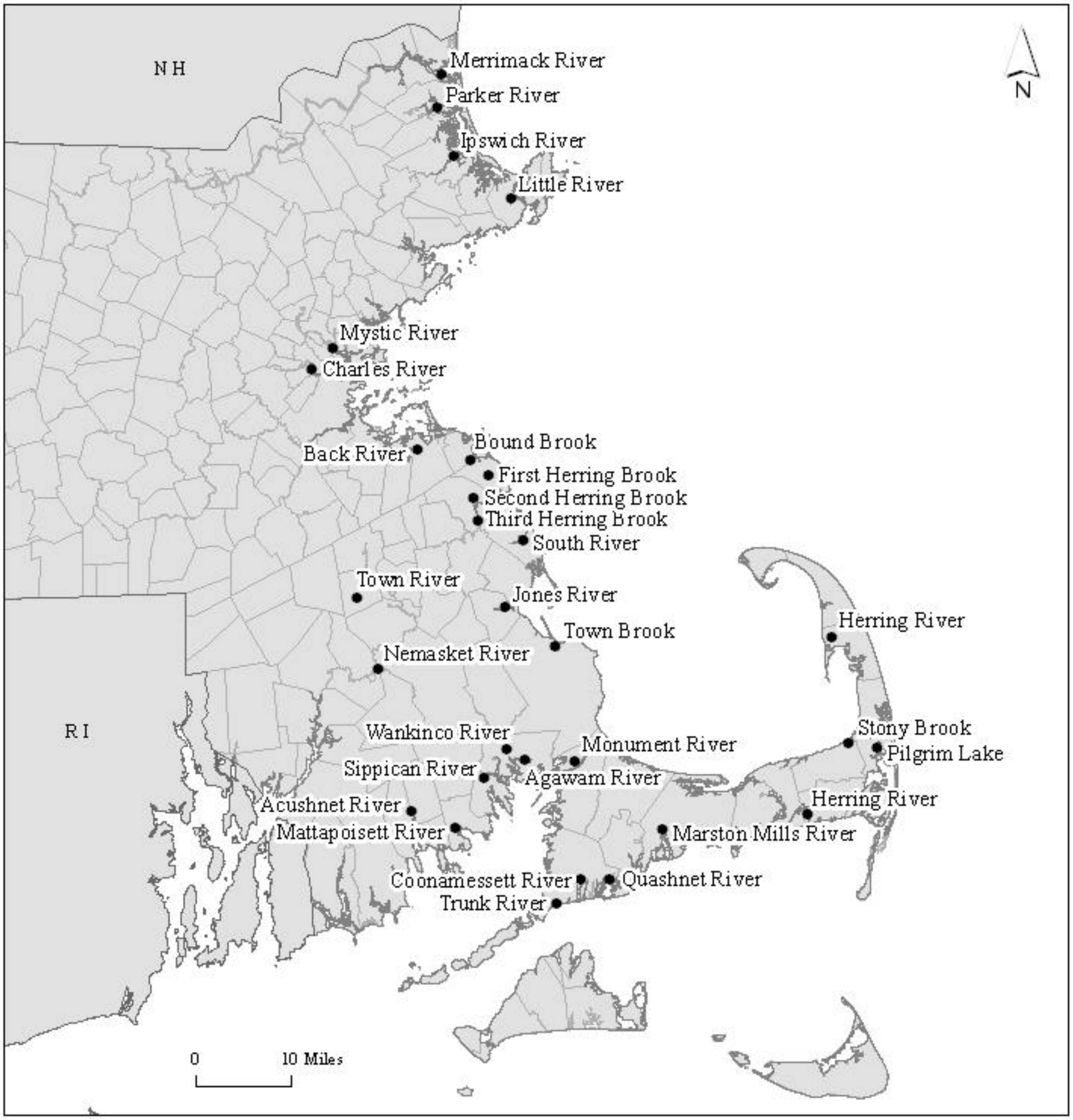


Figure 7.3. Massachusetts rivers for which historical and/or current data on river herring are available.

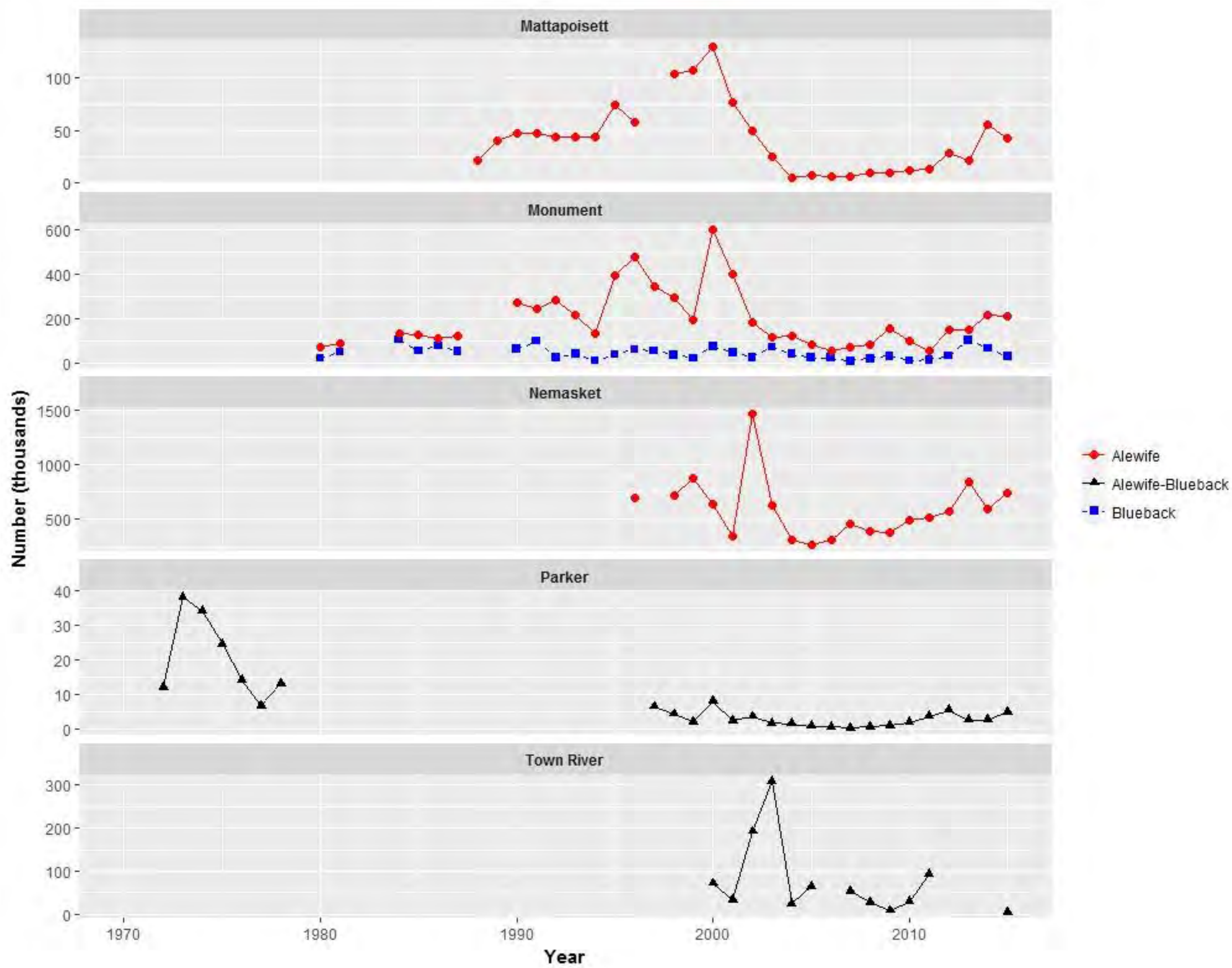


Figure 7.4. Passage and total run size counts for alewife and blueback herring in five Massachusetts Rivers.

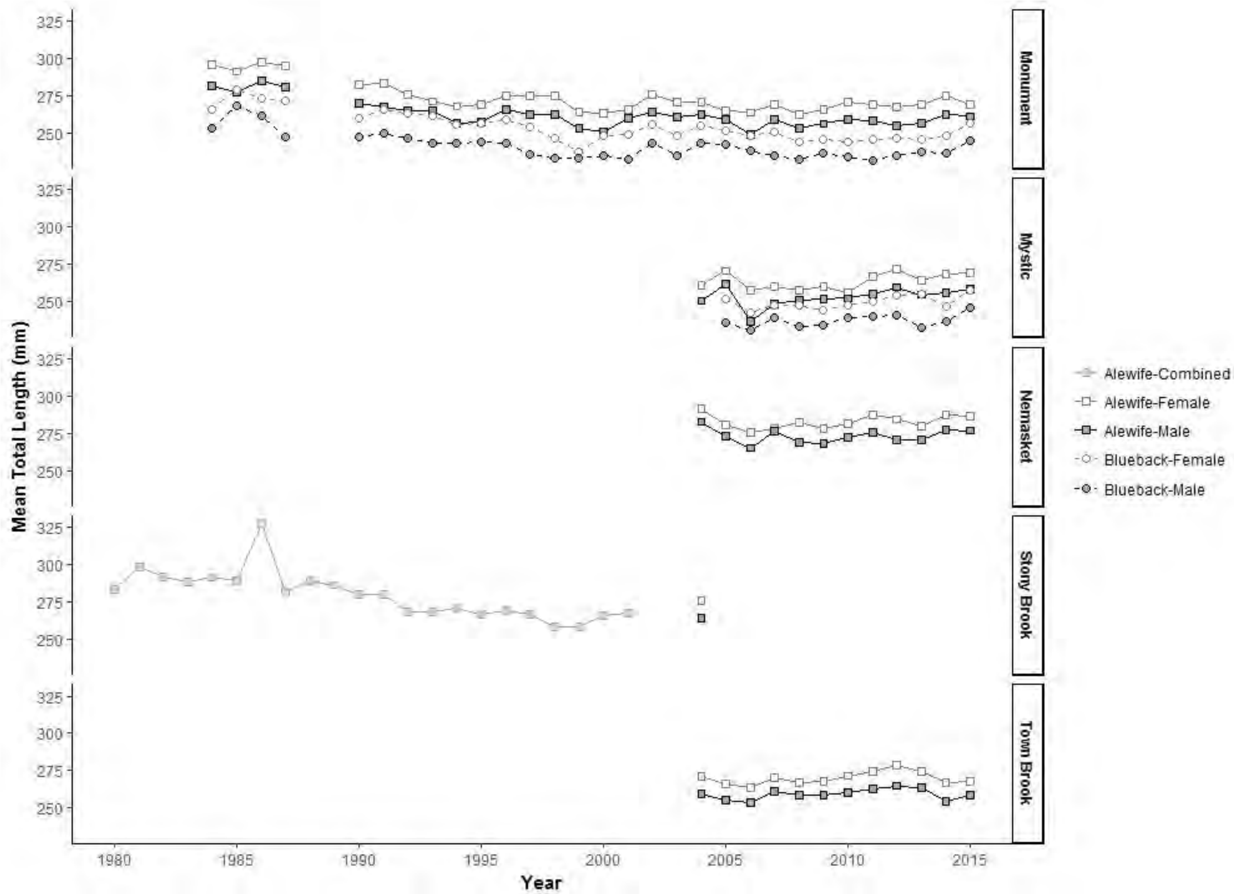
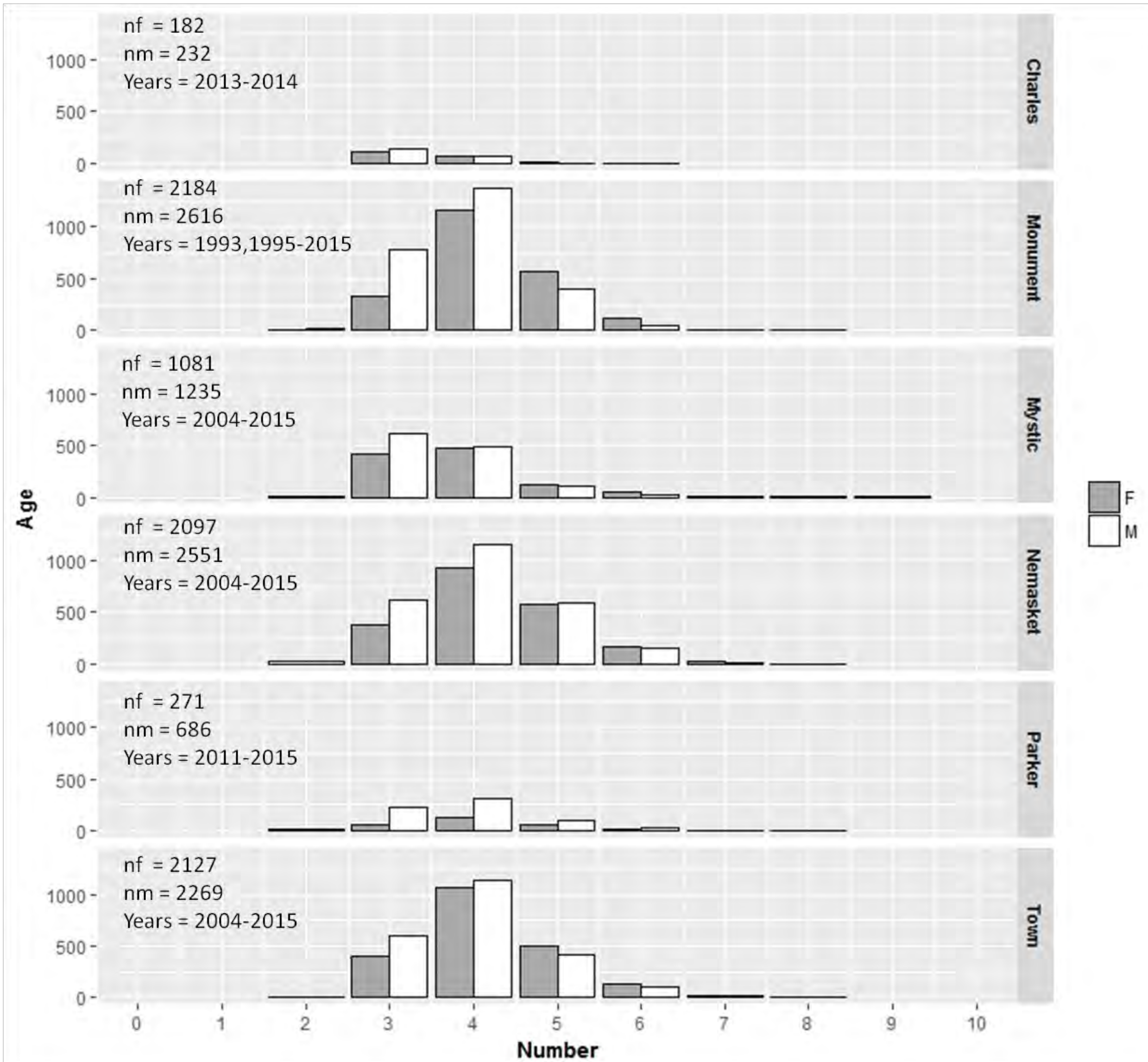


Figure 7.5. Mean total lengths of alewife and blueback herring in the Monument River, Mystic River, Nemasket River, Stony Brook, and Town Brook, 1978-2015.


nf = 182
nm = 232
Years = 2013-2014
Charles
nf = 2184
nm = 2616
Years = 1993,1995-2015
Monument
nf = 1081
nm = 1235
Years = 2004-2015
Mystic
nf = 2097
nm = 2551
Years = 2004-2015
Nemasket
nf = 271
nm = 686
Years = 2011-2015
Parker
nf = 2127
nm = 2269
Years = 2004-2015
Town
Age
Number
F
M
0
500
1000
0
1
2
3
4
5
6
7
8
9
10

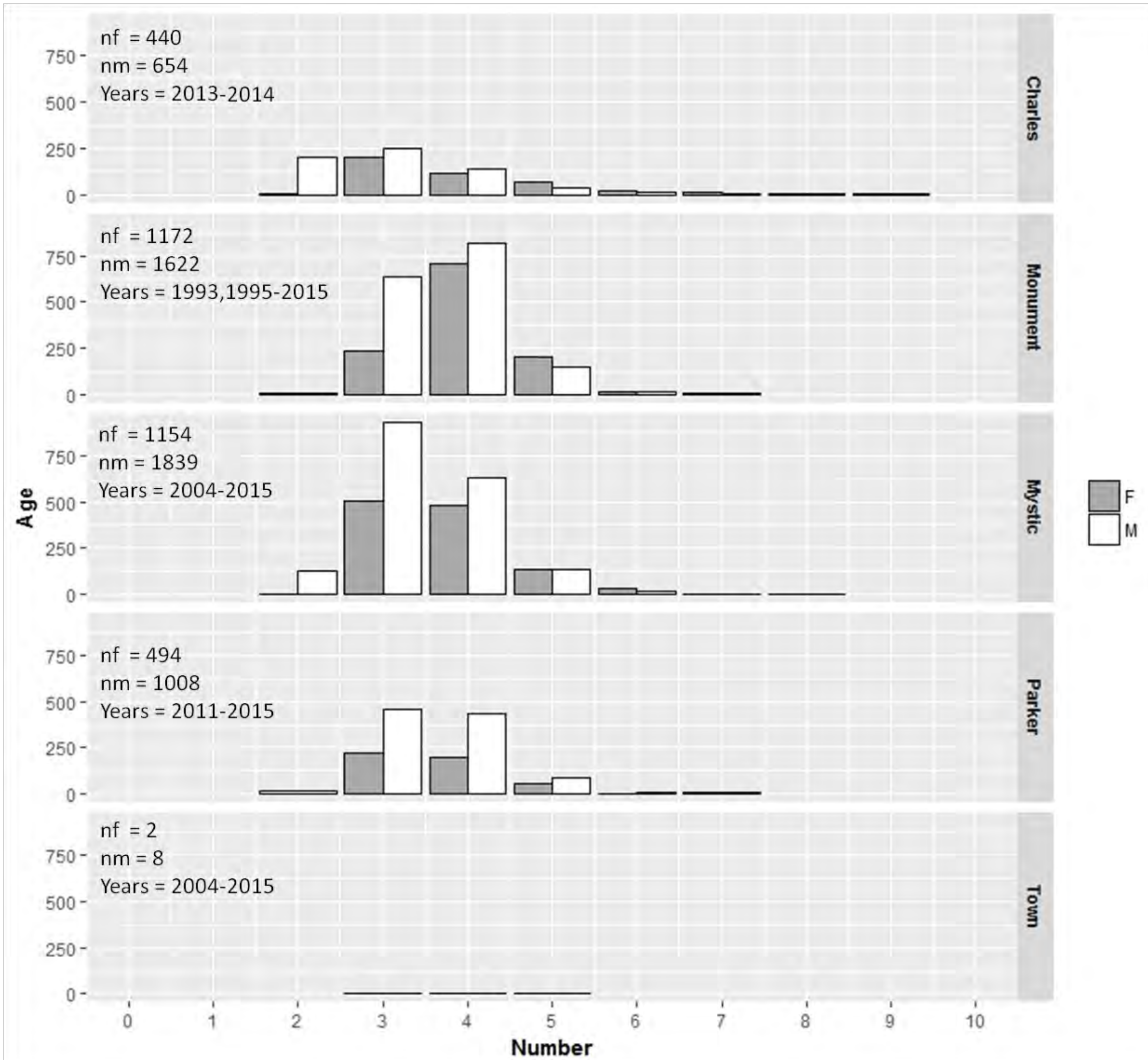


Figure 7.6. Age structure of alewife and blueback herring by sex (female: dark grey bars; male: white bars) in Massachusetts rivers from sampling, 2004-2015. *nf* is female sample size and *nm* is male sample size. Rivers with new data collected between assessments were included.

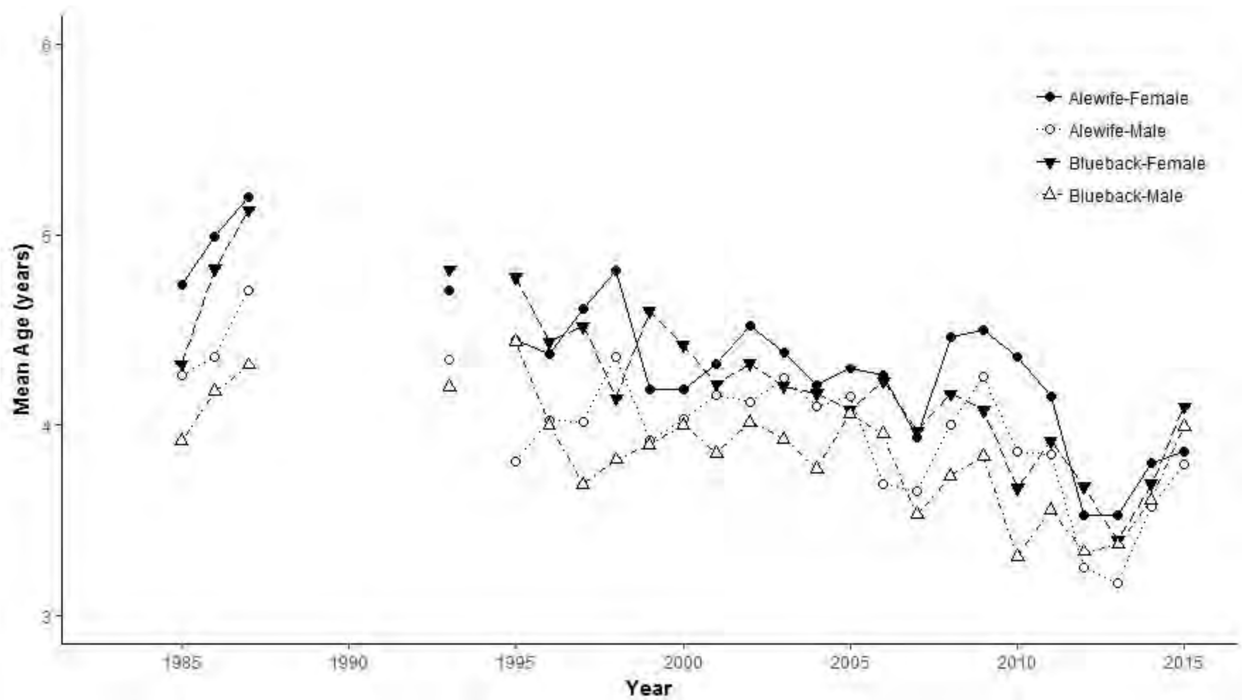
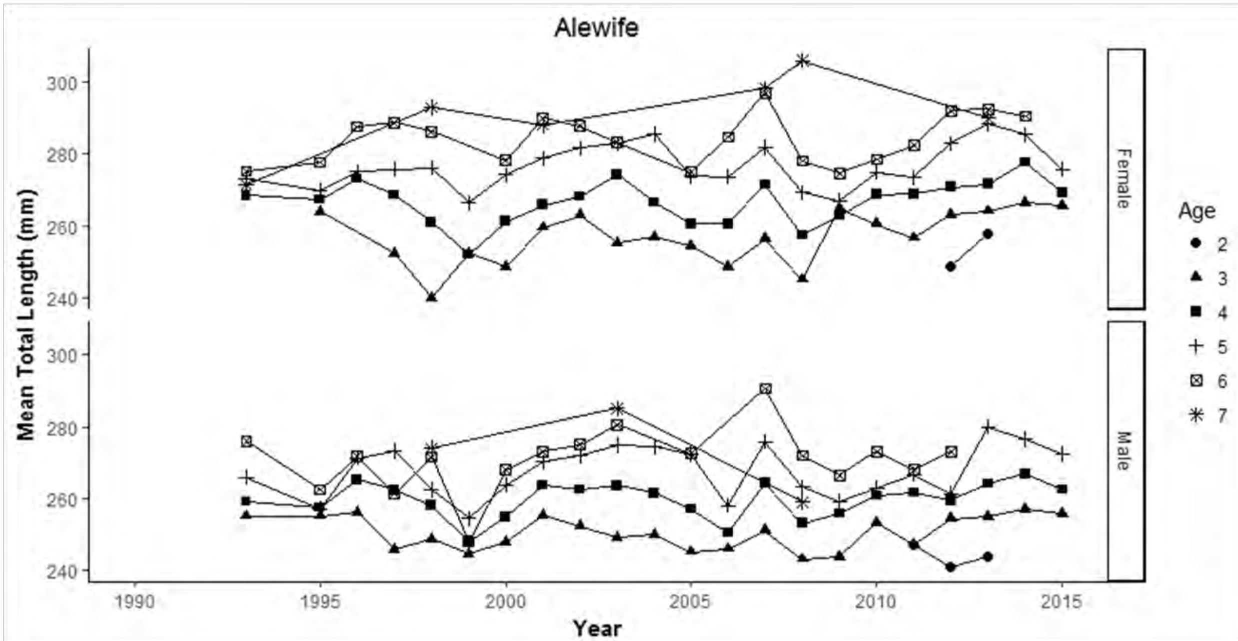


Figure 7.7. Mean age of Monument River alewife and blueback herring by sex, 1985-2015.



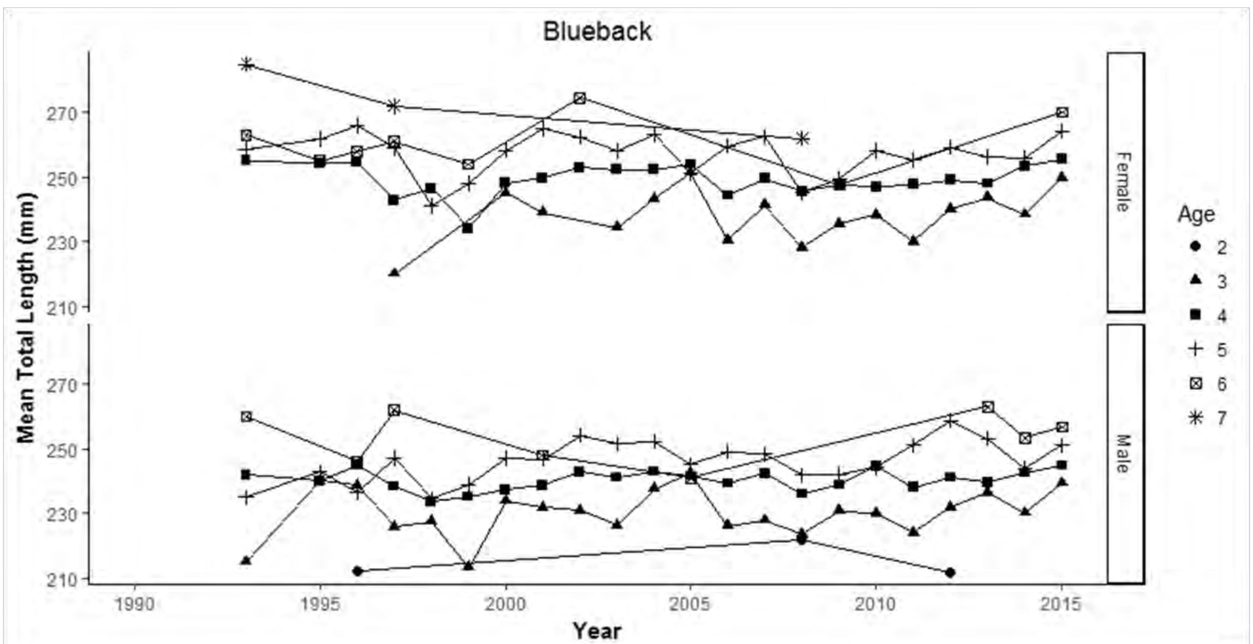


Figure 7.8. Mean length-at-age of alewife and blueback herring by year and sex for the Monument River, 1990-2015.

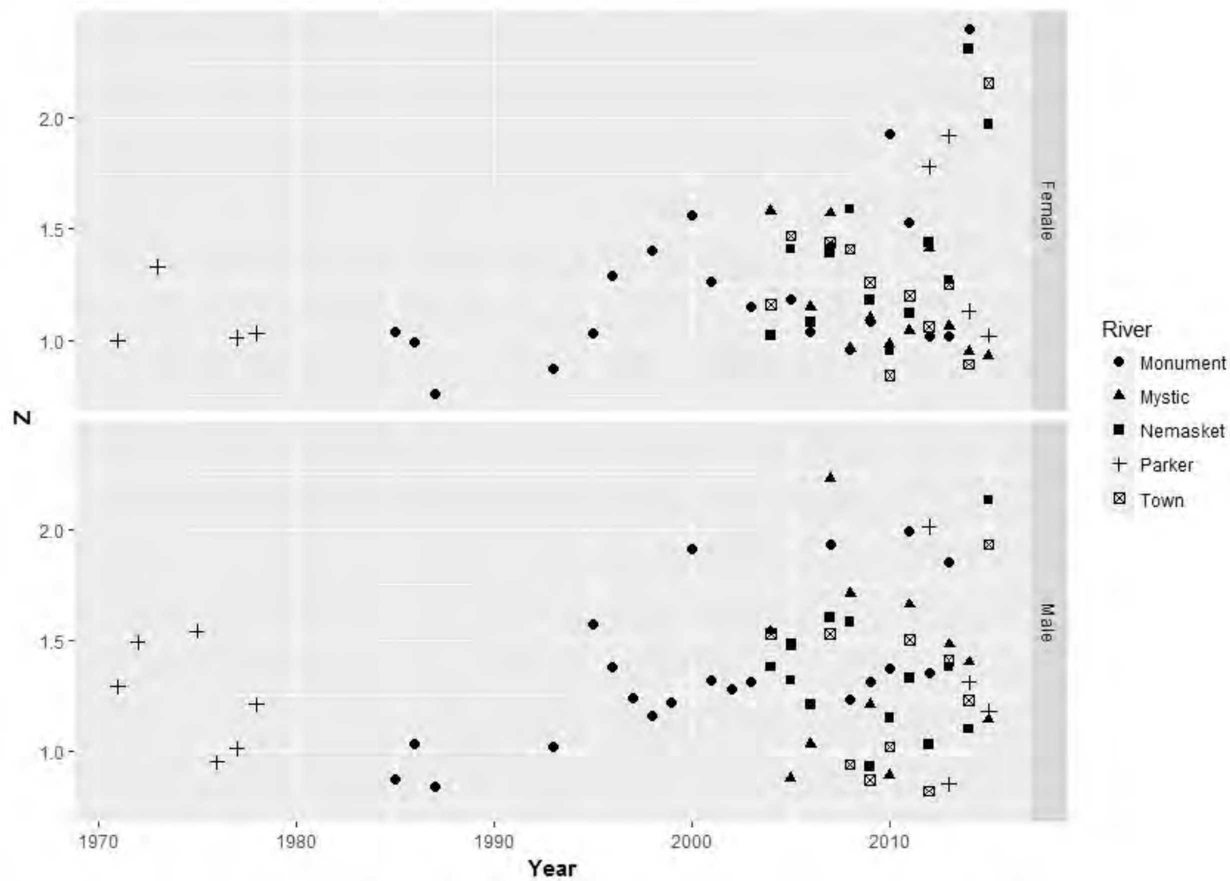


Figure 7.9. Estimates of total instantaneous mortality (Z) from age data for alewife in several Massachusetts rivers, 1985-2015. The Chapman-Robson survival estimator was applied to age frequency data.

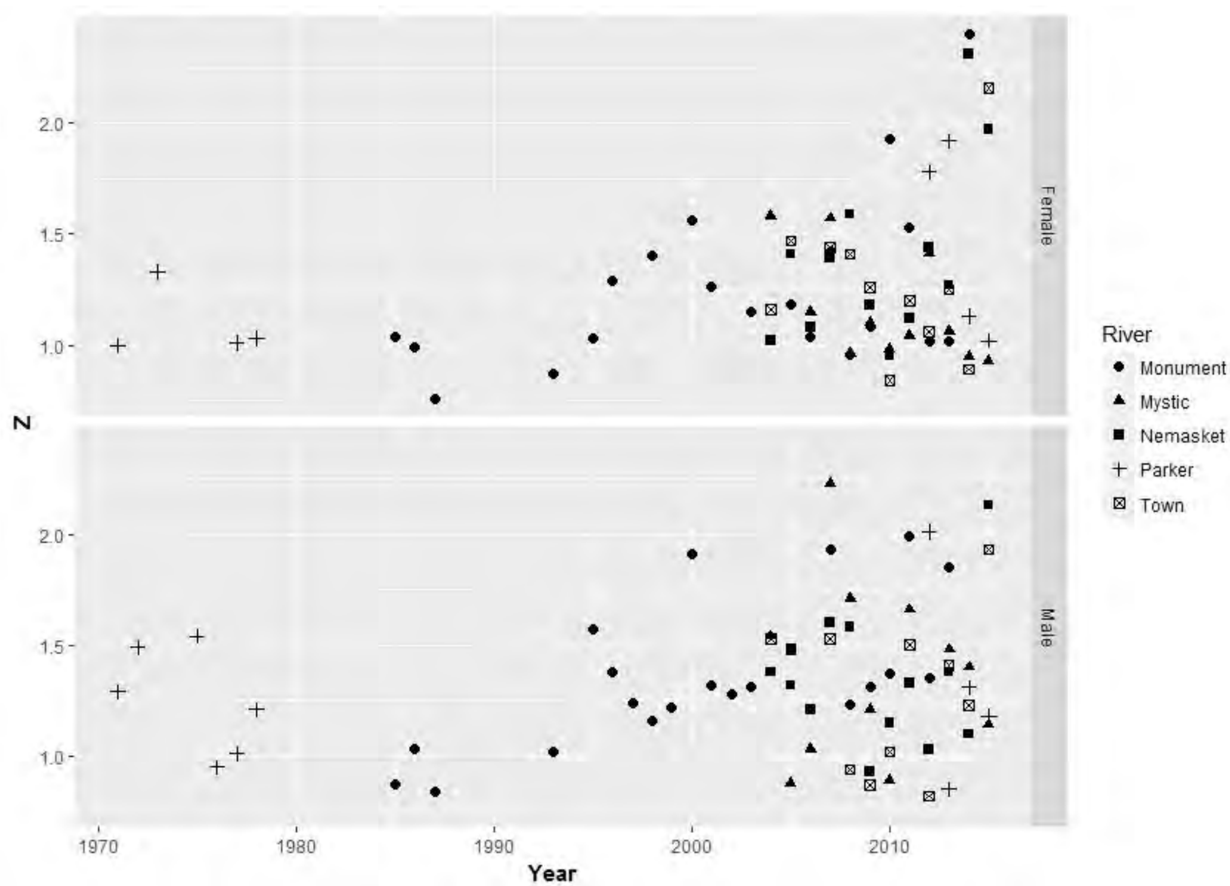


Figure 7.10. Estimates of total instantaneous mortality (Z) from age data for blueback herring in several Massachusetts rivers, 1985-2015. The Chapman-Robson survival estimator was applied to age frequency data.

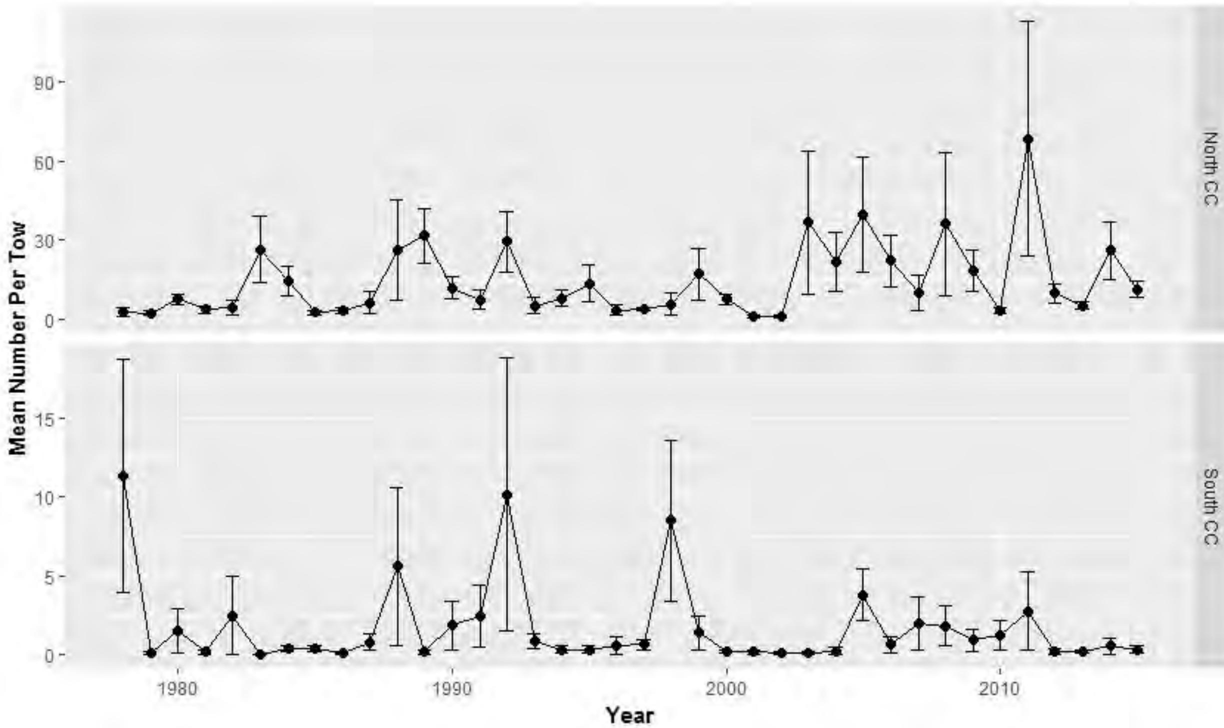


Figure 7.11. Indices of relative abundance (stratified mean number per tow) for age-1 alewife and blueback herring north and south of Cape Cod from the spring Massachusetts inshore bottom trawl survey, 1978-2015. Whiskers are +/-1 standard error.

Appendix Table 7.1. Commercial landings (pounds) of river herring in Massachusetts by gear type, 1887-2007. Source: National Marine Fisheries Service and ASMFC (1985).

Commercial Landings

Year	Dip Net	Purse Seine	Float Trap	Fyke Net	Gillnet	Beach Seine	Lift Net	Trawls	Pound Net	Unknown Gear	Total
1887										4,130,000	4,130,000
1888										6,292,000	6,292,000
1889										3,911,000	3,911,000
1890										-	-
1891										-	-
1892										3,651,000	3,651,000
1893										-	-
1894										-	-
1895										-	-
1896										5,356,000	5,356,000
1897										4,779,000	4,779,000
1898										2,900,000	2,900,000
1899										-	-
1900										-	-
1901										-	-
1902										4,517,000	4,517,000
1903										-	-
1904										-	-
1905										4,861,000	4,861,000
1906										-	-
1907										-	-
1908										4,062,000	4,062,000
1909										-	-
1910										-	-
1911										-	-
1912										-	-
1913										-	-
1914										-	-
1915										-	-
1916										-	-
1917										-	-
1918										-	-
1919										3,064,000	3,064,000
1920										-	-

Appendix Table 7.1 cont.

	Commercial Landings										
Year	Dip Net	Purse Seine	Float Trap	Fyke Net	Gillnet	Beach Seine	Lift Net	Trawls	Pound Net	Unknown Gear	Total
1921										-	-
1922										-	-
1923										-	-
1924										2,593,000	2,593,000
1925										-	-
1926										-	-
1927										-	-
1928										2,248,000	2,248,000
1929										1,386,000	1,386,000
1930										1,790,000	1,790,000
1931										2,212,000	2,212,000
1932										1,164,000	1,164,000
1933										923,000	923,000
1934										-	-
1935										959,000	959,000
1936										-	-
1937										1,086,000	1,086,000
1938										958,000	958,000
1939										946,000	946,000
1940										879,000	879,000
1941										-	-
1942										984,000	984,000
1943										-	-
1944										2,266,000	2,266,000
1945										988,000	988,000
1946										1,249,000	1,249,000
1947										633,000	633,000
1948										468,000	468,000
1949										502,000	502,000
1950	0	25,100	300	0	0	244,500	0	0	0	0	269,900
1951	0	42,300	3,700	0	0	230,000	0	0	0	0	276,000
1952	0	87,000	12,700	0	0	1,804,000	0	500	0	500	1,904,700
1953	0	4,538,200	240,100	0	0	751,600	0	4,800	0	0	5,534,700
1954	0	2,843,000	54,000	0	0	119,500	0	3,700	0	0	3,020,200
1955	0	1,869,800	75,600	0	400	675,300	0	0	0	0	2,621,100

Appendix Table 7.1 cont.

Commercial Landings

Year	Dip Net	Purse Seine	Float Trap	Fyke Net	Gillnet	Beach Seine	Lift Net	Trawls	Pound Net	Unknown Gear	Total
1956	0	8,752,500	77,000	0	0	92,000	0	0	0	0	8,921,500
1957	14,800	16,439,200	54,000	0	0	140,000	0	2,379,100	0	0	19,027,100
1958	16,200	32,482,400	106,800	0	0	1,167,000	0	42,300	0	0	33,814,700
1959	30,000	9,729,400	27,500	0	0	1,711,200	0	105,700	14,200	0	11,618,000
1960	0	16,151,300	26,900	0	0	1,387,900	0	0	85,000	0	17,651,100
1961	0	19,107,600	0	0	0	1,230,600	500,000	0	0	0	20,838,200
1962	0	6,123,200	0	0	0	2,150,000	0	2,500	0	0	8,275,700
1963	40,000	10,882,200	0	0	0	798,300	0	13,000	1,600	0	11,735,100
1964	339,900	3,998,600	0	0	0	1,190,300	0	0	0	0	5,528,800
1965	66,200	6,332,200	0	0	0	532,900	0	0	4,000	0	6,935,300
1966	90,100	6,106,400	0	0	0	436,700	0	0	0	0	6,633,200
1967	95,000	5,105,800	3,100	0	0	228,000	0	0	0	0	5,431,900
1968	14,200	0	0	0	0	102,500	0	0	0	0	116,700
1969	0	0	0	0	0	100,000	0	0	0	0	100,000
1970	0	813,600	0	0	0	100,000	0	242,700	0	0	1,156,300
1971	0	44,600	500	0	0	143,200	0	34,000	0	0	222,300
1972	38,800	1,171,700	700	0	0	128,500	0	567,700	0	0	1,907,400
1973	32,500	518,200	7,400	0	0	106,000	0	31,300	0	0	695,400
1974	175,300	0	2,500	0	0	0	0	50,700	0	0	228,500
1975	37,800	1,631,900	17,200	0	0	30,000	0	0	0	0	1,716,900
1976	6,400	0	0	0	0	38,500	0	0	0	0	44,900
1977	0	18,000	1,500	0	0	50,000	0	62300	0	0	131,800
1978	0	619,700	0	0	0	81,000	0	600	0	0	701,300
1979	0	0	0	0	0	52,000	0	300	0	0	52,300
1980	45,000	0	0	0	0	99,000	0	0	0	0	144,000
1981	36,300	0	0	0	0	47,700	0	0	0	0	84,000
1982	28,000	0	0	0	0	25,500	0	0	0	0	53,500
1983	13,000	0	0	0	0	80,000	0	100	0	0	93,100
1984	37,700	110,800	0	500	0	45,000	0	100	0	0	194,100
1985	35,200	0	0	400	0	11,000	0	0	0	0	46,600
1986	23,900	0	0	0	0	8,500	0	0	0	0	32,400
1987	24,000	0	0	0	0	8,500	0	0	0	0	32,500
1988	35,580	0	0	0	0	7,000	0	0	0	0	42,580
1989	14,200	237,500	0	0	0	4,000	0	0	0	0	255,700
1990	18,200	0	0	0	0	2,500	0	0	0	0	20,700

Appendix Table 7.1 cont.

Commercial Landings

Year	Dip Net	Purse Seine	Float Trap	Fyke Net	Gillnet	Beach Seine	Lift Net	Trawls	Pound Net	Unknown Gear	Total
1991	17,800	0	0	0	0	2,500	0	0	0	0	20,300
1992	16,200	0	0	0	0	2,500	0	0	0	0	18,700
1993	16,400	0	0	0	0	2,500	0	0	0	0	18,900
1994	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	180	0	0	180
1998	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	89	0	89
2005	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0

Appendix Table 7.2. Marine Recreational Fisheries Statistics Survey estimates of numbers and associated statistics of river herring (alewife and blueback) harvested and released in Massachusetts by the recreational anglers.

MRFSS Estimates of Harvest and Releases Numbers of Fish in Massachusetts

Alewife

Year	Total Catch	SE	Releases	SE	Harvest	SE
1982						
1983	81	81	81	81	0	0
1984						
1985						
1986	32,506	20424	0	0	32,506	20424
1987						
1988						
1989						
1990						
1991						
1992	9,411	9411	0	0	9,411	9411
1993						
1994						
1995						
1996						
1997						
1998						
1999						
2000						
2001	2,124	1651	0	0	2,124	1651
2002						
2003						
2004	237,564	85369	0	0	237,564	85369
2005						
2006						
2007						
2008						
2009						

Blueback

Year	Total Catch	SE	Releases	SE	Harvest	SE
1982						
1983						
1984						
1985						
1986	804	804	0	0	804	804
1987	83,281	66,261	20,163	20,163	63,118	63,118
1988						
1989	639	295	0	0	639	295
1990	5,632	3,274	5,632	3,274	0	0
1991	562	413	0	0	562	413
1992						
1993	5,707	2,219	1,182	1,182	4,525	1,878
1994	1,246	747	0	0	1,246	747
1995	352	350	0	0	352	350
1996	5,504	3,904	0	0	5,504	3,904
1997	9,496	6,440	0	0	9,496	6,440
1998	739	739	739	739	0	0
1999						
2000						
2001						
2002						
2003	75,752	41,962	19,392	13,837	56,360	39,614
2004						
2005	11,657	11,657	0	0	11,657	11,657
2006						
2007	1,191	1,191	1,191	1,191	0	0
2008	18,543	15,360	18,543	15,360	0	0
2009						

Appendix Table 7.3. Passage, total and removal numbers of river herring from select Massachusetts rivers.

	Mattapoisett River	
	Alewife	
Year	Passage	Removals
1972		
1973		
1974		
1975		
1976		
1977		
1978		
1979		
1980		
1981		
1982		
1983		
1984		
1985		
1986		
1987		
1988	22,000	0
1989	40,000	3,000
1990	47,000	3,960
1991	47,000	16,320
1992	44,000	3,960
1993	44,000	12,000
1994	44,000	24,000
1995	75,000	6,000
1996	58,000	6,000
1997		
1998	104,000	6,000
1999	107,000	2,500
2000	130,000	2,500
2001	77,000	0
2002	50,000	0
2003	25,000	0
2004	5,385	0
2005	8,000	0
2006	6,270	0
2007	6,011	0
2008	9,987	0
2009	10,356	0
2010	12,319	0
2011	12,857	0
2012	28,447	0
2013	21,613	0
2014	55,429	0
2015	42,332	0

	Monument River		
	Blueback	Alewife	Combined
Year	Total Count	Total Count	Removals
1972			
1973			
1974			
1975			
1976			
1977			
1978			
1979			
1980	20,357	70,736	62,280
1981	49,483	85,796	33,480
1982			
1983			
1984	104,645	130,709	97,000
1985	53,715	124,316	47,000
1986	75,734	110,803	31,320
1987	52,686	122,935	49,350
1988			35,280
1989			17,520
1990	62,397	269,502	53,950
1991	99,646	245,151	53,880
1992	24,017	280,001	73,002
1993	39,117	213,249	56,380
1994	9,665	134,590	56,210
1995	37,912	395,201	66,513
1996	59,008	477,432	93,339
1997	53,855	345,074	83,045
1998	36,210	292,970	80,881
1999	21,754	191,516	70,973
2000	73,902	597,937	29,859
2001	46,478	400,422	32,552
2002	25,530	182,031	49,211
2003	70,181	116,718	18,990
2004	39,602	121,184	23,954
2005	22,944	79,483	1,192
2006	22,192	52,472	0
2007	8,140	69,385	0
2008	18,532	84,196	0
2009	30,536	154,532	0
2010	9,358	96,355	0
2011	13,632	55,009	0
2012	32,145	147,937	0
2013	101,863	151,008	0
2014	64,595	213,539	0
2015	29,305	211,067	0

	Nemasket River	
	Alewife	
Year	Passage	Removals
1972		
1973		
1974		
1975		
1976		
1977		
1978		
1979		
1980		
1981		
1982		
1983		
1984		
1985		
1986		
1987		
1988		
1989		
1990		
1991		
1992		
1993		
1994		
1995		
1996	696,666	
1997		
1998	651,441	64,200
1999	766,694	114,632
2000	560,986	75,426
2001	284,498	61,668
2002	1,361,691	101,302
2003	548,835	80,971
2004	244,832	72,763
2005	225,904	43,741
2006	313,242	0
2007	462,000	0
2008	392,451	0
2009	383,338	0
2010	489,931	0
2011	512,139	0
2012	567,952	0
2013	840,033	0
2014	590,105	0
2015	741,048	0

Appendix Table 7.3 cont.

Year	Parker River Combined Passage	Marston-Mills Combined Passage	Stony Brook Combined Passage	Agawam Combined Passage	Wankinco Combined Passage	Sippican Combined Passage	Town River Combined Passage	Pilgrim Lake Alewife Passage	Herring R. (Harwich) Combined Passage	Herring R. (Wellfleet) Combined Passage
1972	12,097									
1973	38,163									
1974	34,163									
1975	24,539									
1976	13,998									
1977	6,654									
1978	13,116									
1979										
1980										
1981										
1982										
1983										
1984										
1985										
1986										
1987										
1988										
1989										
1990										
1991										
1992										
1993										
1994										
1995						326				
1996						680				
1997	6,396					610				
1998	4,242					671				
1999	7,965									
2000	7,894					959	72,000			
2001	2,244					558	33,000			
2002	3,500					359	193,069			
2003	1,500						310,000			
2004	1,447						25,000			
2005	747						65,826			
2006	500	6482		53,173		89				
2007	60	15,136	30,252	100,473	2,788		53,315			
2008	485	43,948	33,383	30,429	8,246		27,783	1,647		
2009	800	11,668	19,197	36,354	6,539		8,596	1,090	19,336	31,589
2010	1,800	4,174	71,026	30,057	10,665		29,465	1,461	41,254	12,052
2011	3,624	494	37,091	19,064	10,442		93,312	1,370	10,466	9,534
2012	5,416	87,308	41,028	73,186	24,764			5,931	101,624	11,653
2013	2,500	56,987	153,262	33,637	8,734			3,001	91,167	24,985
2014	2,491	47,006	271,364	48,873	18,625			4,202	247,894	61,779
2015	4,911	23,840	251,530	24,398	14,170		5,427	4,245	127,860	18,025

Counter performance and fishway issues in 2012-2014

Appendix Table 7.4. Length frequencies of alewife and blueback herring from various rivers by sex and year. Length intervals are 10-mm total length bins with the label equal to the lower limit of the bin.

Alewife

Back River

	2004		2005		2006		2007		2008		2009		2010	
TL mm	M	F	M	F	M	F	M	F	M	F	M	F	M	F
190														
200														
210														
220														
230														
240							1	5						
250							19	16						
260							59	57						
270							78	64						
280							54	48						
290							15	15						
300							2	5						
310														
320								1						
330														
340														
Total	0	0	0	0	0	0	228	211	0	0	0	0	0	0

Mattapoisett River

	1995		2004		2005		2006		2007		2008		2009		2010	
TL mm	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
190																
200																
210																
220									1							
230																
240	1						3									
250	4						11	2	1	2						
260	12	5					14	9	6	3						
270	19	8					3	7	3	4						
280	7	6					2	4	3	8						
290	8	18					2	2		5						
300	2	7								1						
310	1	6								1						
320																
330																
340																
Total	54	50	0	0	0	0	35	24	14	24	0	0	0	0	0	0

Quashnet River

	2004		2005		2006		2007		2008		2009		2010	
TL mm	M	F	M	F	M	F	M	F	M	F	M	F	M	F
190														
200														
210														
220														
230	2	1												
240	11	2												
250	20	13												
260	18	21												
270	11	26												
280	4	20												
290		4												
300														
310														
320														
330														
340														
Total	66	87	0	0	0	0	0	0	0	0	0	0	0	0

Stony Brook

	2004		2005		2006		2007		2008		2009		2010	
TL mm	M	F	M	F	M	F	M	F	M	F	M	F	M	F
190														
200														
210														
220														
230	2	1												
240	14	3												
250	23	6												
260	34	12												
270	30	36												
280	13	24												
290	1	14												
300		1												
310														
320														
330														
340														
Total	117	97	0	0	0	0	0	0	0	0	0	0	0	0

Appendix Table 7.4 cont.

Alewife

Town Brook

	2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015	
TL mm	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
190																								
200																								
210	1								1															
220	1		3	1	5				3	1	1										2		2	
230	5	2	8	3	10	4	9	2	10	3	13	1	6	1	3	1	5	1	2		21		8	2
240	12	1	33	9	27	12	43	6	43	16	35	14	45	4	18	3	15	3	21	5	40	13	31	5
250	16	12	62	32	50	23	74	32	83	35	82	42	85	25	39	11	46	16	37	17	55	41	102	53
260	25	20	30	44	34	46	108	78	70	74	70	56	85	64	74	42	35	27	65	42	33	47	63	90
270	22	40	14	31	11	36	60	73	31	49	37	63	44	79	34	69	47	40	30	46	18	45	25	72
280	3	16	4	13		5	15	40	12	20	7	22	9	38	8	38	23	60	15	40	4	18	9	24
290		3		9		2		14	4	6		11	3	14	3	12	4	24	4	16	1	9	2	9
300		1		1			1			3		3		2		2		15	1	8		1	1	
310													1			1		1		1				
320								1										1						
330																								
340																								
Total	85	95	154	143	137	128	310	246	257	207	245	212	278	227	179	179	175	188	175	175	174	174	243	255

Agawam

	1991	
TL mm	M	F
190		
200		
210		
220		
230		
240	6	
250	13	1
260	23	8
270	23	18
280	14	25
290	6	13
300	1	5
310		1
320		
330		
340		
Total	86	71

Parker River

	2011		2012		2013		2014		2015	
TL mm	M	F	M	F	M	F	M	F	M	F
190										
200										
210										
220			3		1					
230	1		12	1	2		1			
240	3	2	22	2	23	3	14	3	1	
250	4		35	6	50	5	17	6	8	
260	2	2	53	8	70	11	29	10	41	4
270	1	1	36	22	62	19	55	15	41	7
280			10	26	32	18	39	19	41	5
290			1	9	11	10	14	20	18	4
300				2	1	7	3	12	5	3
310						2	1	7	1	1
320										
330										
340										
Total	11	5	172	76	252	75	173	92	156	24

Appendix Table 7.4 cont.

Alewife
Mystic River

	2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015	
TL mm	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
190																								
200																								
210	1				6				1															
220	7			1	3		6	2	1	1	2						1				1			
230	16	8	2		3	2	29	6	21	7	6	3	1		8		10		19		7	1	3	
240	10	6			9	7	44	28	28	8	13	8	7	8	48	9	20	11	74	1	38	13	22	9
250	12	8	3	2	1	5	35	36	25	11	27	22	2	10	73	35	52	14	84	26	46	24	60	30
260	12	15	2	2	2	7	10	26	28	14	13	15	2	7	48	29	53	34	46	66	27	29	37	47
270	9	15	2	4		7	12	21	3	9	1	12	2		14	23	32	40	28	42	18	35	21	56
280	3	4		2		1	3	10	1			4			1	17	6	32	8	35	3	16	4	18
290	1							3		2						5		9		16	2	8		7
300			1	1				2		1		1		1		4		2		7		2		4
310																				7		2		
320																								
330																								
340																								
Total	71	56	10	12	24	29	139	134	108	53	62	65	14	26	192	122	174	142	259	200	142	130	147	171

Nemasket River

	2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015	
TL mm	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
190																								
200																								
210							1																	
220									1															
230			1		1								1		1								1	
240	1		6	2	19	1	1		14		4	1	2		5		10		7		1			
250	10	1	25	7	51	9	21	15	47	9	74	7	29	8	24	3	30	1	25	2	19	3	19	4
260	20	9	30	21	59	35	84	51	76	17	106	30	81	27	50	15	79	22	94	27	59	7	55	12
270	23	16	40	40	40	43	131	76	64	66	77	72	96	62	96	28	55	35	102	87	92	49	91	52
280	35	31	19	25	18	19	96	67	39	67	40	51	51	78	79	79	37	41	48	66	108	77	69	77
290	34	28	17	19	6	14	45	29	17	33	11	23	15	45	27	67	16	36	7	23	39	62	33	65
300	14	29	9	10	2	2	14	14	1	15	1	6	1	5	1	24	2	14	1	7	6	34	7	32
310	2	11		6	1	4		2		5		1		6		4		4		1		3	1	5
320		2					1	1		1								1				1		
330																								
340																								
Total	139	127	147	130	197	127	394	255	259	213	313	191	276	231	283	220	229	154	284	213	324	236	276	247

Appendix Table 7.4 cont.

Blueback

Town Brook

	2004		2005		2006		2007		2008		2009		2010	
TL mm	M	F	M	F	M	F	M	F	M	F	M	F	M	F
190														
200														
210														
220														
230			3	1										
240			2											
250			1											
260		1	1											
270														
280														
290														
300														
310														
320														
330														
340														
Total	0	1	7	1	0	0	0	0	0	0	0	0	0	0

Quashnet River

	2004		2005		2006		2007		2008		2009		2010	
TL mm	M	F	M	F	M	F	M	F	M	F	M	F	M	F
190														
200														
210														
220	2													
230	2													
240	1													
250		2												
260		1												
270														
280														
290														
300														
310														
320														
330														
340														
Total	5	3	0	0	0	0	0	0	0	0	0	0	0	0

Mystic River

	2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015	
TL mm	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
190					1				3						2									
200			2		1		2		6		8				5		2		6					
210					17		1		8		21		3		3		13		40		5		2	
220			14	2	41		36	8	43	4	49	3	37	1	23	4	18	1	34	1	41		0	
230			22	11	37	5	97	50	50	4	145	37	112	25	91	20	44	8	28	6	129	39	13	
240			14	13	28	16	70	64	28	5	87	74	105	43	122	40	52	28	46	15	66	85	53	7
250			5	18	3	8	31	60	14	10	19	29	27	38	44	59	38	36	22	43	17	26	32	36
260			2	13	1	3	5	25	3	5	1	6	3	10	6	19	9	29	4	14	1	11	2	25
270				3		1	1	7	2					1		4	2	12	1	9	2	9		3
280								3												2		3		
290																								
300																								
310				5																				
320																								
330																								
340																								
Total	0	0	59	65	129	33	243	217	157	28	330	149	287	118	296	146	178	114	181	90	261	173	102	71

Appendix Table 7.4 cont.

Blueback

	Parker River									
	2011		2012		2013		2014		2015	
TL mm	M	F	M	F	M	F	M	F	M	F
190										
200										
210					3					
220	2		4		7		2			
230	23		11		9	1	32	1	1	
240	77	5	39	2	57	10	108	39	36	
250	61	16	92	9	98	27	92	57	120	21
260	20	9	57	34	60	39	30	28	71	38
270	1	4	9	23	18	28	5	12	33	29
280				7	3	21	2	8	2	20
290						3				4
300										
310										
320										
330										
340										
Total	184	34	212	75	255	129	271	145	263	112

	Agawam		Charles										Nemasket	
	1991		1985		1993		2012		2013		2014		2004	
TL mm	M	F	M	F	M	F	M	F	M	F	M	F	M	F
190														
200					3		10		12					
210					10	3	39		103					
220	2				16	1	104	2	99	2	9	17	1	
230	2	1	3		7	5	73	7	61	5	65	47	1	
240			16	2	8	4	40	8	113	28	53	40		
250	1		19	10	7	9	13	15	46	45	43	30		
260	2	3	16	20	5	16	5	7	9	25	10	10		
270		2	8	11	4	15	1	5	1	5		3		
280			1	14	1	9		1		2				
290						2								
300				7		4								
310				3										
320				1										
330				1										
340				1										
Total	7	6	63	70	61	68			444	112	180	147	2	0

Appendix Table 7.5. Length frequencies of alewife and blueback herring by sex and year from the Monument River. Length bins are +/- 2.5 mm total length around the midpoint shown.

Alewife Male

Total Length (mm)	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
205																																
210																																
215																												1				
220																												1				
225											1			1			1								1	1						
230		1									2	1		4		1	3	1					2	1	7	2		1		2		
235							2		2		7	2		2	1	9	10	2	2	1	2	2	3	3	20	3	1	5	7	2	4	1
240							1	2	2	4	10	2	3	10	4	12	14	2	4	1	4	4	7	14	37	11	15	7	9	9	8	
245	1	2	1				4	12	2	1	12	11	10	11	4	13	24	6	6	3	3	5	10	18	39	9	25	16	22	7	11	7
250	1	2		3			9	16	6	3	26	20	8	20	15	22	19	15	5	6	9	10	15	24	47	25	32	18	27	13	21	13
255	4	4	2	2			9	22	8	14	16	24	16	22	16	28	27	21	19	7	15	15	15	32	34	42	38	21	27	13	31	23
260	5	6	3	3			9	26	18	11	22	25	29	18	12	23	12	18	27	5	13	16	6	38	36	28	51	26	23	25	42	29
265	8	9	8	11			14	21	14	15	20	24	46	31	15	13	15	23	16	9	16	12	3	40	24	16	50	25	20	15	38	25
270	11	6	7	8			17	25	20	12	8	10	38	33	13	5	4	12	20	8	13	10		22	22	12	26	17	10	6	37	19
275	14	7	4	11			26	33	8	8	7	3	27	19	8	2	3	10	15	2	13	3		13	11	6	15	15	5	5	26	7
280		14	8	15			14	25	6	6	4	1	8	10	8	3			12	3	4	3		12	5	2	5	2		2	9	2
285	10	10	14	17			5	8	4	4	4		7	9	2			2	7		2	1		2	3		3	2	1		8	1
290	16	9	5	9			8	6	3	1			4	6	2						1					1	2		1		2	
295	14	4	16	7			3	7					1	1	1							1		1				1				1
300	8	2	8	5			3	2																			1					
305	2	1	3	4																												
310	2	6		3																												
315			3	1																												
320			1																													
325																																
330																																
Total	96	83	83	99			124	205	93	79	139	123	197	197	101	131	132	112	133	45	95	82	61	220	286	158	264	158	152	99	237	128

Alewife Female

Total Length (mm)	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
205																																
210																																
215																																
220																			1													
225																																
230											2						2															
235																2	2	1					1		9							
240							1			1	1	1	1		1	3	4	2				1	3	2	5	2	2	1	2		2	
245							1				6	2		6	3		4	7		2		0	1	6	13	3	4	4	1	1	1	1
250							1	3	1	3	11	3	2	3	1	9	5	7	3	3	2	10	8	12	20	6	3	7	7	3	4	3
255							6	5	6	5	10	10	3	7	10	11	16	10	7	1	6	8	8	14	27	22	11	9	11	4	7	13
260		3		1			4	6	8	11	15	14	16	13	5	13	17	12	5	1	12	8	8	20	23	28	29	12	16	8	9	20
265	3	2	4	2			8	12	12	10	14	15	19	16	9	11	20	15	7	8	12	9	10	26	22	32	37	17	17	15	20	28
270	4	3	2				10	18	14	16	15	11	23	25	11	9	18	16	17	10	12	14	3	29	34	29	30	28	26	12	22	30
275	6	5	3	9			12	17	16	21	16	10	15	30	11	10	16	13	15	7	8	7	5	35	12	18	36	18	7	6	21	22
280	10	13	9	18			20	18	14	14	14	12	23	25	9	7	10	5	23	7	5	6	6	14	17	11	39	15	12	3	20	15
285	11	12	5	22			23	13	9	7	8	9	18	23	10	2	3	8	13	3	8	3	1	15	7	6	17	11	4	5	21	7
290	14	14	10	7			22	19	8	3	4	3	5	14	7			1	10	1	4		2	3	2		5	2	4	4	15	3
295	18	20	13	9			10	19	4	1	4		7	5	7	1		1	5	1	2		2	4	1		1	1	3	1	6	3
300	20	13	5	13			9	13	4		1	1	4	5	4	1		1	2		1			4	1		2				3	
305	17	8	11	8			3	8			1	1	1	2	2										1					1		
310	11	7	12	5			4	7																1	0							
315	11	3	5	12				2	1																							
320	1	1	3	6			1	1																								
325	1		1	4																												
330			1																													
335			2	1																												
340			1	1																												
Total	127	104	87	118			135	161	97	92	122	92	137	174	90	79	117	99	108	44	72	66	58	185	194	157	216	125	110	63	151	145

Appendix Table 7.5 cont.

Blueback Male

Total Length (mm)	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
200																									1			1				
205							1									1								1				2	1			
210														0		1				2		1		2	4	2	5	4	1			
215							1		1	2	1		1	9		4		1		5	2	1	4	8	12	3	4	3	3			
220	2			3			7	1		2		1		14	2		3	4	2	3	2	4	7	12	8	10	9	21	3	1	18	
225	7			1			5	2	1		1	1	1	16	2	3	6	8	3	9	3	3	6	10	9	14	18	25	12	9	36	4
230	14		1	9			5	3		2	2	3	2	21	1	5	6	13	7	10	6	8	11	13	12	19	18	14	24	41	33	7
235	20		2	11			8	1	3		2	1	4	14	4	1	7	7	9	15	14	9	16	12	12	24	13	13	36	65	29	22
240	13	2	2	13			12	8	5	6	5	5	7	13		7	9	3	10	11	7	7	13	12	11	14	8	19	16	59	39	40
245		3	3	5			11	9	1	2	5	4	11	12	2	9	3	6	13	13	8	9	2	12	2	4	2	13	14	36	35	48
250	13	2	3	6			14	14	3	6	3	3	5	8	1		2	1	11	4	5	7	5		1	2	3	9	3	8	17	29
255	8	2	5	4			23	11	3		1	1	2	8				1	11	4	1	1	1					4	1	3	8	29
260	15	3	6	1			15	9	3	2	2	1	1	7			1		3		1	1						1	4	1	4	5
265	17	3	9	4			9	3	1		1	1	1	2					1		1							0	1	1	1	2
270	7	8	10	3			3	2		1																						
275	5	4	8	3			1	1																								
280		2	2	3					1			1																				
285	5	2																														
290	6	3		3						1																						
295	4																															
300		1																														
305	2	1																														
310																																
315																																
320																																
325																																
330																																
Total	138	36	51	69			115	64	22	24	23	22	35	124	12	31	37	44	70	76	50	51	65	82	71	92	80	128	119	224	220	186

Blueback Female

Total Length (mm)	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
205																																
210																																
215																						1										
220	1							1						1		1									1	1	1	4				
225														1		1				1		1	2		4			6	1	1	3	
230	2						1				3			3				2		3	1	1	4	1	1	3	4	13	5	4	4	
235	2						1	1			1			7			1	1	3	10			6	5	11	7	10	4	9	5	15	1
240	4		1	3			1	1			1		2	8	5		5	7	1	6	5	3	6	8	11	14	20	5	15	25	6	7
245				1			10	4	2	1	5	5	2	17	7		4	5	6	11	7	4	14	17	18	24	10	20	15	26	16	13
250	5	2	1	2			6	4	2	1		3	1	16	2	1	4	3	7	10	10	11	5	13	11	14	8	15	12	18	21	30
255	13	3	4	2			11	11	2	3	2	4	4	8	3	1	3	5	8	21	7	5	4	9	4	12	6	15	12	5	24	21
260	13	4	3	3			11	6	1	3	6	3	3	6	1		2	1	7	4	7	8	8	8	2	2	4	10	5	5	11	26
265	17	3	4	3			11	4	1	2	3	2	3	13				2	5	3	5	3	2	6	4	3	4	3	3	4	7	17
270	17	4	8	2			9	10	2		1	4	2	7			1	1	3		5	3	3					2			1	13
275	8	8	5	3			7	6	1	2	2		3	8					1	1	1		2	1				1				5
280	7	8	7	4			2	6	2	0	1			3				1	2		1			1					1			
285		3	6	5				3	1	1				2																		
290	5	9	1	4			1	3			1																					
295	3	7	2	2				1																								
300	2	3	1	1				2																								
305	1																															
310	1																															
315		1																														
320																																
325																																
330																																
Total	101	55	43	35			71	63	14	13	26	21	20	100	18	4	20	28	43	70	49	40	56	69	67	80	67	98	78	93	108	133

Appendix Table 7.6. Sample size (n), mean, and standard deviation (SD) of total length distributions of alewife and blueback herrings by sex collected in nine rivers, 1985-2015.

Alewife - Females

	Agawam			Back			Mattapoisett			Mystic			Nemasket			Parker			Quashnet			Stony Brook			Town Brook		
	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD
1991	71	282.2	11.88																								
1995							50	289.4	14.52																		
2004										56	260.9	14.57	127	291.5	14.36				87	270.9	11.96	97	275.5	12.53	95	271.0	12.11
2005										12	270.7	18.69	130	280.4	15.22										143	265.9	13.67
2006							24	273.4	10.61	23	257.9	13.51	127	275.3	13.66										128	263.6	11.10
2007				211	283.9	12.69	24	282.6	13.73	134	260.3	15.83	255	278.1	12.41										246	270.2	12.18
2008										53	257.9	16.01	213	282.1	12.51										207	266.7	13.00
2009										65	260.5	13.12	191	278.3	11.33										212	268.1	12.74
2010										26	255.7	12.16	231	281.4	11.67										227	271.5	11.22
2011										122	267.2	15.03	220	287.1	11.21	5	259.0	12.43							179	274.3	11.31
2012										142	271.5	13.70	154	284.3	13.44	76	277.3	13.09							188	278.7	14.69
2013										200	264.1	14.71	213	279.5	9.79	75	279.1	15.46							175	274.8	13.76
2014										130	268.3	15.45	236	287.2	11.63	92	284.6	17.30							174	266.9	12.77
2015										171	269.3	12.30	247	286.6	11.92	24	283.5	13.38							255	267.5	10.75

Alewife - Males

	Agawam			Back			Mattapoisett			Mystic			Nemasket			Parker			Quashnet			Stony Brook			Town Brook		
	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD
1991	86	269.8	13.63																								
1995							54	274.9	13.94																		
2004										71	250.6	18.00	141	282.6	15.15				66	259.8	11.59	117	264.4	12.56	85	259.1	14.25
2005										10	262.2	20.21	147	273.0	16.16										154	255.1	11.17
2006							35	263.1	11.51	16	237.0	13.37	197	265.1	13.35										137	253.8	11.44
2007				228	273.7	11.00	14	266.6	15.78	139	248.9	13.16	395	276.6	12.84										310	261.2	11.75
2008										108	250.9	12.03	259	269.1	13.03										257	258.5	12.79
2009										62	251.8	10.88	313	268.1	11.06										245	258.6	11.33
2010										14	252.3	11.71	276	272.1	10.67										278	260.1	11.49
2011										192	255.1	9.91	283	275.2	11.42	11	254.0	11.92							179	262.7263	10.83938
2012										174	259.8	11.95	229	270.3	12.50	172	260.9	13.48							175	264.8286	13.61094
2013										259	254.8	11.62	284	270.5	10.14	252	266.4	13.26							175	263.9657	12.38645
2014										142	256.1	12.52	324	277.2	11.24	173	272.9	14.35							174	254.3276	12.80948
2015										147	258.6	10.42	276	276.8	11.87	156	276.4	12.60							243	258.4198	11.41609

Appendix Table 7.6 cont.

Blueback - Females

	Agawam			Charles			Mystic			Nemasket			Parker			Quashnet			Town Brook		
	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD
1985				70	276.8	20.58															
1991	6	262.3	16.71																		
1993				68	264.1	20.18															
2004																3	259.0	4.3589	1	261.0	NA
2005							61	251.5	14.31										1	232.0	NA
2006							38	242.8	13.99												
2007							217	248.0	11.77												
2008							28	247.4	12.70												
2009							150	244.2	7.76												
2010							118	247.6	9.48												
2011							146	250.5	10.54				34	258.4	8.59						
2012				45	252.3	13.16	114	254.4	10.96				75	267.9	9.28						
2013				112	253.7	10.91	90	255.1	11.41				129	266.6	12.22						
2014				147	252.8	11.52	173	246.9	10.93				145	256.5	11.34						
2015							71	258.0	7.12				112	269.3	10.42						

Blueback - Males

	Agawam			Charles			Mystic			Nemasket			Parker			Quashnet			Town Brook		
	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD
1985				63	256.7	11.81															
1991	7	242.9	17.61																		
1993				61	235.8	20.30															
2004										2	232.5	6.36				5	231.6	5.4129			
2005							58	236.1	10.59										7	244.43	9.9809
2006							131	230.6	11.20												
2007							243	239.0	10.04												
2008							157	233.4	14.05												
2009							333	234.7	10.42												
2010							287	238.9	8.74												
2011							296	240.3	11.06				184	248.2	8.64						
2012				285	230.4	12.06	178	240.8	13.54				212	254.3	9.61						
2013				444	231.9	14.27	181	232.7	15.33				255	254.1	11.62						
2014				180	243.1	9.86	261	236.6	8.98				271	249.5	9.67						
2015							102	246.1	7.28				263	258.4	8.61						

Appendix Table 7.7. Sample size (n), mean, and standard deviation (SD) of total length distributions of alewife and blueback herrings by sex collected in the Monument River, 1984-2010.

Monument River

Alewife

	Female			Male		
Year	n	Mean Length	SD	n	Mean Length	SD
1984	127	295.6	13.17	96	281.3	14.85
1985	104	291.3	12.80	83	277.8	16.72
1986	87	297.5	16.51	83	284.6	15.34
1987	118	295.1	16.30	99	281.1	14.25
1988						
1989						
1990	135	282.1	14.27	124	270.0	13.87
1991	161	283.4	15.49	205	267.6	13.34
1992	97	275.5	12.54	93	265.2	11.69
1993	92	271.2	10.36	79	264.7	11.28
1994	122	267.8	14.55	139	256.2	12.65
1995	92	269.2	12.45	123	257.4	8.99
1996	137	274.6	11.95	197	265.8	10.48
1997	174	274.9	12.77	197	262.7	13.97
1998	90	274.8	15.27	101	262.3	12.42
1999	79	263.9	12.78	131	253.5	10.44
2000	117	263.5	12.02	132	251.1	10.58
2001	99	265.5	13.01	112	259.7	10.22
2002	108	275.4	12.72	133	264.2	11.62
2003	44	270.5	11.35	45	260.7	10.80
2004	72	270.8	11.59	95	262.4	11.17
2005	66	265.1	10.73	82	259.2	11.17
2006	58	263.7	14.04	61	249.4	7.89
2007	185	269.1	12.88	220	259.4	11.41
2008	194	262.6	13.75	286	253.0	12.23
2009	157	265.5	9.54	158	256.2	10.23
2010	216	270.7	10.70	264	259.4	10.84
2011	125	269.1	11.20	158	258.4	12.37
2012	110	267.7	11.61	152	254.9	10.46
2013	63	269.4	11.96	99	256.6	10.88
2014	151	274.7	12.47	237	262.6	11.36
2015	145	269.1	9.78	128	261.2	9.18

Blueback Herring

	Female			Male		
Year	n	Mean Length	SD	n	Mean Length	SD
1984	101	265.9	16.17	138	253.4	20.45
1985	55	279.4	14.59	36	268.5	16.29
1986	43	272.9	12.87	51	261.7	12.44
1987	35	271.7	17.32	69	247.4	18.00
1988						
1989						
1990	71	259.7	11.65	115	247.2	14.19
1991	63	265.9	16.00	64	249.6	11.17
1992	14	263.2	13.67	22	246.8	14.35
1993	13	261.9	11.09	24	243.3	17.24
1994	26	255.6	15.90	23	242.8	11.66
1995	21	256.4	9.24	22	243.6	13.64
1996	20	259.0	11.19	35	242.9	9.57
1997	100	254.1	14.40	124	235.4	13.24
1998	18	246.7	6.18	12	233.3	9.85
1999	4	237.5	17.56	31	232.9	12.23
2000	20	248.5	8.75	37	234.9	9.17
2001	28	248.8	11.83	44	232.4	8.92
2002	43	255.7	11.10	70	243.2	10.36
2003	70	248.1	10.01	76	234.9	11.04
2004	49	254.8	10.71	50	242.9	10.07
2005	40	251.9	11.82	51	242.4	10.72
2006	56	247.9	12.31	65	238.0	9.51
2007	69	250.3	10.04	82	235.0	10.55
2008	67	244.1	9.52	72	232.5	10.78
2009	80	246.0	8.07	92	236.3	8.47
2010	67	244.3	9.66	80	233.7	9.20
2011	98	245.6	12.72	129	231.8	12.03
2012	78	246.3	9.79	119	235.1	9.71
2013	93	245.5	8.02	224	237.7	6.58
2014	108	248.6	10.03	220	236.4	10.05
2015	133	256.5	8.94	186	244.9	7.81

Appendix Table 7.8. Age composition of alewife and blueback herring from Massachusetts rivers, 2004-2015.

Alewife

Back River

Age	Female 2004	Female 2005	Female 2006	Female 2007	Female 2008	Female 2009	Female 2010	Male 2004	Male 2005	Male 2006	Male 2007	Male 2008	Male 2009	Male 2010
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	34	0	0	0	0	0	0	36	0	0	0
4	0	0	0	119	0	0	0	0	0	0	152	0	0	0
5	0	0	0	48	0	0	0	0	0	0	35	0	0	0
6	0	0	0	5	0	0	0	0	0	0	4	0	0	0
7	0	0	0	3	0	0	0	0	0	0	1	0	0	0
8	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	210	0	0	0	0	0	0	228	0	0	0

Quashnet River

Age	Female 2004	Female 2005	Female 2006	Female 2007	Female 2008	Female 2009	Female 2010	Male 2004	Male 2005	Male 2006	Male 2007	Male 2008	Male 2009	Male 2010
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	11	0	0	0	0	0	0
4	61	0	0	0	0	0	0	48	0	0	0	0	0	0
5	23	0	0	0	0	0	0	6	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	85	0	0	0	0	0	0	65	0	0	0	0	0	0

Mattapoisett River

Age	Female 1995	Female 2004	Female 2005	Female 2006	Female 2007	Female 2008	Female 2009	Female 2010	Male 1995	Male 2004	Male 2005	Male 2006	Male 2007	Male 2008	Male 2009	Male 2010
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	4	0	0	9	0	0	0	0	9	0	0	15	0	0	0	0
4	20	0	0	9	0	0	0	0	26	0	0	16	0	0	0	0
5	13	0	0	5	0	0	0	0	10	0	0	4	0	0	0	0
6	9	0	0	1	0	0	0	0	9	0	0	0	0	0	0	0
7	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	50	0	0	24	0	0	0	0	54	0	0	35	0	0	0	0
	4.78								4.352							

Stony Brook

Age	Female 2004	Female 2005	Female 2006	Female 2007	Female 2008	Female 2009	Female 2010	Male 2004	Male 2005	Male 2006	Male 2007	Male 2008	Male 2009	Male 2010
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	7	0	0	0	0	0	0	22	0	0	0	0	0	0
4	40	0	0	0	0	0	0	60	0	0	0	0	0	0
5	43	0	0	0	0	0	0	33	0	0	0	0	0	0
6	6	0	0	0	0	0	0	1	0	0	0	0	0	0
7	1	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	97	0	0	0	0	0	0	116	0	0	0	0	0	0

Mystic River

Age	Female 2004	Female 2005	Female 2006	Female 2007	Female 2008	Female 2009	Female 2010	Female 2011	Female 2012	Female 2013	Female 2014	Female 2015	Male 2004	Male 2005	Male 2006	Male 2007	Male 2008	Male 2009	Male 2010	Male 2011	Male 2012	Male 2013	Male 2014	Male 2015
2	1	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	6	2	1	0
3	4	0	1	37	10	4	14	39	35	124	64	83	25	2	6	57	39	5	9	84	60	137	100	87
4	40	5	9	75	25	30	9	58	80	21	56	67	34	4	3	68	56	35	2	88	88	21	38	52
5	9	6	4	7	10	18	3	8	19	19	6	17	10	3	1	7	11	14	2	15	20	15	1	7
6	2	1	1	5	8	4	0	14	6	4	3	3	1	1	0	1	2	4	1	5	0	0	2	1
7	0	0	0	2	0	0	0	3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	56	12	15	126	53	56	26	122	142	171	130	171	71	10	10	133	108	58	14	192	174	175	142	147

Appendix Table 7.8 cont.

Alewife

Nemasket River

	Female												Male											
Age	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	11	0	2
3	0	4	27	22	2	0	22	17	59	115	73	44	4	10	62	41	36	8	42	36	91	113	103	71
4	23	50	56	163	38	48	80	95	72	48	93	169	39	50	91	257	76	118	88	98	61	42	59	177
5	52	54	34	59	134	60	71	57	19	6	6	28	65	63	31	82	110	96	51	44	12	6	11	22
6	40	19	6	5	34	36	14	7	2	2	1	2	30	17	9	12	36	29	7	4	1	0	2	1
7	8	1	1	1	5	4	2	2	2	0	1	0	1	6	1	1	1	1	1	0	1	0	0	1
8	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Total	123	128	124	250	213	148	189	178	154	171	174	243	139	146	194	393	259	252	189	182	175	172	175	274

Town Brook

	Female												Male											
Age	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2
3	5	20	25	27	4	2	20	18	49	59	93	72	17	16	45	61	24	10	47	25	73	72	127	88
4	52	79	75	164	81	65	69	108	78	81	49	168	50	104	80	190	113	91	73	116	71	77	30	137
5	35	26	26	38	89	75	63	39	50	24	26	11	14	27	11	45	94	74	47	33	28	16	11	9
6	1	3	0	13	28	27	25	12	10	11	5	5	2	5	0	10	24	27	12	4	2	5	5	7
7	1	1	0	0	4	8	2	2	1	0	1	1	0	1	0	1	2	4	1	1	1	2	1	1
8	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	94	129	126	242	206	177	179	179	188	175	174	257	83	153	136	307	257	206	180	179	175	175	174	244

Parker River

	Female					Male				
Age	2011	2012	2013	2014	2015	2011	2012	2013	2014	2015
2	0	0	0	0	0	0	11	0	0	1
3	2	16	23	23	0	7	69	87	56	11
4	3	53	22	42	14	4	82	47	82	97
5	0	4	27	20	7	0	7	37	27	34
6	0	1	1	6	3	0	2	3	8	11
7	0	2	2	0	0	0	1	0	0	1
8	0	0	0	0	0	0	0	0	0	1
Total	5	76	75	91	24	11	172	174	173	155

Agawam

	Female	Male
Age	1991	1991
2	0	
3	1	6
4	35	49
5	28	27
6	6	4
7	1	0
8	0	0
Total	71	86

Charles

	Female		Male	
Age	2013	2014	2013	2014
2	0	0	0	0
3	89	16	130	17
4	12	51	25	50
5	6	5	2	4
6	1	2	2	2
7	0	0	0	0
8	0	0	0	0
Total	108	74	159	73

Appendix Table 7.8 cont.

Blueback

Mystic River

	Female												Male											
Age	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	5	22	1	5	13	72	7	2
3	0	3	2	62	4	75	71	17	34	60	148	26	0	18	42	81	55	207	135	51	78	82	147	33
4	0	32	18	94	12	49	44	115	47	10	16	44	0	22	58	125	67	54	41	121	52	14	20	55
5	0	3	9	49	8	9	2	13	30	9	6	1	0	2	10	30	23	15	2	6	31	4	0	8
6	0	2	2	7	3	3	1	1	3	6	2	0	0	0	0	1	6	2	0	0	4	7	0	0
7	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1
8	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	0	40	31	213	28	136	118	146	114	90	172	71	0	42	110	237	157	300	180	183	178	180	174	99

Town Brook

	Female								Male							
Age	2004	2005	2006	2007	2008	2009	2010	2015	2004	2005	2006	2007	2008	2009	2010	2015
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1
4	1	1	0	0	0	0	0	0	0	4	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1	1	0	0	0	0	0	0	0	7	0	0	0	0	0	1

Parker River

	Female					Male				
Age	2011	2012	2013	2014	2015	2011	2012	2013	2014	2015
2	0	0	0	0	0	0	5	12	0	0
3	20	9	67	116	9	125	53	90	145	47
4	13	54	17	25	93	50	138	22	26	197
5	1	10	38	3	7	8	15	48	2	16
6	0	0	3	1	1	1	1	3	2	2
7	0	2	4	0	1	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
Total	34	75	129	145	111	184	212	175	175	262

Quashnet River

	Female							Male						
Age	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	3	0	0	0	0	0	0
4	2	0	0	0	0	0	0	2	0	0	0	0	0	0
5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	3	0	0	0	0	0	0	5	0	0	0	0	0	0

Agawam

	Female	Male
Age	1991	1991
2	0	0
3	0	1
4	3	2
5	2	2
6	1	2
7	0	0
8	0	0
Total	6	7

Charles

	Female					Male				
Age	1985	1993	2012	2013	2014	1985	1993	2012	2013	2014
2	0	0	3	5	0	0	1	118	85	1
3	2	3	18	83	97	7	22	32	65	124
4	21	23	16	12	44	30	28	17	12	51
5	26	29	7	5	3	19	5	7	7	3
6	8	9	0	6	1	6	5	1	3	0
7	6	3	0	1	0	1	2	0	2	0
8+	7	1	1	0	0	0	0	0	0	0
Total	70	68	45	112	145	63	63	175	174	179

Appendix Table 7.9. Age composition of alewife and blueback herring from the Monument River, 1985-2010.

Alewife

Female

Age	1985	1986	1987	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0
3	7	2	1	0	5	0	2	1	6	6	5	8	3	2	6	10	52	18	1	30	12	64	39	34	27
4	28	29	38	24	43	60	20	29	18	77	60	35	34	53	35	26	97	89	80	61	87	29	12	84	111
5	29	30	32	19	17	23	22	35	13	18	24	45	17	17	24	17	22	69	48	83	21	14	2	5	7
6	5	19	20	7	11	5	5	14	0	4	4	6	4	0	1	4	3	16	12	6	5	1	4	2	0
7	4	5	15	1	0	0	0	1	0	0	1	0	0	0	0	0	4	1	0	0	0	0	1	0	0
8	3	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Total	76	86	110	51	76	88	49	80	37	105	94	94	58	72	66	57	178	194	141	180	125	110	59	125	145

Male

Age	1985	1986	1987	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	11	1	0	0
3	17	10	2	6	34	25	16	6	17	13	16	23	6	6	9	24	93	83	11	64	40	100	80	78	29
4	26	40	39	21	48	59	30	56	20	83	60	62	44	71	54	32	100	129	88	77	100	34	16	92	96
5	12	27	34	13	12	22	9	25	11	15	29	36	16	15	17	5	16	65	30	37	12	6	1	4	3
6	8	5	13	4	2	3	4	6	1	1	2	1	2	0	2	0	2	8	8	1	3	1	0	0	0
7	2	1	2	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	65	83	90	44	96	109	59	94	49	112	107	122	69	92	82	61	211	286	137	179	156	152	98	174	128

Blueback

Female

Age	1985	1986	1987	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	9	0	4	0	0	0	1	0	0	1	2	0	5	5	11	5	11	7	13	30	15	33	60	28	8
4	22	14	1	5	7	10	30	12	3	9	14	29	44	30	14	33	48	46	45	29	76	37	29	55	105
5	19	19	16	4	8	5	16	2	1	9	7	9	19	13	14	18	9	12	13	8	7	8	4	2	19
6	2	5	7	1	3	1	3	0	1	0	0	2	0	0	0	0	0	0	3	0	0	0	0	0	1
7	1	1	3	1	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	53	39	31	11	18	16	52	14	5	19	23	40	68	48	39	56	68	67	74	67	98	78	93	85	133

Male

Age	1985	1986	1987	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0
3	12	5	8	1	1	6	25	4	5	6	17	9	13	14	8	14	44	22	31	60	58	79	115	85	23
4	17	32	31	11	7	11	27	5	22	16	14	40	48	31	33	40	31	44	37	15	70	34	54	86	144
5	5	14	16	2	8	4	5	2	2	6	9	10	8	3	9	11	6	5	17	5	1	4	4	8	16
6	2	0	4	1	0	2	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	3	3
7	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	36	51	60	15	16	24	58	11	29	28	41	59	69	48	51	65	81	72	85	80	129	119	174	182	186

Appendix Table 7.10. Average age (years) of alewife and blueback herring collected by sex, river and year. *=not calculated due to small sample size.

Alewife

Female

River	1971	1972	1973	1974	1975	1976	1977	1978	1985	1986	1987	1991	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Agawam	-	-	-	-	-	-	-	-	-	-	-	4.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Back	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.2	-	-	-	-	-	-	-	-
Charles	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.3	3.9	-
Mattapoisett	-	-	-	-	-	-	-	-	-	-	-	-	-	4.8	-	-	-	-	-	-	-	-	-	-	3.9	-	-	-	-	-	-	-	-	-
Monument	-	-	-	-	-	-	-	-	4.7	5.0	5.2	-	4.7	4.4	4.4	4.6	4.8	4.2	4.2	4.3	4.5	4.4	4.2	4.3	4.3	3.9	4.5	4.5	4.4	4.2	3.5	3.5	3.8	3.9
Mystic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.1	4.7	4.4	3.9	4.3	4.4	3.6	4.0	4.0	3.5	3.6	3.6
Nemasket	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.3	4.8	4.2	4.4	5.0	5.0	4.4	4.3	3.8	3.4	3.6	4.0
Parker	6.0	5.2	4.3	4.5	5.3	5.7	5.1	4.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.6	3.9	4.2	4.1	4.5
Quashnet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.3	-	-	-	-	-	-	-	-	-	-	-
Stony Brook	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.5	-	-	-	-	-	-	-	-	-	-	-
Town Brook	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.4	4.3	4.0	4.2	4.8	4.9	4.6	4.3	4.1	3.9	3.7	3.8

Male

River	1971	1972	1973	1974	1975	1976	1977	1978	1985	1986	1987	1991	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Agawam	-	-	-	-	-	-	-	-	-	-	-	4.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Back	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	-	-	-	-	-	-	-	-
Charles	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.2	3.9	-
Mattapoisett	-	-	-	-	-	-	-	-	-	-	-	-	-	4.4	-	-	-	-	-	-	-	-	-	-	3.7	-	-	-	-	-	-	-	-	-
Monument	-	-	-	-	-	-	-	-	4.3	4.4	4.7	-	4.3	3.8	4.0	4.0	4.4	3.9	4.0	4.2	4.1	4.2	4.1	4.1	3.7	3.7	4.0	4.3	3.9	3.8	3.3	3.2	3.6	3.8
Mystic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.8	4.3	3.5	3.6	3.8	4.3	3.6	3.7	3.7	3.3	3.3	3.5
Nemasket	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.9	4.7	4.0	4.1	4.6	4.6	4.1	4.1	3.5	3.3	3.5	3.8
Parker	5.7	4.2	4.0	4.5	5.0	5.4	5.1	4.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.4	3.6	3.7	3.9	4.3
Quashnet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.9	-	-	-	-	-	-	-	-	-	-	-
Stony Brook	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.1	-	-	-	-	-	-	-	-	-	-	-
Town Brook	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	4.0	3.8	4.0	4.5	4.6	4.2	4.1	3.8	3.7	3.4	3.7

Blueback

Female

River	1971	1972	1973	1974	1975	1976	1977	1978	1985	1986	1987	1991	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Agawam	-	-	-	-	-	-	-	-	-	-	-	4.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Charles	-	-	-	-	-	-	-	-	5.2	-	-	-	4.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.7	3.3	3.4	-
Monument	-	-	-	-	-	-	-	-	4.3	4.8	5.1	-	4.8	4.8	4.4	4.5	4.1	4.6	4.4	4.2	4.3	4.2	4.2	4.1	4.2	4.0	4.2	4.1	3.7	3.9	3.7	3.4	3.7	4.1
Mystic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.1	4.4	4.0	4.5	3.6	3.4	4.0	4.0	3.5	3.2	3.6
Parker	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.4	4.1	3.9	3.2	4.0
Quashnet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-	-
Town Brook	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-

Male

River	1971	1972	1973	1974	1975	1976	1977	1978	1985	1986	1987	1991	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Agawam	-	-	-	-	-	-	-	-	-	-	-	4.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Charles	-	-	-	-	-	-	-	-	4.4	-	-	-	4.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.5	2.8	3.3	-
Monument	-	-	-	-	-	-	-	-	3.9	4.2	4.3	-	4.2	4.4	4.0	3.7	3.8	3.9	4.0	3.9	4.0	3.9	3.8	4.1	4.0	3.5	3.7	3.8	3.3	3.6	3.3	3.4	3.6	4.0
Mystic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.5	3.7	3.8	3.8	3.2	3.3	3.7	3.6	2.9	3.1	3.7
Parker	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.4	3.8	3.7	3.2	3.9
Quashnet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-	-
Town Brook	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-	*

Appendix Table 7.11. Repeat spawner frequencies for alewife and blueback herring by river, sex and year. 0 = new spawner, 1=second-time spawner, 2= third-time spawner, etc.

Alewife

Back River

	Female							Male						
RPS	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
0	0	0	0	186	0	0	0	0	0	0	202	0	0	0
1	0	0	0	16	0	0	0	0	0	0	23	0	0	0
2	0	0	0	7	0	0	0	0	0	0	3	0	0	0
3	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	210	0	0	0	0	0	0	228	0	0	0

Mattapoisett River

	Female								Male							
RPS	1995	2004	2005	2006	2007	2008	2009	2010	1995	2004	2005	2006	2007	2008	2009	2010
0	33	0	0	23	0	0	0	0	44	0	0	34	0	0	0	0
1	14	0	0	1	0	0	0	0	9	0	0	1	0	0	0	0
2	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	49	0	0	24	0	0	0	0	54	0	0	35	0	0	0	0

Quashnet River

	Female							Male						
RPS	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
0	79	0	0	0	0	0	0	62	0	0	0	0	0	0
1	6	0	0	0	0	0	0	3	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	85	0	0					65	0	0				

Stony Brook

	Female							Male						
RPS	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
0	77	0	0	0	0	0	0	102	0	0	0	0	0	0
1	17	0	0	0	0	0	0	13	0	0	0	0	0	0
2	2	0	0	0	0	0	0	1	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	97	0	0	0	0	0	0	116	0	0	0	0	0	0

Appendix Table 7.11 cont.

Alewife

Mystic River

RPS	Female 2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Male 2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
0	36	11	15	110	40	40	22	79	76	134	48	7	10	125	91	46	12	149	115	147
1	18	0	0	12	7	14	3	24	50	27	19	3	0	7	16	10	2	39	53	21
2	1	1	0	3	5	2	1	12	12	7	4	0	0	2	0	2	0	4	6	7
3	1	0	0	1	1	0	0	5	2	1	0	0	0	0	1	0	0	0	0	0
4	0	0	0	0	0	0	0	2	1	3	0	0	0	0	0	0	0	0	0	0
Total	56	12	15	126	53	56	26	26	26	26	71	10	10	134	108	58	14	192	174	175

Alewife

Nemasket River

RPS	Female 2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Male 2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
0	70	98	112	218	167	103	146	131	124	142	78	104	176	347	207	208	159	134	148	136
1	31	24	11	30	37	42	35	44	26	28	34	30	15	47	43	38	25	45	20	33
2	21	5	1	3	8	3	8	3	2	1	24	8	3	0	9	4	5	3	6	3
3	1	2	0	1	1	0	0	0	2	0	3	4	1	0	0	2	0	0	1	0
Total	123	129	124	252	213	148	189	178	154	171	139	146	195	394	259	252	189	182	175	172

Town Brook

RPS	Female 2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Male 2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
0	81	110	116	202	146	122	142	138	119	124	69	134	130	237	174	140	150	135	127	121
1	11	18	10	37	50	50	30	34	50	38	13	17	6	64	70	58	21	38	37	46
2	0	2	0	3	11	5	7	7	17	12	1	2	0	6	13	6	9	6	10	6
3	2	0	0	1	0	0	0	0	2	1	0	0	0	0	0	2	0	0	1	2
Total	94	130	126	243	207	177	179	179	188	175	83	153	136	307	257	206	180	179	175	175

Agawam

RPS	Fem 1991	Male 1991
0	63	77
1	6	9
2	2	0
3	0	0
Total	71	86

Appendix Table 7.11 cont.

Blueback

Mystic River

	Females										Males									
RPS	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
0	0	36	26	180	18	120	100	115	55	74	0	33	87	195	114	262	156	147	91	162
1	0	0	3	27	6	15	17	29	54	11	0	2	23	37	34	37	22	36	73	10
2	0	1	2	6	3	1	1	2	4	5	0	0	0	5	7	2	1	0	14	8
3	0	0	0	0	1	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0
Total	0	37	31	213	28	136	118	146	114	90	0	35	110	237	157	301	179	183	178	180
		0.027																		

Quashnet River

	Females							Males						
RPS	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
0	3	0	0	0	0	0	0	5	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	3	0	0	0	0	0	0	5	0	0	0	0	0	0
	0													

Town Brook

	Females							Males						
RPS	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
0	1	1	0	0	0	0	0	0	7	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1	1	0	0	0	0	0	0	7	0	0	0	0	0

Agawam

	Fem	Male
RPS	1991	1991
0	6	7
1	0	0
2	0	0
3	0	0
Total	6	7

Charles

	Female				Male			
RPS	1985	1993	2012	2013	1985	1993	2012	2013
0	32	37	29	96	32	47	151	152
1	18	18	13	12	21	10	23	17
2	10	11	2	3	10	4	1	5
3	3	0	0	1	0	2	0	0
4	7	0	1	0	0	0	0	0

Appendix Table 7.12. Repeat spawner frequencies for alewife and blueback herring from the Monument River by sex and year. 0 = new spawner, 1=second-time spawner, 2= third-time spawner, etc.

Alewife

Female

RPS	1986	1987	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
0	47	62	41	70	72	35	47	33	97	81	67	51	71	61	49	163	165	122	156	105	97	52	109	136
1	25	26	9	4	14	9	28	4	7	10	24	3	1	5	8	12	26	17	17	19	11	5	15	8
2	12	17	1	2	2	5	5	0	1	3	3	4	0	0	1	3	3	2	7	1	2	2	0	1
3	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Total	86	110	51	76	88	49	80	37	105	94	94	58	72	66	58	178	194	141	180	125	110	59	125	145

Male

RPS	1986	1987	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2009	2009	2009	2009	2009	2009
0	51	53	34	91	83	46	67	43	101	88	84	56	87	79	58	198	250	123	167	142	143	94	155	122
1	24	27	9	4	26	8	22	6	10	18	34	10	5	3	3	13	34	14	11	13	9	4	18	6
2	8	9	1	1	0	5	5	0	1	1	3	3	1	0	0	0	2	0	1	1	0	0	1	0
3	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	83	90	44	96	109	59	94	49	112	107	122	69	93	82	61	211	286	137	179	156	152	98	174	128

Blueback

Female

RPS	1986	1987	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
0	24	19	9	16	15	43	14	4	19	23	37	66	46	37	48	67	63	70	66	92	69	87	0	0
1	12	7	1	2	1	9	0	1	0	0	3	2	2	2	8	1	4	4	1	6	9	6	0	0
2	2	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	39	31	11	18	16	52	14	5	19	23	40	68	48	39	56	68	67	74	67	98	78	93	0	0

Male

RPS	1986	1987	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
0	40	48	13	15	20	58	8	26	28	40	51	67	45	48	56	76	68	82	79	120	101	167	0	0
1	10	9	1	1	4	0	3	3	0	1	8	2	3	3	9	5	4	3	1	9	18	7	0	0
2	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	51	60	15	16	24	58	11	29	28	41	59	69	48	51	65	81	72	85	80	129	119	174	0	0

Appendix Table 7.13. Yearly estimates of instantaneous total mortality (Z) from age-repeat spawner frequency and length data for alewives and blueback herring from Massachusetts Rivers by sex. *=not calculated due to small sample size.

Alewife

Females

Chapman-Robson Z Estimates (Age Data)

Year	Agawam	Back	Mattapoisett	Monument	Mystic	Nemasket	Parker	Stony	Town
1971							1.00		
1972									
1973							1.33		
1974									
1975									
1976									
1977							1.01		
1978							1.03		
1979									
1980									
1981									
1982									
1983									
1984									
1985				1.04					
1986				0.99					
1987				0.76					
1988									
1989									
1990									
1991	0.96								
1992									
1993				0.87					
1994									
1995			0.72	1.03					
1996				1.29					
1997									
1998				1.4					
1999									
2000				1.56					
2001				1.26					
2002									
2003				1.15					
2004					1.58	1.02		1.96	1.16
2005				1.18		1.41			1.47
2006			1.1	1.04	1.15	1.08			
2007		1.24		1.42	1.57	1.39			1.44
2008				0.96	0.96	1.59			1.41
2009				1.08	1.1	1.18			1.26
2010				1.93	0.98	0.95			0.84
2011				1.53	1.04	1.12			1.2
2012				1.02	1.41	1.44	1.78		1.06
2013				1.02	1.06	1.27	1.92		1.25
2014				2.4	0.95	2.31	1.13		0.89
2015				*	0.93	1.97	1.02		2.16

Appendix Table 13 cont.

Alewife

Males

Chapman-Robson Z Estimates (Age Data)

Year	Agawam	Back	Mattapoisett	Monument	Mystic	Nemasket	Parker	Stony	Town
1971							1.29		
1972							1.49		
1973									
1974									
1975							1.54		
1976							0.95		
1977							1.01		
1978							1.21		
1979									
1980									
1981									
1982									
1983									
1984									
1985				0.87					
1986				1.03					
1987				0.84					
1988									
1989									
1990									
1991	1.18								
1992									
1993				1.02					
1994									
1995			0.94	1.57					
1996				1.38					
1997				1.24					
1998				1.16					
1999				1.22					
2000				1.91					
2001				1.32					
2002				1.28					
2003				1.31					
2004					1.54	1.38		1.3	1.53
2005				1.48	0.88	1.32			1.48
2006					1.03	1.21			
2007		1.64		1.93	2.23	1.6			1.53
2008				1.23	1.71	1.58			0.94
2009				1.31	1.21	0.93			0.87
2010				1.37	0.89	1.15			1.02
2011				1.99	1.66	1.33			1.5
2012				1.35	*	1.03	2.01		0.82
2013				1.85	1.48	1.38	0.85		1.41
2014				*	1.4	1.1	1.31		1.23
2015				*	1.14	2.13	1.18		1.93

Appendix Table 13 cont.

Blueback
Females

Chapman-Robson Z Estimates (Age Data)

Year	Agawam	Charles	Monument	Mystic	Parker
1971					
1972					
1973					
1974					
1975					
1976					
1977					
1978					
1979					
1980					
1981					
1982					
1983					
1984					
1985		0.67	0.98		
1986			1.49		
1987			1.07		
1988					
1989					
1990					
1991	0.81				
1992					
1993		1.19	0.75		
1994					
1995					
1996			1.15		
1997			1.02		
1998					
1999			0.85		
2000					
2001					
2002			1.39		
2003					
2004					
2005				1.82	
2006				1.15	
2007				1.19	
2008			1.54	0.86	
2009			1.43	1.02	
2010			0.9	1.19	
2011				2.25	1.16
2012		0.81	*	1.16	1.73
2013		1.23	1.25	0.99	0.73
2014		1.31	*	1.8	1.66
2015			1.93	*	2.24

Blueback
Males

Chapman-Robson Z Estimates (Age Data)

Year	Charles	Monument	Mystic	Parker
1971				
1972				
1973				
1974				
1975				
1976				
1977				
1978				
1979				
1980				
1981				
1982				
1983				
1984				
1985	0.96	1.27		
1986				
1987		1.06		
1988				
1989				
1990				
1991				
1992				
1993	1.05	1.45		
1994				
1995				
1996		1.1		
1997		1.72		
1998				
1999				
2000				
2001		0.76		
2002				
2003				
2004				
2005		1.54		
2006				
2007		1.05	1.77	
2008			1.26	
2009			1.39	
2010		1.43	1.55	
2011		*	*	1.3
2012	1.07	1.32	0.83	2.3
2013	0.84	1.3	1.13	0.82
2014	1.41	2.06	*	1.76
2015	*	2.12	1.99	2.46

8 Status of River Herring in Rhode Island

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Executive Summary

Major declines in river herring run sizes occurred at Gilbert Stuart and Nonquit during 2000 to 2005. These declines were followed by increasing trends from 2006 to 2014 until 2015 when the majority of Rhode Island's river herring runs decreased. Gilbert Stuart river herring spawning stock size drastically decreased each year from 290,814 in 2000 to a low of 7,776 fish in 2005. Between 2010 and 2014 the average run size was 95,267 and in 2015 decreased to 11,135. Likewise, Nonquit run size decreased from 185,524 fish in 2000 to a low of 25,417 in 2004. Between 2010 and 2014 the average run size was 50,567 and in 2015 decreased to 32,330. Likewise mortality rates and percentage of repeat spawners showed some improvement until 2015. Mortality rates (Z) decreased for both sites prior to 2015, and percentage of repeat spawners increased until 2015. All of Rhode Island's runs decreased in 2015, therefore Rhode Island continued with the statewide closure imposed in 2006, on the harvest of river herring (alewives and bluebacks) in fresh and marine waters.

8.1. INTRODUCTION

In Rhode Island, the Division of Fish and Wildlife currently manages 21 river herring runs and operates and maintains 26 fishways on 11 of the systems. These systems include small brooks and streams to large rivers and impoundments. Since the 1960s, the Division of Fish and Wildlife has worked toward restoring anadromous fish to Rhode Island. These efforts include partnering with various organizations on anadromous habitat restoration projects, conducting anadromous fish stocking, monitoring anadromous fish populations throughout the state, providing seasonal adjustments and maintenance to existing fishways, and setting harvest regulations.

The two Rhode Island systems with the most complete quantitative data sets on river herring are the Gilbert Stuart and Nonquit. Available data include spawning stock size, length at age, mortality rates, proportion of repeat spawning and juvenile abundance indices. Gilbert Stuart has an Alaskan steeppass fishway which provides access to 68 acres of nursery and spawning habitat. Gilbert Stuart Pond empties into the Narrow River and discharges into the Atlantic Ocean (Figure 8.1). River herring at Gilbert Stuart have been monitored by the Division of Fish and Wildlife since 1980. Nonquit has a Denil fishway which provides access to 202 acres of nursery and spawning habitat. Nonquit Pond spills into Almy Brook which joins the Sakonnet River and empties into the Atlantic Ocean (Figure 8.2). Nonquit River herring stocks have been monitored since 1999.

In addition, to assessing the status of the Gilbert Stuart and Nonquit stocks, this report will summarize spawning stock size results from Buckeye Brook, JAI results from the Pawcatuck River seine survey, and river herring data collected from three marine fishery-independent surveys.

8.2. MANAGEMENT UNIT DEFINITION

The Rhode Island Department of Environmental Management (RIDEM) has management authority over river herring (alewives and bluebacks) occurring in the state's fresh and marine waters [RI Gen. Laws].

8.3. REGULATORY HISTORY

Currently there is a moratorium on harvest of river herring (alewives and bluebacks) in Rhode Island's fresh and marine waters (RIDFW Reg; RIMF Reg.). Due to drastic declines in spawning stock size beginning in 2001, Rhode Island passed regulations in March 2006 for the complete closure. Prior to 1998, the freshwater daily river herring limit was 12 fish per day and closed Sunday, Monday, and Tuesday. There were no regulations for marine waters. In 1998 the daily freshwater limit was increased to 24 fish per day with the same closed days, and then decreased to 12 fish per day in 2005. The 2006 closure marked the first time there were reciprocal regulations for Rhode Island marine and fresh waters. The marine and freshwater closure continued through 2015 and is planned for 2016. Table 8.1 summarizes current and past Rhode Island river herring regulations.

8.4. ASSESSMENT HISTORY

In the 2012 ASMFC Stock Assessment Report No.12-02 the two Rhode Island systems assessed were Gilbert Stuart and Nonquit. The assessment showed Gilbert Stuart and Nonquit run sizes decreased between 2001 to 2005 and the declines were followed by increasing trends from 2006 to 2010. Prior to 2012, the last formal assessment was prepared by Crecco and Gibson in 1990. The Rhode Island system assessed in the report was the Annaquatucket River which in the 1970s had a spawning stock size over 300,000 (Durbin 1979). At the time of the assessment, the status of the river herring population was partially exploited with no trend in stock condition. Currently, only presence/absence data are recorded at the Annaquatucket River, therefore this system will not be covered in this report.

8.5. STOCK-SPECIFIC LIFE HISTORY

Gilbert Stuart and Nonquit river herring stocks are iteroparous and predominately alewives. Between 2000 and 2005, weekly species identification results showed Rhode Island's spring returns were 100% alewives. Since 2005, species identification at both sites has been over 95% alewives. Gilbert Stuart river herring were used as Rhode Island's main broodstock source between 1966 and 1978 to stock into the Annaquatucket, Hunt, and Pawcatuck rivers. Gilbert Stuart was again used as a broodstock source between 1999 and 2004, and sparingly in years following due to the drastic declines in run size in 2004. Both the Gilbert Stuart and Nonquit systems were stock between 1990 and 1993 with alewife broodstock from Massachusetts systems.

8.6. HABITAT DESCRIPTION

Gilbert Stuart has an Alaskan steeppass fishway which provides access to 68 acres of nursery and spawning habitat. Gilbert Stuart Pond empties into the Narrow River and discharges into the Atlantic Ocean (Figure 8.1). Nonquit has a Denil fishway which provides access to 202 acres of nursery and spawning habitat. Nonquit Pond spills into Almy Brook which joins the Sakonnet River and empties into the Atlantic Ocean (Figure 8.2). Buckeye Brook is a natural free flowing system that provides access to 91 acres of spawning habitat in Warwick and Spring Green Ponds. Buckeye Brook empties into Narragansett Bay. The Pawcatuck River is a riverine system and currently has two Denil fishways which provide access to miles of riverine habitat, Watchaug Pond (573 acres), and Chapman Pond (164 acres). In addition to a river herring run, the Pawcatuck River is also managed for American shad.

8.7. RESTORATION PROGRAMS

8.7.1. Recovery Target

The state of Rhode Island has informally adopted a recovery target of greater than 50% of the spawning stock size estimated by Gibson (1984). Target goals for spawning stock size at Buckeye Brook, Gilbert Stuart and Nonquit are shown in Table 8.3. The estimates are calculated based on habitat size and are used as indicators to predict the spawning stock size potential of restored habitat or strength of existing runs.

8.7.2. Restoration Objectives

The Rhode Island Division of Fish and Wildlife is partnering with many government agencies, NGO's, and private entities on a wide variety of anadromous habitat restoration projects throughout the state. Projects include constructing new fishways, culvert modifications, and dam removals to enhance spawning and nursery habitat. Since the last assessment fish passage projects have been completed on the Pawcatuck, Pawtuxet, Ten Mile and Woonasquatucket Rivers. Currently several fish passage projects are proposed or currently being implemented on the Blackstone River, Pawcatuck River, and Factory Brook (Edwards 2015; Erkan 2002).

8.7.3. Stocking Efforts

Stocking has been important to Rhode Island's river herring restoration efforts (Table 8.2). Each year trap and transport is conducted utilizing out-of-state and in-state broodstock sources to supplement existing runs or restore extirpated systems that have been restored. Gilbert Stuart was Rhode Island's only broodstock source for river herring between 1966 and 1972, and today is still an important source. Nonquit has not been utilized as a broodstock source, but was considered in 2001, prior to the drastic decrease in spawning stock size. Between 1990 and 1993, both Gilbert Stuart and Nonquit received supplemental stockings from the Agwam and Bourne rivers located in Massachusetts. Since 2001 it has become increasingly difficult to obtain available out-of state and in-state broodstock sources, due to the declines in river herring run sizes.

8.7.4. Fish Passage

The Alaskan steeppass at Gilbert Stuart has been the primary survey site for monitoring adult river herring since 1981. The eight foot obstruction at the Gilbert Stuart Birthplace, is a dam with various water control structures serving the historic grist mill (Erkan 2002). In 2000, the fishway passed over 290,000 fish and in recent years estimates of one thousand fish per hour have been observed (Edwards 2015). The Denil fishway at Nonquit has been the primary survey site for monitoring adult river herring since 1999. The seven foot obstruction is owned by the City of Newport Water Company and the impoundment is used as a secondary water supply (Erkan 2002). In 1999, the fishway passed over 230,000 fish (Edwards 2015). Buckeye Brook is a free-flowing system and river herring migrate to Warwick Pond without obstruction. The connection between Warwick Pond and Spring Green Pond passes through the T.F Green Airport property.

8.8. AGE

Scale samples collected from Rhode Island Division of Fish and Wildlife's anadromous fish sampling projects at Gilbert Stuart and Nonquit were pressed between glass slides and analyzed by techniques described in Rothschild (1963) and Marcy (1969). The age of each fish and number of spawning marks were recorded. Regenerated scales are not considered reliable for ageing. Two groups have carried out most of the ageing work for river herring. Biologists from both groups have worked together to ensure consistency of methodology in the collection, processing, and age determination of scale samples. Approximately 150 scale samples are collected throughout the spring run at Gilbert Stuart and Nonquit. For both sites, the typical ages for males are 3 and 4, and females are typically ages 4 and 5 (Table 8.6, Table 8.7, Table 8.11, Table 8.12). Age-two males and age seven females were the minimum and maximum ages observed between 2011 and 2015.

8.9. FISHERIES-DEPENDENT MONITORING

8.9.1. Commercial Fisheries

Rhode Island commercial landings are shown in Table 8.14 (NMFS, Fisheries Statistics Division, Silver Spring, MD, personal communication). The river herring fishery was an inshore fishery and landings occurred throughout the late 1800's in New England waters (NMFS 1989). Oviatt et al. (2003) estimated over 1,100,000 kg ww of alewives were landed at Rhode Island ports in 1880, which is a substantial increase compared with the reported Rhode Island river herring commercial landings of zero in 1960 (NMFS 2010). The majority of the river herring landings between 1950 and 1980 were from seine hauls and trap net fisheries. The trap net fishery was the predominate source of landings throughout the 1990's. The reported landings have been zero or negligible since 1987. In March 2006, Rhode Island passed the moratorium on the harvest of river herring (alewives and blueback herring) in marine and freshwaters of the state.

8.9.2. Recreational Fisheries

No recreational data are available.

8.9.3. Bycatch Estimates

Bycatch is known to take place in the Atlantic herring bait fisheries, however no bycatch data is available.

8.9.4. Subsistence Fishery

No subsistence fishery data is available.

8.9.5. Characterization of Other Losses

No data is available.

8.10. FISHERIES-INDEPENDENT MONITORING

8.10.1. Spawning Stock Surveys

Each spring river herring spawning stock size is estimated using electronic fish counters or direct count methods on several Rhode Island river systems. The anadromous life history of river herring allows for a unique sampling and monitoring opportunity when they return to their native freshwater systems to spawn. In addition to estimating run sizes, a representative sample of river herring from Gilbert Stuart and Nonquit were sampled for biological data. River herring were sampled and measured for length, weight, and scale samples taken for age analysis. Approximately 50 alewives were sampled three times throughout each spring migration. Gilbert Stuart has a break in the biological data time series between 1993 and 2000; however spawning stock size was estimated during those years. Mortality rates (Z) are estimated by a percentage of repeat spawners method (Crecco and Gibson 1988).

Gilbert Stuart

The Division has estimated spawning stock size since 1981 using electronic fish counters or direct count methods. River herring were sampled for biological data during two time periods. The first sampling period was between 1980 and 1992, and the second from 2000 to present. The break in the biological data time series between 1993 and 1999 was due to changes in staff, but spawning stock size estimates were continued during this time period. Due to low run size, data could not be collected in 2015 following numerous attempts to sample fish.

Nonquit

The Division has estimated spawning stock size at Nonquit since 1999 using a solar operated electronic fish counter. The only known data, which included run size estimates, were collected in 1976 and reported as 80,000 fish (Lynch 1976). River herring were sampled for biological data since 2000, except for in 2010 when river herring were unable to be captured after numerous attempts.

Buckeye Brook

The Buckeye Brook Coalition and Division partnered in 2003 to initiate a direct count program utilizing volunteers (Puriton 2000; Stevenson 1997). River herring have not been sampled for biological data, nor have JAI's been performed at Buckeye Brook.

Pawcatuck River

A fishway trap is installed and operated each spring to monitor American shad returns. The increased number of river herring compared to American shad and high water volume make utilizing the fishway trap unfeasible for estimating river herring run size. Direct count techniques have failed, due to visibility and electronic counters are not efficient at the site. Since 2006, in addition to observations (presence/absence) the Division has initiated a four factor ranking system in which personnel estimate the number of herring in the trap and fishway each day the trap is checked for American shad. In addition, video techniques should assist in estimating the Pawcatuck River run size in the future.

Annaquatucket River and remaining RI herring runs

At other Rhode Island river herring systems, the Division conducts periodic qualitative analysis which consists of determining the presence and absence of adult and juvenile river herring. Methods include random net surveys, visual observations and electrofishing to determine spawning success. The Annaquatucket River experienced a complete collapse during the 1990's which may have resulted from other factors unrelated to the factors responsible for the recent decline.

8.10.2. Ocean Trawl Survey Indices

The Marine Division of Rhode Island Fish and Wildlife conducts a trawl survey, a Narragansett Bay seine survey, and coastal pond seine survey. The marine surveys are conducted in Narragansett Bay, Block Island Sound and surrounding coastal ponds. All three surveys collect river herring numbers and length frequency data.

Trawl Survey

The methodology used in the allocation of sampling stations employs both random and fixed station allocation. Fixed station allocation began in 1988 in Rhode Island and Block Island Sounds. This was based on the frequency of replicate stations selected per depth stratum since 1979. With the addition of the Narragansett Bay monthly segment which started in 1990, an allocation system of 13 fixed stations was employed. Sampling stations were established by dividing Narragansett Bay into a grid of cells. The seasonal trawl survey is conducted in the spring and fall of each year. Usually 42 stations are sampled each season; however this number has ranged from 26 to 72 over the survey time series. The stations sampled in Narragansett Bay during the seasonal segment are a combination of fixed and random sites. Thirteen fixed during the monthly portion and 26, (14 of which are randomly selected) during the seasonal portion. The random sites are randomly selected from a predefined grid. All stations sampled in Rhode Island and Block Island Sounds are fixed.

Depth Stratum Identification:

Area	Stratum	Area nm2	Depth Range (m)
Narragansett Bay	1	15.50	<=6.09
	2	51.00	>=6.09
Rhode Island Sound	3	0.25	<=9.14
	4	2.25	9.14 – 18.28
	5	13.5	18.28 – 27.43
	6	9.75	>=27.43
Block Island Sound	7	3.50	<=9.14
	8	10.50	9.14 – 18.28
	9	11.50	18.28 – 27.43
	10	12.25	27.43 – 36.57
	11	4.00	>=36.57

At each station, an otter trawl equipped with a ¼ inch liner is towed for twenty minutes covering .83 nautical miles. Data on wind direction and speed, sea condition, air temperature and cloud cover as well as surface and bottom water temperatures, are recorded at each station. Catch is sorted by species. Length (cm/mm) is recorded for all finfish, skates, squid, scallops, lobster, blue crabs and horseshoe crabs. Similarly, weights (gm/kg) and number are recorded for each species (Lynch 2007). The survey is a random / fixed stratified trawl survey that operates throughout state waters. Adults and juveniles are collected (Olszewski 2015).

Narragansett Bay Seine Survey

Since 1988, eighteen stations have been sampled monthly from June through October. The survey is a fixed station seine survey using a 200ft seine net that samples throughout Narragansett Bay. Predominately juveniles are collected (McNamee 2015).

Coastal Pond Seine Survey

Since 1992, twelve stations have been sampled monthly from May through November. The survey is a fixed station seine survey using a 160 ft seine net that takes place in Rhode Island's coastal ponds. The majority of the samples collected are juveniles but occasionally adults are captured and reported with the length frequency data (Lake 2015).

8.10.3. Juvenile Abundance Indices

Gilbert Stuart

Between 1988 and 1996 a trapnet was installed during the fall to capture juveniles exiting the freshwater impoundment. The trapnet was connected to the exit of the Alaskan steeppass fishway, therefore trapped fish endured high velocities of water. Due to high juvenile mortality the JAI was discontinued in 1996. During the 2007 season a different style trapnet, which prevents juvenile mortality was utilized. This weir based trap located 200 yards below the fishway allows trapped out-migrating juveniles a safe holding pen. The trap is set for one hour and juveniles are enumerated and length measurements are collected.

Nonquit

Since 2001 a trapnet was installed weekly each fall in the Denil fishway. The trap is placed in slots located at the front of the turning pool, and juveniles are captured as they exit the freshwater impoundment and held in the turning pool.

Pawcatuck River

Seine survey conducted weekly each fall since 1988 at five fixed stations in the lower Pawcatuck River (O'Brien 1986). Majority of the samples collected are juveniles but occasionally age one river herring are captured and reported with the length frequency data.

Remaining Rhode Island Runs

Periodic qualitative analysis which consists of determining the presence and absence of adult and juvenile river herring is selected Rhode Island systems. Methods include random net surveys, visual observations and electrofishing to determine spawning success.

8.11. ASSESSMENT APPROACHES AND RESULTS

8.11.1. Trends in Spawning Stock Size

Rhode Island river herring spawning stock sizes drastically decreased from 2000 to 2004. Since the statewide closure in 2006, the run sizes have increased but are still well below the run sizes estimated between 1999 and 2002 (Table 8.15; Figure 8.).

Gilbert Stuart

Between 1998 and 2001, the Gilbert Stuart stock displayed a stable trend and passed over one million herring. The annual mean spawning stock size during this period was 266,853. After 2001, the run declined to a low of 7,776 in 2005 (Table 8.15; Figure 8.). Since the closure in 2006, the spawning stock size has increased but was still substantially below the annual mean for the 1998 through 2001 time frame. The Gilbert Stuart run size has been below the predicted target population size of 64,000 since 2003, until the 2010 river herring run size was estimated at 110,000 (Table 8.3).

Nonquit

When the current time series began in 1999 the run size was estimated at 230,853 fish (Table 8.15; Figure 8. After 1999, the run size declined to a low of 25,417 fish in 2004. As with Gilbert Stuart, the Nonquit run size drastically decreased between 2002 and 2005. Since the closure in 2006, the spawning stock size has increased but was still substantially below 1999 returns, with the exception of 2008 when the run size reached 224,000. The Nonquit run size was below the predicted target population size of 138,000 each year since 2000, with the exception of 2008 (Table 8.3).

8.11.2. Trends in Length

Annual mean fork length results for the past two segments were less for both males and females for river herring sampled at Gilbert Stuart between 2000-2010 and 2011-2015, as compared with results from fish sampled between 1980 and 1992 (

Table 8.4 and Table 8.5). The last mean lengths reported for Nonquit were in 1976 and since 2000 the Nonquit mean lengths were below those previously reported (Lynch 1976, Table 8.9; Table 8.10; Figure 8.4).

8.11.3. Trends in Age

Pooled age data (1980-1992) at Gilbert Stuart showed fifteen percent of the river herring sampled was ages 6, 7 or 8 (Gibson 1992). Annual mean age for both males and females has decreased since 1980 (Figure 8.4). Age data from 2003 to present show no age 8 river herring and a decrease in percentages of 6 and 7 year olds sampled at Gilbert Stuart.

Table 8.6 and Table 8.7 show number and percent at age for males and females sampled at Gilbert Stuart.

Table 8.12 show the number and percent at age for males and females sampled at Nonquit. Mean age for males and females in the Nonquit has remained stable from 2000 to present (Figure 8.5).

8.11.4. Trends in Length at Age

River herring from Gilbert Stuart and Nonquit have displayed a decrease in length at age over time (Table 8.4). Since 2000, the mean length at ages recorded for Gilbert Stuart, were consistently lower for all age classes than reported in 1992 (Gibson 1992). Mean fork length at age for males and females at Gilbert Stuart is shown in Tables 8.4 and 8.5. Age results at Nonquit show the same decrease in percentages of 6 and 7 year olds sampled as compared from fish sampled at Gilbert Stuart between 1984 and 1992. Mean fork length at age for males and females at Nonquit is shown in Tables 8.9 and 8.10.

8.11.5. Trends in Proportion of Repeat Spawners

Percent repeat spawning at Gilbert Stuart and Nonquit decreased between 2000 and 2007, but have improved since 2007. Historical percentages for Nonquit were lacking, but historic percentages were available for Gilbert Stuart. Pooled estimates (1983-1992) resulted in a repeat spawning value of 42 % (Gibson 1992). The five year average (2003-2007) for Gilbert Stuart and Nonquit was 8.9% and 6.8%, respectively. Since the closure in 2006 the percentage of repeat spawners has increased at both locations, but compared to the historic data (1984-1992) the percentage of repeat spawning has decreased for both sites (Figure 8.). The three year average for this segment for Gilbert Stuart and Nonquit were 18.7% and 24.2%, respectively. This showed the percentage of repeat spawners continued to increase compared to the three year average (2008-2010) following the closure for Gilbert Stuart at 12.5% and Nonquit at 17.9%.

8.11.6. Total Mortality (Z) Estimates

The instantaneous mortality (Z) rates were calculated using the repeat spawning method (Crecco and Gibson 1988). Results are presented in Figure 8. Mortality rates substantially increased between 2003 and 2005. Both sites displayed the highest mortality rates in 2004 with Z values estimated at 3.9 for Gilbert Stuart and 4.1 for Nonquit. Historical mortality rate data for Nonquit was lacking, but historic data was available for Gilbert Stuart. Pooled estimates (1984-1992) utilizing the repeat spawning method resulted in a Z value of 1.2 (Gibson 1992). Gilbert Stuart and Nonquit mortality rates increased between 1992 and 2007, but following the closure, mortality rates for both sites had decreased. The exception was Gilbert Stuart in 2015 when results showed low run size and a mortality rate over 4.0.

8.11.7. Trends in Juvenile Abundance

Relative abundance indices in juveniles from the trawl survey are shown in Figure 8., and expressed in mean number per tow. Length frequency results are shown in Table 8.16 (Olszewski 2015). The trawl survey river herring indices decreased beginning in 2002 and have increased since 2010. The timing of this decrease coincides with the drastic decline in RI river herring spawning stock sizes. Relative abundance indices of juveniles from the Narragansett Bay Seine Survey are shown in Figure 8., and expressed in mean number per seine haul. Relative abundance indices of juveniles from the Coastal Pond Seine Survey are shown in Figure 8., and expressed in mean number per seine haul. Majority of the samples collected are juveniles but occasionally adults are captured and reported with the length frequency data (Lake 2015). Relative abundance indices for juveniles in the Gilbert Stuart River are shown in Table 8.17, and expressed in mean number per one hour trap set. Relative abundance indices for juveniles in the Nonquit River are shown in Table 8.17, and expressed in mean number per one hour trap set. The juvenile abundance indices from the Gilbert Stuart and Nonquit trap showed no correlation with the spawning stock size estimates for either system. Relative abundance indices for juveniles in the Pawcatuck River are shown in Table 8.18, and expressed in mean number per seine haul. The Pawcatuck River seine survey abundance indices for river herring have decreased since 2004 and have continued to remain low.

8.12. BENCHMARKS

The state of Rhode Island has informally adopted a recovery target for river herring run sizes of greater than 50% of the predicted spawning stock sizes based on available habitat, estimated by Gibson (1984). Target goals for spawning stock size at Buckeye Brook (39,461), Gilbert Stuart (32,150) and Nonquit (69,124) are shown in Table 8.3. In addition, Rhode Island has informally adopted a Z benchmark value of less than 2.5 using the percentage of repeat spawner technique (Crecco and Gibson 1988) and a percentage of repeat spawning benchmark of greater than 10 percent.

8.13. CONCLUSIONS AND RECOMMENDATIONS

Between 2000 and 2006, Rhode Island river herring stocks experienced sharp declines in spawning stock size, increases in mortality rates (Z) and decreases in percentage of repeat spawners causing Rhode Island to impose a statewide closure in 2006 to the harvest of river herring in fresh and marine waters. Since the closure in 2006, Rhode Island's run sizes increased until 2015. The majority of the run sizes in 2015 drastically decreased. Between 2010 and 2014, the Gilbert Stuart five year average was 95,267 and the run size decreased to 11,135 in 2015. The Nonquit five year average was 50,567 and decreased to 32,330 in 2015 (Figure 8.). In addition, prior to 2015, Gilbert Stuart and Nonquit showed decreases in mortality rates and increases in the percentage of repeat spawners. Truncated age structures remained the same.

Recent results prior to 2015 show there has been some improvement since the closure, but current run sizes are still well below the estimated run sizes (1999-2001) recorded prior to the decline (Table 8.15). Gilbert Stuart and Buckeye Brook exceeded the recovery target for river herring run sizes from 2011 to 2014, but were below the target in 2015. During the same timeframe (2011-2015), Nonquit only exceeded the target value in 2014. Likewise mortality rates (Z) and percentage of repeat spawners has shown some improvement (Figure 8.9 and Figure 8.10). Between 2011 and 2015, Gilbert Stuart and Nonquit mortality rates were below the target value of 2.5 with the exception of Gilbert Stuart in 2015 which displayed a value of 4.1. Likewise both sites displayed higher percentage of repeat spawner values then the target value of 10 percent, except for in 2012, when Nonquit displayed a value of 8.2.

The decrease in river herring run sizes between 2002 and 2005 warranted drastic regulatory changes in which the Rhode Island moratorium was imposed in March 2006. The moratorium is still in place and will continue through 2017. Reasons for the drastic declines in Rhode Island river herring run sizes may be related to a combination of factors which may have affected river herring stocks prior to the closure. Some theories include degradation of spawning and nursery habitat, an increase in predator populations, and overfishing. Degradation of spawning habitat could be the result of changes in water quality in the freshwater systems affecting egg development or juvenile mortality. Predator population increases in certain sportfish and bird species, may have been affecting river herring stocks. Overfishing may have been a result of an increase in the in-river fishery, an unregulated marine fishery in Rhode Island marine waters prior to 2006, or an ocean by-catch fishery intercepting Rhode Island river herring stocks during seasonal migrations.

In summary, Rhode Island's best available results are from river herring data collected at Gilbert Stuart and Nonquit. The Buckeye Brook spawning stock size estimates, Pawcatuck River JAI data, and results from the marine surveys are additional valued data sets. Gilbert Stuart and Nonquit have the best available quantitative data sets and the longest run size time series. In the past the Division has used the results from these two systems to gauge river herring stocks throughout the state and make recommendations for regulatory changes. The JAI time series is short for both systems, but if continued could provide useful information in the future. The Buckeye Brook spawning stock size estimates are available, and will continue in the future. River herring have not been sampled for biological data and no JAI's have been conducted. The Pawcatuck River spawning stock size estimates are still being developed, therefore not included in this report. Sampling for biological characteristics has occurred but is incomplete therefore not included. Pawcatuck River seine survey is available and there is a long time series, but there are not any accurate spawning stock size estimates available to compare with. The seine survey is used for American shad monitoring and therefore the river herring results were included in this report. Marine trawl and seine surveys offer long time series which provide catch indices and length frequency data. Results may be useful for tuning other models or indexing the broader river herring populations in state waters (mixed-ocean stocks). In addition, the Division is continuing to develop qualitative and quantitative assessments at remaining river herring runs throughout the state.

Future monitoring recommendations include:

1) Mandatory- Continue spawning stock size monitoring at Gilbert Stuart, Nonquit and Buckeye Brook to extend the existing time series and evaluate the stock status. Continue sampling river herring for biological data at Gilbert Stuart, Nonquit, and Pawcatuck River to determine age composition, growth rates, percent repeat spawning, and mortality rates. Continue JAI survey at Gilbert Stuart, Nonquit, and

the Pawcatuck River to extend the existing time series. Begin utilizing video technology for estimating run sizes on the Pawcatuck, Saugatucket, and Ten Mile River.

2) Recommended- Initiate JAI survey and adult biological sampling at Buckeye Brook. Continue modifying the four-factor system to estimate the Pawcatuck River herring run size. Continue collecting river herring data from the three marine surveys. Continue monitoring success of stocking program by various sampling methods to determine spawning success.

3) Desired- As new river systems are restored and river herring populations become established, set up monitoring projects to determine spawning stock size, biological characteristics, and juvenile abundance indices.

Towards a river herring restoration goal and stock recovery, the Rhode Island Division of Fish and Wildlife will continue to monitor runs throughout the state, transplant adult broodstock into extirpated or restored systems, work with partners on numerous fish passage projects, and represent the state at regional meetings.

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Table 8.1 Rhode Island river herring regulation change summary.

Year	Regulation Change
Prior to 1998	12 fish bag limit per person per day
1998	Part II freshwater regulations – Increased bag limit to 24 fish per person per day
2002	Part II freshwater regulations – Changed the freshwater/saltwater boundary at Nonquit pond
2004	Part II freshwater regulations – Closed Prince Pond to harvest and reduced bag limit to 12 fish per person per day in Hardig and Buckeye Brook
2005	Part II freshwater regulations – Reduced bag limit to 12 fish per person per day statewide
2006	Part II RI freshwater regulations – Imposed moratorium in all fresh water systems; Part 7.20 RI marine regulations – Imposed moratorium in all state marine waters

Table 8.2 Alewife broodstock stocking summary.

Date	Location Stocked	Number		Date	Location Stocked	Number
4/12/2001	Bellville	2,500		4/21/2008	Woonasquatucket	600
4/12/2001	Echo Lake	2,500		4/22/2008	Echo Lake	700
4/24/2001	Prince Pond	600		4/22/2008	Brickyard Pond	300
4/25/2001	Crossmills, Charlestown	1,200		4/23/2008	Turner Reservoir	1,000
5/2/2001	Warwick Pond, Warwick	1,000		5/5/2008	Woonasquatucket	600
5/4/2001	Crossmills, Charlestown	1,100		5/7/2008	Blackstone	500
5/4/2001	Hamilton Reservoir	1,100		2008	Omega-volunteers lifting	3,000
4/9/2002	Echo Lake	2,500		4/15/2009	Indian Lake	1,000
4/11/2002	Bellville	2,500		4/17/2009	Echo Lake	500
4/16/2002	Crossmills, Charlestown	600		4/17/2009	Brickyard Pond	500
4/17/2002	Chapmans	1,000		4/22/2009	Turner Reservoir	1,000
4/17/2002	Crossmills, Charlestown	1,500		2009	Omega-volunteers lifting	800
4/18/2002	Prince Pond	1,000		4/14/2010	Indian Lake	1,000
4/19/2002	Turner Reservoir	1,500		4/15/2010	Turner Reservoir	1,000
4/22/2002	Watchaug Pond	250		4/16/2010	Kickemuit	1,000
4/23/2002	Wesquage	500		2011	Ten-mile	1,000
4/23/2002	Wordon's Pond	500		2011	Kickemuit	1,000
4/26/2002	Turner Reservoir	1,500		2011	Indian Lake	1,300
5/1/2002	Wesquage	600		2011	Watchaug Pond	300
4/15/2003	Turner Reservoir	1,200		2011	Woonasquatucket	600
4/17/2003	Turner Reservoir	2,250		4/9/2012	Kickemuit	1,000
4/16/2003	Echo Lake	2,500		4/9/2012	Blackstone	1,000
4/22/2003	Factory Pond	2,500		4/10/2012	Worden Pond	700
4/24/2003	Belleville	2,500		4/10/2012	Woonasquatucket A.Mills	1,000
4/28/2003	Wesquage	1,000		4/11/2012	Worden Pond	900
4/29/2003	Prince Pond	700		4/12/2012	Pawtuxet River	1,000
5/1/2003	Chapmans	200		4/12/2012	Watchaug Pond	1,450
5/6/2003	Crossmills, Charlestown	800		4/16/2012	Worden Pond	1,400
5/8/2003	Warwick Pond, Warwick	750		4/16/2012	Watchaug Pond	1,600
4/15/2004	Turner Reservoir	1,500		4/17/2012	Hunts River	1,000
4/20/2004	Turner Reservoir	1,500		4/17/2012	Chapman Pond	1,000
4/13/2004	Echo Lake	2,300		4/18/2012	Blackstone	250
4/13/2004	Prince Pond	200		4/24/2012	Blackstone	1,000
4/15/2004	Belleville	2,500		4/9/2013	Worden Pond	1,300
4/20/2004	Indian Lake	2,500		4/10/2013	Worden Pond	1,410
4/21/2004	Warwick Pond, Warwick	750		4/10/2013	Turner Reservoir	1,000
4/22/2004	Crossmills, Charlestown	750		4/11/2013	Kickemuit	1,000
4/23/2004	Crossmills, Charlestown	500		4/15/213	Worden Pond	230
4/23/2004	Factory Pond	1,500		4/17/2013	Pawtuxet River	1,000
4/28/2004	Wordon's Pond	1,000		4/17/2013	Watchaug Pond	1,400
4/28/2004	Wesquage	400		4/18/2013	Pawtuxet River	1,000
4/20/2005	Brickyard Pond	1,000		4/18/2013	Watchaug Pond	700
4/20/2005	Echo Lake	660		4/22/2013	Watchaug Pond	400
4/21/2005	Belleville	1,660		4/25/2013	Woonasquatucket	1,000
4/18/2005	Prince Pond	200		4/25/2013	Bellville	700
4/19/2005	Factory Pond	1,000		4/25/2013	Secret Lake	300
4/22/2005	Crossmills, Charlestown	600		4/14/2014	Worden Pond	1,500
4/25/2005	Wesquage	250		4/14/2014	Watchaug Pond	1,400
4/29/2005	Wesquage	200		4/15/2014	Turner Reservoir	1,000
4/26/2005	Turner Reservoir	1,000		4/15/2014	Worden Pond	1,300
4/13/2006	Echo Lake	500		4/17/2014	Kickemuit	1,000
4/13/2006	Brickyard Pond	500		4/21/2014	Watchaug Pond	400
4/14/2006	Factory Pond	1,000		4/22/2014	Factory Pond	1,100
4/18/2006	Belleville	700		4/23/2014	Pawtuxet River	1,000
4/21/2006	Indian Lake	1,000		4/29/2014	Woonasquatucket	1,000
4/28/2006	Crossmills, Charlestown	350		4/16/2015	Kickemuit	1,000
4/28/2006	Wesquage	350		4/21/2015	Turner Reservoir	1,000
4/17/2007	Echo Lake	300		4/22/2015	Pawtuxet River	1,000
4/17/2007	Brickyard Pond	300		4/23/2015	Woonasquatucket	1,000
4/23/2007	Indian Lake	1,400		4/27/2015	Worden Pond	750
4/24/2007	Kickemuit	200		4/29/2015	Pawtuxet River	1,000
4/24/2007	Kickemuit	100		4/30/2015	Potowamut	1,000
4/15/2008	Indian Lake	1,000		5/1/2015	Watchaug Pond	400
4/18/2008	Kickemuit	350				

Table 8.3 River herring spawning stock size estimates based on habitat size (Gibson 1984).

Location	Estimated Spawning Stock Size	Actual 2004-2007 Mean Spawning Stock Size	Actual 2008-2010 Mean Spawning Stock Size	Actual 2013-2015 Mean Spawning Stock Size
Gilbert Stuart Habitat Size 68 acres	64,306	20,440	67,921	68,261
Nonquit Habitat Size 202 acres	138,248	50,473	104,288	52,131
Buckeye Brook Habitat Size 91 acres	78,923	12,933	24,875	35,946

Table 8.4 Mean fork length (mm) at age for female river herring sampled at Gilbert Stuart.

	Mean Fork Length-at-Age							
Year	2	3	4	5	6	7	N	Annual Mean FL
1984	221.8	165.7	292.3	309.7	321.4	333.0	138.0	265.7
1985	232.4	271.3	296.9	307.3	323.0	334.5	35.0	266.5
1986			302.8	304.5	320.4	326.3	74.0	273.3
1987								
1988	240.0	269.0	284.0	311.0	317.0	331.0	81.0	260.2
1989		273.0	286.0	299.0	318.0	324.0	115.0	256.3
1990			286.0	293.0	308.0		17.0	259.6
1991			*Data Not Available*				42.0	250.0
1992		259.9	271.9	302.6	311.4	320.0	*Not Available*	249.1
1993								
1994								
1995								
1996								
1997								
1998								
1999								
2000		229.8	241.4	245.5	260.0		58.0	242.2
2001	224.5	233.3	241.6	244.4	252.0		47.0	251.8
2002		237.7	246.8	249.0	260.5		42.0	255.9
2003		242.0	250.8	255.3	263.3		29.0	254.7
2004		215.0	237.0	242.0	257.0		66.0	231.6
2005		212.0	233.0	251.0	241.0		82.0	239.0
2006		227.0	237.0	255.0	262.0		32.0	243.0
2007			239.0	244.0	278.0		39.0	242.3
2008			228.0	244.0	254.0	270.0	43.0	240.4
2009			233.0	239.0	237.0		30.0	234.5
2010		207.0	326.0	237.0	242.0		24.0	231.9
2011		234.0	240.9	248.7	256.1		62.0	246.3
2012			239.3	253.0	270.0		17.0	246.8
2013		230.0	240.1	251.2	267.3	270.0	30.0	247.7
2014			241.3	255.1	258.0		26.0	247.9
2015				*Data Not Available*				

Table 8.5 Mean fork length (mm) at age for male river herring sampled at Gilbert Stuart.

	Mean Fork Length-at-Age							
Year	**2**	**3**	**4**	**5**	**6**	**7**	**N**	**Annual Mean FL**
1984	224.2	264.9	287.4	297.6			75.0	251.5
1985	224.4	260.9	279.4	295.0	305.3		41.0	252.3
1986		261.0	287.3	292.0	301.5		43.0	256.2
1987								
1988	238.0	262.0	278.0	299.0	310.0		122.0	236.0
1989		263.0	278.0	288.0	317.0	318.0	111.0	250.9
1990			283.0	291.0			15.0	252.2
1991			*Data Not Available*				89.0	231.9
1992	239.5	251.3	268.1	291.3	302.5		*Not Available*	226.6
1993								
1994								
1995								
1996								
1997								
1998								
1999								
2000		220.9	235.1	231.3			43.0	232.3
2001		231.0	246.5	254.1	253.3		101.0	241.2
2002	222.8	230.1	238.1	244.2			99.0	234.3
2003		231.7	241.2	248.1	245.0		75.0	239.5
2004	206.0	219.0	233.0	240.0			53.0	224.6
2005	211.0	215.0	232.0	233.0			42.0	224.9
2006	209.0	221.0	224.0	241.0	245.0		100.0	225.8
2007		220.0	227.0	234.0			110.0	225.8
2008		216.0	227.0	236.0	237.0		94.0	225.8
2009	201.0	208.0	227.0	235.0	226.0		67.0	228.9
2010	216.0	221.0	226.0	231.0			85.0	223.8
2011	202.0	222.4	232.1	237.8			171.0	230.1
2012		222.0	231.0	239.7	245.0		28.0	231.1
2013	219.0	223.7	230.2	239.0			29.0	229.4
2014		234.0	237.4	244.4			54.0	238.2
2015				*Data Not Available*				

Table 8.6 Number and percent at age for female river herring sampled at Gilbert Stuart.

	Number-at-Age								Percent-at-Age					
Year	2	3	4	5	6	7	Total	Mean Age	2	3	4	5	6	7
1984		12	70	40	15	1	138	4.4	0.0%	8.7%	50.7%	29.0%	10.9%	0.7%
1985		6	17	4	6	2	35	4.5	0.0%	17.1%	48.6%	11.4%	17.1%	5.7%
1986			13	35	18	7	73	5.3	0.0%	0.0%	17.8%	47.9%	24.7%	9.6%
1987														
1988	1	27	9	22	17	5	81	4.5	1.2%	33.3%	11.1%	27.2%	21.0%	6.2%
1989		6	60	39	7	2	114	4.5	0.0%	5.3%	52.6%	34.2%	6.1%	1.8%
1990			8	9			17	4.5	0.0%	0.0%	47.1%	52.9%	0.0%	0.0%
1991														
1992														
1993														
1994														
1995														
1996														
1997														
1998														
1999														
2000		5	34	17	2		58	4.3	0.0%	8.6%	58.6%	29.3%	3.4%	0.0%
2001		1	11	32	3		47	4.8	0.0%	2.1%	23.4%	68.1%	6.4%	0.0%
2002		11	13	14	4		42	4.3	0.0%	26.2%	31.0%	33.3%	9.5%	0.0%
2003		1	17	7	4		29	4.5	0.0%	3.4%	58.6%	24.1%	13.8%	0.0%
2004		11	37	17	1		66	4.1	0.0%	16.7%	56.1%	25.8%	1.5%	0.0%
2005		19	9	18	36		82	4.9	0.0%	23.2%	11.0%	22.0%	43.9%	0.0%
2006		9	7	10	6		32	4.4	0.0%	28.1%	21.9%	31.3%	18.8%	0.0%
2007			30	8	1		39	4.3	0.0%	0.0%	76.9%	20.5%	2.6%	0.0%
2008			16	23	3	1	43	4.7	0.0%	0.0%	37.2%	53.5%	7.0%	2.3%
2009			16	13	1		30	4.5	0.0%	0.0%	53.3%	43.3%	3.3%	0.0%
2010		1	10	12	1		24	4.5	0.0%	4.2%	41.7%	50.0%	4.2%	0.0%
2011	0	1	25	28	8	0	62	4.7	0.0%	1.6%	40.3%	45.2%	12.9%	0.0%
2012	0	0	9	7	1	0	17	4.5	0.0%	0.0%	52.9%	41.2%	5.9%	0.0%
2013	0	1	15	9	4	1	30	4.6	0.0%	3.3%	50.0%	30.0%	13.3%	3.3%
2014	0	0	14	10	2	0	26	4.5	0.0%	0.0%	53.8%	38.5%	7.7%	0.0%
2015														

Table 8.7 Number and percent at age for male river herring sampled at Gilbert Stuart.

	Number-at-Age								Percent-at-Age					
Year	2	3	4	5	6	7	Total	Mean Age	2	3	4	5	6	7
1984	3	17	41	14			75	3.1	4.0%	22.7%	54.7%	18.7%	0.0%	0.0%
1985		17	9	12	3		41	4.0	0.0%	41.5%	22.0%	58.5%	7.3%	0.0%
1986		2	6	24	11		43	5.0	0.0%	4.7%	14.0%	55.8%	25.6%	0.0%
1987														
1988	2	90	13	10	7		122	3.4	1.6%	73.8%	10.7%	8.2%	5.7%	0.0%
1989		16	70	22	1	2	111	3.3	0.0%	14.4%	63.1%	19.8%	0.9%	1.8%
1990			2	10	3		15	5.1	0.0%	0.0%	13.3%	66.7%	20.0%	0.0%
1991														
1992														
1993														
1994														
1995														
1996														
1997														
1998														
1999														
2000		7	30	6			43	4.0	0.0%	16.3%	69.8%	14.0%	0.0%	0.0%
2001	2	16	52	30	1		101	4.1	2.0%	15.8%	51.5%	29.7%	1.0%	0.0%
2002	4	49	33	13			99	3.6	4.0%	49.5%	33.3%	13.1%	0.0%	0.0%
2003		20	45	9	1		75	3.9	0.0%	26.7%	60.0%	12.0%	1.3%	0.0%
2004	7	20	22	4			53	3.4	13.2%	37.7%	41.5%	7.5%	0.0%	0.0%
2005	2	8	6	26			42	3.9	4.8%	19.0%	14.3%	61.9%	0.0%	0.0%
2006	3	28	52	16	1		100	3.8	3.0%	28.0%	52.0%	16.0%	1.0%	0.0%
2007		28	71	11			110	3.9	25.5%	64.5%	10.0%	10.0%	0.0%	0.0%
2008		26	44	23	1		94	4.0	0.0%	27.7%	46.8%	24.5%	1.1%	0.0%
2009	1	4	42	19	1		67	4.2	1.5%	6.0%	62.7%	28.4%	1.5%	0.0%
2010	5	30	42	8			85	3.6	5.9%	35.3%	49.4%	9.4%	0.0%	0.0%
2011	4	35	111	21	0	0	171	3.9	2.3%	20.5%	64.9%	12.3%	0.0%	0.0%
2012	0	8	12	7	1	0	28	4.0	0.0%	28.6%	42.9%	25.0%	3.6%	0.0%
2013	1	7	17	4	0	0	29	3.8	3.4%	24.1%	58.6%	13.8%	0.0%	0.0%
2014	0	3	43	8	0	0	54	4.1	0.0%	5.6%	79.6%	14.8%	0.0%	0.0%
2015														

Table 8.8 Summary of Gilbert Stuart river herring data between 1980 and 2015.

Year	Population Size	N Sampled	Sex Ratio (% Female)	Mean Age (Male)	Mean Age (Female)	Mean Length (Male)	Mean Length (Female)	Percent Repeat Spawner
1980	54,042		58.9	4.93	5.09	261.0	272.0	
1981	64,297		42.6	4.71	4.98	252.9	265.8	
1982	88,194		24.0	4.50	4.97	255.8	272.0	
1983	68,919		57.8	4.26	4.62	244.2	264.0	
1984	52,873	213	64.8	3.13	4.46	251.5	265.7	22.0
1985	56,224	76	46.0	4.02	4.45	252.3	266.5	28.9
1986	51,986	107	43.9	5.02	5.26	256.2	273.3	66.7
1987	50,893			4.16	5.29	275.8	304.4	66.7
1988	74,324	203	39.9	3.43	4.52	236.0	260.2	32.5
1989	89,577	226	50.9	3.33	4.46	250.9	256.3	28.3
1990	11,009	32	53.1	5.07	4.53	252.2	259.6	50.0
1991	21,540	131	32.1	3.37	3.97	231.9	250.0	23.3
1992	32,384			3.52	4.56	226.6	249.1	26.3
1999	259,336							
2000	290,814	101	57.4	3.98	4.28	232.3	242.2	18.8
2001	254,948	148	31.8	4.12	4.79	313.5	251.8	20.3
2002	152,056	141	29.8	3.56	4.26	234.3	255.9	17.0
2003	67,172	104	27.9	3.88	4.48	239.5	254.7	7.7
2004	16,960	119	55.5	3.43	4.12	224.6	231.6	8.4
2005	7,776	124	66.1	3.90	4.87	224.9	239.0	5.0
2006	21,600	132	24.2	3.84	4.41	225.8	243.0	15.9
2007	36,864	149	26.2	3.86	4.26	225.8	242.3	7.4
2008	58,640	137	31.4	3.99	4.74	225.8	240.4	19.9
2009	34,835	97	30.9	4.22	4.50	228.9	234.5	10.3
2010	110,287	109	22.0	3.62	4.54	223.8	231.9	7.3
2011	64,500	223	26.7	3.87	4.69	230.1	246.3	16.4
2012	107,901	45	37.8	4.04	4.53	231.1	246.8	15.6
2013	91,240	59	50.9	3.83	4.63	229.4	247.7	25.4
2014	102,408	80	32.5	4.09	4.54	238.2	247.9	15.0
2015	11,135							

Table 8.9 Mean fork length (mm) at age for female river herring sampled at Nonquit.

	Mean Fork Length-at-Age							
Year	**2**	**3**	**4**	**5**	**6**	**7**	**N**	**Annual Mean FL**
2000		227.2	237.8	244.2	244.8		66.0	239.0
2001		238.5	246.0	250.8	256.5		79.0	248.0
2002		237.7	246.8	249.0	260.5		71.0	248.0
2003		242.0	250.8	255.3	263.3		79.0	252.3
2004		228.0	245.9	256.4	260.7		54.0	234.6
2005		219.0	228.0	237.0	243.0		92.0	230.9
2006			221.0	234.0	237.0		46.0	231.2
2007		228.0	242.0	244.0	253.0		55.0	242.1
2008		227.0	235.0	241.0	244.0		64.0	238.9
2009		222.0	230.0	241.0	244.0	248.0	61.0	235.9
2010				*No Data Available: No Sampling Done*				
2011			237.5	247.0	252.8	252.5	31.0	243.7
2012		225.7	235.1	244.8	251.3	263.0	57.0	239.4
2013		235.0	247.7	252.8	263.0	260.0	25.0	251.9
2014			246.1	253.5	270.1		67.0	251.5
2015			244.5	259.0	263.3		44.0	257.1

Table 8.10 Mean fork length (mm) at age for male river herring sampled at Nonquit.

	Mean Fork Length-at-Age							
Year	**2**	**3**	**4**	**5**	**6**	**7**	**N**	**Annual Mean FL**
2000		226.6	233.1	241.7			77.0	231.0
2001	223.5	233.6	240.0	243.4	251.0		76.0	238.0
2002	223.8	233.8	237.8	241.8			74.0	235.0
2003		233.2	241.4	246.1			64.0	238.6
2004		234.7	240.6	244.5			74.0	224.7
2005	208.0	214.0	232.0	229.0			50.0	221.8
2006	210.0	220.0	222.0	236.0	242.0		97.0	221.8
2007		221.0	230.0	235.0	234.0		85.0	229.1
2008		215.0	223.0	228.0	236.0		85.0	223.5
2009		217.0	225.0	230.0	237.0	232.0	74.0	226.1
2010	*No Data Available: No Sampling Done*							
2011		226.0	232.5	241.0	237.0		44.0	234.7
2012		217.4	228.4	237.2	245.5		90.0	230.1
2013	209.0	230.8	233.9	239.9			49.0	233.4
2014		232.0	239.0	249.7			77.0	240.6
2015			242.1	245.8	247.0		43.0	244.0

Table 8.11 Number and percent at age for female river herring sampled at Nonquit.

	Number-at-Age								Percent-at-Age					
Year	2	3	4	5	6	7	Total	Mean Age	2	3	4	5	6	7
2000		9	39	13	5		66	4.21	0.0%	13.6%	59.1%	19.7%	7.6%	0.0%
2001		6	42	25	6		79	4.39	0.0%	7.6%	53.2%	31.6%	7.6%	0.0%
2002		7	33	25	6		71	4.42	0.0%	9.9%	46.5%	35.2%	8.5%	0.0%
2003		1	33	37	8		79	4.66	0.0%	1.3%	41.8%	46.8%	10.1%	0.0%
2004		2	33	16	3		54	4.37	0.0%	3.7%	61.1%	29.6%	5.6%	0.0%
2005		12	14	32	34		92	4.96	0.0%	13.0%	15.2%	34.8%	37.0%	0.0%
2006		12	25	9			46	3.93	0.0%	26.1%	54.3%	19.6%	0.0%	0.0%
2007		2	41	10	2		55	4.22	0.0%	3.6%	74.5%	18.2%	3.6%	0.0%
2008		2	18	32	12		64	4.84	0.0%	3.1%	28.1%	50.0%	18.8%	0.0%
2009		3	25	25	6	2	61	4.66	0.0%	4.9%	41.0%	41.0%	9.8%	3.3%
2010	*No Data Available: No Sampling Done*													
2011		0	15	9	5	2	31	4.81	0.0%	0.0%	48.4%	29.0%	16.1%	6.5%
2012		3	33	12	8	1	57	4.49	0.0%	5.3%	57.9%	21.1%	14.0%	1.8%
2013		2	7	11	4	1	25	4.80	0.0%	8.0%	28.0%	44.0%	16.0%	4.0%
2014		0	34	26	7	0	67	4.60	0.0%	0.0%	50.7%	38.8%	10.4%	0.0%
2015		0	8	29	7	0	44	4.98	0.0%	0.0%	18.2%	65.9%	15.9%	0.0%

Table 8.12 Number and percent at age for male river herring sampled at Nonquit.

	Number-at-Age								Percent-at-Age					
Year	2	3	4	5	6	7	Total	Mean Age	2	3	4	5	6	7
2000		31	39	7			77	3.69	0.0%	40.3%	50.6%	9.1%	0.0%	0.0%
2001	2	21	44	8	1		76	3.80	2.6%	27.6%	57.9%	10.5%	1.3%	0.0%
2002	6	32	31	5			74	3.47	8.1%	43.2%	41.9%	6.8%	0.0%	0.0%
2003		22	33	9			64	3.80	34.4%	51.6%	51.6%	14.1%	0.0%	0.0%
2004		27	41	6			74	3.72	36.5%	55.4%	55.4%	8.1%	0.0%	0.0%
2005	5	9	6	30			50	4.22	10.0%	18.0%	12.0%	60.0%	0.0%	0.0%
2006	2	50	37	7	1		97	3.54	2.1%	51.5%	38.1%	7.2%	1.0%	0.0%
2007		13	58	11	3		85	4.05	0.0%	15.3%	68.2%	12.9%	3.5%	0.0%
2008		13	50	17	5		85	4.16	0.0%	15.3%	58.8%	20.0%	5.9%	0.0%
2009		8	40	23	2	1	74	4.30	0.0%	10.8%	54.1%	31.1%	2.7%	1.4%
2010	*No Data Available: No Sampling Done*													
2011	0	5	23	15	1	0	44	4.27	0.0%	11.4%	52.3%	34.1%	2.3%	0.0%
2012	0	9	56	21	4	0	90	4.22	0.0%	10.0%	62.2%	23.3%	4.4%	0.0%
2013	2	8	31	8	0	0	49	3.92	4.1%	16.3%	63.3%	16.3%	0.0%	0.0%
2014	0	10	49	18	0	0	77	4.10	0.0%	13.0%	63.6%	23.4%	0.0%	0.0%
2015	0	0	22	19	2	0	43	4.53	0.0%	0.0%	51.2%	44.2%	4.7%	0.0%

Table 8.13 Summary of Nonquit river herring data sampled from 2000-2015.

Year	Population Size	N Sampled	Sex Ratio (% Female)	Mean Age (Male)	Mean Age (Female)	Mean Length (Male)	Mean Length (Female)	Percent Repeat Spawner
2000	185,524	143	46.2	3.69	4.21	231.0	239.0	14.0
2001	129,518	155	51.0	3.80	4.39	238.0	248.0	10.3
2002	97,444	145	49.0	3.47	4.42	235.0	248.0	9.0
2003	74,998	143	55.2	3.80	4.66	238.6	252.3	15.4
2004	25,417	128	42.2	3.72	4.37	224.7	234.6	4.7
2005	42,192	142	64.8	4.22	4.96	221.8	230.9	6.4
2006	74,902	143	32.2	3.54	3.93	221.8	231.2	2.1
2007	59,380	140	39.3	4.05	4.22	229.1	242.1	5.3
2008	224,506	149	43.0	4.16	4.84	223.5	238.9	18.8
2009	49,841	135	45.2	4.30	4.66	226.1	235.9	17.0
2010	38,516	*No Data*						
2011	30,126	75	40.8	4.27	4.81	234.7	243.7	17.1
2012	60,132	147	38.8	4.22	4.49	230.1	239.4	8.2
2013	52,563	74	33.8	3.92	4.80	233.4	251.9	24.3
2014	71,501	144	46.5	4.10	4.60	240.6	251.5	14.6
2015	32,330	87	57.1	4.53	4.98	244.0	257.1	33.8

Table 8.14. NMFS reported river herring commercial landings (1950-2010).

Year	Haul seines	Pound net	Fyke & Hoop nets	Trawl	Hand Lines	Fish Pots	Total (pounds)	Total (kg)
1950	157,000	155,100					312,100	141,542
1951	104,300	801,500					905,800	410,794
1952	163,000	17,300		600			180,900	82,041
1953	184,300	31,300		700			216,300	98,095
1954	13,400	3,200		400			17,000	7,710
1955	2,400	43,700					46,100	20,907
1956	54,500						54,500	24,717
1957	29,300						29,300	13,288
1958		11,400					11,400	5,170
1959	301,300		39,300				340,600	154,467
1960							0	0
1961							0	0
1962							0	0
1963	112,000	17,300					129,300	58,639
1964	140,000						140,000	63,492
1965	210,000						210,000	95,238
1966	189,000	3,500					192,500	87,302
1967	175,000	10,500					185,500	84,127
1968	168,000	22,000					190,000	86,168
1969	196,000	18,900					214,900	97,460
1970	102,200	23,800		17,600			143,600	65,125
1971	52,500			100			52,600	23,855
1972	34,000						34,000	15,420
1973	15,100						15,100	6,848
1974	34,000	2,000			100		36,100	16,372
1975	35,500	6,000					41,500	18,821
1976	31,200	2,800					34,000	15,420
1977	32,500	2,800					35,300	16,009
1978	24,000	2,200					26,200	11,882
1979	5,500	6,200					11,700	5,306
1980	5,000	2,400					7,400	3,356
1981							0	0
1982		4,800					4,800	2,177
1983		6,100					6,100	2,766
1984		900					900	408
1985		400					400	181
1986							0	0
1987		2,600					2,600	1,179
1988							0	0
1989							0	0
1990							0	0
1991							0	0
1992							0	0
1993							0	0
1994							0	0
1995				400		3	403	183
1996		750					750	340
1997							0	0
1998							0	0
1999							0	0
2000				574			574	260
2001							0	0
2002				12			12	5
2003	*Moratorium After 2002*							

Table 8.15 Spawning stock size estimates for river herring at Gilbert Stuart, Nonquit and Buckeye Brook.

Gilbert Stuart			Nonquit			Buckeye Brook	
Year	Alewives		Year	Alewives		Year	Alewives
1981	64,297						
1982	88,194						
1983	68,919						
1984	17,337						
1985	16,492						
1986	48,011						
1987	50,893						
1988	74,324						
1989	89,577						
1990	11,009						
1991	21,540						
1992	32,384						
1993	21,754						
1994	43,342						
1995	95,331						
1996	70,904						
1997	122,720						
1998	262,315						
1999	259,336		1999	230,853			
2000	290,814		2000	185,524			
2001	254,948		2001	129,518			
2002	152,056		2002	97,444			
2003	67,172		2003	74,998		2003	38,949
2004	15,376		2004	25,417		2004	5,010
2005	7,776		2005	42,192		2005	18,707
2006	21,744		2006	74,902		2006	9,428
2007	36,864		2007	59,380		2007	18,587
2008	58,640		2008	224,506		2008	34,629
2009	34,835		2009	49,841		2009	31,697
2010	110,287		2010	38,516		2010	8,299
2011	64,500		2011	30,126		2011	50,517
2012	107,901		2012	60,132		2012	90,625
2013	91,240		2013	52,563		2013	45,244
2014	102,408		2014	71,501		2014	47,263
2015	11,135		2015	32,330		2015	15,333

Table 8.16 Trawl survey length frequency data collected for river herring (1996-2015).

Length	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2			1												1					
3	11		9	11		1								1						
4	114	3	7	19	14	19		49	46	7	1		36	119	20					
5	243	7	24	36	29	51		197		2	66		33	48	57	20	1		2	
6	122	6	3	65	97	7	4	59			4		1	1	5	30	27	20	146	
7	12	7		54	20	1	1	10			1			2	9	237	449	3	120	1
8	6	8		16	3	1								3	13	745	1059	2	39	2
9	2	6		1	4										5	709	646	20	183	6
10	1	1		1									1		2	411	507	21	208	105
11				2		1										986	782	3	354	1169
12			1													1481	898	42	451	1433
13																1823	2242	88	373	988
14																1188	3698	99	392	220
15		1														550	902	51	122	26
16																262	219	20	4	1
17																126	108	2	2	2
18																22	73	7	1	11
19																23	41	1	1	1
20																22	54			
21		6														11	22		1	1
22		17														16	24		1	1
23	1	29														19	60			
24	3	27														10	33		1	
25	4	8														9	10		1	
26		5														4	3			

Table 8.17 Gilbert Stuart and Nonquit juvenile river herring mean catch rates.

Gilbert Stuart	Catch/Hr	SE
1988	112.07	46.81
1989	79.13	40.26
1990	152.25	71.34
1991	163.3	59.5
1992	343.3	125.3
2007	94.9	86.5
2008	97.25	75.54
2009	6.6	4.47
2010	10.89	6.79
2011	12.11	8.84
2012	16.53	9.78
2013	1.53	1.45
2014	189.81	90.28
2015	223.96	137.38

Nonquit	Catch/Hr	SE
2001	161.25	83.4
2002	66.57	7.9
2003	415.04	242.58
2004	2,110.33	1,906.33
2005	887.91	451.73
2006	62.39	40.8
2007	110.15	71.49
2008	2,219.58	1,954.64
2009	40.67	9.59
2010	31.87	25.57
2011	578.32	485.64
2012	400.65	410.36
2013	32.35	33.35
2014	40,293.90	39,979.90
2015	265	234.93

Table 8.18 Pawcatuck River JAI results for river herring (1993-2010).

Year	Number of Hauls	Number of Fish	Geometric Mean YOY	LL 95%CL	UL 95%CL	Zero Hauls	Arithmetic Mean	SE
1993	35	520	0.37	-0.05	0.97	28	7.09	1.23
1994	25	43	0.31	-0.07	0.85	22	1.72	1.34
1995	30	240	0.9	0.14	2.17	23	8	4.21
1996	30	145	0.31	-0.08	0.87	26	4.83	4.6
1997	40	5	0.08	-0.02	0.18	35	0.13	0.09
1998	55	1122	1.51	0.63	2.87	36	20.4	12.57
1999	45	10	0.18	0.05	0.32	38	0.43	0.09
2000	65	527	2.03	1.2	3.17	27	8.11	1.01
2001	65	35	0.21	0.06	0.39	56	0.54	0.23
2002	50	500	2.34	1.3	3.86	19	19.61	10.47
2003	54	226	0.67	0.24	1.24	41	4.19	2.13
2004	60	533	1.43	0.68	2.5	37	8.88	4.09
2005	57	27	0.08	-0.04	0.22	54	0.47	0.44
2006	67	184	0.27	0.03	0.55	60	2.75	2.02
2007	70	186	0.3	0.05	0.61	62	2.66	1.44
2008	60	10	0.08	-0.01	0.17	56	0.17	0.11
2009	60	0	0	0	0	60	0	0
2010	55	17	0.15	0.03	0.28	48	0.309	0.15
2011	60	12	0.067	-0.026	0.169	58	0.2	0.13
2012	70	11	0.05	-0.026	0.122	68	0.16	0.14
2013	70	81	0.13	-0.13	0.31	66	1.16	0.14
2014	65	141	0.29	0.054	0.58	56	2.17	1.29
2015	60	205	0.74	0.31	1.31	45	3.42	1.12

Figure 8.1 Gilbert Stuart Fishway, North Kingstown, Rhode Island

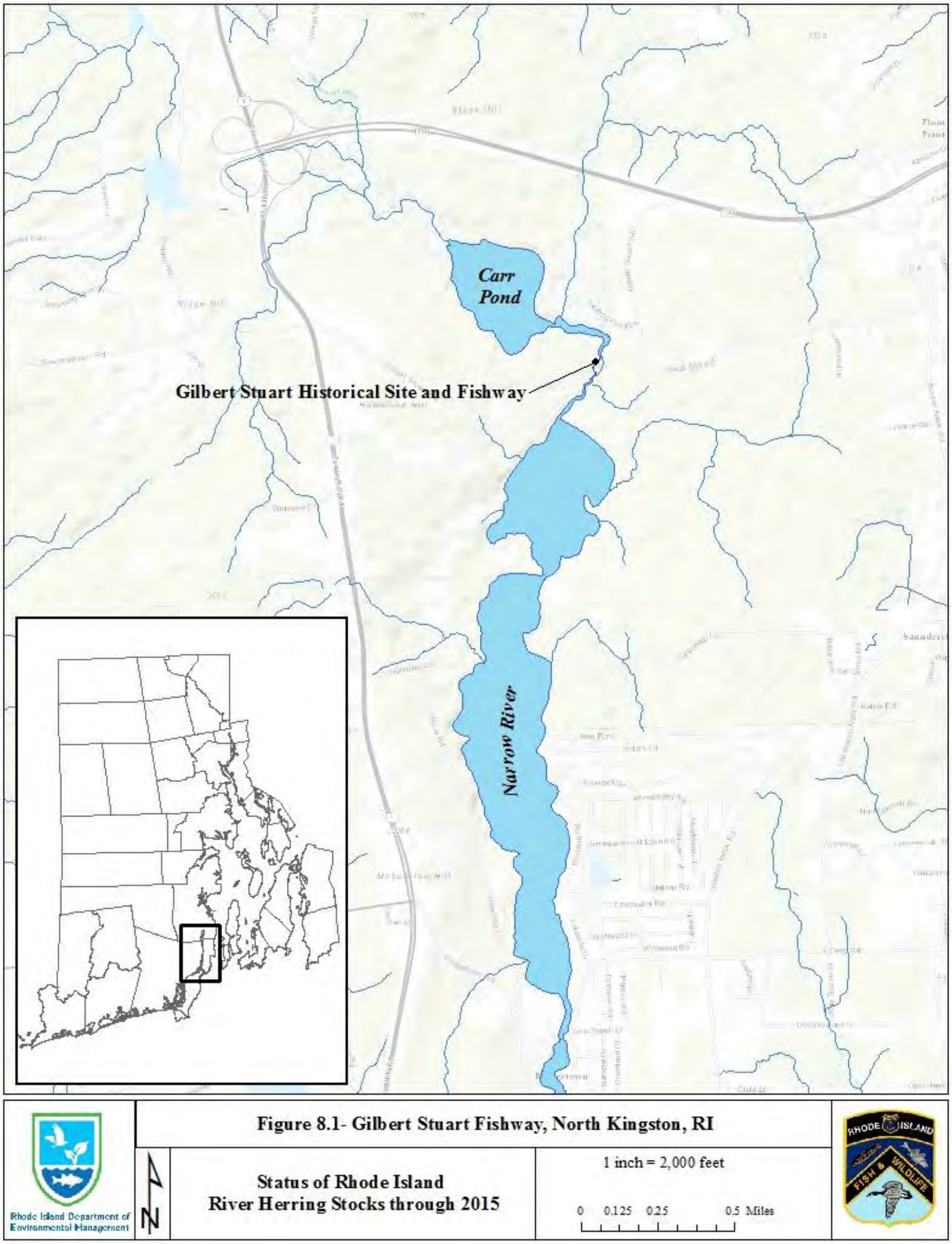
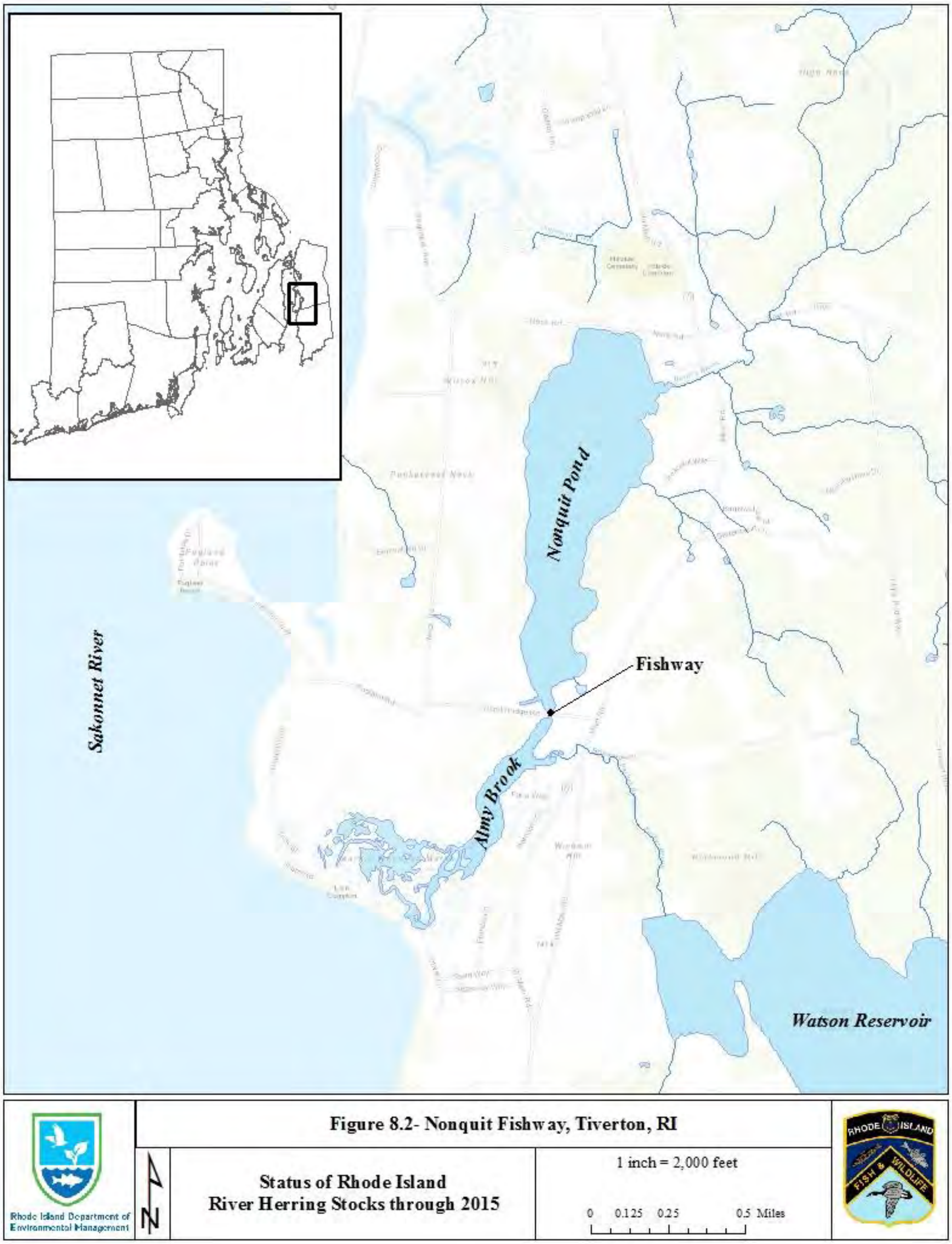


Figure 8.2 Nonquit Fishway, Tiverton, Rhode Island



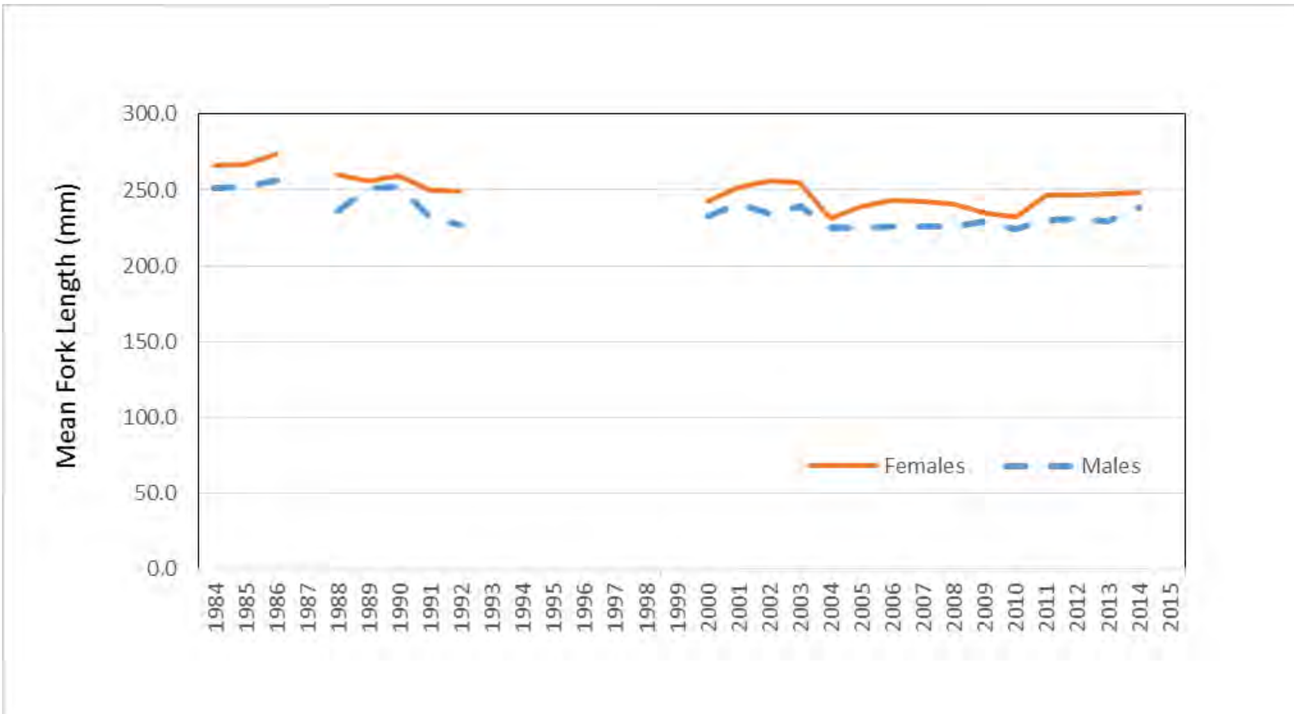


Figure 8.3 Annual mean fork length (mm) for river herring sampled at Gilbert Stuart.

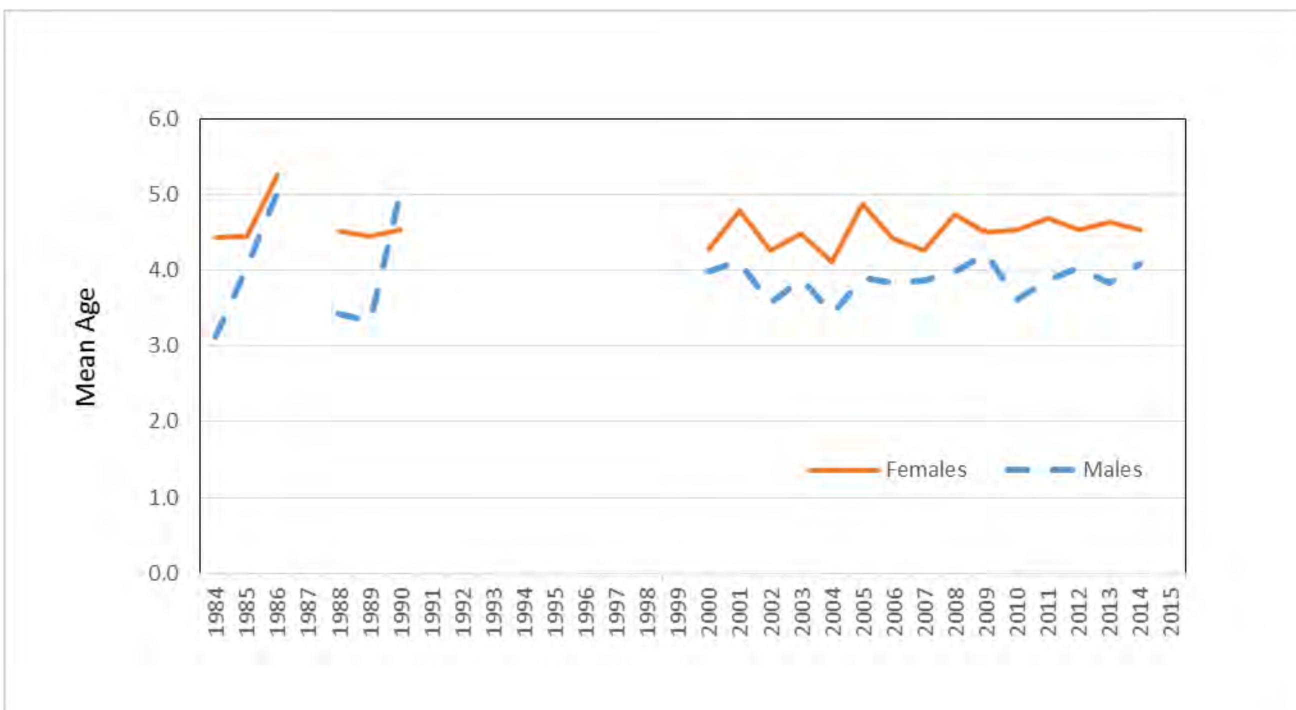


Figure 8.4 Annual mean age for river herring sampled at Gilbert Stuart.

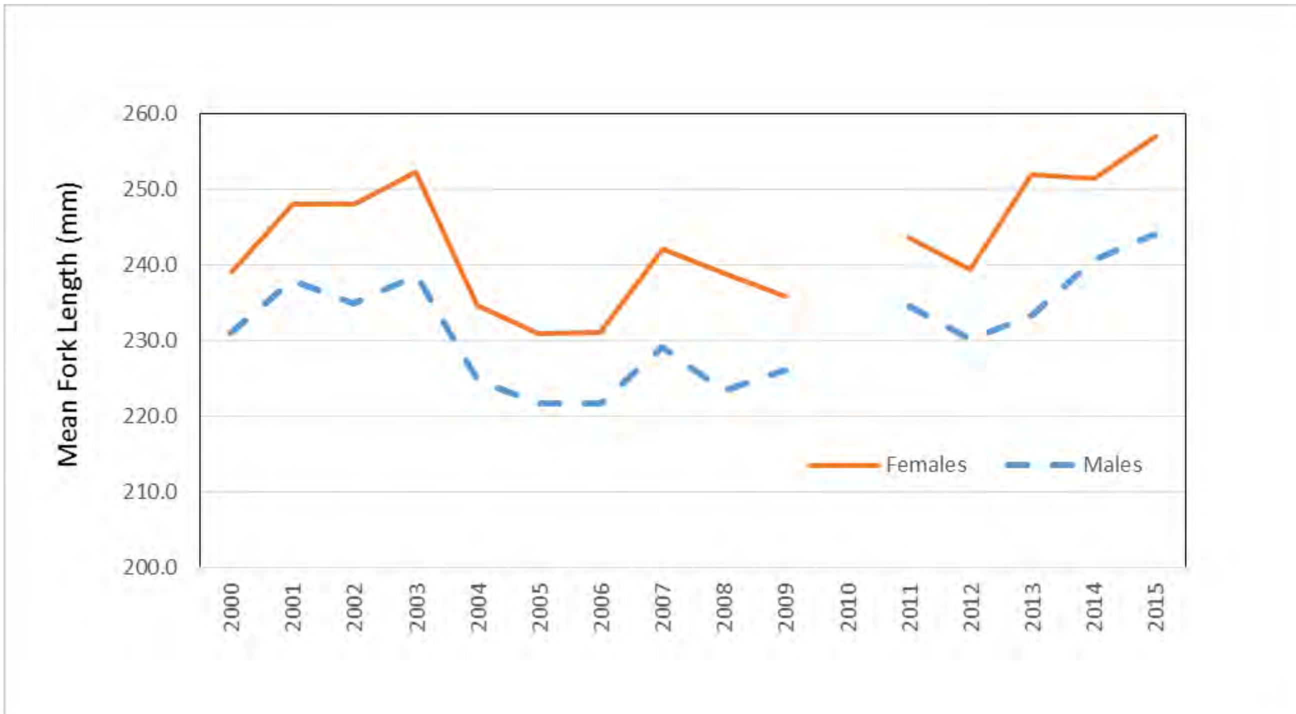


Figure 8.5 Annual mean fork length (mm) for river herring sampled at Nonquit.

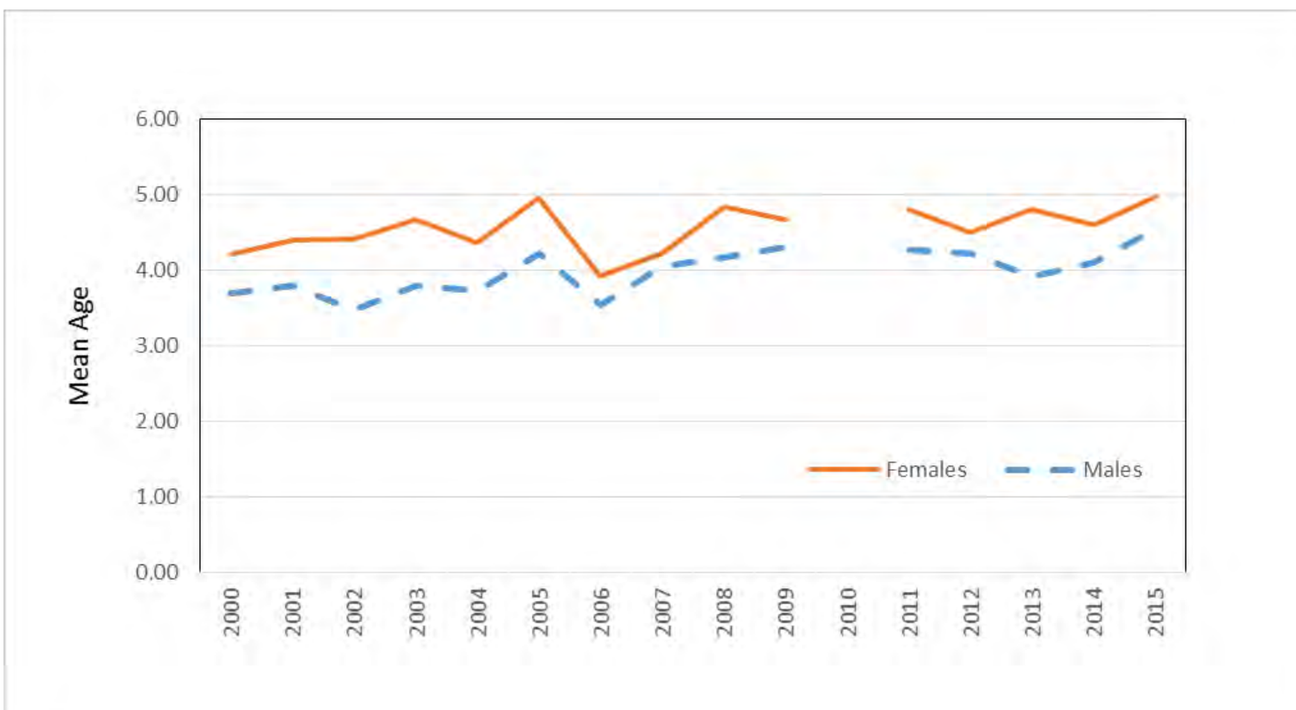


Figure 8.6 Annual mean age for river herring sampled at Nonquit.

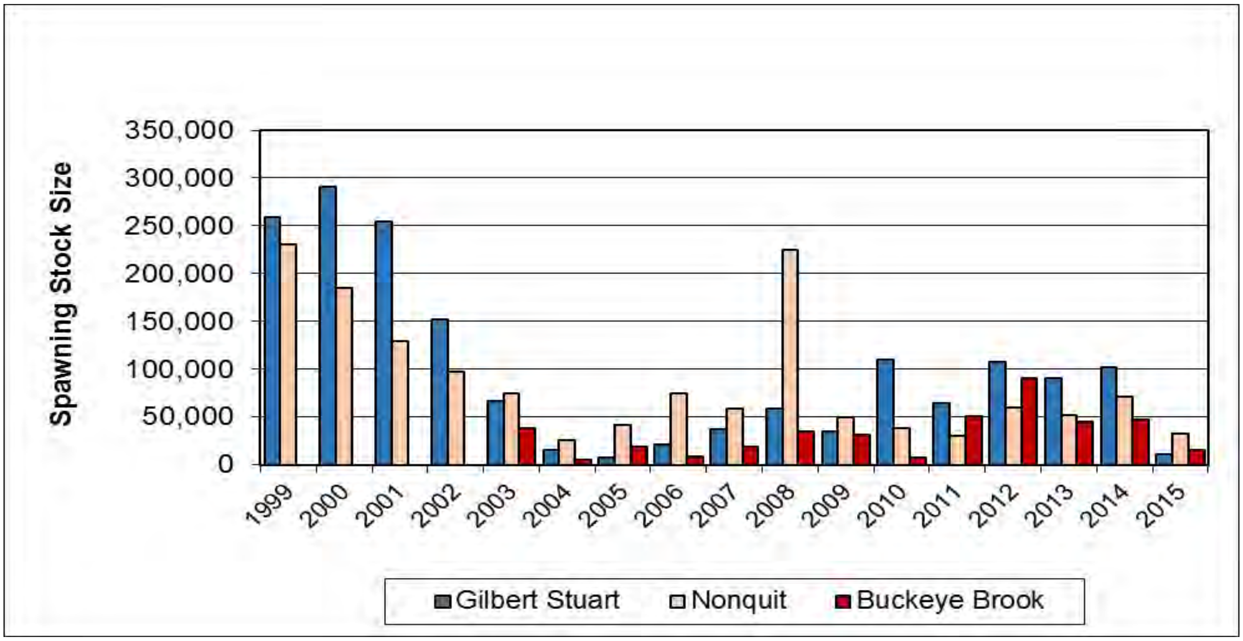


Figure 8.7 Spawning stock size estimates for Gilbert Stuart, Nonquit and Buckeye Brook.

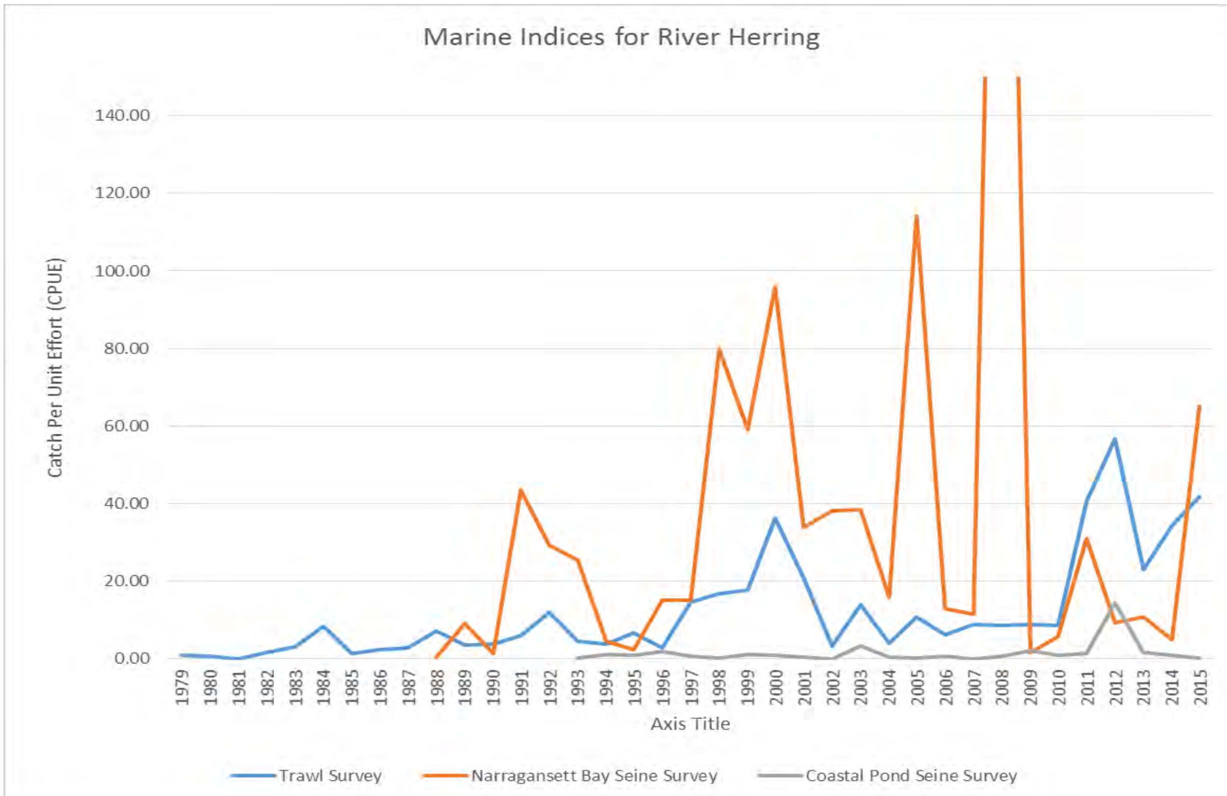


Figure 8.8 Marine Survey Indices-Annual mean river herring catch per tow or seine haul (arithmetic mean)

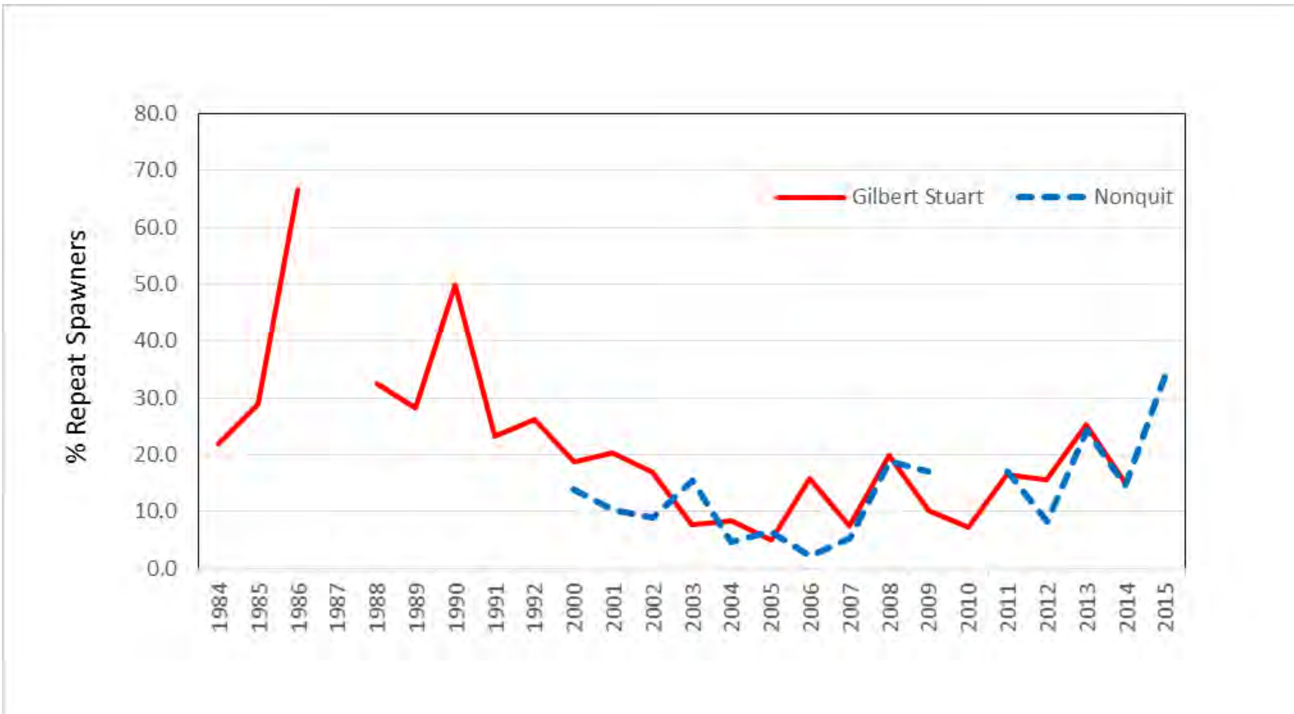


Figure 8.9 Percent repeat spawning for river herring sampled at Gilbert Stuart and Nonquit.

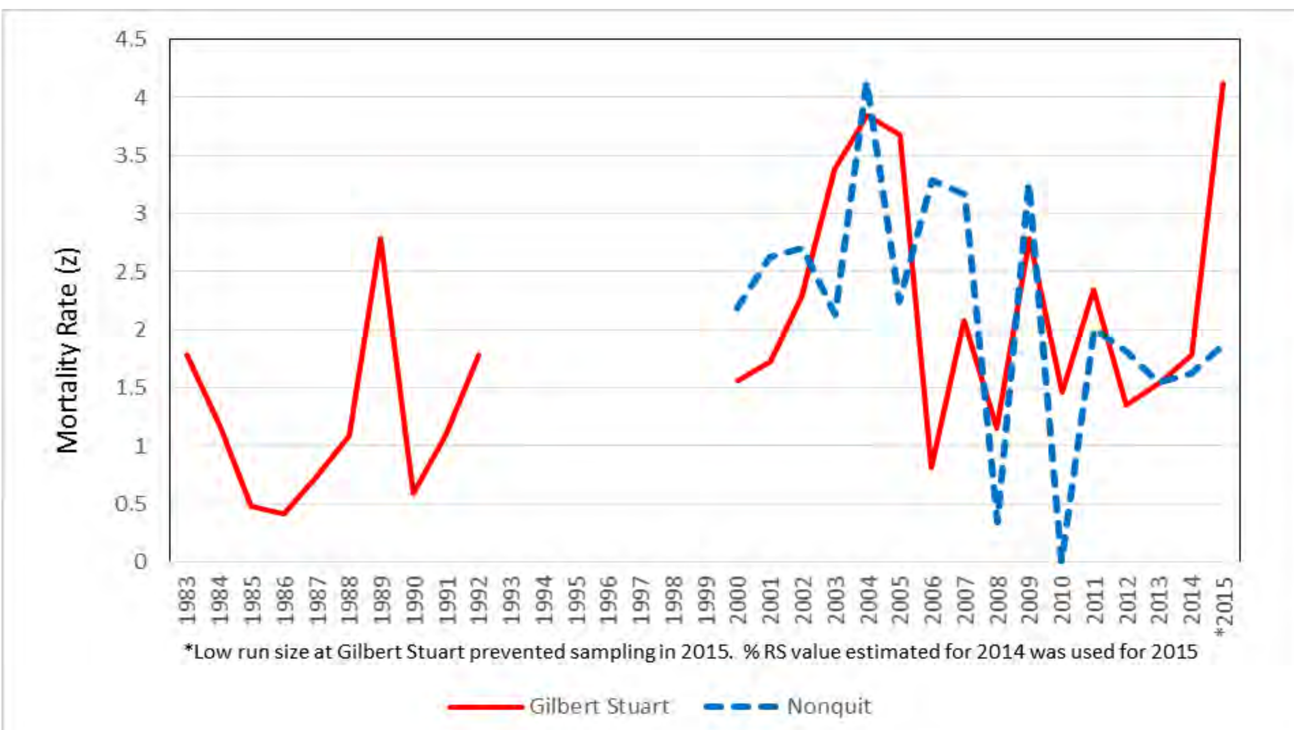


Figure 8.10 Total Mortality Rate (Z) for river herring sampled at Gilbert Stuart and Nonquit.

9 Status of River Herring in Connecticut

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Executive Summary

A statewide moratorium on the take of anadromous river herring (blueback herring, *Alosa aestivalis,* and alewife, *Alosa pseudoharengus*) in Connecticut waters, has been in effect since 2002. Commercial river herring fisheries historically occurred primarily in the Connecticut River, but effort quickly declined after the 1960s. Recreational fisheries, thought mostly to be for bait use, have never been quantified. Adult blueback herring lift counts at the Connecticut River Holyoke Dam reached peak levels in 1985, experienced drastic declines in the 1990s, and have remained at low levels to date. Investigations of the decline during the 1990s, demonstrated statistically and empirically that striped bass population increases, and attendant increases in predation, were a likely contributing factor to the decline of Connecticut River blueback herring (Davis et al. 2012; Davis 2016; Savoy and Crecco 2004).

Connecticut River alosine juvenile production has been monitored by the Connecticut Department of Energy and Environmental Protection (CT DEEP) since 1978. Despite the fact that there have been less than 2,000 adult blueback herring passed annually at Holyoke Dam fish lift since 1993, there have still been some moderate to strong blueback juvenile index (JI) values that have ranked in the top 20 of the index time series. This includes an unexpectedly strong 2010 blueback JI geometric mean value of 12.8, when less than 100 adults were passed at the Holyoke lift. Juvenile indices comparable to the 2010 index value were also produced in 1981, 1984 and 1992 when counts at the fish lift ranged from 300,000 to 480,000. This suggests that the blueback production within the lower river has been able to sustain the stock, albeit, at lower population levels. Despite the statewide landings closure, adult blueback stock size in the upper river has shown no sign of recovery.

Adult alewife abundance has not been monitored in the main stem of the Connecticut River. Passage counts of adult river herring are collected within several Connecticut tributaries by the CT DEEP Diadromous Fisheries Project. Alewife counts at Bride Lake in East Lyme Connecticut have fluctuated since 2003 and produced the highest counts of adult alewives in 2012 and 2013. Alewife and blueback herring relative abundance of mixed stocks age 1+ are documented by the Long Island Sound Trawl Survey (LISTS) and have had variable trends. Additional fishery independent monitoring occurs within other rivers and streams throughout the state, however, there is not yet sufficient data to conduct a formal assessment on any of these systems. Fish restoration and habitat improvement projects are ongoing in an effort to provide river herring access to historical spawning habitats.

9.1. INTRODUCTION

Historically, Connecticut had both commercial and recreational river herring fisheries that were collectively reported as alewives. While there are no reliable historical population estimates, annual anecdotal observations of the fishery were typically reported in the local newspapers. These anecdotes described the widely fluctuating trends of commercial catches in any given year, as ranging from "scarce" to "plentiful" (Hartford Courant 1906; Hartford Courant 1915).

While Connecticut has numerous river herring runs throughout the state, there is little continuous, long-term data on stocks. The annual Connecticut River adult blueback herring counts at the Holyoke Fish lift have been widely circulated, but were only representative of adult blueback herring that migrate beyond the Holyoke Dam at river kilometer 139. CT DEEP has monitored Connecticut River juvenile American shad and blueback herring abundance since 1978. There also are some more recent monitoring efforts which focus on obtaining adult counts at several fishways throughout the state (Gephard et al 2016). The US Fish and Wildlife Service Connecticut River Fish and Wildlife Conservation office (CRFWCO) initiated an electrofishing survey in 2013 for Connecticut River adult alewife and blueback herring (Sprankle 2016). The CRFWCO has also initiated discussions on coordinating juvenile studies in the Massachusetts portion of the river.

9.2. MANAGEMENT UNIT DEFINITION

The Connecticut Department of Energy and Environmental Protection manages river herring populations located within Connecticut state waters. The demarcation line between the marine and inland districts typically occurs at the first bridge upstream from the river mouth or cove unless otherwise specified. The moratorium for river herring is in effect for all state waters. Long Island Sound is jointly managed by Connecticut and New York.

9.3. REGULATORY HISTORY

9.3.1 Commercial Fishery

From 2002 to present there has been a statewide moratorium on commercial and recreational take of anadromous blueback herring and alewife. Under emergency declaration authority of section 26-102 of the Connecticut General Statutes, the commercial or recreation taking of migratory alewives and blueback herring is prohibited from all marine waters and most inland waters. This prohibition is determined on an annual basis.

Historically, Connecticut's river herring commercial fisheries were not heavily regulated. Regulations placed on the commercial river herring fishery, such as restrictions in coves and tributaries, were typically put into place to protect other species. Most of the focus of alosine regulations were for the American shad fishery, which at one time was one of the most important commercial species in the state (Blake and Smith 1984).

Connecticut has three major rivers (Connecticut, Housatonic and Thames) and several smaller rivers and coastal streams (**Error! Reference source not found.**). While river herring fisheries likely occurred in all f these systems, the bulk of Connecticut's river herring fisheries occurred in the Connecticut River (Blake and Smith 1984). Regulatory jurisdictions of the fisheries were divided into marine and freshwater districts.

During the early 19th century, Connecticut regulations applied penalties for preventing fish migration. Laws were enacted prohibiting constructing dams unless there was a proper opening for fish to pass from April through June. Any obstructions created to catch fish near a dam in the river during spring migration would result in a fine. Rest days prohibited seining and scoop netting in the Shetucket River below the junction with the Quinebaug (Thames River Watershed) during designated nights in the spring. Seining was prohibited at the mouth of Housatonic River during the spring (Goodrick *et al.* 1821). No weirs or other obstructions, were allowed across Bride Brook outlet in East Lyme, between sunset on Saturday and sunrise on the following Friday from late March early May (Connecticut General Assembly, 1900). In the mid-20th century, Connecticut state statutes identified specific coves within the Connecticut River prohibiting the use of seines and fyke nets during spring anadromous spawning runs.
Haul seine was the primary gear for commercial river herring fisheries in the Connecticut River. Use of haul seines eventually phased out in the 1980s (Table 9.1). Since the 1990s, there were landings reported using gill nets and trawls.

9.3.2 Recreational Fishery
Prior to the statewide fishery moratorium in 2002, the recreational limit for both inland and marine waters was 25 blueback herring or alewife, in aggregate, per person per day, for personal use purposes. Land locked alewives from specific lakes were allowed to be taken recreationally by angling and scoop net. There is no historical data on catch and effort in the river herring recreational fishery. Catches were most likely used for bait purposes, but no attempt has been made to determine the magnitude of these fisheries in Connecticut.

9.4. ASSESSMENT HISTORY

The first coastwide river herring stock assessment was conducted in 1990 (ASMFC) by Crecco and Gibson. Connecticut River blueback herring was one of the 15 stocks on the coast analyzed using long-term commercial catch & effort, fishing mortality, and relative population abundance data to estimate maximum sustainable yield (MSY), annual fishing rates at MSY (u_{msy}) and annual fishing rates at stock collapse (u_{coll}) to determine whether trends were consistent with overfishing. Based on the analyses, five of the 15 river herring stocks (St. John blueback and alewife, Damariscotta, Potomac and Chowan River alewife) had been overfished. The shape of the stock recruitment curve (r^2=0.59) for Connecticut River blueback herring showed that recruitment levels rose to a maximum at low to intermediate spawning stock sizes and then declined slightly thereafter at higher spawning stock levels. Fishing rates ($u<0.3$) were very low for the Connecticut River because at that point, in-river directed fisheries no longer existed. The conclusion of the 1990 assessment was that the blueback herring stock in the Connecticut River was partially exploited and not overfished.

When the second stock assessment was completed in 2012 (ASMFC), Connecticut's river herring commercial and recreational fisheries had been closed for a decade and the adult blueback herring counts at the Holyoke Dam were no longer a meaningful index of abundance. State alewife stocks have never been included in a formal stock assessment, but there were some fishway counts initiated after the state harvest closure that were provided for the assessment to be included for coastwide trend analysis. Statistical and empirical evidence linked the blueback herring stock collapse in the Connecticut River to striped bass predation. The rise in abundance due to the successful rebuilding of the striped bass population was coincident with the decline of blueback herring in the river (Savoy and Crecco 2004).

9.5. STOCK SPECIFIC LIFE HISTORY

9.5.1. Growth

Marcy's age study (1969) of blueback herring and alewife reported mean lengths-at-age ranging from 283.7mm-324.8mm for female alewives ages 4-8 and from 264.6mm-300.7mm for male alewives ages 4-7. Blueback herring mean lengths ranged from 261.3mm-310.9mm for females ages 4-7, and 258.0mm to 298.1mm for males ages 4 to 7.

A more recent study of blueback herring in the Connecticut River (Davis 2016) suggests that mean length-at-age may have decreased since the 1960s: for instance, mean length of age-4 blueback herring (sex-aggregated) during 2005-07 ranged from 245-253 mm vs. 267 mm for male and 277 mm for female blueback herring during the 1960s (Davis 2016; Marcy 1969). A more recent study of alewife at Bride Brook (the same run studied by Marcy) did not provide indications of similar decadal shifts in growth for this population (Davis et al. 2009).

9.5.2. Reproduction

Blueback herring have an extended spawning season in Connecticut waters. Loesch (1968), detected blueback herring in Connecticut in mid-April when water temperatures were around 8 degrees C. The highest abundance near spawning areas occurred during the latter half of June and early July. Smaller spawning groups historically have been observed from mid-May to mid-July (Loesch and Lund 1977). Blueback herring choose spawning sites with swift flow and hard substrate and avoided shallow areas. While parts of the spawning season for the alewife and blueback herring overlap, the two species were observed spatially isolated by selecting different spawning sites. Alewife spawning migrations in Connecticut start as early as the beginning of March and continue in some rivers until mid-June. In an examination of alewife spawning behavior in Bride Lake from 1966-1969, alewives immigrated in March when water temperatures were 4 or 5 deg C and alewives stopped entering Bride Lake in early June when water temperatures were 19-20 degrees. Alewives were observed on the spawning grounds for 3-82 days (Kissil 1974).

9.5.3. Maturity

Marcy (1969) examined Alewife scales from the Connecticut River and Bride Brook, and blueback herring scales from the Connecticut and Thames Rivers. Alewives reached a maximum age of 8, while bluebacks reached a maximum age of 7. The majority of alewives in the spawning run were ages 5 and 6. Majority of male alewives initially spawned at age 4 (68%) and the rest at age 5. Majority of female alewives (68%)

initially spawned at age 5. Forty seven percent of male bluebacks spawned first for the first time at age 3 and 50% at age 4. Seventy five percent of female bluebacks initially spawned at age 4 and 16% at age 5.

More recent studies of Connecticut river herring populations suggest shifts towards earlier age-at-maturity. A study of the Bride Brook alewife run in the early-mid 2000s revealed that the majority of spawners were age 3, with fish as young as age 2 participating in the run; Marcy (1969) reported no fish younger than age 4 in this run during the 1960s (Davis et al. 2009). A similar study of the Connecticut River blueback herring run in the mid-2000s documented runs dominated by age-3 and age-4 fish in most study years (with fish as young as age-2 collected), whereas Marcy (1969) reported that approximately 85% of blueback herring collected from the Connecticut and Thames River in the 1960s were age-5 or older and fish younger than age-4 were rare (Davis 2016).

9.5.4. Fecundity

Previous studies of the variation in estimated egg counts for individual Connecticut River blueback herring ranged from 45,800 (238-mm fish) to 349,700 (310-mm fish). (Loesch and Lund 1977). A more recent study of river herring reproductive dynamics (Ganias et al. 2015), using alewives collected from the Bride Lake run, demonstrated that anadromous alewives are batch spawners with indeterminate fecundity – meaning that they can develop and spawn batches of oocytes during the spawning season, and therefore previous estimates of oocyte production that assumed determinate fecundity (e.g. Loesch and Lund) are likely underestimates of annual capacity for oocyte production. Therefore, accurate assessments of annual oocyte production by river herring will require additional information on within-season reproductive dynamics (e.g. frequency of batch production and duration on the spawning grounds) and cannot rely only on enumeration of oocytes in pre-spawn fish (Ganias et al. 2015).

9.6. HABITAT DESCRIPTION

The Connecticut River is the largest river in New England and flows 410 miles from the Canadian border to Long Island Sound. Historically, river herring could be found in all three of Connecticut's major watersheds (the Connecticut, Housatonic, and Thames Rivers) (Figure 9.1) as well as most of the coastal rivers and streams across the State. Blueback herring are more abundant in the larger rivers of the state and have been known to ascend the Connecticut River nearly 200 miles (Gephard and McMenemy 2004). Blueback herring also enter the smaller coastal streams in the state, but less often than alewives and typically are thought to be more common in the western end of the state.

In the 1700s, Connecticut River American shad and herring were so abundant that anyone who consumed shad was looked down upon. The river falls were great places for fishing. Shad and herring were barreled, salted and exported. According to Judd (1905), during this era before dam construction it was not necessary to regulate fisheries. The first dam at South Hadley around 1795 and the dam at Turners Falls heavily impacted anadromous fish. Accounts of fisheries at the falls were described as the best fishing in springtime and shad were caught in seines and with scoop nets below the falls. Boats fished near the falls and collected shad by scoop net and could collect several thousand fish in a day. Shad were so abundant that is was said that oars would strike the fish while paddling across the river.

Connecticut's river herring runs during the late 18th and early 19th century were greatly affected by settlement and industrialization which ultimately led to impacts from deforestation, dam construction and water pollution. More recently, river herring populations have benefitted from water quality improvement, declines in commercial fishing effort, as well as ongoing restoration of access to spawning habitat through fish passage projects. Barrier dams are identified as one of the greatest threats to river herring populations in the freshwater environment. There are over 500 dams within the historic range of river herring in Connecticut.

9.6.1. Habitat Water Quality

The Connecticut River, once famously referred to as "New England's most beautifully landscaped sewer," has a long history of poor water quality due to heavy industrial expansion of textiles, heavy metal processing, logging and sewage. Natural disasters such as hurricanes, droughts and flooding events have also had large impacts on the water quality of the river. Connecticut has been progressive in the development of water quality management following some the dismal times of heavily polluted waters. Connecticut's Clean Water Act (1967) was developed 5 years ahead of the Federal Clean Water Act of 1972.

From the 19th century up until the development of Connecticut's Clean Water Act, untreated or minimally treated waste discharge caused water quality issues in the Connecticut River. Concentrations of dissolved oxygen in the Connecticut River below the Holyoke Dam were measured close to zero during the mid 1960s and early 1970s.

Legislative interest in water pollution dates back as far as 1887 when the Connecticut General Assembly authorized the formation of a sewer study commission to investigate sewage disposal. The commission report in 1889 recommended the State find ways to stop further pollution. A Legislative study commission was created in 1913 to investigate factory wastes and, again, in 1921 to investigate solutions to eliminate pollution. In 1925 laws were enacted to create a State Water Commission, but the commission had few resources and a lack of direct regulatory authority. The State and Federal Clean Water Acts resulted in several downward trends in pollutants and increasing trends in dissolved oxygen. Downward trends in sulfate concentrations likely are attributable to reductions in sulfur dioxide emissions mandated by the Clean Air Act of 1970. Water quality challenges for the Connecticut River still remain and include: reducing nitrogen loads from point and nonpoint sources, reducing bacteria and other contaminant concentrations in storm water runoff, and separating storm water and sanitary sewers at some locations to prevent combined sewer overflows (Mullaney, J.R. 2004). Microplastics are a recent pollution issue, and while they are known to be a threat to the marine and aquatic life that consume them, their impact on fish health is largely unknown. Both the federal government and the state of Connecticut have passed legislation to phase out the use of plastic microbeads from cosmetic products.

9.6.2. Habitat Alterations

Connecticut River

One of the most significant impacts to anadromous fish habitat in Connecticut, was the construction of dams. The Connecticut River was the first river in the country to be improved by canals, with the construction of locks at South Hadley Falls in 1795, which enabled traffic on the Connecticut River to move past the 40 foot falls at South Hadley. Shad and salmon stocks began to show signs of depletion after the construction of Turners Falls Dam in 1798. A timber dam constructed at South Hadley falls was completed in 1849, although a smaller version of a dam was built during construction of the canals and was maintained and enlarged 3 to 4 times with a wing dam in place until the construction of the timber dam (Kirtland, 1897). The dams caused immediate declines to anadromous fish populations.

The first type of fish passage at Holyoke was attempted in 1873 and was unsuccessful at passing shad. In 1900 the present form of the dam was constructed and in 1940 a second attempt was made to construct a fishway, which was also unsuccessful. In 1949 the Holyoke Water Power Company was granted a license to construct a new power plant. A stipulation was for the power company to build fish passage. The finished product was completed in 1952, but was ineffective and replaced by a fish elevator in 1955 (Henry 1976). Daily counts of American shad lifted have been made annually from 1955 to 2015 (Watson 1970; Moffit *et al.* 1982; Leggett *et al.* 2004). Major technological improvements in the Holyoke lift have been made in 1969, 1975 and 1976 (Henry 1976) which resulted in increased annual passage rates (mean number/lift day) of American shad. After 1976 no further improvements in the fish lift were made until 2005. Improvements in 2005 include new tailrace lift tower, bucket and hoist, new spillway lift tower, bucket and hoist, redesigned spillway entrance gallery and crowder, a wider exit flume, a new shad trap and truck facility, a new counting room and second counting window (Slater 2016). As part of a settlement agreement, Holyoke Gas and Electric was required to incorporate downstream fish passage measures. The new downstream facility was constructed in 2015 and opened for operation as of April 2016 (Sprankle 2016).

The Enfield Dam (RKM 110), was constructed around 1829 to avoid the rapids and to divert water to the Windsor Locks Canal. The dam was a wooden crib structure nearly 1,500 feet in length. The low-head dam was often submerged during high flows in the spring and became an obstruction to fish migration only during low flows. The dam fell into disrepair in the late 1970s and is now breached and no longer an impediment to anadromous fish migration (Leggett *et al.* 2004).

Thames River

The Greeneville Dam was built on the Thames River in 1829 to provide grist and paper mills with water (US Census Office 1880). Norwich Public utilities completed construction of a fish lift elevator in 1996 to pass fish above the dam. Daily anadromous fish counts at the fish lift (Table 9.1) are reported to CT DEEP by Norwich Public Utilities.

Housatonic River
The Derby dam, the first dam of the Housatonic River was completed in 1868 (Leffel 1874). The Stevenson Dam, bordering Monroe and Oxford, is the largest of the five Connecticut Light & Power hydroelectric dams on the Housatonic River (HVA 1999).

Bride Lake
Historically, Bride Brook supported one of the largest alewife runs amongst Connecticut coastal streams. However, registered ground water diversions from nearby public water supply wells contribute to dry stream conditions in the brook just downstream of Bride Lake, significantly decreasing the viability of this alewife breeding ground. (Gephard *et al.* 2000). Replacement of an entrance culvert coincides with increases in adult alewife entering the lake over recent years (**Error! Reference source not found.**).

9.6.3. Habitat Loss

Connecticut's river herring runs during the late 18th and early 19th century were greatly impacted by settlement and industrialization which resulted in deforestation, dam construction and water pollution. Since then, river herring populations have benefitted from water quality improvement, declines in commercial fishing effort, as well as ongoing restoration of access to spawning habitat through fish passage projects. The CT DEEP Diadromous program's restoration efforts have focused on increasing fish passage and transplanting river herring. Barrier dams are identified as one of the greatest threats to river herring populations in the freshwater environment. There are over 500 dams within the historic range of river herring in Connecticut. Access to habitat previously blocked has been restored through construction of fishways and dam removal, providing more spawning habitat to increase production. Since 1990, 11 dams have been removed and 53 fishways have been constructed throughout the state with more projects being completed each year.

9.7. RESTORATION

9.7.1. Objective/Target

The CT DEEP Diadromous program, is responsible for the enhancement and restoration of diadromous fish in Connecticut. Efforts have focused on increasing access to fish habitat through increasing fish passage, removing dams, and transplanting river herring from donor streams to streams that historically had river herring. Pre-spawned adults are also transplanted from healthy runs to streams where the run requires rebuilding. In 2016, DEEP staff operated and maintained nine State-owned fishways and assisted partners with the operation and maintenance of another 52 fishways in the state (Gephard *et. al* 2016).

The Connecticut River watershed spans across 4 states which includes Connecticut, Massachusetts, New Hampshire and Vermont. The Connecticut River Anadromous Fish Restoration Program is a cooperative interjurisdictional management effort that began in 1967. In 1983 an interstate compact relating to the restoration of Atlantic salmon and diadromous fish was created including the four states located in the Connecticut River watershed, the U.S. Fish and Wildlife Service and the National Marine Fisheries Service (Public Law 98-138). While the initial focus of the compact was Atlantic salmon, the Connecticut River Atlantic Salmon Commission (CRASC) also works on diadromous fish recovery and restoration. Goals outlined in the CRASC River herring management plan include increasing passage through upstream barriers, maximizing outmigrating juvenile survival, and enhancing and restoring habitat in the Connecticut River Basin (CRASC 2004).

The US Fish and Wildlife Service Connecticut River Fish and Wildlife Conservation Office (CRFWCO) works with CT DEEP and CRASC to coordinate and participate in population assessment and restoration activities in the Connecticut River Basin. Ongoing river herring data assessments conducted by CRFWCO, include a river herring electrofishing survey and truck and transport of blueback herring (Sprankle, 2016)

9.8. AGE

Several studies have examined age structure of Connecticut's river herring populations, but unfortunately, there is not a continuous time series of data. Loesch and Lund (1977) reported age structure and mean length, by sex, for blueback herring collected from 1966 to 1968. Ages ranged from 3 to 7 for both sexes. During 1966 and 1967, Marcy (1969) examined age structure from CT River alewives and blueback herring, Bride Brook alewives, and Thames River blueback herring. Alewives reached a maximum age of 8 years, while blueback herring reached seven years. Bride Brook alewives were predominately 5 and 6 years old, while blueback herring were predominately ages 3 and 4.

More recent examination of the Bride Brook alewife age structure demonstrated a decrease in mean age and size of spawners, as well as decreased rates of repeat spawning relative to the 1960s (Davis and Schultz 2009). A Connecticut River blueback herring study conducted from 2005 to 2007 documented truncation of age structure, a decrease in average length and a decrease in the rate of repeat spawning relative to the 1960s (Davis 2016).

The CT DEEP diadromous program collects biological samples from the Bride Lake alewife spawning run. It is anticipated that there will be a 10 year age structure time series for Bride Lake that can be included in the next benchmark assessment

The USFWS CRFWCO collects biological samples from blueback herring and alewives collected during their CT River electrofishing survey. This time series does not meet the minimum 10 year cutoff recommended by the SAS for assessment. Data will be presented in the next benchmark assessment.

9.9. FISHERIES DESCRIPTIONS

9.9.1. Commercial Fishery

Currently there are no directed commercial or recreational fisheries in Connecticut. Although commercial fishermen on the Connecticut River have reported their annual catches to the State of Connecticut since 1890, this information may not be reliable to determine fluctuations in abundance. In early years, license data did not include catch effort (Smith et al. 1989). Better documentation of landings started in 1975 when all lobster pot and otter trawl fishermen licensed by the State of Connecticut were required to report their monthly catch by species in monthly logbooks. From 1981 to 1995, all haul seine and gillnet commercial fishermen licensed in Connecticut were also required to report their annual landings and fishing effort to the State by September of following year. After 1995, all gillnet and haul seine fishermen were required to report their landings in the monthly logbook system. Because of the difficulty of differentiating blueback herring from alewife, commercial landings reported for most years were not separated by species.

River herring contributed a low percentage to total commercial finfish landings and landings of all species including shellfish in Connecticut. River herring were harvested primarily by haul seine with 2-6% harvested by gillnet (Table 9.1). Commercial fishing for river herring occurred predominately in the Connecticut River and was used mostly for lobster bait and bait for game fishing. During the 1950s they were used as industrial fish, being reduced to fish meal. Two peak periods in the recorded historical landings occurred from 1892-1908 and 1950-1955. During these periods annual landings exceeded 500,000 pounds. A record landing of 1.94 million pounds occurred in 1950 (Blake and Smith 1984). Landings generally remained at less than 100,000 pounds since 1960. The majority of the river herring landings from the ocean in the mid-1980s to the mid-1990s were taken within Long Island Sound with a little over 20% occurring in the Atlantic Ocean and from Block Island Sound. Landings in the 1990s dwindled to a few thousand pounds except for two years of large landings in 1995 and 2000 which were attributed to catches in Block Island Sound and the Exclusive Economic Zone (EEZ) (Figure 9.2).

9.9.2. Recreational Fishery

There was a directed recreational fishery in the Connecticut River system for use of live bait in the striped bass fishery in the river and for marine fisheries in Long Island Sound. Harvested primarily by scoop or dip netting, pressure on river herring was likely higher in rivers with the strongest runs. The magnitude of the recreational harvest has never been estimated (Savoy and Crecco 2004).

9.9.3. Bycatch Estimates

Connecticut commercial fishermen are required to submit monthly logbook reports detailing their catch. There have been no reports of river herring in logbooks since the statewide moratorium was implemented. Species-specific river herring incidental catch estimates by gear type and region collected through the Northeast Fisheries Observer Program, are presented in the coastwide assessment section of this update document.

9.10. FISHERIES INDEPENDENT MONITORING

9.10.1. Juvenile Surveys

A long (1979-2016) time series of juvenile blueback herring relative abundance has been established in the Connecticut River (Table 9.2, Figure 9.5). The average juvenile indices (JI) were expressed as the geometric mean catch per seine haul from 7 stations located between Essex, CT (river km 10) and Holyoke, MA (river km 139) (Marcy 1976). Each year this beach seine survey has been conducted weekly during the months of July through October. One seine haul is made at each station using a 30.5m bag seine (Crecco et al. 1981; Marcy 1976). Although some juvenile alewife remain in the lower river throughout summer and fall when the survey is conducted (Crecco et al. 1981), few are taken in the seine. Loesch (1987) reported juvenile alewife are distributed mainly in deeper (> 5 m) water and are less susceptible than juvenile blueback herring and shad to the beach seine.

9.10.2. Spawning Stock Surveys

Holyoke Lift Counts - Counts of blueback herring lifted at the Holyoke dam on the Connecticut River (rkm 139) are collected annually by the Massachusetts Division of Fisheries and Wildlife. The Holyoke lift counts were used as a proxy of adult blueback herring abundance during the 1980s and early 1990s. When the lift numbers rapidly declined and stayed at low levels, they became non-informative as an indicator of adult blueback abundance for the Connecticut River system.

Fishway counts – Fishway counts are monitored by CT DEEP Diadromous Fisheries Project. Counts of river herring at several fishways are available to monitor population trends. Additionally, Bride Brook (East Lyme, CT), lacks a fishway, but has a counting weir which allows enumeration of the run prior to the fish entering the lake.

Some of the fishway counts provided to the SAS for trend analysis are used by CT DEEP as index sites for river herring. The sites selected should be free of influence, human or artificial, that affect the number of herring that are counted. In most cases, Connecticut fishways are effective at passing river herring in the same manner and same efficiency, year-after-year. Therefore, changes in counts are more likely to reflect true run abundance. However, at the Rainbow Dam Fishway (Farmington River) and the Kinneytown Dam Fishway (Naugatuck River), this is not the case. At Rainbow Dam, there is a vertical slot fishway that does not effectively pass river herring. There are years when the tailrace below the dam appears full of blueback herring, with an estimated tens of thousands of fish observed, yet only two or three individual fish are passed. Because of the design of the Rainbow fishway, the counts are not representative of run abundance. At the Kinneytown Dam fishway, river herring seem to use the Denil fishway when they find it. However, almost on an annual basis the dam's flashboards fail and large amounts of water pass over the spillway and attract migrant fish away from the fishway and toward a long bypass reach under the spillway. Often, fewer than 10 river herring are passed in the fishway, yet there are thousands of river herring observed under the spillway. The fishway counts are not representative of run abundance. Because of the discrepancies between observed river herring presences and fishway counts, we chose to withdraw both of these datasets from the stock assessment update (S Gephard, personal communication).

Long Island Sound Trawl Survey (LISTS) – The LISTS has been conducted annually throughout Long Island Sound since 1984 and has documented age 1+ alosines. Alosines collected in the survey have emigrated from their natal rivers. There are small numbers of adults collected as well as alosines that remain in Long Island Sound for 1 or 2 years before they join coastal migratory stocks (Savoy and Crecco 2004). Relative abundance is expressed as the annual geometric mean catch per tow (Gottschall et al. 2011). Length frequencies (cm, FL) of all finfishes including blueback herring and alewife have been monitored by LISTS annually from 1989 to 2010 (Table 9.4-Table 9.7). The trawl survey employs a Sound-wide stratified random design with four depth strata and three bottom substrate types. Forty stations are usually sampled monthly during spring (April-June) and fall (September-October) for a total of 200 samples each year. Most (90%) of the trawl strata from the CT DEEP trawl survey are located in the central (west of the

Connecticut River) and western basins of LIS. Marcy (1969) suggested that many juveniles (age 1+) spend their first winter close to the mouth of their natal river due to their presence in the lower portion of the Connecticut River in early spring.

9.11. ASSESSMENT APPROACHES AND RESULTS

9.11.1. Trends in Run Size

River herring runs appeared to be abundant and stable during the 1970s and 1980s (Crecco and Gibson 1990). A large decrease in numbers of blueback herring lifted over the Holyoke Dam (rkm 139) in the 1990s was well documented and widely reported. A similar decline in American shad also took place in the Connecticut River. Several hypotheses were examined and strong statistical and empirical evidence was shown to support striped bass predation as a contributing factor to the decline of alosines in the Connecticut River (Davis et al. 2012; Davis 2016; Savoy and Crecco 2004).

The Holyoke fish lift was the only long-term source of adult blueback herring counts. More than 630,000 blueback herring were counted at the fish lift in 1985. However, the number counted at the lift had decreased to less than 1,000 fish being passed on an annual basis since 2004 (**Error! Reference source not ound.**, Figure 9.3**Error! Reference source not found.**). A shorter time series of alewife abundance shows fluctuation in the numbers of fish entering Bride Lake with a peak count occurring in 2013 (**Error! eference source not found.**, Figure 9.4). The LISTS survey has mixed age classes and does not show a definitive trend in abundance partially because those collections of river herring are a mixture from of different stocks from several rivers and streams (Figures 9.6, Figure 9.7). Alewife catches in the LISTS survey are typically higher than blueback herring.

Unlike American shad, there is no direct Connecticut River population estimate for adult blueback herring. Prior to 1996, the total number of adult blueback herring passed annually at the Holyoke Dam fish lift (Savoy and Crecco 2004) was assumed to be an informative index of river-wide stock size (**Error! Reference source not found.**; **Error! Reference source not found.**). No adult alewife ve been counted at the Holyoke fish lift because alewife spawn mainly in the lower river (Marcy 1969). When lift numbers of adult blueback herring fell below 1,000 fish per year from 2004 to 2016, it became increasingly evident that annual counts at Holyoke overstated the decline in river-wide stock abundance. The passage of 21 to 976 blueback herring per year from 2004 to 2010 would suggest that the river-wide stock had declined by 99% since about 1990 (**Error! eference source not found.**, **Error! Reference source not found.**3). It is unlikely that a 99% drop in stock since 1990 could have produced measurable juvenile production as indicated from 2004 to 2016 (Table 9.2, Figure 9.5). The use of annual blueback lift data to monitor river-wide trends in abundance became even less reasonable in 2010, when a large 2010 juvenile index emerged when only 76 adult blueback herring were passed at the Holyoke fish lift (Table 9.2).

Fishway counts and fish counter data collected over the past ten years vary by river system. Large inland fishways on the Connecticut and Shetucket have low counts of river herring. Annual passage at the Greeneville Dam fishlift on the Shetucket River has varied from 13 to 800 bluebacks and 129 to 2,422 alewives. Bride Brook is one of the more consistently monitored coastal systems, where a stable trend of alewife returns has been seen since 2002, with increased counts of 287,000 and 354,000 in 2012 and 2013, respectively.

9.11.2. Trends in Size Structure

Connecticut does not have continuous long term length frequency data on adult river herring. Annual river herring length frequencies collected by the Long Island Sound Trawl Survey are comprised of multiple age classes (primarily sub-adults) of river herring from NY and CT waters. Natal river origin of river herring collected by LISTS is unknown. The LISTS length frequencies of blueback herring and alewife have been monitored annually from 1989 to 2010 (Table 9.4, Table 9.5, Table 9.6, Table9.7). The CT DEEP Diadromous Fisheries Project collects annual length frequency data for alewives at Bride Brook that will be presented in the next benchmark stock assessment. Since 2013, The CRFWCO collects length frequency data from adult blueback herring and alewives captured during their electrofishing. This data will be presented in the next assessment when the duration reaches the 10 year duration as recommended by the SAS. Additional short-term studies in the CT River have documented the decline in mean length at age, truncation of age structure and decline in rate of repeat spawners for Connecticut River blueback herring and Bride Lake alewives (Davis 2016; Davis and Schultz 2009).

9.11.3. Trends in Age Composition

Truncation of age structure has been documented for Connecticut River blueback herring (Davis 2016) and Bride Lake alewife (Davis and Schultz 2009). There are no long-term data sets available on age structure of Connecticut river herring stocks.

9.11.4. Trends in Proportion of Repeat Spawner

Reductions in frequency of repeat-spawning has been documented for Connecticut River blueback herring (Davis 2016) and Bride Lake alewife (Davis and Schultz 2009). There are no long-term data sets available on repeat spawning frequencies in Connecticut river herring stocks.

9.11.5. Trends in Z

Mortality rates were not calculated. Length frequencies and age structure data is being collected, but the time series do not meet the 10 year mark needed to be included in this assessment update.

9.11.6. Fishing Mortality

There are no directed commercial or recreational fisheries in Connecticut.

9.11.7. Trends in Age – 1 Indices of Relative Abundance

Juvenile blueback herring production was high and relatively stable from 1978 to about 1997, but juvenile indices dropped thereafter and remained relatively low from 1998 through 2009. The juvenile index in 2010 was unexpectedly strong, being the highest in the time series since 1994. There are 5 juvenile index values that have ranked in the top 20 since the stock decline at the Holyoke lift. The unexpectedly strong 2010 blueback JI value of 12.8 occurred when less than 100 adults were passed at the Holyoke lift. It is interesting to note that comparable juvenile index values were also produced in 1981, 1984 and 1992 when the counts at the lift ranged from 300,000 to 480,000. This suggests that the blueback production within the lower river is still able to sustain the stock.

9.11.8. Potential Sources of Increased Mortality

Sources of mortality to river herring that exist outside of their natal systems are addressed in the coastwide section of this assessment. While most streams and rivers have no information on mortality available, there are sources within the Connecticut River that have been examined.

Striped bass abundance in Connecticut waters and along the Atlantic coast had risen since 1995 to record high levels (ASMFC 2007) coincident with the decline of blueback herring in the Connecticut River. Unlike many other marine finfish predators, adult (> 70 cm) striped bass have the ability to move into freshwater and have been sampled in large and increasing numbers well above the salt wedge in the Connecticut River since 1993 (Davis et al. 2012; Davis 2016; Savoy 1995).

A study of striped bass abundance, size structure, and food habits conducted in the Connecticut River from May-June of 2005-08 demonstrated that striped bass predation was a likely contributor to the decline of the Connecticut River blueback herring run to Holyoke Dam during the 1990s, and is also likely continuing to suppress blueback herring production in the upper river. The study estimated that during the mid-2000s, approximately 125,000 striped bass >30 cm were present in the 64 km river stretch between Wethersfield, CT and the Holyoke Dam during the spring migration season, and that this migratory contingent of striped bass consumed approximately 400,000 (90% CI 200,000-800,000) adult blueback herring annually (Davis et al. 2012; Davis 2016).

9.12. BENCHMARKS

No benchmarks were established for Connecticut.

9.13. CONCLUSIONS AND RECOMMENDATIONS

Fishing mortality rates for river herring in Connecticut waters have been negligible in recent history as Connecticut has had a moratorium on harvest since 2002. The Connecticut River blueback herring population below the Holyoke Dam is of unknown size. Despite the lack of adults passed at the Holyoke Dam, there continues to be stable juvenile blueback production in recent years with index values comparable to values produced with passage of several hundred thousand of fish at the lift. It is unknown as to whether or not the peak values of passage at the Holyoke Dam are a sustainable population for the Connecticut River above Holyoke since there is not enough historical data to estimate population size. Anadromous fish had no access above the Holyoke Dam from 1849-1955. Over 60% of the annual lift values since 1975 have remained below 50,000. The decrease in blueback herring adults documented at the Holyoke lift during the 1990s could not be attributed to directed fisheries in Connecticut since there were no longer commercial fisheries in state waters targeting river herring.

Recent studies of alewife and blueback herring runs in Connecticut suggest that in recent decades river herring runs have experienced a truncation in age structure, reduced size and age of spawners, and decreased rates of repeat spawning. These changes have likely produced a reduction in the resilience of river herring populations, as reduced size and age of spawners likely translates to lower annual reproductive outputs; further, the reduced number of age classes within runs exacerbates the impact of poor year classes.

The LISTS mixed stock indices for age 1+ river herring in Connecticut has been variable. Since the benchmark assessment alewife appear to be more available to the trawl. Mixed age alewife indices from LISTS shows a fluctuating but increasing trend since 1984.

We recommend the continuation of surveys on the Connecticut River and Bride Lake. Catch effort data and biological samples from these surveys should reach sufficient length to be included in the next benchmark stock assessment.

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Table 9.1 Annual River Herring fishway passage counts Holyoke=CT River, Greeneville=Thames River, Bride Brook=Bride Lake.

Year	Fishway	BBH	Fishway	ALW	BBH	Fishway	ALW
1966						Bride Brook	184,151
1967						Bride Brook	140,203
1968							
1969							
1970							
1971							
1972							
1973							
1974							
1975	Holyoke	1,600					
1976	Holyoke	4,745					
1977	Holyoke	32,492					
1978	Holyoke	40,765					
1979	Holyoke	39,895					
1980	Holyoke	197,950					
1981	Holyoke	419,734					
1982	Holyoke	586,808					
1983	Holyoke	454,247					
1984	Holyoke	482,954					
1985	Holyoke	632,255					
1986	Holyoke	517,521					
1987	Holyoke	358,607					
1988	Holyoke	343,361					
1989	Holyoke	286,537					
1990	Holyoke	392,157					
1991	Holyoke	412,344					
1992	Holyoke	312,863					
1993	Holyoke	103,465					
1994	Holyoke	31,843					
1995	Holyoke	112,124					
1996	Holyoke	55,011	Greeneville	129	13		
1997	Holyoke	63,945	Greeneville	142	808		
1998	Holyoke	11,146	Greeneville	337	137		
1999	Holyoke	2,699	Greeneville	3,722	464		
2000	Holyoke	10,587	Greeneville	480	29		
2001	Holyoke	10,602	Greeneville	702	187		
2002	Holyoke	1,939	Greeneville	2,288	14		
2003	Holyoke	1,392	Greeneville	335	216	Bride Brook	117,158
2004	Holyoke	151	Greeneville	329	2	Bride Brook	81,350
2005	Holyoke	534	Greeneville	592	5	Bride Brook	68,757
2006	Holyoke	21	Greeneville	2,412	9	Bride Brook	129,114
2007	Holyoke	75	Greeneville	2,422	0	Bride Brook	66,975
2008	Holyoke	84	Greeneville	535	0	Bride Brook	73,268
2009	Holyoke	39	Greeneville	190	0	Bride Brook	74,774
2010	Holyoke	76	Greeneville	90	0	Bride Brook	164,149
2011	Holyoke	138	Greeneville	362	0	Bride Brook	196,996
2012	Holyoke	39	Greeneville	244	1	Bride Brook	287,003
2013	Holyoke	976	Greeneville	713	24	Bride Brook	354,862
2014	Holyoke	647	Greeneville	794	297	Bride Brook	260,926
2015	Holyoke	87	Greeneville	502	10	Bride Brook	218,076
2016	Holyoke	137	Greeneville	1,456	114	Bride Brook	148,596

Table 9.1 River herring NMFS landings by gear for Connecticut from NMFS Commercial Fisheries Statistics. DN=Dip Nets, Common, ENGU=Entangling Nets (Gill) UNSP, FHN=Fyke and Hoop nets, Fish, GNDO=Gill Nets, Drift, other, GNDS=Gill Nets, Drift, Shad, GNO=Gill Nets, Other, GNS=Gill Nets, Salmon, GN=Gill Nets, Stake, HSB=Haul Seine, Beach, LHO=Lines Hand, Other, NC=Not Coded, OTBF= Otter Trawl Bottom, Fish, PU=Pots, Unclassified, PNO=Pound Nets, Other, TU=Trawls, unspecified, PNF=Pound Nets, Fish.

Year	DN	EN	FHN	GNDO	GNDS	GNO	GNS	GN	HSB	LHO	NC	OTBF	PU	PNO	TU	PNF	Total
1950			600	200					1,947,100								1,947,900
1951				7,000					482,900								489,900
1952		100							758,100					1,300	302,000		1,061,500
1953				4,200					328,500				100		7,500		340,300
1954				2,000					970,700								972,700
1955				600					889,700								890,300
1956	1,000		1,200	37,000					40,200								79,400
1957				600					62,600						100		63,300
1958	2,400								7,100								9,500
1959	2,400		1,100						4,000						300		7,800
1960	2,400		1,000	12,000					2,600						2,000		20,000
1961	1,800					1,000			200						3,000		6,000
1962	6,000						7,000		6,000								19,000
1963	2,000								1,400								3,400
1964	600								12,700			1,500					14,800
1965	2,400								16,700			5,000					24,100
1966	2,900			100					1,600			2,000					6,600
1967	2,900			16,000					2,300			2,200					23,400
1968	3,600								23,300			5,900					32,800
1969	2,100			600					6,900			1,000					10,600
1970	15,400			400					13,900			92,600					122,300
1971	5,800			4,900					12,400			1,900					25,000
1972	7,600		1,400	1,900		400			11,500								22,800
1973			1,800	2,000	3,000	4,000			3,500								14,300
1974	13,600			2,900					500								17,000
1975			1,200	4,000					20,000								25,200
1976	1,600			4,200					61,100	200							67,100
1977			100						61,200								61,300
1978	500			900					37,400	1,000							39,800

Table 9.2 Continued

Year	DN	EN	FHN	GNDO	GNDS	GNO	GNS	GN	HSB	LHO	NC	OTBF	PU	PNO	TU	PNF	Total
1979				2,200					59,000	500		1,000					62,700
1980				1,100					54,000			0					55,100
1981				3,200					49,200	0							52,700
1982	400			2,000					39,300	0		100					41,800
1983	500			2,100					34,700			200					37,500
1984				1,200					30,700			500					32,400
1985	3,400			1,100					33,600			800					38,900
1986				7,700					32,200	200							40,100
1987	500		900	900					19,000			100					21,400
1988	1,100			200					100	300		400					2,100
1989	200			300					500			600					1,600
1990			150	800						200							1,150
1991			200	800						200							1,200
1992	300		300	2,300					300								3,200
1993				1,090						1,350							2,440
1994											2,000						2,000
1995											14,044						14,044
1996				184				68									252
1997																	0
1998																	0
1999												102,060					102,060
2000								700				74,990				2,295	77,985
2001								20									20

Table 9.2 Annual blueback herring juvenile abundance index for the Connecticut River expressed as arithmetic and geometric mean catch per unit effort, 1979-2015.

Year	GM CPUE
1979	24.8
1980	26.75
1981	11.49
1982	6.09
1983	16.47
1984	11.57
1985	18.23
1986	13.61
1987	21.58
1988	17.04
1989	7.52
1990	14.41
1991	13.33
1992	10.19
1993	14.43
1994	13.92
1995	5.03
1996	5.91
1997	10.28
1998	4.39
1999	5.57
2000	4.17
2001	3.83
2002	3.95
2003	5.88
2004	2.36
2005	4.1
2006	3.5
2007	6.61
2008	2.2
2009	1.77
2010	12.82
2011	2.93
2012	2.22
2013	6.89
2014	3.69
2015	8.63

Table 9.4 Long Island Sound Trawl Survey Alewife Spring Length Frequencies, 1989-2015.

													Spring													
length	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
6	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
7	0	0	0	0	2	0	0	0	0	0	0	4	0	0	1	0	1	0	0	4	0	2	1	0	0	0	3
8	0	0	0	0	18	3	3	0	0	0	2	9	16	0	3	1	2	0	0	4	1	10	0	1	3	2	12
9	0	0	2	0	15	9	6	1	6	0	6	21	32	1	18	6	16	0	0	4	6	10	0	3	7	5	11
10	0	0	0	1	11	19	18	2	22	7	6	28	23	5	32	55	32	0	8	5	11	23	5	6	16	7	16
11	0	0	5	4	10	44	11	2	64	11	20	52	14	6	27	87	26	29	13	32	10	9	22	8	11	16	13
12	6	0	4	7	6	83	17	8	127	12	32	43	5	29	25	100	55	44	34	131	17	6	54	27	19	15	7
13	1	0	4	4	47	122	48	16	63	44	42	99	4	70	11	83	61	15	38	193	24	12	48	98	18	24	6
14	0	0	9	7	77	172	35	26	69	61	56	234	7	139	28	63	37	9	37	178	51	6	50	187	14	33	6
15	3	0	8	5	68	140	54	32	56	51	120	334	6	157	25	33	50	49	85	86	101	8	59	123	12	48	7
16	2	0	8	5	84	159	38	86	44	50	144	320	4	86	26	31	74	25	128	46	106	7	37	56	5	53	5
17	5	4	4	16	63	108	32	203	28	34	330	85	5	82	21	33	73	78	161	47	142	5	7	27	10	16	5
18	4	4	9	8	59	81	7	254	32	22	136	15	4	15	19	18	71	93	182	25	196	2	11	17	21	30	5
19	6	7	7	2	37	33	7	180	9	11	99	20	3	6	26	42	59	86	122	49	215	7	11	24	22	24	9
20	3	1	7	2	27	24	10	161	17	17	82	22	9	17	13	30	26	76	105	38	137	7	9	19	10	50	3
21	1	0	3	1	13	17	14	107	34	22	72	27	12	28	22	50	21	40	71	21	53	18	9	18	28	58	9
22	4	2	8	2	10	26	12	103	48	18	47	41	18	46	25	48	18	18	41	14	29	22	10	24	34	25	20
23	5	1	8	6	3	12	12	76	44	16	47	90	36	63	40	36	7	5	28	16	13	12	16	27	39	8	17
24	7	0	3	2	1	12	7	34	28	14	21	58	45	49	42	13	6	1	10	7	14	4	7	18	15	18	12
25	3	2	1	0	3	5	2	9	9	2	11	11	23	12	29	11	3	1	3	0	11	2	4	11	4	12	10
26	1	0	1	2	1	5	1	3	1	2	2	1	5	7	17	5	2	0	2	0	1	0	2	3	3	4	7
27	2	0	1	0	0	1	0	0	0	0	0	1	2	1	2	2	1	0	0	0	0	0	0	1	0	1	1
28	1	0	0	0	1	1	0	0	0	1	0	0	0	1	0	2	1	0	0	1	0	0	2	0	0	0	0
29	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**56**	**21**	**93**	**74**	**556**	**1,076**	**334**	**1,304**	**701**	**395**	**1,275**	**1,515**	**274**	**820**	**452**	**749**	**642**	**569**	**1,068**	**901**	**1,138**	**172**	**364**	**698**	**291**	**449**	**185**

Table 9.5 Long Island Sound Trawl Survey Alewife Fall Length Frequencies, 1989-2015.

													Fall													
length	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
6	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	-	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	0	0	1	0	-	0	0	0	0	0
9	0	0	0	0	3	1	0	0	1	0	0	1	6	1	1	0	1	0	3	2	0	-	1	0	0	1	3
10	0	0	0	0	5	1	4	1	1	0	1	4	23	0	7	1	7	0	8	2	1	-	1	0	0	2	9
11	0	0	0	0	27	30	5	5	6	1	3	5	59	0	33	6	14	0	22	1	2	-	9	0	8	0	23
12	0	0	0	1	120	82	9	25	12	9	6	9	86	4	64	7	8	0	44	0	2	-	22	2	14	7	32
13	0	0	3	0	88	84	14	21	21	7	9	17	72	0	4	12	17	0	87	5	10	-	14	3	16	27	88
14	0	0	2	4	16	36	11	30	31	0	11	10	23	3	3	16	15	0	134	14	10	-	22	0	34	48	26
15	0	0	1	8	21	31	0	9	53	0	5	8	24	3	5	28	15	2	118	4	8	-	28	2	6	12	53
16	3	0	3	10	53	14	4	1	110	1	25	2	36	17	20	30	12	4	31	0	1	-	14	1	2	4	37
17	2	0	0	12	25	33	1	2	194	4	34	0	27	8	19	12	3	0	8	3	1	-	19	2	2	0	11
18	3	0	0	9	13	24	1	1	62	3	11	1	5	0	0	1	5	0	6	0	1	-	17	0	0	2	14
19	0	0	0	2	1	11	0	0	0	1	4	1	0	1	0	0	0	0	7	1	0	-	1	0	1	0	3
20	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	-	0	0	0	0	0
21	0	0	0	0	3	1	1	0	0	1	2	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	1
22	0	1	0	0	2	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
23	0	0	0	0	0	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	-	0	0	0	1	1
24	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
25	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
27	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
Total	**8**	**1**	**9**	**46**	**377**	**354**	**50**	**95**	**492**	**27**	**117**	**58**	**364**	**38**	**156**	**113**	**98**	**6**	**468**	**33**	**37**	**0**	**148**	**10**	**83**	**104**	**301**

Table 9.6 Long Island Sound Trawl Survey Blueback Spring Length Frequencies, 1989-2015.

													Spring													
length	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
6	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	6
7	0	0	2	0	2	7	2	0	0	2	0	4	1	0	3	2	1	0	0	1	0	4	0	0	5	1	17
8	0	0	3	0	2	76	20	4	0	5	0	10	7	12	7	9	8	1	0	8	0	1	0	0	9	8	30
9	0	0	2	0	3	114	11	5	21	15	0	14	5	9	23	23	14	8	1	11	7	4	3	3	9	3	24
10	0	0	5	10	7	74	9	19	45	45	0	18	2	9	26	47	6	23	9	14	19	19	5	18	5	1	32
11	0	0	3	4	9	41	9	10	258	48	0	28	1	6	11	39	10	2	3	12	25	38	9	12	8	2	29
12	3	0	5	0	2	9	5	3	4	16	0	18	2	3	4	20	12	0	5	2	27	8	3	5	1	2	10
13	0	0	0	4	0	13	5	2	0	2	0	12	1	1	1	12	3	1	3	4	17	10	6	1	1	0	3
14	0	0	0	15	0	5	3	1	1	1	0	3	0	0	0	0	7	0	1	1	5	4	2	0	0	0	0
15	0	0	1	27	1	3	4	7	0	0	1	2	0	4	0	0	8	1	2	2	9	1	0	0	0	0	0
16	0	0	0	65	0	8	3	7	0	3	5	1	1	1	4	4	13	2	23	1	30	4	2	2	7	0	0
17	0	0	1	11	3	9	1	10	4	0	5	3	10	7	4	4	11	2	37	7	64	2	12	2	5	6	0
18	0	1	0	2	0	3	0	4	2	0	0	5	15	2	3	3	1	2	7	3	49	1	3	2	3	11	1
19	0	0	0	0	1	2	4	3	2	0	0	0	3	0	0	3	2	1	3	2	17	2	1	0	1	4	0
20	0	0	0	4	0	1	1	0	0	0	0	2	1	1	0	0	5	2	0	1	2	0	1	0	1	3	0
21	2	1	2	0	0	1	1	3	0	0	0	1	3	0	0	3	2	3	2	0	1	1	0	0	7	2	1
22	1	0	0	1	0	3	0	4	0	1	0	3	0	0	1	0	1	0	1	1	0	1	0	0	5	2	0
23	0	0	3	2	0	3	2	3	1	0	0	5	0	1	0	1	0	0	1	1	0	1	0	0	0	0	0
24	0	1	2	0	0	0	0	2	0	0	0	3	0	0	0	0	0	0	2	0	0	1	0	0	1	0	0
25	0	0	0	1	0	1	1	1	0	0	0	1	0	0	2	0	0	1	1	0	0	0	0	0	0	0	0
26	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**6**	**3**	**29**	**147**	**30**	**373**	**83**	**90**	**338**	**140**	**11**	**136**	**52**	**56**	**89**	**173**	**104**	**49**	**101**	**71**	**272**	**102**	**47**	**45**	**68**	**47**	**153**

Table 9.7 Long Island Sound Trawl Survey Blueback Fall Length Frequencies, 1989-2015.

													Fall													
length	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
6	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
7	0	0	0	0	0	0	5	0	2	0	0	0	0	0	0	1	0	0	0	0	0	-	0	0	0	0	0
8	0	0	0	0	0	0	33	0	2	0	0	0	0	0	0	0	0	0	1	0	0	-	0	0	0	0	0
9	0	0	0	0	0	0	21	3	2	2	1	0	0	0	0	0	0	0	1	0	2	-	0	0	0	0	0
10	0	0	0	0	0	1	3	0	8	1	0	1	0	0	0	0	0	0	0	0	0	-	0	0	0	0	1
11	0	0	0	0	3	13	4	0	3	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	1
12	0	0	3	9	8	227	14	0	12	1	1	0	7	0	0	2	0	0	0	0	0	-	0	0	0	1	0
13	38	1	4	11	24	225	48	0	117	18	0	0	36	2	0	15	2	2	0	0	0	-	0	1	0	1	0
14	77	0	1	6	18	247	40	1	111	28	1	0	117	7	0	17	3	8	1	1	3	-	4	0	0	2	26
15	24	0	0	1	20	94	3	3	34	16	0	3	52	3	4	6	2	4	14	2	5	-	9	0	0	3	60
16	0	0	0	0	2	14	0	0	0	5	2	1	10	0	4	0	0	0	31	0	2	-	9	0	0	1	6
17	0	0	0	0	0	2	0	0	0	1	1	2	2	0	1	0	0	0	7	0	1	-	3	0	0	2	0
18	1	0	0	0	0	1	0	0	0	0	0	1	3	0	0	0	0	0	0	0	5	-	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
20	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	-	0	0	0	0	0
22	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
24	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
25	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
Total	**140**	**2**	**9**	**27**	**76**	**827**	**172**	**7**	**292**	**72**	**8**	**8**	**227**	**12**	**9**	**42**	**8**	**14**	**55**	**3**	**18**	**0**	**25**	**1**	**0**	**10**	**94**

Table 9.8. LISTS spring and fall alewife indices of abundance, 1984-2015.

Year	Alewife Spring	Alewife Fall
1984	0.43	0.42
1985	0.10	0.01
1986	0.66	0.05
1987	1.00	0.04
1988	0.47	0.19
1989	0.72	0.16
1990	0.54	0.11
1991	0.39	0.07
1992	0.39	0.19
1993	0.84	0.40
1994	1.83	0.66
1995	0.96	0.16
1996	2.18	0.24
1997	1.44	1.23
1998	1.11	0.11
1999	1.89	0.42
2000	1.53	0.25
2001	0.75	0.55
2002	0.95	0.22
2003	1.14	0.58
2004	1.86	0.26
2005	1.30	0.43
2006	0.78	0.05
2007	1.62	0.95
2008	1.32	0.42
2009	1.04	0.18
2010	1.29	
2011	0.94	0.43
2012	0.77	0.07
2013	1.06	0.40
2014	0.88	0.18
2015	0.77	0.64

Table 9.8. LISTS spring and fall blueback herring indices of abundance, 1984-2015.

Year	Blueback Fall*	Blueback Spring
1984	0.38	5.42
1985	0.16	0.30
1986	0.07	0.34
1987	0.13	0.14
1988	0.53	0.03
1989	0.34	0.05
1990	0.10	0.08
1991	0.04	0.11
1992	0.08	0.20
1993	0.11	0.08
1994	0.93	0.55
1995	0.27	0.29
1996	0.05	0.28
1997	0.75	0.25
1998	0.16	0.15
1999	0.06	0.02
2000	0.06	0.37
2001	0.20	0.19
2002	0.06	0.15
2003	0.10	0.27
2004	0.09	0.46
2005	0.06	0.33
2006	0.15	0.13
2007	0.24	0.29
2008	0.05	0.21
2009	0.09	0.43
2010		0.37
2011	0.08	0.14
2012	0.01	0.13
2013	0.00	0.26
2014	0.04	0.15
2015	0.17	0.42

Figure 9.1 Map of Connecticut's 3 major rivers (Connecticut, Housatonic, Thames) and Long Island Sound.

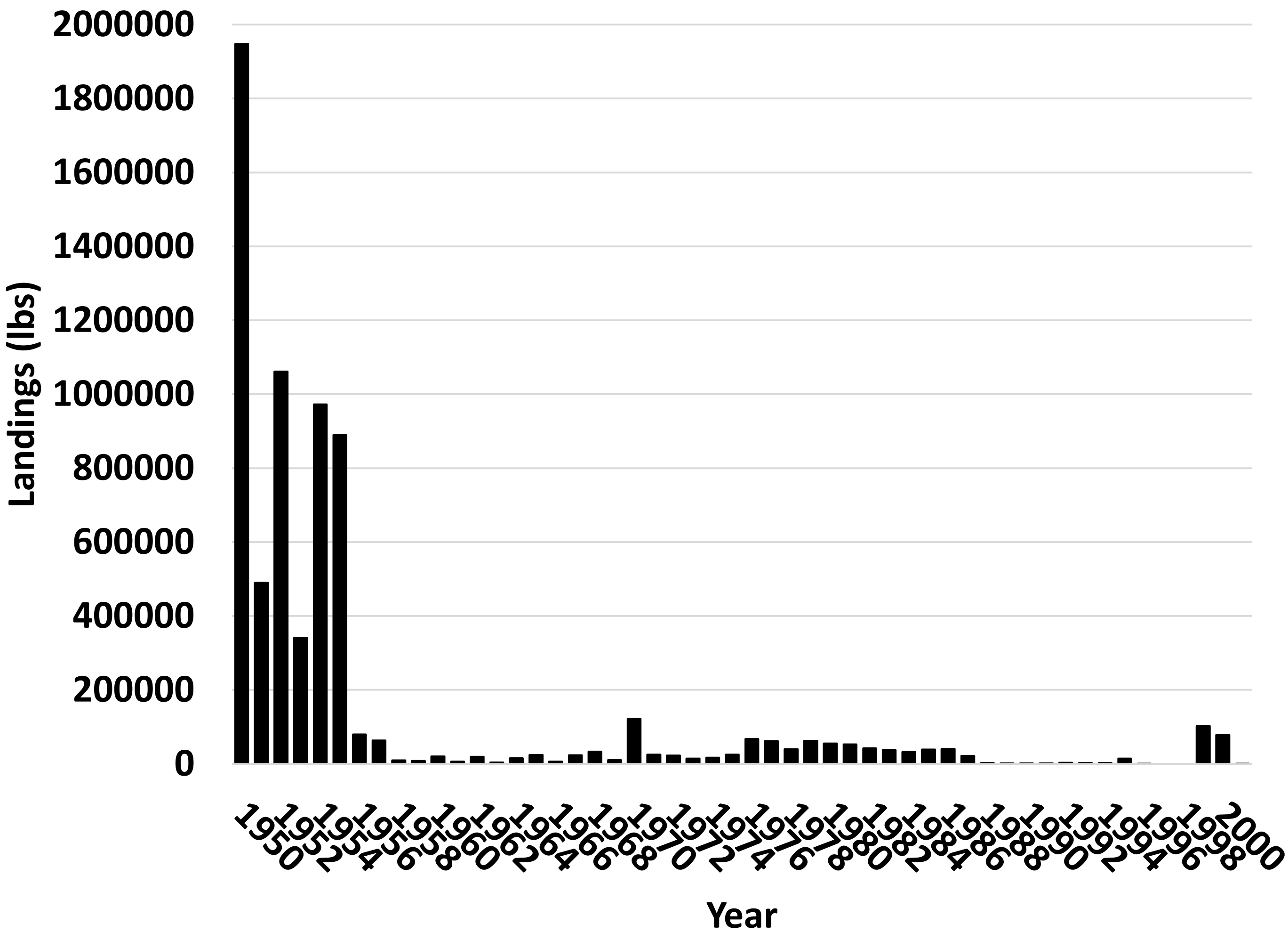

Figure 9.2 Connecticut Commercial landings (lbs.) reported to NMFS 1950-2001.

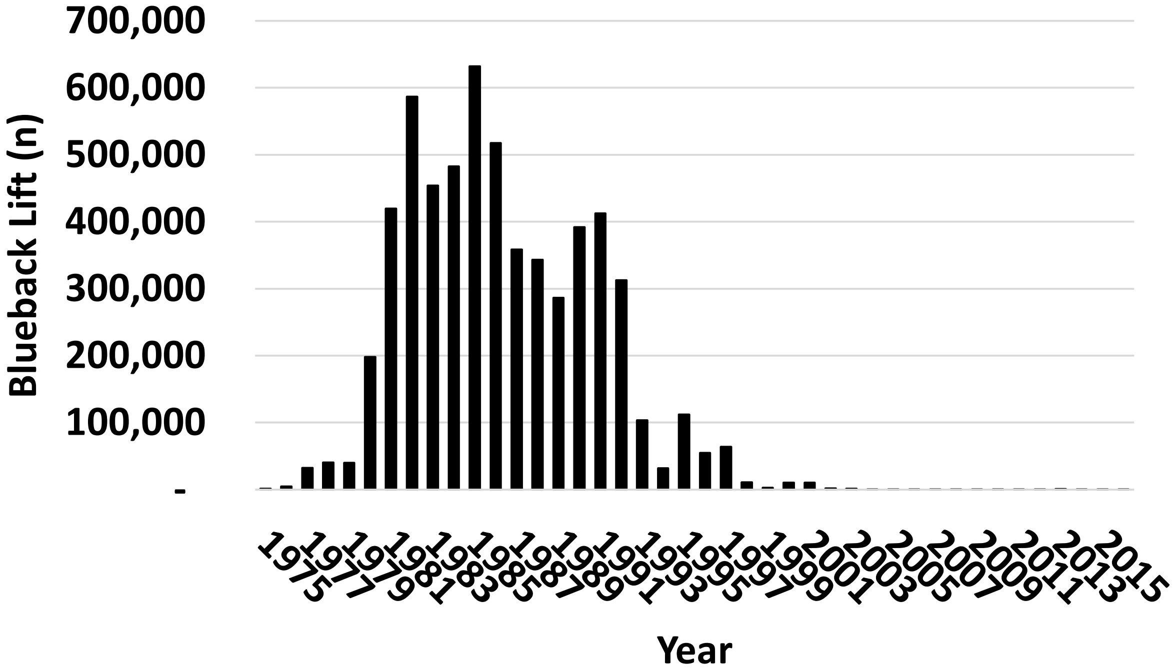

Figure 9.3 Number of blueback herring lifted at the Holyoke Dam, 1975-2016.

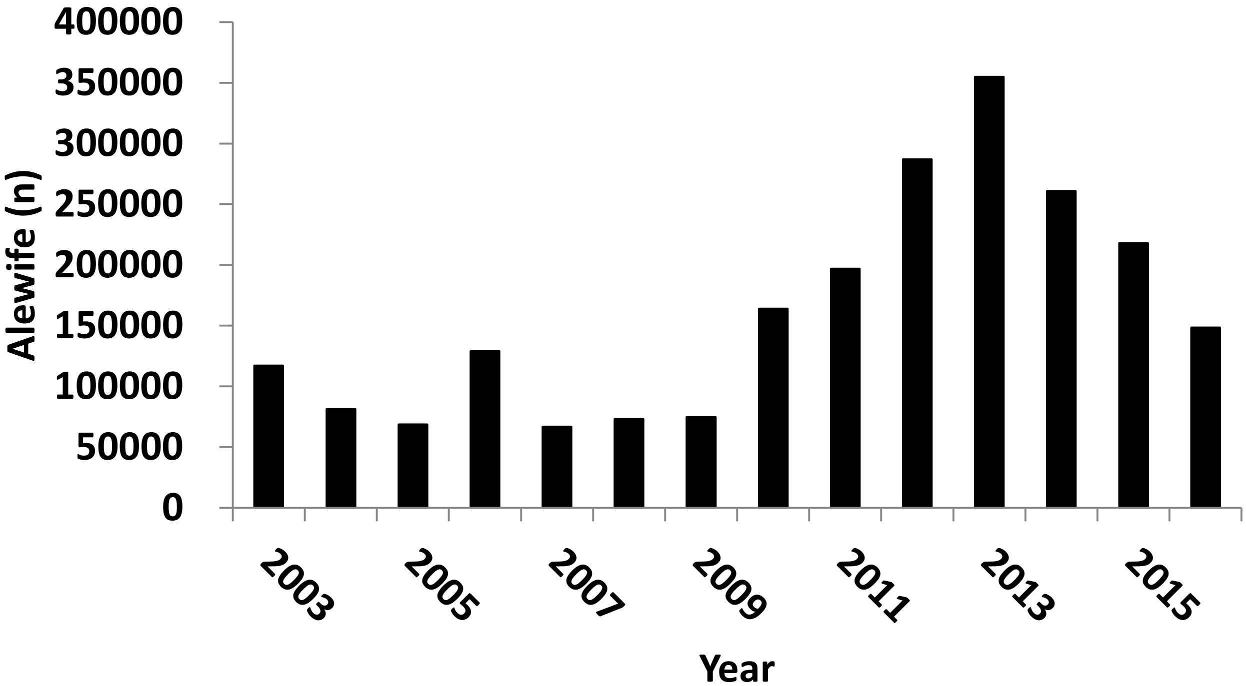

Figure9.4 Number of alewives passed at Bride Brook, 2003-2016.

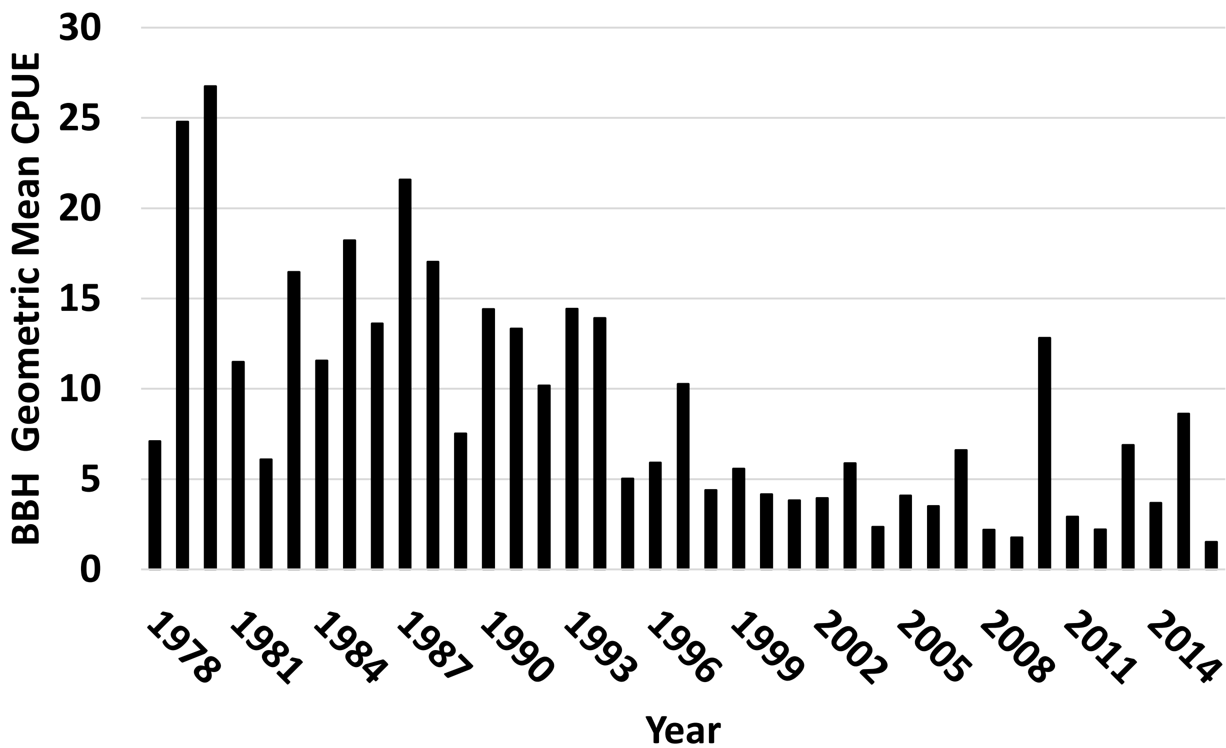

Figure 9.5. CT River juvenile blueback herring indices, 1979-2016.

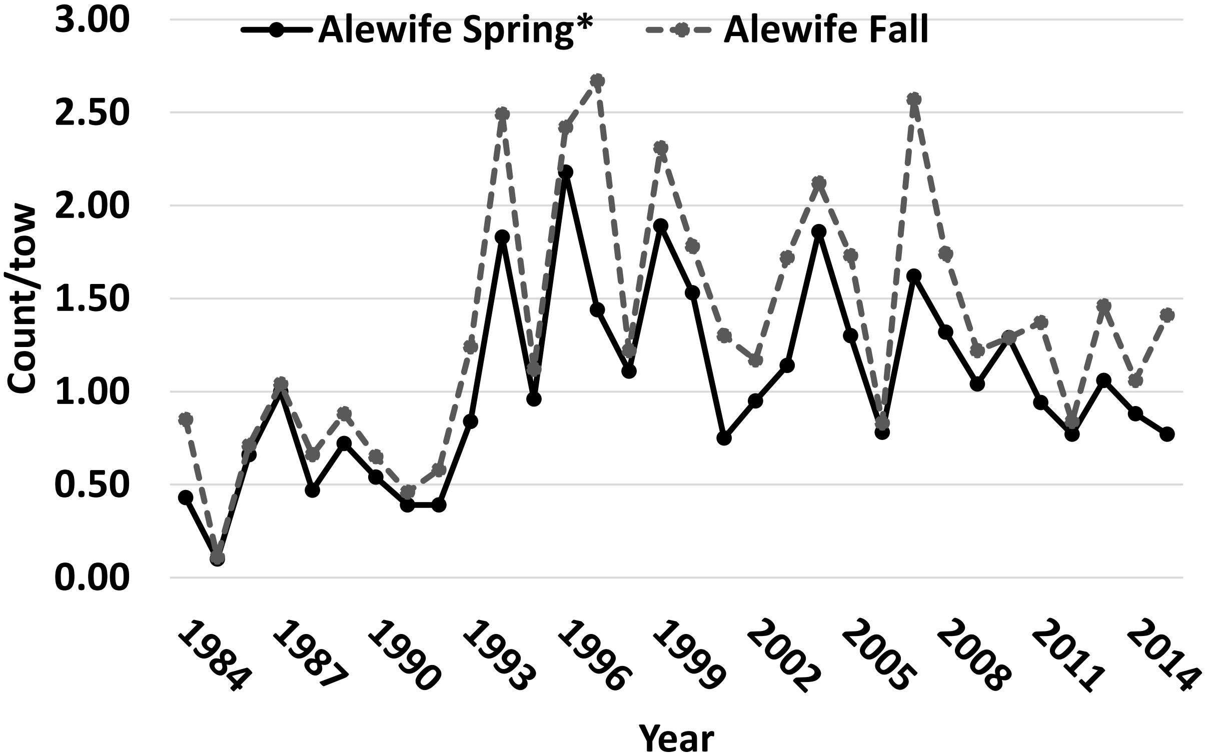

Figure 9.6 Long Island Sound Trawl Survey Alewife spring and fall geometric mean per tow, 1984-2015.

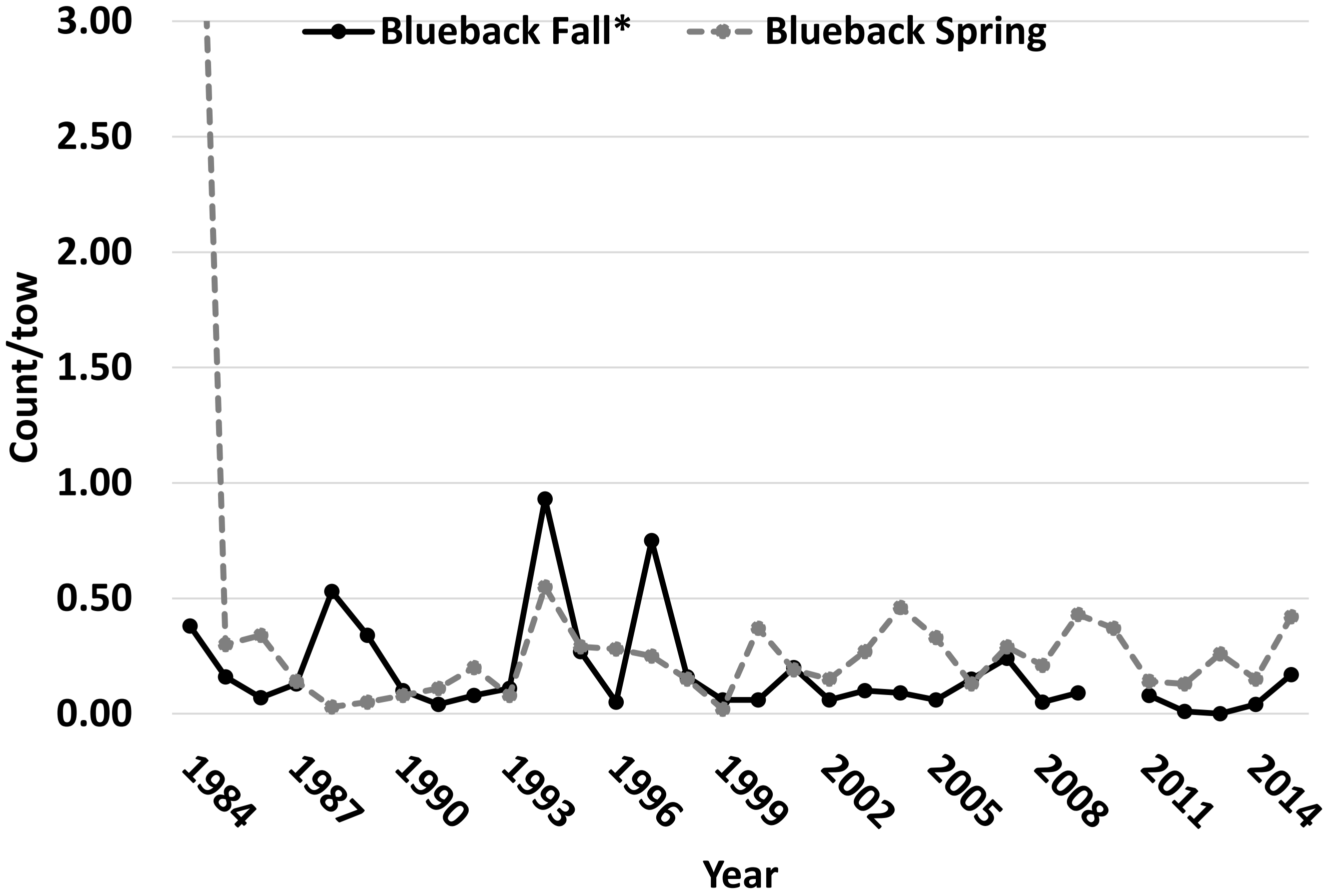

Figure 9.7 Long Island Sound Trawl Survey river herring spring and fall geometric mean per tow, 1984-2015. Note: the 1984 value (not shown on axis) is 5.4.

10 Status of River Herring in New York

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10.1. INTRODUCTION

The fisheries that existed back in colonial days in the Hudson Valley of New York undoubtedly included river herring among the many species harvested. River herring, comprised of both alewife (*Alosa pseudoharengus*), and blueback herring (*Alosa aestivalis*) were among the fish mentioned by early explorers and colonists – the French Jesuits, Dutch and English. Archaeological digs along the Hudson in Native American middens indicates that the fishery resources in the river provided an important food source to them.

Written records of the Hudson's river herring fishery were over-shadowed by the shad fishery. Records for herring begin in the early 1900s and follow a path of increased landing through the years of WWII followed by a quick dramatic decline to the mid-1960s. Since then harvest remained relatively low. Just as for American shad, factors, other than fishing, contributed to keeping the population low: habitat destruction (filling of shallow water spawning habitat) and water quality problems associated with pollution, creating dissolved oxygen blocks in major portions of the river (Albany and New York City).

In this chapter, we summarize the history and characteristics of the Hudson stock of river herring, provide abundance trends, describe possible benchmarks, and make recommendations for the stock.

10.2 MANAGEMENT UNIT

The management unit for river herring stocks in New York State comprises three sub-units. All units extend throughout the stock's range on the Atlantic coast.

- The largest consists of the Hudson River Estuary from the Verrazano Narrows at New York City to the Federal Dam at Troy including numerous tributary streams (Figure 1).
- The second is made up of all Long Island streams that flow into waters surrounding Long Island and streams on the New York mainland (Bronx and Westchester Counties) that flow into the East River and/or Long Island Sound (Figure 2).
- The third subunit consists of the non-tidal Delaware River and tributaries upriver of Port Jervis

10.3 REGULATORY HISTORY

During the 19th century, regulating fisheries within New York waters was the sole responsibility of the state. In 1868, in response to an apparent decline in American shad, the New York State legislature implemented fishing net restrictions, an escapement (net free) period and a season to control fishing on the Hudson. It is likely that these restrictions (season and net use) also affected the take of river herring, as all three Alosines (American shad [*Alosa sapidissima*], alewife and blueback herring) occurred in the river at the same time. Prior to 2013, take of river herring in New York remained relatively unregulated.

Most restrictions concerned the use of gear to take fish, with no limits on take for either recreational or commercial use.

In response to Amendment 2 New York State proposed, and ASMFC approved, the 2012 Sustainable Fishery Management Plan (SFMP) for New York River Herring Stocks (Hattala et al. 2011a). This SFMP included an experimental five year restricted fishery in the Hudson River, a partial fishery closure in tributaries, a moratorium for all non-Hudson waters, and annual stock monitoring in the Hudson River. Monitoring included young of year indices, and for adults: age and length characteristics, mortality estimators, and commercial fishing catch per unit effort (CPUE). The sustainability target for both species was set using the young-of-year indices. The sustainability target value was defined as the 25th percentile of the time series, such that three consecutive years with index values below this target would trigger management action. From 2012-2016, the indices did not fall below the target for three consecutive years for either species.

In 2017, New York State submitted a an update to the 2012 SFMP (Hattala et al. 2011a), which proposed a continuation of the moratorium in non-Hudson waters, a restricted fishery in the Hudson River, annual stock monitoring, and sustainability target described in the original SFMP. This update was approved by the ASMFC Management Board in February 2017 (Eakin et al. 2017).

10.4 ASSESSMENT HISTORY

The first ASMFC assessment of the coast-wide river herring stocks occurred in 1990 (Crecco and Gibson 1990). New York stocks were not included in this analysis.

A second, benchmark ASMFC assessment took place in 2012 (ASMFC 2012). Data for Hudson River stocks of both species were inconsistent. Total lengths were decreasing, while commercial CPUE's were increasing. The young-of-year indices were extremely erratic, potentially indicating instability in the system. As a result of these conflicting stock indicators, the Hudson River stocks for both species were classified as depleted but stable, warranting a reduced commercial and recreational fishery rather than a moratorium.

10.5 STOCK SPECIFIC LIFE HISTORY

Hudson River and tributaries

River herring in the Hudson River spawn in the spring. Alewives are the first to enter the estuary, arriving as early as mid-March and spawning through mid-May. Blueback herring arrive slightly later, generally in April and spawn into early June (Hattala et al. 2011b; Eakin, Cornell University, unpublished data). River herring spawn in the entire freshwater portion of the Hudson and its tributaries up to the first impassible barrier. Adults of both species spawn in Hudson River tributaries, but also spawn in shallow waters of the main-stem Hudson. The nursery area for river herring includes the spawning reach and extends south to Newburgh Bay (rkm 90) encompassing the freshwater portion of the estuary.

Some river herring migrate upstream of the Federal Dam through the Champlain and Erie Canal lock systems. We do not know: 1) if a significant number of river herring move upstream of the dam relative to the entire Hudson River spawning population 2) how many post-spawn adult river herring survive their return trip out of the canal system or 3) if the juvenile herring are able to survive and return to the Hudson River below the Federal Dam. Construction of passage on the Federal Dam will facilitate upstream and downstream migration.

Adults of both species initially enter the Hudson tributaries, but also spawn in the shallow waters of the main stem Hudson. Alewife prefer to spawn over gravel, sand and stone in back water and eddies whereas bluebacks tend to spawn in fast moving water over a hard bottom. Herring spawn in the entire freshwater portion of the Hudson and its tributaries up to the first impassible barrier for approximately six to ten weeks. Once spawning ends, most fish quickly return to ocean waters.

A portion of the Hudson's blueback herring stock are known to move as far inland as Rome NY (439 km inland), via the Erie Canal and Mohawk River. Blueback herring access the canal via the Troy Lock and the Waterford flight (series of locks into the Mohawk river/Erie Canal, see description in Section 6). The canal system opens in New York on or about May 1st. Because of this late opening, most alewives are already spawning. Many blueback have yet to spawn and congregate below the lock at Troy to move into the canal system.

Long Island, Bronx and Westchester Counties

The herring runs in streams on Long Island are comprised almost exclusively of alewife (B. Young, NYSDEC retired, personal communication). Most streams are relatively short runs to the ocean from either head ponds (created by dammed streams) or deeper kettle-hole lakes. Either can be fed by a combination of groundwater, run-off or area springs. Spawning occurs in April through May in the tidal freshwater streams below most of the barriers. Passage for spawning adults into the head ponds or kettle lakes occurs on just a few streams.

Little is known about runs in the Bronx and Westchester County streams. We have no record of river herring in any of the streams in southern Westchester County. In the Bronx River (Bronx County) alewives were introduced to this river in 2006 and 2008 and some adult fish returned in 2009 (Jackman and Ruzicka 2009). Monitoring of this run is in its early stages.

Delaware River

River herring in the New York portion of the Delaware River are very rare. While there have been individual young-of-year (YOY) fish occasionally found (Horwitz et al 2014), we have no record of any fishing effort for either species.

10.5.1 AGE

There are several historical sampling efforts that report age data for spawning adult river herring in the Hudson River watershed. A blueback herring study, conducted in 1989 and 1990, collected data on length and scales for aging from fish in the upper Hudson Estuary and the Mohawk River, a major tributary of the Hudson. Additional length and age data for both species came from the 1936 Biological Survey of the lower Hudson River watershed (Greeley 1937) and a 1999-2001 state-contracted survey conducted by Normandeau Associates, Inc. (NAI 2008) on the Hudson River and its tributaries. In 2012 New York established the river herring spawning stock survey. The objectives of the survey were to evaluate species, size, age, and sex composition of spawning river herring. Table 1 lists the number at age by survey, species, and sex.

Unfortunately, aging techniques have varied among these studies. The 1989-90 study used Cating's (1954) technique, developed for aging American shad scales. NAI (2008) developed their own aging criteria after noting many discrepancies on annuli placement compared to the Cating shad technique. It is not known what criteria Greeley used to age the few fish reported from the 1936 Biological Survey. Current NYSDEC protocols were developed through training sessions and workshops with aging experts along the coast (see ASMFC 2014). The revised protocol can be found in Appendix 2 of the 2017 SFMP (Eakin et al. 2017). With no overlap among the agers, the use of different sampling gears, and no uniform aging protocols among the surveys, any comparison of ages or lengths at age across surveys and years should be done with extreme caution.

10.5.2 GROWTH

Growth characteristics of river herring were estimated using the Von Bertanlanffy and Gompertz Growth models (Ricker 1975). Both models use the annual age and associated lengths and weights of aged samples from the fishery independent surveys described above in Section 5.1. In all calculations, the same young-of-year values were used to anchor the models. These values came from samples from the NYSDEC Alosine Beach Seine Survey. Resulting estimates for each survey and time period are found in Table 2 for Von Bertanlannfy growth and Table 3 for Gompertz growth. Though these estimates may provide a snapshot of the growth characteristics of each species, they should be used with caution, as they can be highly influenced by sample size, aging protocol, inter-year class variation and changes in fishing mortality. It is anticipated that with a longer time series (5-10 more years) of ages, lengths, and weights collected in the current sampling strategy and aged with current aging methodologies, will come more robust growth estimates and associated error values for the existing fishery.

10.5.4 REPRODUCTION

Spawning begins in the Hudson Estuary in April for alewife when water temperatures reach 10-11°C. It continues through early May; blueback spawn when water temperatures reach about 14°C and cease spawning by early June (Smith 1985). The rate of post-spawning mortality is unknown for either species.

10.5.5 MATURITY SCHEDULE

The spawning stock survey (2012-present) is the most consistent dataset to evaluate maturity for both species. From these data, maturity was estimated from age at first spawn, subtracting the number of spawning marks from the age of each fish. Maturity schedule is presented as percent mature at age present in the river for each species and sex. As with growth rates, annual variations in recruitment and fishing mortality have significant impacts on maturity schedules. To address these potential problems, we will compare inter-annual maturity estimates with those calculated by year class once enough long-term age and spawning mark data are available.

Age data from 2012-2015 (see Figure 3) indicate that alewife herring primarily begin to spawn at age three and are fully mature by age five. Blueback herring begin to spawn at age two and the majority reach full maturity by age four.

10.5.6 FECUNDITY

Limburg and Blackburn (2003) performed a fecundity and condition analysis for blueback herring collected during a large river herring study conducted by the Normandeau Associates, Inc. (NAI 2008) from 1999 to 2001. NAI collected fish from the lower Hudson River's Tappan Zee (rkm 40) to Lock 17 at Little Falls in the Mohawk River (rkm 382). A total of 169 females and 75 males were examined.

The blueback herring of the Hudson and Mohawk Rivers embark on a long and complex spawning run. Condition, measured as a Gonadosomatic Index (GSI), levels decreased in both males (30%) and females (26%) as fish stayed longer and swam further up river. Feeding was documented in blueback herring and likely supplemented energy loss due to migration. Total fecundity varied with "age" (as determined from otoliths by Limburg and Blackburn) and ranged from 3,993 to 177,948 for "green" (ripe) fish. Estimated egg standing crop was 98,870 eggs (256 mm length-standardization of "green" fish). This number is low compared to other similar estimates from Canada, the Connecticut and Altamaha Rivers. The identification of multiple size modes of eggs indicate batch spawning in blueback herring, similar to that seen in American shad (Olney and McBride 2003).

Limburg and Blackburn (2003) also stated that fecundity was positively related to fish aged three to six, with wide confidence intervals. However, a lack of relationship with length was most likely the result of the selectivity of the gill net sampling gear. It is also possible that some ages derived from otoliths were not correct since accuracy of ageing river herring by otoliths has not been verified.

10.6 HABITAT DESCRIPTION

10.6.1 SPAWNING AND NURSERY HABITAT

Hudson River Estuary

The Hudson River flows from Lake Tear of the Clouds in the Adirondacks to the Battery in New York City. It is influenced by tides to the Federal Dam in Troy, 245 km from the Battery (Figure 1). The salt front moves, depending on freshwater inputs from Hudson River tributaries and tidal flow, and generally varies in location from Tappan Zee (rkm 45) to Newburgh (rkm 95). The river includes two major estuarine bays: Haverstraw Bay (rkm 55) and Tappan Zee Bay (rkm 45). These bays are mainly shallow water less than four meters deep where the river extends up to five and a half kilometers from shore to shore. The river also includes a narrow and deep section, the Hudson Highlands, where the river is less than one kilometer wide and over 30 meters deep (Stanne et al., 2007).

The Hudson River below the Federal Dam at Troy has approximately 68 primary tributaries, most of which provide some spawning habitat for river herring (Schmidt and Cooper 1996). The largest of these tributaries is the Mohawk River, which enters the Hudson two kilometers north of the Troy Dam. Diadromous fish access to the Mohawk River, and portions of the non-tidal Hudson above the Federal Dam, is possible only through the Erie Canal and Champlain lock system. Fish passage for migratory species at the Troy dam is required by a 2009 FERC relicensing settlement agreement and is in the design phase. Other major tributaries of the Hudson River, all in the estuary, include the Croton River, Wappingers Creek, Rondout Creek, Esopus creek, Catskill Creek, and Stockport Creek.

Long Island, Bronx, and Westchester County

Freshwater tributaries in the New York portion of the Atlantic Ocean and Long Island Sound watershed are also important for New York river herring (Figure 2). This watershed drains most of the New York City Metropolitan Area, all of Long Island, and portions of Westchester County. The Atlantic Ocean coastline extends 189 kilometers from Rockaway Point to Montauk Point. The watershed includes 840 kilometers of freshwater rivers and streams.

The herring runs in streams on Long Island are comprised almost exclusively of alewife (B. Young, NYSDEC retired, personal communication). Most streams are relatively short runs to saltwater from either head ponds (created by dammed streams) or deeper kettle-hole lakes. Either can be fed by a combination of groundwater, run-off, or area springs. Spawning occurs mid-March through May in the tidal freshwater below most of the barriers. Natural passage for spawning adults into the head ponds or kettle lakes is present in very few streams.

There have been limited efforts to understand river herring runs on Long Island since 1995. Several known runs of alewives on Long Island occur in East Hampton, Southampton, Riverhead and Brookhaven. With the advent of a more aggressive restoration effort in Riverhead on the Peconic River other runs have come to light. Since 2006, an annual volunteer alewife spawning run survey has been conducted. This volunteer effort predominantly documents the presence or absence of alewives in Long Island coastal streams. In 2010, a volunteer investigation was initiated to quantify the Peconic River alewife run. Size and sex data have been collected annually since 2011. A first order estimate of the Peconic River spawning run size has been attempted since 2010; attempts have been made to improve these observations with video counts. These efforts have been undertaken to understand the Long Island coastal streams and to improve the runs that exist there.

10.6.2 HABITAT LOSS AND ALTERATION

Hudson River Estuary

Hudson River tributaries provide important habitat to both migrating and resident fishes, as well as other wildlife. Barriers to upstream and downstream movement exist in tributaries to the Hudson River, many of them in relatively short distance upstream from the confluence with the Hudson River. While many of these barriers are natural features, such as waterfalls and ledges, there exist numerous anthropogenic barriers, including dams (some opportunistically built on top of existing natural barriers), undersize and improperly positioned culverts, and undersized bridges. Thus, many opportunities exist to remove man-made barriers in order to restore historical upstream and downstream access to important habitats for both diadromous and resident fishes. Based on NOAA's 2009-2014 evaluation of 67 lower Hudson tributaries, the first barrier upstream from the Hudson are man-made on 27 tributaries, while 37 are natural and three are undetermined (Alderson and Rosman 2014). After further assessment to consider where barrier removal is practical and beneficial to river herring, this research estimated that 56 tributary kilometers have the potential to be opened to river herring via the removal of 27 barriers on 14 tributaries. The largest gains in total stream miles can be found on the following five tributaries: Claverack, Croton, Moodna, Rondout, and Sparkill Creeks. Restoration opportunities on these five tributaries could enhance access to river herring habitat for an estimated 35.8 kilometers. Removal of man-made barriers in the Hudson River Estuary is a high priority because of the potential for habitat gains and the perceived limitation of number of opportunities for large-scale restoration.

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

Another factor that is not well researched or understood is the potential barriers posed by the railroads along both the east and west sides of the Hudson River. Tributaries once flowed freely, with unobstructed hydraulics, from the upland valley to the wide estuary. While these connections still exist, they are much different today than they were historically. Tributaries are forced through bridge and culvert constrictions under the tracks as they make their way to the Hudson River. The impact of this funneling effect on access from the Hudson into tidal tributary mouths is not well understood.

Long Island, Bronx, and Westchester County

Most streams on Long Island and in Westchester County were impacted by human use as the population expanded. Many streams were blocked off with dams to create head ponds, initially used to contain water for power or irrigation purposes for agriculture. The dams remain; only a few with passage facilities. Many streams were also negatively affected by the construction of highways, with installations of culverts or other water diversions which impact immigrating fishes.

10.7 HABITAT RESTORATION

Hudson River Estuary

The Hudson River Estuary Habitat Restoration Plan (Miller 2013) has identified a number of river and tributary restoration activities that will benefit river herring, including barrier mitigation and side channel restoration. Recent research has highlighted important barrier removal opportunities for river herring habitat in the Hudson River Estuary (Alderson and Rosman, 2014). Mitigation of these barriers is an important priority for many researchers, non-profits, and local governments in the estuary, and features prominently in the Hudson River Estuary Program's Action Agenda 2015-2020 (2015).

In May 2016, the first dam upstream of the confluence with the Hudson River was removed from the Wynants Kill, a relatively small tributary in Troy, NY, downstream of the Federal Dam. Within days of the May 2016 removal, hundreds of herring moved past the former dam location into upstream habitat. Subsequent sampling efforts yielded river herring eggs, providing evidence that river herring were actively spawning in the newly available habitat. This dam removal will provide an additional half kilometer of spawning habitat for river herring that has not been available for 85 years.

There are also a number of side-channel restoration projects under development that will improve habitat for river herring in the estuary. Side channels within the river bed provide important shallow water and intertidal habitats that are isolated from the higher energy regime of the main channel. These side channels historically occurred in the northern third of the estuary as part of a braided river-channel system dominated by vegetated shallows and intertidal wetlands. These habitats were destroyed on a large scale in the early twentieth century, particularly in the upper estuary, as a result of dredge and fill activities associated with construction of the federal navigation channel.

Gay's Point (rkm 196) has been identified as a potentially suitable location for side channel creation. The site consists of an artificially created tidal embayment that is separated from the main river channel by dredge spoils. Contiguous backwaters, such as those at Gay's Point, typically have lower current velocities, greater sediment deposition resulting in finer substrates, higher water temperatures, and lower dissolved oxygen levels than side channels with relatively unimpeded flow. Increasing tidal flow through the embayment at Gay's Point is anticipated to improve water quality, provide coarser-grained bed materials, and ultimately create more productive spawning, nursery, and foraging habitat for river herring. This project is currently under way and is being overseen by the New York State Department of Environmental Conservation.

Long Island, Bronx, and Westchester County

Initial barrier mitigation to benefit river herring was summarized in the last SFMP, and included restoration of herring runs on the Carmans and Peconic Rivers (Hattala et al. 2011a), and rudimentary fish passage at Beaver Lake, Oyster Bay. Since 2011, additional completed barrier mitigation projects that benefit alewife include the installation of passage devices at five locations (Canaan Lake, Brookhaven; Twin Ponds, Centerport; Argyle Lake, Babylon; Udall's Mill Pond, Saddle Rock; and Massapequa Creek, Massapequa); a box culvert modification at Alewife creek, Southampton; and a dam removals at Harrison Pond in Smithtown and at Sunken Meadow. Additionally, the installation of fish passage devices on the Bronx River and at the Edwards Avenue dam in Riverhead may provide additional spawning habitat once further barriers have been mitigated.

Barrier mitigation remains a priority for a number of environmental groups and local, state, and federal agencies. We are aware of at least six additional projects that are likely to occur in the next five years.

10.8 FISHERY DESCRIPTION

Historical fisheries for river herring in New York State waters occurred in the Hudson River Estuary and tributaries, some streams on Long Island, and as bycatch in commercial fisheries in marine waters around Long Island. The herring taken in the bycatch ocean fishery were of unknown mixed stock origin. Currently, the Hudson River Estuary fishery is the only remaining fishery in New York. Current commercial and recreational fishing restrictions for the Hudson Estuary are listed in Appendix 1.

10.8.1 FISHERY DEPENDENT - COMMERCIAL

Hudson River Estuary

Anecdotal reports indicate that herring played a small part in the historical commercial fishing industry in the Hudson River. The current commercial fishery in the Hudson River exploits the spawning migration of both alewife and blueback herring. River herring may be commercially caught in the Hudson River from March 15th to June 15th, dates inclusive. The primary use of commercially caught herring is for bait in the recreational striped bass fishery. An annual commercial Hudson River permit allows use of the following gears: gill nets, scoop/dip/scap nets, seines, fyke nets, and trap nets. Permit holders are required to report effort and harvest to the Department. In response to Amendment 2, more stringent regulations were put into place in 2013. Highlights include the closure of tributaries to nets, net size restrictions for scap nets, and monthly reporting (Appendix 1).

Fishing effort and commercial gear use has historically been different south of the Bear Mountain Bridge (rkm 75) than in the northern reaches. This is roughly the location of the salt front in the spring. As such, this bridge is used as a demarcation for gear use. The fishery below the Bear Mountain Bridge intercepts fish moving to freshwater spawning areas, while the fishery north of the bridge targets river herring in their spawning aggregation areas.

The intercept fishery is a fixed gill net fishery that occurs in the main-stem river from rkm 40 to rkm 75 (Piermont to Bear Mountain Bridge, Figure 1). In this stretch, the river is fairly expansive (up to 5.5 km) with wide, deep-water (~ six to eight m) shoals bordering the channel. Most fishers in this portion of the fishery choose specific locations within these shoals and sample in the same locations each year. The fishermen generally fish these nets from 12-24 hours per trip. Since 2013, an average of 22 active fishers annually participated in this lower river fixed gill net fishery. Nets are 7.6 to 91 m long, with meshes ranging from 4.4 to 8.9 cm stretch.

Fishermen in the freshwater portion of the fishery, above Bear Mountain Bridge, use drift gill nets to sample the main-stem of the Hudson River. This gear is used up to rkm 225 (Castleton) where the river is much narrower (1.6 to 2 km wide). Since 2013, an average of 49 fishers annually participate in this mid river gill net fishery. Nets range in length from 6 to 183 m with mesh size ranges from 3.8 to 8.9 cm stretch. These nets must be tended at all times, and most are fished for less than two hours per trip. Though restricted from use in the 2013 regulation changes, commercial reports indicate fixed gill nets have been used in roughly 19% of gill net trips above Bear Mountain since 2013.

Scap nets (also known as lift and/or dip nets) are the other major gear used in the freshwater river herring fishery. Prior to 2013, this gear was primarily used in the major river herring spawning tributaries. The current scap/lift net fishery occurs in main-stem river from roughly rkm 90 to rkm 228 (Cornwall-on-Hudson to Port of Albany). Scap/lift nets range in size from 0.28 to 59.7 m^2. On average, 31 fishers have annually reported the use of this gear type since 2013.

It is important to note that many commercial permit holders are recreational anglers taking river herring for personal use as bait or food. From 2013 to 2015, an average of 156 gill nets and 121 scap nets permits were sold annually. According to the required annual reports, however, only 35% of the permitees actively fished in those three years (Table 4), and of those that used the commercial gears, roughly half of gill net users and the majority of scap net users reported catches as taken for "personal use" or "personal bait" (Figure 4).

10.8.2 Commercial Landings and License Reporting

Recorded landings of river herring in New York State began in the early 1900s (Table 9 and Figure 5). Anecdotal reports indicate that herring only played a small part in the historic commercial fishing industry in the Hudson River. Total New York commercial landings for river herring include all herring caught in all gears and for both marine and inland waters. Several different time series of data are reported in Table 9, including several state sources, National Marine Fisheries Service (NMFS), and more currently Atlantic Coastal Cooperative Statistics Program (ACCSP). NMFS data do not specify river or ocean source(s) and landings are often reported as either alewife or blueback herring, but not both in a given year. It is unlikely that only one species was caught. From 1995 to the present, the Department has summarized landings and fishing effort information from mandatory state catch reports required for Hudson River marine permits. Full compliance for this reporting started in 2000. All Hudson River data are sent to NMFS and ACCSP for incorporation into the national databases.

Because of the discrepancies among the data series and the lack of information to assign the landings to a specific water body source, only the highest value from all sources is shown in Figure 5. This method limits double counting. Several peaks occur during the time period. The first peak was in the early 1900's (501,438 pounds) followed by a lull until the period prior to World War II when landings peaked a second time in 1935 (274,405 pounds). Post WW II there was another period of low landings until a final peak in 1982 (229,201 pounds). Combined ocean and river landings in New York waters has remained relatively low, with some data gaps, during the rest of the 1980s through present. In 1966, roughly 4.2 million pounds were landed (omitted on Figure 5), followed by a series of years of low landings with another peak in 1982. Landings were low, with some data gaps during the rest of the 1980s through present.

Hudson River Landings

Since 1995, landings are separated between the Hudson and other waters (Table 9). However due to optional participation and minimal enforcement of commercial reporting, any in-river reporting from 1995-1999 is unreliable. It is likely that additional effort was shifted to river herring catches during this time-period than is reported. Moving forward, analyses on in-river landings begin in 2000.

The primary outlet for harvest taken by commercial Hudson River permits is for the in-river bait industry. From 2000 to 2012, nearly all reported commercial river herring landings were split between scap/lift nets (~49% of the catch) and gill nets (~16% drift and ~35% fixed) (Figure 6). From 2000 to 2012, combined landings averaged 15,061 pounds, peaking in 2002 at 20,346 pounds. Post regulation change in 2013, landings declined to roughly 45% of the average from 2000 through 2012. Scap nets accounted for the largest portion of this decline. This is a result of the ban on nets from tributaries, where most commercial scap netting occurred. As the demand for bait has probably not diminished, we expected an increase in landings for the other gears. Though there was a slight increase in drift gill net landings, a big portion of this missing harvest has likely shifted to non-commercial gears, such as hook and line, cast nets, and small scap nets. These personal use gears do not have a mandatory reporting requirement.

10.8.3 Commercial Discards

Hudson River fishery discard rate

From 1996 to 2010, river herring were not reported as discards on any mandatory reports targeting herring. Some minimal discards were reported after 2011, but these have been less than 1% of total catch (see values in black in Figure 4).

Mixed stock ocean fisheries

Level of discard and discard rate is unknown.

10.8.4 Commercial Catch Rates

10.8.4.1 *Hudson River Catch Rates - Mandatory reports*

Relative abundance of river herring is tracked through catch per unit effort (CPUE) statistics of fish taken from the targeted river herring commercial fishery in the estuary. All commercial fishers fill out monthly mandatory reports. Reports include catch, discards, gear, effort, and fishing location for each trip. CPUEs are calculated as total catch divided by total effort (square yards of net * hours fished), separately by gear type (fixed gill nets, drift gill nets, and scap nets). Annual mean CPUEs are summarized differently based on the location of fishing effort.

Above the Bear Mountain Bridge (rkm 75 in Figure 1) and within the spawning reach, drift gill nets and scap nets are the primary gears. In this section of river, fishermen catch fish that are either staging or moving into areas to spawn. Gears are generally not deployed until fish are present. CPUEs for gears above the Bear Mountain Bridge are calculated as total annual catch/total annual effort. Below the Bear Mountain Bridge (rkm 75) and thus below the spawning reach, fixed gill nets are the primary commercial gear. In this section, nets are fished in roughly the same location each year by a consistent group of fishermen. These fishermen capture fish moving upriver to spawning locations and run size is determined by number (density) of spawners each week as well as duration (number of weeks) of the run. Annual CPUEs in this reach are calculated as the sum of weekly CPUEs to best capture the periodicity of run. Annual efforts and CPUEs for the main commercial river herring gears are shown in Figure 7. Values for drift gill and scap net values in Figure 7 are only for trips above rkm 75, while fixed gill net values are only for trips made below rkm 75.

As shown in Part A of Figure 7, drift gill net CPUEs have increased steadily since 2000, with efforts declining since 2006. Annual drift gill net trips by river section above the Bear Mountain Bridge are shown in Table 10. On average, 74% of drift gill net trips take place in the Saugerties and Catskill reaches. Based on historical information on spawning (Schmidt et al. 1994; Schmidt and Lake 2000) as well as the recent results from the fishery independent survey described in Section 9 below, these sections make up a small portion of the habitat available for spawning. In addition, there are two significant stretches of river where gill net use is prohibited. Due to the opportunistic nature of the upriver fishery (fishermen only fish when river herring are present), as well as the large amount of variability in effort within the freshwater spawning reach, this dataset is not reliable to track annual abundance.

Annual scap net CPUEs and efforts are shown in Part B of Figure 7. Efforts were relatively steady through 2012, but dropped dramatically in 2013 when net use became illegal in tributaries. Scap net CPUEs declined from 2000 to 2007, and have increased from 2007 to present. Due to significant changes in the fishery due to regulation changes, CPUES from this commercial gear are not reliable to monitor changes in relative abundance.

Part C of Figure 7 shows effort and CPUEs for the lower river fixed gill net fishery. Effort in this fishery has decreased steadily since 2000, but the annual sum of weekly CPUEs has been increasing since 2010. Because most river herring must pass through this fishery on the way to freshwater spawning reaches and tributaries, it has the best chance at sampling the entirety of the spawning stocks of both species. As such, these CPUEs likely provide the best abundance indicator of the three main commercial gears and are best suited for trend analysis.

10.8.4.2 *Hudson River Commercial Monitoring Program*

Catch Rates

Until the mid-1990s, the Department's commercial fishery monitoring program was directed at the American shad gill net fishery, a culturally historic and economically important fishery. We expanded monitoring to the river herring fishery in 1996, but remain limited by available manpower and the ability to connect with the fishers. Monitoring focuses on the lower river fixed gill net fishery since we considered it to be a better measure of annual abundance trends (see section above).

While onboard commercial fishing vessels, technicians record numbers of fish caught, gear type and size, fishing time, and location. Scale samples, lengths and weights are taken from a subsample of the fisher's catch. CPUE is based on gear type and location and is calculated by the method used for summarizing mandatory report data.

Since 1996, staff monitored 122 trips targeting river herring. Annually, these trips were sporadic and sample sizes were low, from zero to 20 trips per year (Table 11). Because of minimal sample size, the resulting CPUE is potentially unreliable for tracking relative abundance. However, as shown in Figure 8, the commercial monitoring CPUE for fixed gill nets in the lower river follows the same trend as the lower river CPUE from the same gear in mandatory commercial catch reports (correlation value 0.81, $p < 0.001$). This is indicative that our monitoring efforts capture trends in the reported fishery. With increased sample sizes for commercial monitoring, we expect this relationship to improve. In addition, active monitoring provides the only data on catch composition of commercial harvest.

Catch Composition, Size and Age Structure

Catch composition in the fixed gill net fishery varies annually, most likely due to small sample sizes and when the samples occurred (early or late in the run) (Table 12). Annual observed landings ranged from 44 to 2,450 fish, with alewives observed more often than blueback herring. The sex ratio of alewives was nearly equal (~ 50:50) in all years; however, female blueback herring were observed more often than male blueback herring most likely due to the size selectivity of gill nets fished and timing of fishery.

Mean lengths and weights of dockside subsamples are shown in Figure 9. Though sample sizes are relatively low for certain years, there is an increasing trend in length and weight for both species since 2010. This trend is similar to that observed for both species in the spawning stock survey (***Section 8.1.3***).

Age data for samples collected during the commercial monitoring program were processed and analyzed in the methods described in Appendix 2 of the 2017 NY river herring SFMP (Eakin et al. 2017). Ages were estimated for a subsample of the scale samples in 2012 and we used an age length frequency table from these data to estimate ages for the remaining scale and length samples from the 2012 commercial fishery. Mean length at age for 2012 commercial samples were then compared to the mean length at age for fish taken in the Fishery Independent survey in 2012 (Figure 10). As there was little deviation in mean length at age for both species among the surveys, we used the annual age-length keys derived from samples collected during the Fishery Independent Survey to estimate the respective year's commercial fishery age structure from 2013-2015.

Table 13 displays the age structure for dockside samples taken from 2012 to 2015. Mean age for sexes of both species is trending upward, which corresponds with the increase in mean lengths during the same time period as well as the increasing trend in the fishery independent age dataset described in Section 9.

10.8.5 Mixed Stock and Ocean Fishery Catch Rates

Proportion of Hudson River herring caught as ocean fishery by-catch is unknown.

Quantifying the impact of bycatch and incidental fisheries on Hudson River herring remains difficult. Two Federal councils have identified alternatives to reduce catch of river herring in their Fishery Management Plans (FMP). The Mid Atlantic Fisheries Management Council's (MAFMC) Amendment 14 of the Atlantic Mackerel, Squid and Butterfish FMP and the New England Fishery Management Council's (NEFMC) Amendment 5 to the Atlantic herring FMP both identified shad and river herring as incidental catch in these directed fisheries and acknowledged the need to minimize catch of shad and river herring. Both of these plans, through the amendments identified above and subsequent framework adjustments:

- Implemented more effective monitoring of river herring and American shad catch at sea
- Established catch caps for river herring and American shad
- Identified catch triggers and closure areas

Fishery observer data are used to estimate and monitor the river herring and American shad captured by Atlantic herring and Atlantic mackerel vessels that land more than three metric tons (mt) per trip using methodology developed by the Greater Atlantic Regional Fisheries Office (GARFO), of the NOAA Fisheries. River herring and American shad bycatch and bycatch quotas are presented in Table 5 and Table 6.

While the data in Table 5 and Table 6 provide us with an estimate of the incidental catch of river herring and American shad in these fisheries, it does not identify the bycatch by species. However, Amendment 14 of the Mackerel, Squid and Butterfish FMP does present species-specific data by region and fleet from earlier years (Table 7). Observed annual alewife catch between 1989 and 2010 ranged from 2.7 mt to 484 mt with an annual average of 119 mt. Observed annual blueback herring catch between 1989 and 2010 ranged from 19.6 mt to 1,803 mt with an annual average of 290 mt. In some years, large portions of the incidental catch was not identified to species. If the same annual proportion of river herring composition is applied from the known catch to the unknown catch, the total estimated river herring catch in the period 1989-2010 ranged from 42.8 mt to 2,313 mt with an annual average of 499 mt.

Data were only located that distinguished catch by species for the time period 1989-2010. More recent data present incidental harvest data by fishery, but do not distinguish among species. In order to get a general sense of the magnitude of potential harvest from these fisheries (Table 8), the average proportion of known harvest that was river herring from the historic data (80%, from Table 7) is applied to the combined river herring and American shad catch. Unfortunately, it is impossible to determine which river herring stock(s) were affected by the harvest from these mixed stock fisheries. Directed and incidental harvest from New York waters are shown in Figure 5.

10.9 FISHERY DEPENDENT – RECREATIONAL

Hudson River Estuary

The recreational river herring fishery exists throughout the main-stem Hudson River, and its tributaries including those in the tidal section and above the Troy Dam (Mohawk River). Some recreational herring fishers use their catch as food (smoking/pickling). However, the recreational river herring fishery is driven primarily by the need for bait in the recreational striped bass fishery.

In concert with the change in commercial regulations in 2013, new regulations were put into place for the recreational fishery in response to Amendment 2. Regulations for recreational take are found in Table B of Appendix 1. The most significant changes were creel limit of 10 fish per day or 50 fish per boat, as well as the prohibition of personal net use in tributaries. All 2013 changes are denoted in bold in Table B.

The magnitude of the recreational fishery for river herring is unknown for most years. NYSDEC contracted with Normandeau Associates, Inc. (NAI) to conduct creel surveys on the Hudson River in 2001 and 2005 (NAI 2003 and 2007). Estimated catch of river herring in 2001 was 34,777 fish with a 35.2% retention rate. When the 2001 data were analyzed, NAI found that the total catch and harvest of herring was underestimated due to the angler interview methods. In the 2001 survey, herring caught by fishers targeting striped bass were only considered incidental catch, and not always included in herring total catch and harvest data. Fishers were actually targeting herring and striped bass simultaneously. Corrections were made to the interview process for the 2005 survey and estimated catch increased substantially to 152,117 herring (Table 14). Catch rates from 2001 survey were also adjusted using the 2005 survey data. The adjusted catch rose to 93,157 fish.

River herring use by striped bass anglers can also be evaluated using data obtained from our Cooperative Angler Program (CAP). The CAP was designed to gather data from recreational striped bass anglers through voluntary trip reports. Volunteer anglers log information for each striped bass fishing trip including fishing time, location, bait use, fish caught, length, weight, and bycatch. From 2006 through 2015, volunteer anglers were asked to provide specific information about river herring bait use. Due to the difficulties associated with differentiating between alewife and blueback herring, anglers were only asked to report the catch as river herring. The annual proportion of angler days where river herring was used for bait ranged from 25% (2007) to 57 % (2013) with a mean of 46%. The proportion of river herring used by anglers that were caught rather than purchased increased through the time period (Table 14). River herring caught per trip varied from 1.6 to 6.7 with the highest values in the last three years. Herring purchased per trip ranged from 0.63 to 1.7.

The most recent creel information and the CAP trips were combined in an attempt to estimate the current recreational river herring harvest. Annual numbers of striped bass trips taking place after 2007 were calculated as the 2007 creel estimate (Connelly and Brown 2009) multiplied by the ratio of CAP trips in the year of interest to the number of 2007 CAP trips. This value was then multiplied by the annual proportion of angler trips using herring in the CAP, and multiplied again by the number of herring caught or purchased per trip in the CAP. Estimates of river herring use by striped bass anglers ranged from 78,491 fish in 2007 to 386,915 fish in 2015 with an increasing trend of herring use from 2006 to 2015. To put potential recreational herring harvest in context, the average estimated annual recreational harvest from 2013-2015 was 312,036 herring. During the same time period, counts from Black Creek, a small tributary to the Hudson with approximately 1.8 km of available spawning habitat, averaged 409,233 alewives (roughly 139,000 pounds) annually (see Table 15 and *In-stream Fish Counter* in Section 9 below). Black Creek is only one of the 68 primary tributaries to the Hudson River.

This analysis should be interpreted with caution and viewed only as potential recreational river herring harvest scenarios. It should also be noted that these estimates are derived from a group of dedicated striped bass anglers who presumably exert more effort than a typical angler and thus we view these estimates as the maximum potential recreational herring harvest. Until a creel survey can be conducted, this is the Department’s best estimate of recreational herring harvest.

The number of river herring taken from the Hudson River and tributaries for personal use as food by recreational anglers is unknown but expected to be minimal.

Long Island, Bronx and Westchester Counties

As of 2013, recreational river herring fisheries have been closed in the marine and coastal district of NY.

10.10 FISHERY INDEPENDENT SURVEYS

10.10.1 SPAWNING STOCK SURVEYS

Several surveys have sampled the alewife and blueback herring spawning stocks, or production, portion of the population. These are the fish which have escaped from coastal and in-river commercial fisheries. Spawning stock data for river herring in the Hudson River is available from several sources: a New York Conservation Department historical report, a variety of NYSDEC surveys, and a large scale survey contracted to Normandeau Associates, Inc. (NAI 2008).

10.10.2 New York State Surveys

The New York State Conservation Department, predecessor of the current NYSDEC, conducted a biological survey of all state natural resources during the 1930s. The Hudson watershed was sampled in 1936 (Greeley 1937). Number, mean length, and weight for both sexes of blueback herring ('summer' herring) and alewife are reported in the top rows of Table 16 and Table 17; sample size is very small.

NYSDEC river herring data are from several surveys (Table 18). The longest dataset (1975-2000) is from an annual survey of chemical contaminants in fish that targeted multiple species within the Hudson River estuary. Sample size varied among years. In most years, length data were recorded for a sub sample of the total collected. The NYSDEC also conducted a short, two year survey in 1989 and 1990, to examine the population characteristics of blueback herring in the Hudson and the Mohawk River, the Hudson's largest tributary.

From 1985 to the present, the NYSDEC Hudson River Fisheries Unit (HRFU) has conducted an annual American shad and striped bass spawning stock survey. One component of this survey uses electro-fishing gear to collect large numbers of striped bass for tagging; herring are incidental catch. The major gear used for the spawning stock survey is a 154 m or 305 m haul seine, fished at beaches located throughout the spawning area for shad and striped bass. The 10.2 cm stretch mesh in these nets was specifically designed to catch shad and striped bass, but to let smaller river herring escape. However, some large (> 280mm) herring were occasionally caught in these gears. Sampling occurs between Hudson River km 145 and km 232 from late April through early June.

In 1987, the Department added river herring sampling to the existing American shad and striped bass spawning stock survey. Sampling occurred sporadically and when time allowed. From 1987 to 1990, two small mesh (9.5 mm) beach seines (30.5m and 61m) were used with limited success. In 1998, the Department specifically designed a small haul seine (91 m) with an appropriate mesh size (5.1 cm) to target river herring. Similar to the gear design for the American shad and striped bass seine survey to minimize size and age bias (Kahnle et al. 1988), the Department designed the herring seine to capture all sizes present with the least amount of bias. The current herring haul seine design consists of two 46 m long by 3.7 m deep wings attached to a round, center-located bag measuring 1.2 meters in diameter and 3.7 m long. The entire net is 5.08 cm stretch mesh made of twisted nylon twine. The top float line includes fixed foam floats every 0.6 m and fixed chains to the lead line (bottom of seine) every 0.75 m.

To meet the requirements outlined in Amendment 2 (ASMFC 2009) for the mandatory fishery-independent monitoring programs, in 2012 New York established the river herring spawning stock survey. The objectives of the survey were to evaluate species, size, and sex composition of spawning river herring; and then develop the methodology to use the gear to perform an annual assessment of the Hudson River's river herring spawning stock. The sampling target was four sample days per week (March 15 to June 15). A minimum of five beaches were sampled each day, and results were used to evaluate sample sites for future sampling use as well as collect spawning adult river herring in the area.

In 2012, sampling sites ranged from Tappan Zee (rkm 45) to Albany (rkm 232) (Figure 1). Despite much effort in 2012, no river herring were caught in the southern part of the river from Poughkeepsie south to the Tappan Zee. These areas were dropped in 2013, and the sampling area was pared to the mid and upper river sections where river herring were most readily caught. Currently, each sampling day of the week focuses on one river reach from Kingston (rkm 136) to Albany (rkm 232) (Figure 1). Reaches are broken down as follows: Kingston (rkm 136-169), Catskill (rkm 170-190), Coxsackie (rkm 191-213), and Albany (rkm 214-232). Initially, sites were randomly selected from a map of all known beaches within the Hudson River Estuary. After scouting, sites were removed if they no longer had beaches or had major sampling obstructions. Current sampling focuses on 15 fixed sites spread throughout the four reaches. Table 19 lists sampling efforts and catches per river section from 2012-2015.

After each haul, technicians examine each fish for species, gender, and spawning condition. A subsample of ten fish are sampled of each gender and species for total length, weight and scale samples are removed. When possible, 30 extra fish are measured from each sex and species for each sampling event. All other incidental catch is tallied by species.

In-stream Fish Counter

In 2013, a pilot study was initiated using an in-stream fish counter in Black Creek. Black Creek is a small tributary located at rkm 135, just south of Kingston, NY and has a known river herring spawning run. The primary objective was to determine if a fish counting device was an appropriate method to collect absolute abundance data for river herring in small tributaries. The secondary objectives were to identify when river herring migrate into tributaries and identify parameters that may influence those migrations (i.e. moon phase, water level, water temperatures).

The study design consisted of a stream wide weir to guide river herring through a Smith Root SR-1601® multichannel fish counter. NYSDEC staff built the counting head using four inch PVC tubes stacked in two rows of four, forcing fish through one of eight individual counting tubes (Figure 11). The counter was installed at the end of March each year and remained in place until the end of May. The location of the counter is close to the head of tide. Staff attempted to visit the counter on a daily basis. During site visits, technicians recorded fish counts on the counter system, along with any applicable environmental observations, such as weather conditions, temperature, and water level. Once the daily count was recorded, the counter was reset to zero. To compare potential diel patterns, multiple visits were made during the same day. In 2013, a trap was incorporated into the design of the weir to help determine species composition of the fish passing through the counter and assess the accuracy of the electronic counter. This trap was attached to the counter exit directly up stream of the weir. The trap was closed on five occasions at various times throughout the run in 2013. It was hoped that these trapping results could be used as a correction factor to the final count data; however, it was very difficult to capture every fish in the trap due to the stream substrate as well as impaired visibility. At this time there is no accurate correction factor for the counts. To address this in 2014, a video camera system was used to verify counts and create an accurate correction factor. Staff are currently analyzing video footage.

Monitoring of Black Creek has continued on an annual basis since 2013 and annual count data are reported in Table 15. Historic evidence shows the spawning run in Black Creek to be exclusively made up of alewife (Schmidt and Lake 2000). This has been verified in all years of monitoring, as all mortalities and all live captured river herring at or near the weir were identified as alewife. The annual count data from Black Creek is used as ancillary data to support trends identified in the relative abundance indices described in section 3.2.2 and provide a reference for landings in the commercial and recreational fisheries.

10.10.3 Normandeau (State Contracted) Survey

During the period when the NYSDEC was trying to target river herring in their sampling programs, Normandeau Associates Incorporated (NAI 2008) was contracted to survey river herring throughout the Hudson River and its tributaries, including the Mohawk River from 1999-2001. The primary study objective was to determine the best method available to easily characterize the spawning stock over a broad geographic area. Over the three year period, they used many combinations of gear in the various sampling areas (Hudson, tributaries and Mohawk). The most prevalent gear used was gill nets chosen for their mobility and need for small field crews. Scap and cast nets were predominantly used in the tributaries.

A number of difficulties were identified. Not all gears worked equally well both temporally and spatially in the different sampling areas (Hudson, small tributaries and Mohawk). Data from the NAI study were limited by the high selectivity of the gill net gears, inconsistent use of different gill net mesh sizes among years, and lack of comparability of gear uses in the Hudson (gill nets) to that used in the tributaries (angling, scap or cast nets). No one gear could capture both species well, as well as both sexes and sizes of fish in relatively unbiased proportions. Data are presented but should be interpreted with caution due to the selectivity issues that could not be adjusted for. Sample size varied greatly between areas, attributed to gear used (Table 20). Alewives were caught primarily in the tributaries using scap/lift nets, biased heavily to males; fewer alewives were caught by gill nets in the main river. No alewives were found to use the Mohawk. Blueback herring were primarily caught in the main stem Hudson River followed by Mohawk River; few were caught in the estuary tributaries, especially in 2000 and 2001 (Table 20). It is not clear if this was attributed to gear or actual effort expended in the different areas.

NAI (2008) also developed its own aging technique. They began with the aging technique of Cating (1954) developed for American shad, then noted differences in the structure of the scale, and developed their own technique for aging herring. It is not clear if the aging and spawning mark identification techniques for the NAI data is similar to those used to age other data presented in this report; therefore, comparisons should be made with extreme caution and NAI results are not included in trend analyses.

10.10.4 Catch, Size and Age Distribution

Normandeau Survey

Due to the potential size and sex biases listed above, results from the Normandeau Survey are not included in this update. For reference, they can be found in the original benchmark assessment.

NYSDEC spawning stock surveys

Prior to 2012, the intermittent effort (n-hauls) expended to catch river herring resulted in relatively low and variable catches (Table 18). However, with the focused survey, catches and hauls have increased greatly from 2012 to present.

Since 2012, alewife catches have been on average 73.6% males and 26.4% females (Figure 12). The high ratio of male alewives may indicate a possible sex bias in the sampling technique for alewives. It is suspected that males either remain out in the main river close to shore whereas most female alewives could be further offshore, unavailable to gears or they could be staging near tributary entrances. Mid-Hudson tributary sampling conducted by Schmidt and Lake (2000), and the Black Creek counter study (***Section 9.1.1***) resulted in more equal sex ratios. Sex ratios of blueback herring have been more even. On average, blueback herring consisted of 44.6% males and 55.4% females (Figure 12). Bluebacks may be more susceptible to the hauls seine gear because they prefer to spawn in shallow shoals of the main-stem river.

Mean total length and weight of fish was calculated when adequate sample sizes occurred. Prior to 2012, fishery dependent sample sizes were relatively low each year, limiting the usefulness of these data for trend analysis (Tables 16 and 17). In the prior assessment, n of 34 per year was used as the cutoff for inclusion in the analysis based on the method described by Lynch and Kim (2010). This was reevaluated for the update and a different method for selecting historical lengths was used. To determine which historical years to include in the analyses, sample size requirements were calculated using the following equation (Zar 1999):

(Equation 1) $$n = \frac{s^2}{\delta^2}(Z_{\alpha(2)} + Z_{\beta(1)})^2$$

where s^2 = variance observed for all years
δ = minimum detectable change
$Z_{\alpha(2)}$ = critical value for an α (two-sided) at 95% confidence = 1.96
$Z_{\beta(1)}$ = critical value for an β (one-sided) at 80% confidence = 0.84

This equation provides the sample size required to detect a minimum detectable difference between means of different years. Table 21 lists the calculations using Equation 1 for several levels of precision values by species and sex. For length comparisons, the sample sizes required to detect five mm differences in length by sex and species are used and resulting years to include in the analysis are shaded in gray on Tables 16 and 17. Note that since 2012, sample sizes are adequate to detect a 2.5 mm change in mean lengths in a comparison between years.

The overall trends in mean length for all combinations of species and sex show a 'U-Shaped' pattern with a decline in mean length until roughly 2011 and then an increase to present (Figure 13). Further analysis is provided below in ***Section 9.2***. The extreme variances observed for sample weights (Table 16 and Table 17) led to very poor precision in estimating differences in annual means, and will not be examined further.

Through training sessions and workshops with aging experts such as the Massachusetts Division of Marine Fisheries and other Atlantic Coast agencies (ASMFC 2014), HRFU biologists developed criteria for determining what constitutes an annulus and spawning mark in Hudson River fish. (Details in Appendix 2). Prior accepted aging methods such as Cating (1954, previously used for American shad) or Marcy (1969, used for river herring) were not used due to their reliance on transverse grooves to estimate annuli location. This protocol has been used since 2012.

Scale selection and preparation protocols were also changed in 2012. For each catch event, scale samples were removed from a subset of ten individuals of each sex and species. Scales were removed from the left side of the fish directly below the dorsal fin above the midline (Rothschild 1963; Marcy 1969; Hattala 1999) and placed in an individually identified envelope. In the lab, technicians numbered scale envelopes and entered the samples into a database along with the associated sampling program (fishery independent or dependent) data: gear type, species, sex, and length. Due to the large number of age-samples per year since 2012, staff used the Ketchen (1950) method of selecting a stratified sub-sample of fixed numbers of fish aged per 10 mm length bin. In 2012 and 2013, scale samples were separated by sampling program, species, and sex; and then thirty fish were randomly selected per 10 mm length bin. All fish were aged when there were fewer than 30 fish in a length bin. Due to time restraints and based on new literature (Coggins et al. 2013), staff have aged 15 fish per length bin since 2014. The sub-sample of aged fish were used to develop annual age-length keys for each species and sex (Loesch 1987; Devries and Frie 1996;

Davis and Schultz 2009). Sex-specific age-length keys were then used to estimate numbers at age of each sex and species for the entire sample for each year. The resulting estimated numbers at age were used to calculate mean length at age as well as mortality estimates reported in the *Trends in Instantaneous Mortality* section below.

Prior to 2012, sampling was intermittent (Table 18) and no aging was performed on scale samples removed from river herring. However, beginning in 2009, scales were analyzed for number of spawning marks. Age and repeat spawn data are shown in Table 22 and Table 23 for comparison. These data were also used in trend analysis (see ***Sections 10.4*** and ***10.5*** below). Focused sampling on the spawning stock began in 2012, and since that time 4,712 scales samples were taken from alewives and ages were assigned to a stratified random subsample of 1,122 of those samples. Female alewives ranged from age two to nine (Table 22) with zero to five repeat spawn marks and ranged from 68% to 36% virgin fish (Table 23). Since 2012, mean age of female alewives has been stable to slightly increasing. Male alewives ranged two to eight years of age (Table 22) with zero to five repeat spawn marks (Table 23). Male alewives ranged from 82% to 51% virgin fish. Mean age and of male alewives has been stable to slightly increasing since 2012.

From 2012 to 2015, staff removed 2,673 scale samples from blueback herring and assigned ages to 847 of those samples. Female blueback ages ranged from three to seven (Table 22) with zero to three repeat spawn marks (Table 23). Female bluebacks ranged from 79% to 52% virgin fish. Mean age of female blueback herring has remained stable without a trend since 2012. Male bluebacks ranged in age from two to six (Table 22) with zero to three repeat spawn marks and ranged from 92% to 59% virgin fish (Table 23).

Alewife males and females are on average larger than blueback males and females of the same age. Max total lengths and mean length at age of both species are near those reported in Greeley 1937 (Tables 16 and 17). Since 2012, mean length at age for both species across all ages has been either stable or increasing with the majority increasing (Figure 14). Along with increasing mean length at age, the overall age structure for both species has expanded (Figure 15) with increased repeat spawning occurrence (Figure 16). The expanded age structure and increased occurrence of repeat spawning marks in 2014 and 2015 suggests a higher survival rate during both post-spawn emigration and during ocean residency.

10.10.5 VOLUNTEER AND OTHER RIVER HERRING MONITORING

The South Shore Estuary Reserve Diadromous Fish Workgroup (SSER), in partnership with the Seatuck Environmental Association, have been to incorporating citizen volunteers in the collection of data on temporal variation and physical characteristics associated with spawning of river herring in tributaries. These data were not provided by the fishery dependent and independent sample programs discussed above. The volunteer programs also bring public awareness to environmentally important issues.

Long Island Streams

The SSER began a volunteer survey of alewife spawning runs on the south shore of Long Island in 2006. The survey has been organized by the Seatuck Environmental Association, in cooperation with the SSER, as of 2008. The survey is designed to identify alewife spawning in support of diadromous fish restoration projects. The survey also evaluates current fish passage projects (i.e. Carmans River fish ladder), and sets a baseline of known spawning runs. Data were available for surveys in 2006 – 2008. Monitoring occurred on six to nine targeted streams annually, with volunteer participation ranging from 24 to 68 individuals. Monitoring takes place from March through May. Alewife were seen as early as March 5 (2006) and as late as May 31 (2008). Data indicated that alewife use multiple streams in low numbers. It is not clear whether each stream supports a spawning population since total sightings were very low. The Carmans and Swan Rivers showed the most alewife activity and likely support yearly spawning migrations. The first permanent fish ladder on Long Island was installed in 2008 on the Carmans River. Information gathered during this study will aid in future construction of additional fish passage (Kritzer et al. 2007a, 2007b, Hughes and O'Reilly 2008). Byron Young continues to monitor alewife, mostly in the Peconic River. In 2016, the Peconic run was above average. Fish were first observed on March 2, and last observed on May 16, representing a nearly 10 week spawning season (B. Young, retired, NYS Department of Environmental Conservation, personal communication).

In addition to the SSER, other interested individuals have also monitored Long Island runs (see Appendix Table A). Anecdotal data provides valuable information on tracking existing in-stream conditions, whether streams hold active or suspected runs, interaction with human land uses, and suggestions for improvement (L. Penney, Town of East Hampton, personal communication). A rock ramp was constructed around the first barrier to migration on the Peconic River in early 2010 (B. Young, retired, NYS Department of Environmental Conservation, personal communication). The Seatuck Environmental Association set up an automated video counting apparatus at the upriver end of this ramp. Data are still being analyzed. A video can be viewed on their website at https://www.seatuck.org/index.php/fish-counting

The Department has conducted a similar river herring volunteer monitoring program annually since 2008 for tributaries of the Hudson River Estuary (Hattala et al. 2011b). We designed this project to gather presence–absence and temporal information about river herring spawning runs from the lower, middle, and upper tributaries of the estuary. Between nine and 11 tributaries were monitored annually by 70 to 213 volunteers in 2008, 2009, and 2010. Herring were seen as early as 31 March and as late as 1 June. River herring were observed in all but one of the tributaries. However, several tributaries with known strong historical runs had very few sightings. Water temperature seemed to be the most important factor determining when herring began to run up a given tributary. Sightings of herring were most common at water temperature above 50 degrees F. Tributaries in the middle part of the estuary warmed the fastest each spring and generally had the earliest runs.

10.10.6 YOUNG-OF-THE-YEAR ABUNDANCE

Since 1980, the Department has produced an annual measure of relative abundance of YOY alewife and blueback herring in the Hudson River Estuary. Although the program was designed to sample YOY American shad, it also provides data on the two river herring species. Blueback herring appear more commonly than alewife throughout the time series. In the first four years of the program, sampling occurred river-wide (rkm 0-252), bi-weekly from August through October, beginning after the peak in YOY abundance occurred. The sampling program was altered in 1984 to concentrate in the freshwater middle and upper portions of the estuary (rkm 88-225), the major nursery area for young American shad and river herring. Timing of sampling was changed to begin in late June or early July and continue biweekly through late October each year. Gear is a 30.5 m by 3.1 m beach seine of 6.4 mm stretch mesh. Collections are made during the day at 28 fixed sites in nearshore habitats spanning four reaches of the freshwater portion of the river. Catch per unit effort is expressed as the annual geometric mean of fish per seine haul for Julian weeks 26 through 42 (July through October). This period encompasses the major peak of use in the middle and upper estuary.

Other indices are available from the Hudson River generating (HRG) companies Long River Monitoring Program (ASA 2017). The HRG sampling program includes a river-wide beach seine survey and an off shore fall shoal survey (sampling open water areas over the channel and shoals). The HRG beach seine survey (BSS) randomly samples beaches in thirteen river segments spread out the entire 246 km of the Hudson River. Sampling is more highly concentrated in the brackish water portion of the Hudson, as the survey was designed to sample for young of the year striped bass. The BSS began in August for most years of the survey (1974 through 1997), but is now similar in timing to NYSDEC survey running from

July through October. The seine used is similar to the NYSDEC YOY program, except that the stretch mesh size is slightly larger (9.5 mm rather than 4 mm). Catch per unit effort for the BSS survey is expressed as a weighted mean CPUE of samples taken between Julian week 33 and Julian week 40. The fall shoals survey (FSS) uses a beam trawl and samples the same river reaches as the BSS. However, it samples at night in the open water (channel sections) of the river. The CPUE for the FSS survey is expressed as a weighted mean density of samples taken between Julian week 33 and Julian week 40.

CHGE et al. (1999) indicated that neither the BSS nor the FSS samples river herring well, as herring tend to move on and off shore on a periodic cycle. Blueback herring tend to move offshore at night and distribute themselves near the surface of the water; alewives tend to move on shore at night. The "best" herring indices were calculated from FSS samples because the channel stratum represents a larger fraction of the total river habitat than the shore zone. Summary data for the HRG and NYSDEC surveys are found in Table 24.

From 1980 to 1998, the Department's geometric mean YOY annual index for alewife was low, with only one year (1991) having over one fish per haul. Since 1998, the index has generally increased through 2012, and has been stable at roughly one fish per haul since 2013 (Figure 17).

From 1980 through 1994, the Department's geometric mean YOY annual index for blueback herring averaged about 24 fish per haul, with only one year (1981) dropping below 10 fish per haul (Figure 18). After 1994, the mean dropped to around 17 fish per haul. The largest index value for the time series occurred in 2014, which was just over 50 fish per haul.

The underlying reason for the wide inter-annual variation in YOY river herring indices is not clear. The increased inter-annual variation in relative abundance indices of both species may indicate a change in overall stability in the system. Further investigation into temporal and environmental variables that may contribute to this high variability is necessary. By the time of the next benchmark stock assessment, staff will evaluate different standardized models to best account for the influence of covariates, such as salinity, water temperature, time of day, and sampling week on YOY catches.

10.10.7 ENTRAINMENT AND IMPINGEMENT ESTIMATES

A river-wide ichthyoplankton survey occurs annually in the Hudson River Estuary, conducted by consultants under contract with the Hudson River Generating companies. In order better define impacts of the once-through cooling systems on fish, estimates of mortality on various ichthyoplankton life stages were calculated using two models, the Empirical Transport Model and the Conditional Entrainment Mortality Rate (CEMR) model. Detailed methodology for both models can be found in CHG&E et al. (1999).

Estimates of mortality are expressed as conditional entrainment and impingement mortality rates, or the percent reduction in a year-class that would be due to mortality from entrainment and or impingement through once-through cooling water systems if no other causes of mortality operated. Losses for the Hudson River Estuary can occur at one major office complex air conditioning unit, two nuclear power plants, one waste-fuel power plant, and five fossil-fuel power plants located throughout the Hudson Valley above New York City. CEMR at these facilities combined has ranged from 9 to 42 percent for alewife and 8 to 41 percent for blueback herring during the period 1974 to 1997 (Table 25). Estimates have not been made for years since 1997.

10.11 ASSESSMENT APPROACH AND RESULTS

We used an index based approach to assessing status of river herring in the Hudson River. Although data were available to set a benchmark for fishing or total mortality using a biomass per recruit approach, we judged that available techniques for measuring stock specific mortality rates were not adequate. Moreover, approaches using loss estimates to the stock required information on stock specific ocean losses and these data were not available.

10.11.1 TRENDS IN RUN SIZE

As described above in section 9.3.2.1 Hudson River catch rates, annual CPUE is calculated differently for the two component fisheries in the river. The gear of choice for an abundance index is the fixed gill nets below the Bear Mountain Bridge. This gear operates as an intercept fishery, capturing fish on their emigration into the river before they reach their spawning areas. We only use data from 2000 to 2015, when mandatory reporting was enforced. CPUE for this gear declined slightly from 2000 to about 2006 then has gradually increased to present (Figure 19). For all years, 2000 to 2015, there is a significant increasing trend (Mann-Kendall: tau = 0.417; p = 0.027).

10.11.2 TRENDS IN SIZE STRUCTURE

The shaded values in Tables 16 and 17 represent the years included in the trend analysis for each combination of species and sex.

Twelve of the 27 years (1980 to 2015) were used in the trend analysis for alewife males. There is no significant trend (Mann-Kendall: tau = 0.061; p = 0.84) when examining all years (Figure 13). However, as was determined in the last assessment, there was a declining trend from years up to 2010. This trend was strong but not significant (Mann-Kendall: tau = -0.52; p = 0.13). Since the last assessment, there is an increasing trend in mean length. As with the previous stanza, this trend is strong but not quite significant (Mann-Kendall: tau = 0.73; p = 0.06). Seven of 27 years were used to investigate trends in mean lengths of alewife females. As with males, there was no significant trend over all years, but there was a strong increasing trend since the last assessment (Figure 13).

Ten of 25 years of length data were used to examine trends in mean lengths of male blueback herring. There is a weak decreasing trend from 1989-2015 (Figure 13). Splitting the time series at 2010 (the final year of data used in the last assessment), results in a strong decreasing trend from 1989 to 2010 and an equally strong increasing trend from 2010 to 2015. Neither trend is significant. The same overall patterns are observed using the subset of female blueback herring mean lengths: a slight overall decline from 1989 to present, a stronger declining trend until 2010, followed by a strong (and in this case significant) increasing trend from 2010-2015.

In all combinations of species and sex, there is a ‘U-Shaped” pattern to the mean lengths, with the post-assessment trends largely driven by 2014 and 2015. These values coincide with commercial and recreational regulation changes in the river, as well as the onset of the bycatch avoidance system in the fisheries occurring in the mid-Atlantic and further north. These patterns could reflect increased survivorship, but are better evaluated in the next three sections.

10.11.3 TRENDS IN AGE COMPOSITION

As described above in Section 8, many scale samples from NYSDEC surveys remain un-aged or were aged using differing protocols. In the previous assessment, ages from these fish were determined through length at age keys from datasets provided by Maine, Massachusetts, and Maryland. Annual estimated age structures resulted in some similarities, but also major differences resulting in speculative trend analyses.

For this update, there is major concern in using the previous method based on the wide assumptions that must be made regarding the stock specific characteristics for each species. Moving forward, only ages from the current spawning stock survey and aging protocols are used (2012-2015). Although four years of comparable data are not enough for meaningful analysis, there are notable changes in mean age from 2012 to present (Table 22). As expected from the length analysis, the mean age has generally increased in all but blueback herring males.

Coupled with the increases in mean length at age are changing annual proportions at age (Figure 15). There is an increasing trend in higher proportions of older age fish in 2014 and 2015, the largest change appears to be in alewife females and the smallest change is with blueback males. Also of note for blueback males, there were very few two year olds in the 2015 sample. This, along with the decreasing proportions of younger fish for all combinations of sex and species, could signify a problem with recruitment; however it could also be influenced by a large year class coming through. Either way, these proportions at age should continue to be monitored and will be useful with a longer time series of ages.

10.11.4 TRENDS IN PROPORTION OF REPEAT SPAWNERS

No trend analysis of repeat spawn data was done on in the previous assessment due to minimal years of recent data. Since the 2011 assessment, we have seven consecutive years of repeat spawn data from 2009 to 2015 (Figure 16). A very similar trend is observed for annual proportions of repeat spawn data for all but blueback males: a relatively stable pattern of through 2013 followed by a shift in larger proportions of multiple repeat spawn marks in 2014 and 2015. Blueback males also had the same increase in 2014 and 2015; however, there was a decreasing trend in spawn mark proportions from 2009 to 2013. As with the shift in older fish in recent years, these trends may indicate a recruitment issue; however, they also suggest a higher survival rate during both post-spawn emigration and ocean residency.

10.11.5 TRENDS IN TOTAL INSTANTANEOUS MORTALITY

In the previous assessment, the variation in annual age structure, generated by the ME, MA and MD length-age keys, translated into a wide variation in estimates of total mortality when age-based estimation methods (Chapman and Robson 1960) were used. Due to the wide assumptions made using age-length keys from other stocks, trends in the mortality rates varied among species, sexes and methods. As an alternative, mortality estimates were made using the Beverton-Holt length-based method (Gedamke and Hoenig 2006), using growth parameters for length from a very small sample size of river herring capture in 1936. The authors noted issues with the 1936 dataset as well as some of the inputs, especially the arbitrary assignment of length at full recruitment and the sensitivity of $L\infty$ on the results. In addition, they acknowledged the assumption that the stock is in equilibrium, was not met. For these reasons, these results are not replicated in this update, instead only current estimates of instantaneous mortality rates are analyzed.

Total instantaneous mortality rates were calculated on an annual basis since 2012 for age data and 2009 for repeat spawn data using a bias-correction Chapman and Robson mortality estimator described in Smith et al. (2012). To be consistent with the methods used in the 2012 Benchmark Stock Assessment for River Herring, the age of full recruitment was the age of highest abundance and there had to be at least three ages or spawning marks to be included in the respective analyses (ASMFC 2012).

Mortality estimates for both species were calculated using age and repeat spawn data independently. Mortality derived from age data for alewives declined or remained stable from 2012-2014 (Table 22). In 2015, estimates for both sexes of alewives increased; however, we feel that this increase is due to a large year class moving through the fishery resulting in over dispersion of older fish, and is further compounded by fewer age three and age four fish observed in 2015.

Blueback herring age based mortality estimates have been stable since 2012 for both sexes with a slight increase in 2015 (Table 22). Since 2012, both sexes of blueback herring have been comprised of primarily three and four year old fish. Despite blueback herring being dominated by two year classes, a few older fish with increased occurrences of repeat spawning marks are beginning to appear in the fishery (Figure 16).

Mortality estimates were derived from repeat spawning data since 2009 and follow the same trends as mortality estimates derived from age data, with the only exception in 2015 (Table 23). In 2015, alewife and female blueback mortality estimates derived from age data were higher than those derived from repeat spawn data. This is due to increase repeat spawn occurrence and a reduction in the number of virgin fish.

Mortality estimates derived from repeat spawn data for both sexes of alewives slightly increased from 2009-2011 and since declined (Table 23). Female blueback herring mortality estimates were stable from 2009-2012. Male blueback herring mortality estimates increased from 2009-2012. From 2012-present both sexes of blueback herring mortality estimates derived from repeat spawn data have declined.

In most instances, the mortality estimates based on spawning marks were higher than those calculated from ages. This may be a result of the age based method using the most abundant number at age as age at full recruitment. In doing so, we may include ages of the population that may not actually be fully recruited. Once an adequate data set is available for age based mortality estimates, we will compare long-term trends between the two methods. This will identify any potential discrepancies in our mortality estimation methods.

10.11.6 TRENDS IN AGE 0 INDICES OF RELATIVE ABUNDANCE

Alewife: Based on the NYSDEC Alosine Beach Seine Survey, the Hudson River stock of alewife has been erratically increasing over the entire times series. The trend is positive and significant (Mann-Kendall: tau = 0.408; $p < 0.001$; Figure 20). The HRG surveys indicate minimal trends across their respective sampling periods.

Blueback herring: Unlike alewife, NYSDEC Alosine Beach Seine Survey data for bluebacks indicate a decreasing, non-significant trend, but significant decreasing trends for the HRG beach seine survey and fall shoal survey (Figure 20). In all three surveys, the blueback YOY trends have been erratic but stable for the last 20 years.

The underlying reason for the wide inter-annual variation in all three YOY river herring indices is not clear. The increased inter-annual variation since the 1990s may indicate a change in overall stability in the system. Further investigation into temporal and environmental variables that may contribute to this high variability is necessary. By the next benchmark assessment NYSDEC staff will evaluate different standardized models to best account for the influence of covariates, such as salinity, water temperature, and sampling week on YOY catches in all three surveys.

10.12 BENCHMARKS

Stock assessments often set benchmarks for juvenile production and characteristics of the adult stock to prevent over-fishing. Setting mortality benchmarks for the Hudson River stocks has been problematic. In the sections above we raised issues and uncertainties associated with calculating current total mortality estimates. By continuing current sampling methodologies on the spawning stock and using consistent aging methods, mortality estimates may be useful in the future. Until then we choose to use other stock indicators.

10.12.1 JUVENILE INDICES

The recently approved 2017 NY SFMP for river herring set a sustainability target for juvenile indices using NYSDEC seine data from the time period of 1983 through 2015 for both species. It defines a more conservative definition of juvenile recruitment failure than described in section 3.1.1.2 of Amendment 2 to the ASMFC Interstate Fisheries Management Plan for Shad and River herring (ASMFC 2009). Amendment 2's definition is that recruitment failure occurs when three consecutive juvenile index values are lower than 90% of all the values obtained in the base period. This plan was more conservative using a 75% cut off level. The resulting sustainability target value is the 25th percentile of the time series, such that three consecutive years with index values below this target would trigger management action. The target for alewife is 0.37 (Figure 17) and the target for blueback herring is 7.53 (Figure18).

The plan states New York State will take immediate corrective action if the recruitment failure limit is met for three consecutive years. Potential management actions may include but are not limited to: area closures, gear restrictions, and permit fee restructuring. Corrective actions will remain in place until the juvenile index value is above the juvenile recruitment failure level set in Amendment 2 to the ASMFC Interstate Fisheries Management Plan for Shad and River herring for three consecutive years.

There are several measures of stock condition of Hudson River herring that can be used to monitor relative change among years. However, these measures have limitations (described below) that currently preclude their use as targets. These include mean length in fishery independent samples, catch per unit effort (CPUE) in the reported commercial harvest, age structure, and proportion of repeat spawning marks. We propose to monitor these measures during the fishery and use them in concert with the sustainability target to evaluate consequences of a continued fishery.

10.12.2 MEAN LENGTH AND MEAN AGE

Mean total length and mean age reflects age structure of the populations and thus some combination of recruitment and level of total mortality. Mean total length and mean age of both river herring species in the Hudson River system have been increasing since sampling efforts increased and became consistent in 2012. Max total lengths and mean length at age of both species are approaching or have exceeded those reported in Greeley (1937). The increases in mean length and mean age are indicative of reduced mortality both within river and during their ocean residency. However, the ocean bycatch fishery is a large unknown and not solely controlled by New York State to effect a change. We propose to continue monitoring mean total length and mean age during the proposed fishery, with specific investigation of mean length at age as a benchmark once more age data are available.

10.12.3 CATCH PER UNIT EFFORT IN COMMERCIAL REPORTS

CPUEs calculated from the reported harvest as well as commercial monitoring efforts reflect general trends in abundance. However, annual values can be influenced by changes in reporting rate in reported harvest and thus reported CPUE should be used as a target at this time. The small sample sizes of commercial monitoring trips precludes the use of annual CPUEs as a target as well. However, with a longer time series of age data as well as an increase in monitoring trips, staff will validate the commercial CPUEs with YOY relative abundance indices following methods described by Hattala and Kahnle (2007).

10.12.4 AGE STRUCTURE, REPEAT SPAWNING, AND TOTAL MORTALITY

The current spawning stock survey will continue into the near future. Thus, age frequencies, frequency of repeat spawning and total mortality (Z) will continue to be consistently monitored. Once an adequate time series of data is collected, a mortality based benchmark will be developed and used as a sustainability target in future sustainable fishery management plans.

10.13 CONCLUSIONS AND RECOMMENDATIONS

The New York stock of river herring is much reduced from historic levels. In the 2011 Benchmark Stock Assessment, it was determined mean lengths and weights of both river herring species were significantly declining since the early 1980's. Conversely, recruitment of both species was considered erratic but stable, with a slight increasing trend in alewife YOY and a slight decreasing trend in YOY blueback herring. Neither trend in YOY abundance was significant. Taking into account these conflicting trends, along with the upsurge in herring use as bait for the recreational striped bass fishery, NY managers asserted the stocks needed to be managed with caution until further data were collected. They made the following recommendations:

- Restrict directed recreational and commercial fisheries that could potentially affect New York stocks to curtail further decline. Close river herring fishing on Long Island and the Bronx and south shore of Westchester County due to lack of data on stock condition.
- Hudson River and tributaries: Continue fishery independent young of year and spawning stock surveys; and fishery dependent monitoring: CPUE and biological characteristics of catch.
- Long Island, Bronx and south shore of Westchester County: Encourage development of monitoring programs for selected runs.
- Identify and control bycatch from fisheries outside of New York such as the Atlantic herring and mackerel fisheries and inshore small mesh fisheries.

Since the last stock assessment, NY addressed several of these recommendations. In an approved 2012 Sustainable Fishery Management Plan (SFMP) for river herring, NY laid out increased restrictions to the recreational and commercial fisheries which were implemented in 2013 (Appendix 1). Highlights included net size restrictions, a closure of net use in Hudson River tributaries during the spawning season, a recreational possession limit and a moratorium on all other New York waters. In addition, the SFMP laid the groundwork for a river herring spawning stock survey beginning in 2012, which has since provided the consistent sampling and aging methodologies required to better evaluate trends in the Hudson stock. Along with an improved spawning stock survey, more effort was made to monitor commercial trips to obtain better representative samples of commercial harvest characteristics throughout the river. From 2012-2016, both sampling programs provided the necessary data as evidence to continue the fishery in 2017. In spring of 2017, NY submitted and ASMFC approved a new five-year SFMP, with minimal changes from the first plan. In this document, NY pledged to continue the extensive sampling and aging of river herring that will provide more robust targets for the next Benchmark Assessment as well as a potential 2022 five-year SFMP.

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Table 1. Age structure of alewife and blueback herring from spawning stock sampling in the Hudson River Estuary and the Mohawk River.

	Age													
Year	2	3	4	5	6	7	8	9	10	11	12	13	n	Mean Age
Alewife Male														
1936	2	6	1	2									11	3.27
1999		16	108	240	149	34	10						557	5.19
2000		2	179	312	233	109	17	4	2				858	5.40
2001	14	212	196	105	14	2	20						563	3.96
2012	27	385	726	308	91	21	2						1559	4.08
2013		615	782	276	48	15	1						1737	3.89
2014	1	372	933	1233	61	18	29						2647	4.43
2015		105	430	544	203	12	8						1302	4.70
Alewife Female														
1936		4	6	3									13	3.92
1999		1	5	26	41	20	7						100	5.95
2000			15	187	177	101	58	27	5				570	6.18
2001				18	99	38	10	3	1				169	6.31
2012	5	76	210	175	32	11	7	2					518	4.44
2013		148	275	84	58	17	12	1					596	4.26
2014		83	537	383	137	75	27	5					1247	4.75
2015		56	179	372	114	30	8						759	4.87
Blueback Herring Male														
1936			1	2	1								4	5.00
1989		44	164	74	5	1							288	4.15
1990	8	143	100	41	7								299	3.65
1999	23	143	285	250	131	40	11	1					884	4.56
2000		57	354	253	94	26	5	1					790	4.62
2001		15	169	176	97	23	6						486	4.92
2012	64	157	89	16	3								329	3.20
2013	34	483	209	44	17								787	3.40
2014	83	308	205	51	1								649	3.35
2015	3	412	168	44	3								630	3.42
Blueback Herring Female														
1936		4	15	13	4								36	4.47
1989		31	182	77	7								297	4.20
1990	6	86	102	52	8								254	3.88
1999	1	39	223	312	189	63	16	3					846	5.08
2000		21	231	336	197	48	28	17	8		2		888	5.25
2001		4	66	135	176	44	12	4				1	442	5.57
2012		152	168	61	4								385	3.78
2013	1	364	203	97	21	1							687	3.67
2014	7	320	274	77	36	9							723	3.78
2015		248	262	162	36	9							716	4.02

Survey notes:
1936: Greeley (1937) - unknown gear; unknown aging method
1989-90: NYSDEC - electrofishing; unknown scale aging method (likely Cating)
1999-2001: Normandeau Associates - various gears, size and sex selective; scale aging (modified Cating)
2012-2015: NYSDEC - electrofishing and seining; MA DMF based scale aging method (ASMFC workshop)

Table 2. Von Bertanlannfy growth estimates using spawning stock data from the Hudson River Estuary and the Mohawk River.

Alewife					
Survey	sex	n	Linf	K	t0
1936 Greeley	m	8	317.910	0.489	-0.139
	f	9	344.003	0.421	-0.180
1999-2001 NAI	m	366	278.184	0.482	-0.326
	f	376	297.919	0.382	-0.492
2012-2015 NYSDEC	m	571	290.788	0.547	-0.166
	f	551	305.150	0.52	-0.168
Blueback herring					
Survey	sex	n	Linf	K	t0
1936 Greeley	m	4	337.408	0.453	-0.052
	f	4	343.127	0.442	-0.055
1989-1990 NYSDEC	m	587	269.189	0.750	0.088
	f	551	284.457	0.695	0.089
1999-2001 NAI	m	449	284.624	0.497	-0.198
	f	668	284.624	0.497	-0.198
2012-2015 NYSDEC	m	402	266.138	0.817	0.115
	f	445	272.300	0.902	0.197

Table 3. Gompertz growth estimates using spawning stock data from the Hudson River Estuary and the Mohawk River.

Alewife					
Survey	sex	n	Wo	G	sg
1936 Greeley	m	6	0.000	13.655	1.782
	f	8	0.012	9.943	1.383
1999-2001 NAI	m	152	2.030	4.553	0.635
	f	96	3.101	4.428	0.494
2012-2015 NYSDEC	m	548	0.00032	13.291	1.0634
	f	536	0.000	13.446	0.997
Blueback herring					
Survey	sex	n	Linf	K	t0
1936 Greeley	m	4	0.001	12.98	1.439
	f	4	0.625	6.377	0.747
1989-1990 NYSDEC	m	583	0.379	5.980	0.998
	f	547	0.542	5.846	0.941
1999-2001 NAI	m	82	1.417	4.827	0.647
	f	130	1.784	4.731	0.609
2012-2015 NYSDEC	m	394	0.737	5.255	0.995
	f	428	2.540	4.390	0.651

Table 4. Recent records of type of commercial licenses sold for the New York portions of the Hudson River Estuary.

Year	Gill Nets				Scap Nets		Gill net		Scap Net	
	N-Fishers	Shad/herring Gill Net	Gill Net	Total GN permits sold	N-Fishers	Permits sold	N-Fishers reporting herring	% Reporting	N-Fishers reporting herring	% Reporting
1995	112	47	75	122	2	2	5	4%	2	100%
1996	134	54	88	142	2	2	4	3%	2	100%
1997	112	45	74	119	35	35	22	20%	24	69%
1998	140	65	119	184	46	46	33	24%	33	72%
1999	145	77	68	145	31	31	40	28%	20	65%
2000	223	108	123	231	443	449	67	30%	124	28%
2001	190	87	83	170	345	348	67	35%	127	37%
2002	232	141	120	261	291	338	87	38%	113	39%
2003	238	144	106	250	237	278	96	40%	115	49%
2004	275	160	127	287	245	291	89	32%	106	43%
2005	255	162	111	273	215	255	68	27%	80	37%
2006	290	179	129	308	229	273	92	32%	87	38%
2007	290	178	130	308	201	244	87	30%	75	37%
2008	277	173	119	292	182	219	78	28%	85	47%
2009	254	159	108	267	168	199	76	30%	78	46%
2010	181	0	185	185	161	190	74	41%	73	45%
2011	177	0	181	181	144	164	62	35%	61	42%
2012	154	0	155	155	128	151	66	43%	51	40%
2013	157	0	166	166	112	127	77	49%	33	29%
2014	150	0	152	152	109	124	47	31%	27	25%
2015	148	0	150	150	96	112	58	39%	33	34%

Table 5. River herring and American shad catch in metric tons (mt) by Atlantic Mackerel and Atlantic herring vessels, 2014 -2015. Data summarized by NMFS from vessels via the Vessel Monitoring System (VMS), the Vessel Trip Report System (VTR), Dealer Reports, and the Northeast Fisheries Observer Program.

Estimated river herring/shad catch (mt)	**2014**	**2015**
Atlantic mackerel vessels	6.42	12.87
Atlantic herring vessels - ALL	na	176.5
Atlantic herring: GOM Mid-water trawl	na	11.1
Atlantic herring: Cape Cod Mid-water trawl	na	0.7
Atlantic herring: Southern New England bottom trawl	na	100.7
Atlantic herring: Southern New England mid-water trawl	na	64

Table 6. River herring and American shad quotas for Atlantic Mackerel and Atlantic herring vessels, 2014-2015, and anticipated quota for Atlantic herring vessels 2016-2018.

Annual harvest cap for river herring/shad (mt)	**2014**	**2015**	**2016-18 (proposed)**
Atlantic mackerel vessels	236	89	82
Atlantic herring vessels - ALL	312	312	361
Atlantic herring: GOM Mid-water trawl	86	86	76.7
Atlantic herring: Cape Cod Mid-water trawl	13	13	32.4
Atlantic herring: Southern New England bottom trawl	89	89	122.3
Atlantic herring: Southern New England mid-water trawl	124	124	129.6

Table 7. Species- specific total annual incidental catch (mt) across all fleets and regions. Midwater trawl estimates were only included beginning in 2005. Modified from Amendment 14 of the Atlantic Mackerel, Squid and Butterfish Fishery Management Plan for the Mid Atlantic Fishery Management Council.

	ALEWIFE	**AMERICAN SHAD**	**BLUEBACK HERRING**	**Unknown**	**HICKORY SHAD**					
Year	**Catch (mt)**	**Catch (mt)**	**Catch (mt)**	**Catch (mt)**	**Catch (mt)**	**Total Catch (mt)**	**Total identified catch (mt)**	**Proportion of known catch that is River Herring**	**Estimated unknown catch that is River Herring (mt)**	**Total estimated River Herring catch (mt)**
1989	20.4	58.9	19.6	7.1	0.0	106.0	98.9	0.40	2.9	42.8
1990	55.3	25.8	78.9	331.3	0.0	491.4	160.1	0.84	277.9	412.2
1991	68.2	104.3	115.4	110.5	39.4	437.7	327.3	0.56	62.0	245.6
1992	30.6	79.8	458.2	387.5	0.0	956.1	568.5	0.86	333.1	821.9
1993	40.5	51.0	210.6	18.6	0.0	320.6	302.0	0.83	15.5	266.5
1994	5.5	70.3	40.2	9.8	0.2	126.0	116.2	0.39	3.8	49.5
1995	6.4	17.2	213.5	51.9	0.0	288.9	237.1	0.93	48.1	268.0
1996	482.0	40.0	1803.4	28.7	26.6	2380.	2352.1	0.97	27.9	2313.3
1997	41.3	37.0	982.0	67.6	18.3	1146.	1078.6	0.95	64.1	1087.4
1998	80.9	55.3	49.3	0.4	39.2	225.1	224.7	0.58	0.2	130.4
1999	3.9	15.7	206.7	128.8	56.8	411.8	283.0	0.74	95.8	306.3
2000	28.4	74.4	55.5	22.0	0.1	180.2	158.3	0.53	11.6	95.5
2001	93.0	61.9	120.1	2.1	80.6	357.8	355.7	0.60	1.3	214.4
2002	2.7	24.1	173.2	76.5	1.4	277.9	201.4	0.87	66.8	242.8
2003	248.4	21.4	332.5	15.3	14.3	631.9	616.6	0.94	14.4	595.3
2004	99.7	18.2	81.5	176.7	35.0	411.2	234.5	0.77	136.6	317.9
2005	347.4	78.2	220.0	7.2	19.4	672.3	665.1	0.85	6.1	573.6
2006	57.6	29.3	187.5	232.0	13.4	519.8	287.7	0.85	197.6	442.7
2007	484.0	55.1	180.1	105.3	4.8	829.3	724.0	0.92	96.6	760.8
2008	145.0	52.4	526.6	328.0	7.8	1059.	731.8	0.92	301.0	972.6
2009	158.7	59.5	202.0	180.1	10.9	611.2	431.1	0.84	150.6	511.3
2010	118.5	46.1	125.0	86.5	1.1	377.3	290.8	0.84	72.4	316.0
Average	119.0	48.9	290.1	107.9	16.8	582.7	474.8	0.80	90.3	499.4

Table 8. Estimated river herring harvest (mt), based on average rate of known river herring bycatch 1989-2010 applied to actual harvest in 2014-15.

Estimated American shad catch (mt)	**2014**	**2015**
Atlantic mackerel vessels	5.14	10.30
Atlantic herring vessels - ALL	na	141.20
Atlantic herring: GOM Mid-water trawl	na	8.88
Atlantic herring: Cape Cod Mid-water trawl	na	0.56
Atlantic herring: Southern New England bottom trawl	na	80.56
Atlantic herring: Southern New England mid-water trawl	na	51.20

Table 9. New York River river herring landings- all numbers are in kg, unless indicated

		NYSDEC catch summary data					NMFS website				ACCSP database non-confidential				
		Ocean and River		Hudson River ONLY											
Year	**River herring (max value)**	Sheppard[a]	Dept. Annual reports[b]	lbs	kgs	number	HERRING, BLUEBACK	ALEWIFE	"HERRINGS"	***TOTAL Pounds***	Alewife	Blueback herring	River herrings	Herring, unc	***TOTAL Pounds***
1900															
1901															
1902															
1903															
1904	**501438**		501438												
1905	**277225**		277225												
1906															
1907															
1908	**81211**		81211												
1909	**111334**		111334												
1910															
1911															
1912															
1913	**92175**	92175	92175												
1914															
1915															
1916	**21762**		21762												
1917	**49935**	49935	49935												
1918	**88224**	88224	88224												
1919															
1920	**101850**		101850												
1921	**10852**		10852												
1922	**73431**	73431	73431												
1923	**50747**		50747												
1924	**56620**		56620												
1925	**92188**	92188	92188												
1926	**131535**		131535												
1927	**140094**		140094												
1928	**178819**		178819												
1929	**146835**	146835	146835												
1930	**138504**	138504	138504												
1931	**185707**	185707	185707												
1932	**91432**	91432	91432												
1933	**174969**	174969	174969												
1934	**196848**	196848	196848												
1935	**274405**	274405	274405												
1936	**208282**	208282	208282												
1937	**227865**	227865	227865												
1938	**244521**	244521	244521												
1939	**198806**	198806	198806												
1940	**173453**	173453	173453												
1941	**222975**	222975	222975												
1942	**150422**		150422												
1943	**169056**	169056	169056												
1944	**157644**	157644	157644												
1945	**123619**	123619	123619												
1946	**131302**	131302	131302												
1947	**106189**	106189	106189												
1948	**90468**	90468	90468												
1949	**99768**		99768												
1950	**103700**		103258					103700		***103700***		103700			***103700***
1951	**74800**		68987					74800		***74800***		74600			***74600***
1952	**90300**	88501	88501					90300		***90300***		90300			***90300***
1953	**70753**	70753	70753					57200		***57200***		56800			***56800***
1954	**83500**							83500		***83500***		83500			***83500***
1955	**102000**	12400	12400					102000		***102000***		102000			***102000***
1956	**67904**	67904	67904					67800		***67800***		67800			***67800***
1957	**56300**	56100	56100					56300		***56300***		56100			***56100***
1958	**66100**	66100	66100					66100		***66100***		66100			***66100***
1959	**45600**	45600	45600					45600		***45600***		45600			***45600***
1960	**38200**	38200	38200					38200		***38200***		38200			***38200***
1961	**33800**	33800	33800					33800		***33800***		33800			***33800***
1962	**38200**	38200	38200					38200		***38200***		38200			***38200***
1963	**32300**	32300	32300					32300		***32300***		32300			***32300***
1964	**37000**	37000	37000					37000		***37000***		37000			***37000***
1965	**23600**	23600	300					23600		***23600***		23600			***23600***
1966	**4188000**[d]	24500	0					4188000		***4188000***		4188000			***4188000***
1967	**4400**	4400	350					4400		***4400***		4400			***4400***
1968	**7000**	7000	352					7000		***7000***		7000			***7000***
1969	**9200**	9200	150					9200		***9200***		9200			***9200***
1970	**11000**	9400	35					11000		***11000***		11000			***11000***
1971	**68**		68												
1972	**400**		102					400		***400***		400			***400***
1973	**21600**	2000	252					21600		***21600***		21600			***21600***
1974	**16900**	16900	4					15400		***15400***		15400			***15400***
1975	**15300**		500					15300		***15300***		15300			***15300***

Table 9. (cont'd) New York River river herring landings- all numbers are in kg, unless indicated.

Year	River herring (max value)	NYSDEC catch summary data: Ocean and River		NYSDEC catch summary data: Hudson River ONLY			NMFS website				ACCSP database non-confidential				
		Sheppard[a]	Dept. Annual reports[b]	lbs	kgs	number	HERRING, BLUEBACK	ALEWIFE	"HERRINGS"	TOTAL Pounds	Alewife	Blueback herring	River herrings	Herring, unc	TOTAL Pounds
1976	1500							1500		1500		1500			1500
1977	6000							6000		6000		6000			6000
1978	700							700		700		700			700
1979	1000							1000		1000		1000			1000
1980	900							900		900		900			900
1981	64900							64900		64900		64900			64900
1982	229200							229200		229200		229200			229200
1983	24700							24700		24700		24700			24700
1984	4200							4200		4200		4200			4200
1985	150							150		150		150			150
1986	2900							2900		2900		2900			2900
1987	2765							2765		2765		2765			2765
1988	100							100		100		100			100
1989	500							500		500		500			500
1990	0														
1991	0														
1992	0														
1993	0														
1994	0														
1995	50864			511	232	1163								50864	50864
1996	82255			566	257	1187								82255	82255
1997	69318			3166	1436	7241								69318	69318
1998	88505			6247	2834	14241	4867	58		4925		4867		83638	88505
1999	74446			3319	1506	7553								74446	74446
2000	58377			16861	7648	38613	490			490				58377	58377
2001	23491			19607	8894	43537	3235			3235				23491	23491
2002	31778			20346	9229	46269	474			474		390		31388	31778
2003	53288			19644	8910	44811	20467			20467		20467		32821	53288
2004	16435			16435	7455	37816	14446			14446		688		11721	12409
2005	13509			13509	6128	31948	5791			5791		2463		259	2722
2006	20046			10011	4541	25144	11111		8935	20046		9835		6424	16259
2007	30205			13902	6306	35953	28159	24	2022	30205	24	11992	13843		25859
2008	24756			13146	5963	35612	20956	99	3701	24756	99	4	13044		13147
2009	12804			11832	5367	32700	11747	83	974	12804	82	224	11525		11831
2010	14024			12769	5792	36848	12667	101	1256	14024	101	51	12618		12770
2011	25334			10380	4708	31713	25334			25334			10370		10370
2012	21846			17346	7868	48215	17564		4282	21846		257	17463	3155	20875
2013	7545			7545	3365	24724	3233			3233		2038	892		2930
2014	7127			7127	3233	20791	6755		68	6823		254			254
2015	5914			5914	2683	15635						367			367

a Sheppard 1976

b NYSDEC Annual Reports - Historic annual reports

c NYSDEC License Reports - Mandatory commercial license reporting system: pounds and/or numbers estimated

d Max value was 4188000 from NMFS report, removed from Landings Figure

Table 10. Drift gill net trips by river section above Bear Mountain Bridge (rkm 75). From mandatory commercial reports stating mesh less than or equal to 3.5” stretch mesh. Note: Kingston Flats rkm’s are not exclusive and trip rkm’s are based on fishermen descriptions, so any rkm 148-149 trips are moved to the Kingston reach and rkm 154-155 trips are listed with the Saugerties reach.

	West Point rkm 75 - 89	Cornwall rkm 90 - 98	Poughkeepsie rkm 99 - 122	HydePark rkm 123 - 135	Kingston rkm 138 - 147	Kingston Flats rkm 148 - 155	Saugerties rkm 156 - 171	Catskill rm 172 - 200	Coxsackie rkm 201 - 216	Albany rkm 217 - 245
2000			2		3		104	88	2	
2001			1	7	3		31	120	5	
2002		5	3	5	14		37	168	6	
2003				8	10		59	184	14	
2004		2		8	3		37	188	20	
2005				1	12		60	145	17	
2006			1	10	16		69	87	25	
2007		1	11	13	32	**Area closed to gill nets**	57	62	19	**Area closed to gill nets**
2008				4	24		49	67	13	
2009			11		17		64	45	11	
2010			12	3	26		28	38	11	
2011			10	1	10		22	33	1	
2012			20	1	34		34	33	3	
2013		8	13		58		82	88	11	
2014		6	6		69		58	54	8	
2015		10	14		25		44	68	12	
Mean	0.0	5.3	8.7	5.5	22.3	0	52.2	91.8	11.1	0
%	0%	3%	4%	3%	11%	0%	27%	47%	6%	0%

Table 11. Number of river herring monitoring trips and catch per unit effort (CPUE) in the Hudson River commercial gill net fishery from 1996 through 2015.

YEAR	Fixed gill nets below Bear Mtn Bridge					Drift gill nets			
	Trips	Effort^	Catch	Annual CPUE	Sum of Weekly CPUE	Trips	Effort^	Catch	Annual CPUE
1996	0					1	91	43	0.472
1997	5	6830.6	208	0.030	0.055	0			
1998	0					0			
1999	4	11372.2	421	0.037	0.065	0			
2000	5	15650.0	545	0.035	0.126	1	160	7	0.044
2001	7	26688.9	1221	0.046	0.276	0			
2002	8	32222.2	1328	0.041	0.230	0			
2003	2	4800.0	171	0.036	0.071	0			
2004	11	41164.4	1826	0.044	0.230	0			
2005	1	9600.0	428	0.045	0.045	0			
2006	2	5591.1	246	0.044	0.044	1	378	0	0.000
2007	4	25777.8	299	0.012	0.055	2	4767	36	0.008
2008	0					0			
2009	3	19266.7	468	0.024	0.045	0			
2010	1	4326.7	154	0.036	0.036	0			
2011	4	6531.6	329	0.050	0.150	0			
2012	20	50916.4	1066	0.021	0.154	6	7013	560	0.080
2013	4	10719.8	1382	0.129	0.419	1	178	112	0.630
2014	7	14612.8	2161	0.148	0.605	1	2843	289	0.102
2015	5	8435.0	605	0.072	0.176	1	637	197	0.309

^Sq yd net area * hours

Table 12. Observed landings and dockside subsamples for commercial river herring trips made in the Hudson River Estuary for 2001 through 2015.

On-board Observations of Commercial Trips																					
		Alewife					Blueback herring					Unidentified "river herring"									
	N of	Number			Sex ratio		Number			Sex ratio		Number			Sex ratio			Percent			
Year	trips	M	F	U	M	F	M	F	U	M	F	M	F	U	M	F	Total	Alewife	Blueback	Unknown	
2001	7	192	178	851	0.52	0.48											1,221	100%	0%	0%	
2002	8			43			19	41	1225	0.32	0.68						1,328	3%	97%	0%	
2003	2			171													171	100%	0%	0%	
2004	11	124	168	8	0.42	0.58	5	6		0.45	0.55	500	796	297	0.39	0.61	1,904	16%	1%	84%	
2005	1			428										28			456	94%	0%	6%	
2006	3			1					246								247	0%	100%	0%	
2007	6			14					53					268			335	4%	16%	80%	
2008	0											44					44	0%	0%	100%	
2009	3	187	179	4	0.51	0.49	37	61		0.38	0.62						468	79%	21%	0%	
2010	1	23	28	1	0.45	0.55	11	88	3	0.11	0.89						154	34%	66%	0%	
2011	4	163	148	0	0.52	0.48	3	5		0.38	0.63			10			329	95%	2%	3%	
2012	26	439	568	121	0.44	0.56	54	70	68	0.44	0.56			383			1,703	66%	11%	22%	
2013	5	615	586	1	0.51	0.49	98	305		0.24	0.76						1,605	75%	25%	0%	
2014	8	750	830	5	0.47	0.53	236	629		0.27	0.73						2,450	65%	35%	0%	
2015	6	202	291	12	0.41	0.59	77	185		0.29	0.71			35			802	63%	33%	4%	

Table 13. Age structure of river herring samples from the commercial fishery. 2012 commercial scale samples were aged; 2013-2015 ages were estimated using age-length keys derived from fishery independent samples.

	Age									
	2	3	4	5	6	7	8	9	Total	Mean Age
Alewife Male										
2012	4	71	110	37	4	5			231	3.91
2013		26	37	15	3	1			83	3.97
2014		32	82	102	2	1	1		221	4.37
2015		4	42	53	18	1	1		118	4.77
Alewife Female										
2012	1	30	155	121	25	11	2	1	346	4.54
2013		19	39	12	5	1			76	4.07
2014		23	106	62	18	11	3	2	225	4.58
2015		14	41	67	18	4	1		146	4.73
Blueback herring Male										
2012	2	18	40	11	3				75	3.94
2013	0.2	10	9	4	2				25	3.91
2014	0.3	17	55	25	2				99	4.11
2015		7	8	17	1				33	4.35
Blueback herring Female										
2012		32	68	34	2	2			137	4.09
2013		13	11	6	2	1			32	3.92
2014		26	63	23	13	5			130	4.29
2015		6	16	16	4	1			43	4.53

Table 14. Estimated recreational use and take of river herring by Hudson River anglers.

	Herring Use*								
Year	% of all CAP Trips using herring as bait	N-SB Trips using RH	N bought / trip	N caught / trip	Total RH use/trip	% change in annual effort of CAP data	Estimated SB trips**	Trips using herring as bait**	Estimated Herring Use
2001							53,988	39,500	93,157**
2005	89%						72,568	64,500	152,117**
	Cooperative Angler Program Data								
2006	48%	263	1.47	2.57	4.04				
2007	25%	335	1.66	1.80	3.46		90,742	22,685	78,491***
2008	33%	474	0.86	1.64	2.50	+21%	109,557	36,154	84,969***
2009	35%	508	0.63	3.80	4.43	+9%	98,739	34,559	148,303***
2010	52%	532	0.67	4.80	5.48	+1	91,513	47,587	258,150***
2011	48%	885	0.71	4.35	5.06	+14%	103,532	49,695	251,285***
2012	53%	749	1.10	4.76	5.86	-1%	89,735	47,650	278,627***
2013	57%	611	1.04	5.23	6.27	-11%	80,703	46,001	288,579***
2014	55%	512	0.74	5.30	6.04	-14%	78,438	43,141	260,613***
2015	54%	571	0.66	6.04	6.70	+18%	106,961	57,759	386,915***

*Data from NYSDEC - HRFU Cooperative Angler Program (unpublished data)

**Creel survey data: NAI 2003, NAI 2007; 2001 estimated use modified using 2005 RH use per trip* 2001 trips using herring as bait; From 2008 to 2015 estimated using the percent change in annual effort of the CAP data*2007 SB trips from NYSDEC statewide angler survey

***Estimate calculated from the average RH/trip (CAP) and Estimated SB trips from 2007 NYSDEC statewide angler survey adjusted annually using the percent change in effort from CAP data

Table 15. Annual daily count data from Black Creek and commercial and estimated recreational herring harvest.

	Black Creek Daily Alewife Count Data							Hudson River Harvest		
	Min	Max	Mean	SD	SE	Total Counts	n (days)*	Commercial Harvest**	Recreational Harvest***	Total
2013	25	40571	4380.53	7710.69	1124.72	205,885	47	24,612	288,579	313,191
2014	294	58416	18458.75	13206.45	2334.59	590,680	32	20,805	260,613	281,418
2015	26	45186	13064.74	12146.56	2114.45	431,136	33	15,634	386,915	402,549

*Number of days count data were recorded

**Number harvested of combined river herring species from Hudson River commercial reports

***Estimated harvest numbers of combined river herring species derived from CAP data and 2007 NYSDEC statewide angler survey

Table 16. Mean total length and weight of alewives collected during spawning stock sampling in the Hudson River Estuary

	Alewife - Male										Alewife - Female									
	TL					Weight					TL					Weight				
Year	N	Max	Min	Mean	STD	N	Max	Min	Mean	STD	N	Max	Min	Mean	STD	N	Max	Min	Mean	STD
1936	8	291	270	282.9	7.8	6	227	184	210.3	16.6	9	324	288	302.7	12.3	8	340	198	241.3	43.9
1975																				
1976																				
1977																				
1978																				
1979																				
1980	1	298	298	298.0		1	249	249	249.0		1	315	315	315.0		1	318	318	318.0	
1981	2	291	272	281.5	13.4	2	216	179	197.4	26.2	1	292	292	292.0		1	222	222	222.0	
1982											1	310	310	310.0		1	275	275	275.0	
1983																				
1984	1	267	267	267.0		1	168	168	168.0		1	264	264	264.0		1	222	222	222.0	
1985	7	312	249	286.4	22.7	7	281	145	220.7	49.0	3	320	312	316.7	4.2	3	295	272	281.3	12.1
1986																				
1987	26	302	266	279.2	8.9	22	260	160	217.3	35.3	28	353	276	302.6	14.8	26	410	200	268.1	55.9
1988																				
1989																				
1990	89	296	239	267.5	14.9	87	270	100	178.2	35.7	7	327	255	284.7	22.8	7	310	180	218.6	54.9
1991	17	290	234	265.0	15.7	16	200	100	147.5	30.7	5	290	266	273.2	9.7	5	210	150	172.0	23.9
1992	12	286	236	269.7	15.3	12	220	110	176.7	29.6	23	306	240	278.4	16.6	23	290	120	189.1	46.8
1993	17	299	246	268.2	13.8	14	205	120	159.6	18.5	5	300	258	278.4	16.6	5	220	150	178.0	30.3
1994																				
1995	1	252	252	252.0		1	140	140	140.0		1	274	274	274.0		1	200	200	200.0	
1996																				
1997	2	287	230	258.5	40.3	2	200	120	160.0	56.6	8	310	262	280.5	15.4	8	240	140	185.0	31.6
1998	33	277	237	255.9	9.9	33	180	120	145.2	19.4	6	292	251	266.2	13.7	6	240	160	173.3	32.7
1999	7	261	228	245.6	12.8	6	140	50	73.3	34.4	4	283	258	271.0	10.9	4	220	40	106.3	79.1
2000																				
2001	399	300	210	262.7	13.2						123	304	229	272.4	12.9					
2002																				
2003	265	305	222	262.9	13.7	166	220	50	148.7	38.6	139	310	172	272.0	18.3	85	280	100	161.4	40.3
2004																				
2005	96	280	231	252.0	10.2	88	200	80	143.2	30.0	16	291	235	263.0	16.2	13	180	80	123.1	31.5
2006	16	260	220	238.4	8.3	12	180	80	114.6	24.8	10	283	239	255.3	12.6	8	280	80	155.6	60.8
2007	47	290	219	251.6	12.6	47	220	80	140.6	30.7	5	273	240	257.8	12.2	5	180	120	148.0	22.8
2008	202	285	215	243.7	12.1	188	260	60	158.0	38.3	55	305	225	264.5	18.3	55	380	120	208.4	53.2
2009	460	290	214	255.5	10.8	221	220	80	162.6	27.6	85	300	230	267.6	12.1	41	280	140	205.9	32.0
2010	272	295	221	253.0	13.2	115	250	80	155.7	31.6	87	325	237	271.0	18.4	73	300	110	193.3	45.0
2011	105	283	222	249.4	11.5	74	206	85	138.6	28.4	102	300	230	265.5	14.9	53	260	92	173.0	39.0
2012	1574	296	216	258.4	12.9	960	250	80	156.4	30.2	525	321	233	272.1	14.9	355	360	100	180.8	45.4
2013	1742	294	211	255.1	11.1	682	220	65	130.6	26.7	598	318	228	268.1	16.0	344	300	90	163.0	42.0
2014	2647	305	222	266.3	13.3	855	260	50	154.1	39.3	1248	320	227	279.6	14.1	520	330	60	183.1	46.7
2015	1303	310	221	268.2	15.3	508	295	80	168.1	38.1	759	322	245	283.3	14.7	361	335	115	208.5	42.7

*Fish 170 mm or greater; collected using electrofishing, herring haul seine, and beach seine gears

Best values for length/weight analysis

Table 17. Mean total length and weight of blueback herring collected during spawning stock sampling in the Hudson River Estuary

	Blueback herring - Male										Blueback herring - Female									
	TL					Weight					TL					Weight				
Year	N	Max	Min	Mean	STD	N	Max	Min	Mean	STD	N	Max	Min	Mean	STD	N	Max	Min	Mean	STD
1936	4	290	310	299.0	8.5	4	255	213	244.5	21.3	4	266	321	294.0	22.5	4	369	206	279.2	67.6
1975																				
1976											2	330	330	330.0	0.0					
1977																				
1978																				
1979																				
1980																				
1981	1	284	284	284.0		1	194	194	194.0		1	289	289	289.0		1	228	228	227.6	
1982	2	290	268	278.9	15.3	2	219	184	201.7	24.5	2	300	286	292.8	10.2	2	253	213	232.6	28.1
1983																				
1984	16	282	231	259.9	16.6	16	213	132	160.0	26.1	12	300	251	274.8	15.7	12	327	145	212.3	50.5
1985	11	304	245	271.0	18.0	11	231	136	172.6	30.7	10	329	267	284.1	18.0	10	295	159	198.2	38.7
1986																				
1987	21	294	243	268.0	14.0	10	310	140	205.0	42.5	36	340	235	283.7	21.4	24	400	120	242.1	59.6
1988																				
1989	316	285	219	256.1	9.0	316	204	75	136.0	15.9	317	305	228	265.9	10.6	316	275	100	159.6	22.9
1990	345	287	195	246.5	15.1	340	225	70	121.3	26.8	283	314	228	263.5	16.5	279	280	88	163.7	37.3
1991	6	262	225	246.5	15.0	6	180	100	128.3	28.6	11	286	241	261.2	14.9	10	220	100	145.0	46.5
1992	112	295	215	250.5	15.0	99	260	80	142.6	38.0	129	324	228	272.9	21.3	110	380	100	187.7	52.8
1993	1	243	243	243.0		1	130	130	130.0		1	255	255	255.0		1	160	160	160.0	
1994																				
1995																				
1996											1	290	290	290.0						
1997																				
1998	1	230	230	230.0		1	100	100	100.0											
1999	20	286	225	251.0	19.0	18	220	50	135.6	45.1	20	314	225	275.4	19.3	19	260	100	183.7	35.8
2000																				
2001	2	267	235	251.0	22.6						3	280	257	267.3	11.7					
2002																				
2003	4	267	240	254.0	14.5	4	180	100	130.0	34.6	3	283	252	268.7	15.6	2	120	120	120.0	0.0
2004	6	263	234	246.2	11.9	1	240	240	240.0		4	268	242	252.0	11.4					
2005	21	266	228	246.4	10.8	16	220	80	108.8	36.5	16	263	231	245.0	9.3	13	120	70	98.5	18.2
2006	2	256	249	252.5	4.9	2	140	120	130.0	14.1	1	245	245	245.0		1	160	160	160.0	
2007																				
2008	13	253	226	236.6	7.6	13	180	120	130.8	19.3	8	260	227	245.8	10.4	8	200	120	148.8	24.7
2009	108	268	197	243.9	13.7	54	200	60	108.8	35.1	112	275	206	253.7	9.0	54	160	70	128.6	18.6
2010	62	265	202	237.8	12.1	46	180	70	115.6	23.7	50	276	215	250.3	11.5	44	210	100	144.6	25.1
2011	85	264	212	233.0	11.6	48	160	74	107.8	20.1	117	280	210	243.8	14.6	75	178	80	121.9	21.9
2012	333	273	200	238.3	13.8	171	185	60	106.8	23.4	392	299	229	255.1	11.6	186	215	70	129.2	26.8
2013	786	275	205	246.6	9.7	279	185	40	108.6	24.6	688	297	213	257.6	11.1	293	250	75	134.5	30.5
2014	650	287	203	243.4	13.4	289	200	30	101.5	27.1	723	301	214	259.0	14.6	305	290	45	136.6	40.0
2015	653	290	220	249.9	8.5	270	205	90	125.6	17.9	742	303	234	262.7	12.5	310	265	90	156.3	31.6

*Fish 170 mm or greater; collected using electrofishing, herring haul seine, and beach seine gears

Best values for length/weight analysis

Table 18. Annual catch and effort (n-hauls) for alewife and blueback herring.

Year	Annual Effort (N-hauls & Efish events)	Weeks sampled	Annual Catch (Alewife)	Annual Catch (Blueback)
Historical survey data				
1975	2	2	0	4
1976	3	2	0	3
1977	1	1	2	0
1978	0	0	0	0
1979	4	3	69	30
1980	3	3	4	1
1981	3	2	5	2
1982	3	3	3	4
1983	2	1	1	3
1984	3	3	5	28
1985	2	2	19	21
1986	0	0	0	0
1987	5	3	461	1626
1988	1	1	0	0
1989	9	4	98	633
1990	18	7	252	771
1991	2	2	22	17
1992	7	3	35	247
1993	4	2	37	17
1994	0	0	0	0
1995	2	2	2	0
1996	1	1	0	1
1997	1	1	10	0
1998	1	1	39	1
1999	6	3	12	43
2000	2	1	0	0
2001	13	3	1426	33
2002	0	0	0	0
2003	16	4	417	7
2004	3	2	0	10
2005	13	4	120	41
2006	5	2	27	3
2007	6	4	53	0
2008	15	4	262	21
2009	22	5	660	278
2010	63	7	342	117
2011	28	6	208	204
Current survey data				
2012	167	15	2168	1314
2013	119	11	4870	4056
2014	114	10	11231	3054
2015	110	8	4328	3080

*Only includes hauls when gear performed well without any major issues i.e. no hangs, rips in net, or lifting of the lead line

Table 19. Sampling efforts (n-hauls) and catches per river section from 2012-15.

	2012			2013			2014			2015		
River section	N-sites	N-hauls	N-herring caught	N-sites	N-hauls	N-herring caught	N-sites	N-hauls	N-herring caught	N-sites	N-hauls	N-herring caught
Albany	6	37	1978	3	21	4273	3	26	3440	3	21	2247
Catskill	14	52	529	9	38	1639	7	30	3118	5	33	1851
Coxsackie	15	47	477	10	34	2269	5	30	5908	5	33	2113
Kingston	14	46	468	6	32	787	5	36	1898	4	32	1178
Newburgh	4	11	-	-	-	-	-	-	-	-	-	-
Poughkeepsie	14	3	1	-	-	-	-	-	-	-	-	-
IndianPoint	5	6	-	-	-	-	-	-	-	-	-	-
Croton-Haverstraw	3	10	-	-	-	-	-	-	-	-	-	-
TappanZee	6	6	-	-	-	-	-	-	-	-	-	-
Totals	81	218	3453	28	125	8968	20	122	14364	17	119	7389

Table 20. Catch composition of river herring caught during the 1999-2001 survey* in the Hudson River and its tributaries, including the Mohawk River.

		Alewife			Blueback Herring			Total**		
Year	Geographic Region	Female	Male	Total	Female	Male	Total	Female	Male	Total
1999	Hudson River	195	89	335	187	56	262	382	145	597
	Hudson River Above Troy	22	31	57	22	13	37	44	44	94
	Hudson River Tributaries	136	1612	1758	84	272	358	220	1884	2116
	Mohawk River				2739	3988	7083	2739	3988	7083
	Total	353	1732	2150	3032	4329	7740	3385	6061	9890
2000	Hudson River	664	602	1317	1134	600	1784	1798	1202	3101
	Hudson River Above Troy	21	6	27	120	56	183	141	62	210
	Hudson River Tributaries	171	3046	3246	18	56	75	189	3102	3321
	Mohawk River				636	678	1372	636	678	1372
	Total	856	3654	4590	1908	1390	3414	2764	5044	8004
2001	Hudson River	554	607	1213	1312	1051	2471	1866	1658	3684
	Hudson River Above Troy	9	6	15	134	75	213	143	81	228
	Hudson River Tributaries	286	1880	2185	27	16	44	313	1896	2229
	Mohawk River				1172	1086	2379	1172	1086	2379
	Total	849	2493	3413	2645	2228	5107	3494	4721	8520
TOTAL ALL YEARS		2058	7879	10153	7585	7947	16261	9643	15826	26414

* NAI 2008, Vol. 1, Table 5.1

** Total includes herring of undetermined sex

Table 21. Minimum sample sizes required to detect a difference in mean length from Equation 1. Bolded values were used in trend analyses.

		minimum samples sizes		
Species	Sex	***5mm***	2.5mm	1mm
Blueback	male	***56***	222	1387
Blueback	female	***70***	278	1732
Alewife	male	***73***	291	1817
Alewife	female	***92***	367	2293

Table 22. Age and Z estimates (Chapman-Robson) of river herring caught during NYSDEC spawning stock surveys. 1989-1990: electrofishing in Mohawk R/lock 9 to Troy Dam; 2009-2015: Hudson River only- Haul Seine and Electrofishing.

	Age										
Year	2	3	4	5	6	7	8	9	n	Mean Age	Instantaneous mortality (Z)*
Alewife Male											
2012	27	385	726	308	91	21	2		1559	4.08	1.12
2013		615	782	276	48	15	1		1737	3.89	1.30
2014	1	372	933	1233	61	18	29		2647	4.43	0.91
2015		105	430	544	203	12	8		1302	4.70	1.40
Alewife Female											
2012	5	76	210	175	32	11	7	2	518	4.44	0.88
2013		148	275	84	58	17	12	1	596	4.26	0.90
2014		83	537	383	137	75	27	5	1247	4.75	0.76
2015		56	179	372	114	30	8		759	4.87	1.29
Blueback Herring Male											
1989		44	164	74	5	1			288	4.15	1.32
1990	8	143	100	41	7				299	3.65	0.88
2012	64	157	89	16	3				329	3.20	1.10
2013	34	483	209	44	17				787	3.40	1.15
2014	83	308	205	51	1				649	3.35	1.03
2015	3	412	168	44	3				630	3.42	1.21
Blueback Herring Female											
1989		31	182	77	7				297	4.20	1.36
1990	6	86	102	52	8				254	3.88	1.20
2012		152	168	61	4				385	3.78	0.82
2013	1	364	203	97	21	1			687	3.67	0.91
2014	7	320	274	77	36	9			723	3.78	0.81
2015		248	262	162	36	9			716	4.02	1.02

*Z estimates derived from bias-corrected Chapman-Robson mortality estimator as descibed in Smith et al. 2012 using the age at most abundance as the age at full recruitment.

Table 23. Percent repeat spawner and Z estimates of river herring caught in NYSDEC spawning stock surveys. 1989-1990: electrofishing in Mohawk R/lock 9 to Troy Dam; 2009-2015: Hudson River only-Haul Seine and Electrofishing.

	Repeat spawn marks										Instantaneous
Year	0	1	2	3	4	5	n	Mean RS	% Virgin	% Repeat	mortality (Z)*
			Alewife Male								
2009	229	65	12	0			306	0.29	75%	25%	1.48
2010	165	28	11	2			206	0.27	80%	20%	1.53
2011	101	18	2	1	1		123	0.24	82%	18%	1.62
2012	138	35	19	1			193	0.39	72%	28%	1.25
2013	150	23	13	2			188	0.29	80%	20%	1.50
2014	52	19	7	4	2		84	0.63	62%	38%	0.93
2015	54	19	25	6	1	1	106	0.91	51%	49%	0.73
			Alewife Female								
2009	70	41	9	1			121	0.51	58%	42%	1.07
2010	51	32	15	2	1		101	0.71	50%	50%	0.86
2011	84	25	12	2			123	0.45	68%	32%	1.16
2012	124	36	17	5	3		185	0.52	67%	33%	1.06
2013	116	39	24	9	8		196	0.74	59%	41%	0.84
2014	42	13	10	10	4	2	81	1.10	52%	48%	0.64
2015	32	25	20	8	4		89	1.18	36%	64%	0.59
			Blueback herring Male								
1989	187	83	18				288	0.41	65%	35%	1.22
1990	235	46	18				299	0.27	79%	21%	1.52
2009	38	24	2				64	0.44	59%	41%	1.16
2010	63	12	4				79	0.25	80%	20%	1.55
2011	66	12	1				79	0.18	84%	16%	1.83
2012	294	28	7				329	0.13	89%	11%	2.22
2013	118	7	2	1			128	0.11	92%	8%	2.25
2014	57	9	4	1			71	0.28	80%	20%	1.47
2015	48	9	7				64	0.36	75%	25%	1.29
			Blueback herring Female								
1989	224	66	7				297	0.27	75%	25%	1.54
1990	200	44	10				254	0.25	79%	21%	1.59
2009	44	12	3				59	0.31	75%	25%	1.40
2010	46	16	4				66	0.36	70%	30%	1.28
2011	80	26	5	1			112	0.35	71%	29%	1.33
2012	107	26	2	1			136	0.24	79%	21%	1.60
2013	121	19	11	4			155	0.34	78%	22%	1.35
2014	48	10	12	4			74	0.62	65%	35%	0.94
2015	41	21	13	4			79	0.75	52%	48%	0.83

*Z estimates derived from bias-corrected Chapman-Robson mortality estimator as descibed in Smith et al. 2012 using the age at most abundance as the age at full recruitment.

Table 24. NYSDEC and HRG young-of-year Alewife indices. NYSDEC index is a geometric mean CPUE for all hauls between Julian weeks 26 and 42. The HRG BSS index is a weighted arithmetic mean CPUE for weeks 33 to 40. The HRG FSS index is a weighted mean density for the channel strata for weeks 33-40.

	Alewife						Blueback Herring					
	NYSDEC Beach Seine		HRG Beach Seine (BSS)		HRG Trawl (FSS)		NYSDEC Beach Seine		HRG Beach Seine (BSS)		HRG Trawl (FSS)	
Year	CPUE	SE	CPUE	SE	Density	SE	CPUE	SE	CPUE	SE	Density	SE
1974			2.92	0.44					23.51	3.39		
1975			2.47	0.40					69.66	9.49		
1976			2.40	0.63					155.55	23.84		
1977			4.18	0.61					219.37	26.38		
1978			5.49	0.97					229.19	44.49		
1979			1.35	0.23	0.20	0.08			54.45	8.32	3.70	0.75
1980	0.25	0.13	0.50	0.16	0.69	0.35	12.02	0.53	100.84	53.80	2.61	0.75
1981	0.23	0.18	4.15	0.94	0.63	0.21	7.18	0.69	181.93	72.90	21.20	5.86
1982	0.61	0.19	0.79	0.24	0.28	0.08	15.87	0.60	121.72	31.43	10.33	2.06
1983	0.37	0.06	1.79	0.27	0.19	0.07	35.51	0.19	190.86	41.85	6.08	1.07
1984	0.05	0.02	0.49	0.14	0.21	0.13	11.26	0.20	22.66	5.41	20.39	3.67
1985	0.60	0.07	0.74	0.17	0.93	0.41	21.00	0.18	18.82	3.90	17.42	4.58
1986	0.21	0.04	0.83	0.51	0.26	0.08	17.11	0.16	14.10	4.41	6.48	1.38
1987	0.33	0.07	0.65	0.12	0.52	0.27	35.19	0.21	69.80	15.69	25.61	12.36
1988	0.32	0.05	0.42	0.09	0.27	0.13	43.32	0.16	47.41	14.02	26.69	4.30
1989	0.17	0.03	0.16	0.04	0.23	0.07	16.78	0.17	35.88	8.09	16.83	5.41
1990	0.57	0.07	1.05	0.17	0.35	0.14	44.33	0.19	97.85	13.97	29.69	10.64
1991	1.04	0.09	3.47	0.57	0.33	0.12	24.25	0.17	47.44	11.06	12.65	1.47
1992	0.29	0.04	0.30	0.12	0.17	0.08	13.95	0.15	31.10	6.53	15.52	3.87
1993	0.46	0.06	0.54	0.16	0.23	0.08	29.28	0.17	35.23	5.52	7.72	1.59
1994	0.72	0.07	1.40	0.34	0.12	0.06	27.47	0.19	88.84	13.78	5.77	1.90
1995	0.46	0.06	1.14	0.35	0.11	0.03	6.52	0.14	38.18	23.30	1.27	0.42
1996	0.39	0.06	0.10	0.04	0.49	0.15	21.39	0.15	36.71	17.55	50.16	15.89
1997	0.50	0.06	2.26	0.44	0.32	0.10	15.60	0.17	162.11	35.44	7.30	1.43
1998	0.16	0.03	0.21	0.15	0.03	0.02	1.45	0.11	1.28	0.31	0.03	0.03
1999	2.94	0.11	4.53	1.07	0.70	0.17	34.58	0.16	58.67	17.79	2.07	0.78
2000	0.69	0.07	0.60	0.32	0.20	0.08	10.79	0.13	25.98	14.98	2.68	1.16
2001	2.11	0.10	2.73	0.78	0.87	0.72	43.84	0.17	57.61	11.40	5.85	5.00
2002	1.13	0.09	0.58	0.10	0.02	0.01	2.83	0.13	12.63	5.77	0.80	0.55
2003	0.74	0.06	3.39	0.90	0.29	0.12	17.10	0.16	119.20	27.39	5.92	1.89
2004	0.50	0.05	1.27	0.36	0.10	0.04	7.52	0.15	49.56	11.71	1.52	0.35
2005	1.43	0.09	5.29	1.23	0.34	0.09	26.41	0.16	65.86	20.09	2.33	1.05
2006	0.58	0.07	0.80	0.44	0.04	0.02	2.41	0.11	8.28	3.44	0.53	0.15
2007	4.56	0.13	6.69	2.00	1.87	1.14	33.22	0.16	71.60	9.05	5.24	0.91
2008	2.28	0.11	3.89	1.00	0.80	0.54	17.03	0.16	39.99	8.85	5.56	1.35
2009	0.45	0.06	1.37	0.47	0.04	0.03	2.80	0.12	3.88	1.14	0.87	0.25
2010	2.92	0.12	7.28	2.21	0.80	0.34	15.48	0.16	66.64	20.06	4.00	2.11
2011	0.95	0.08	1.79	0.36	0.31	0.11	15.89	0.17	41.62	6.29	13.63	1.96
2012	0.36	0.06	0.25	0.09	0.15	0.06	6.03	0.15	34.66	10.55	4.32	1.43
2013	1.00	0.09	0.25	0.09	0.04	0.03	0.60	0.07	0.78	0.45	0.02	0.02
2014	0.93	0.09	0.53	0.14	1.15	0.26	52.22	0.15	74.18	21.59	27.21	9.10
2015	1.07	0.10	3.01	0.60	1.25	0.34	7.53	0.14	46.78	8.69	2.86	0.75

Table 25. Annual estimates of alewife and blueback herring American shad conditional entrainment and impingement mortality rates from water withdrawals* at power generating and other cooling systems on the Hudson River. (CHGE et al. 1999)

	Alewife			Blueback herring		
Year	Entrainment	Impingement	Total	Entrainment	Impingement	Total
1974	27.19	1.44	28.63	27.19	0.36	27.55
1975	40.67	1.44	42.11	40.67	0.36	41.03
1976	31.10	1.44	32.54	31.10	0.36	31.46
1977	32.99	1.44	34.43	32.99	0.36	33.35
1978	27.50	1.44	28.94	27.50	0.36	27.86
1979	27.42	1.44	28.86	27.42	0.36	27.78
1980	24.71	1.44	26.15	24.71	0.36	25.07
1981	11.98	1.44	13.42	11.98	0.36	12.34
1982	9.74	1.44	11.18	9.74	0.36	10.10
1983	21.22	1.44	22.66	21.22	0.36	21.58
1984	24.80	1.44	26.24	24.80	0.36	25.16
1985	14.68	1.59	16.27	14.68	0.40	15.08
1986	10.09	1.89	11.98	10.09	0.70	10.79
1987	32.36	1.40	33.76	32.36	0.30	32.66
1988	24.12	1.10	25.22	24.12	0.20	24.32
1989	32.67	1.20	33.87	32.67	0.20	32.87
1990	29.65	1.44	31.09	29.65	0.36	30.01
1991	21.63	1.44	23.07	21.63	0.36	21.99
1992	39.45	1.44	40.89	39.45	0.36	39.81
1993	11.24	1.44	12.68	11.24	0.36	11.60
1994	17.03	1.44	18.47	17.03	0.36	17.39
1995	14.34	1.44	15.78	14.34	0.36	14.70
1996	7.69	1.44	9.13	7.69	0.36	8.05
1997	22.36	1.44	23.80	22.36	0.36	22.72

*For Bowline Point, Indian Point, Roseton, Danskammer, Lovett, Empire State Plaza, Albany Steam Station, Westchester Resco

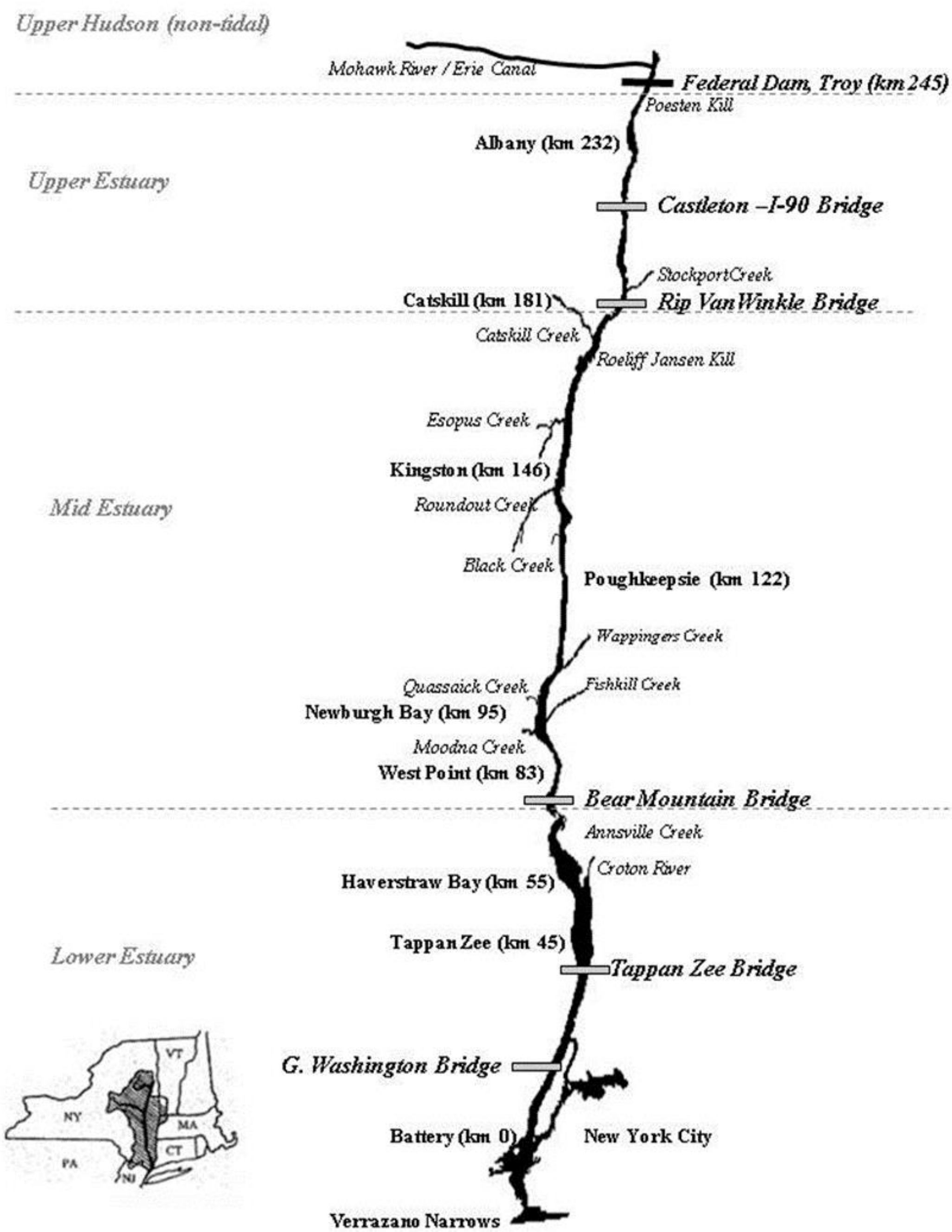

Figure 1. Hudson River Estuary with major spawning tributaries for river herring.

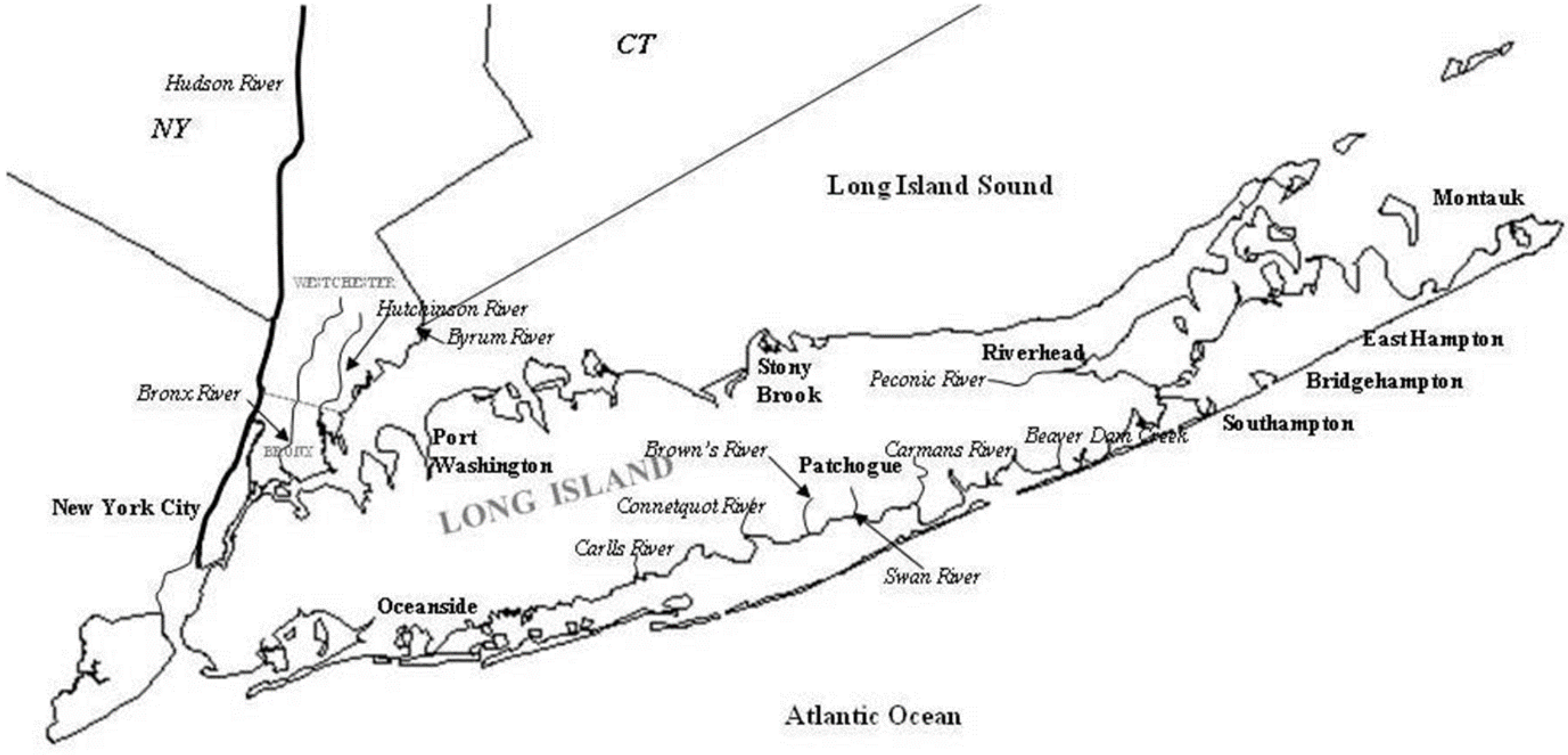

Figure 2. Long Island, Bronx and Westchester Counties, New York, with some river herring (primarily alewife) spawning streams identified.

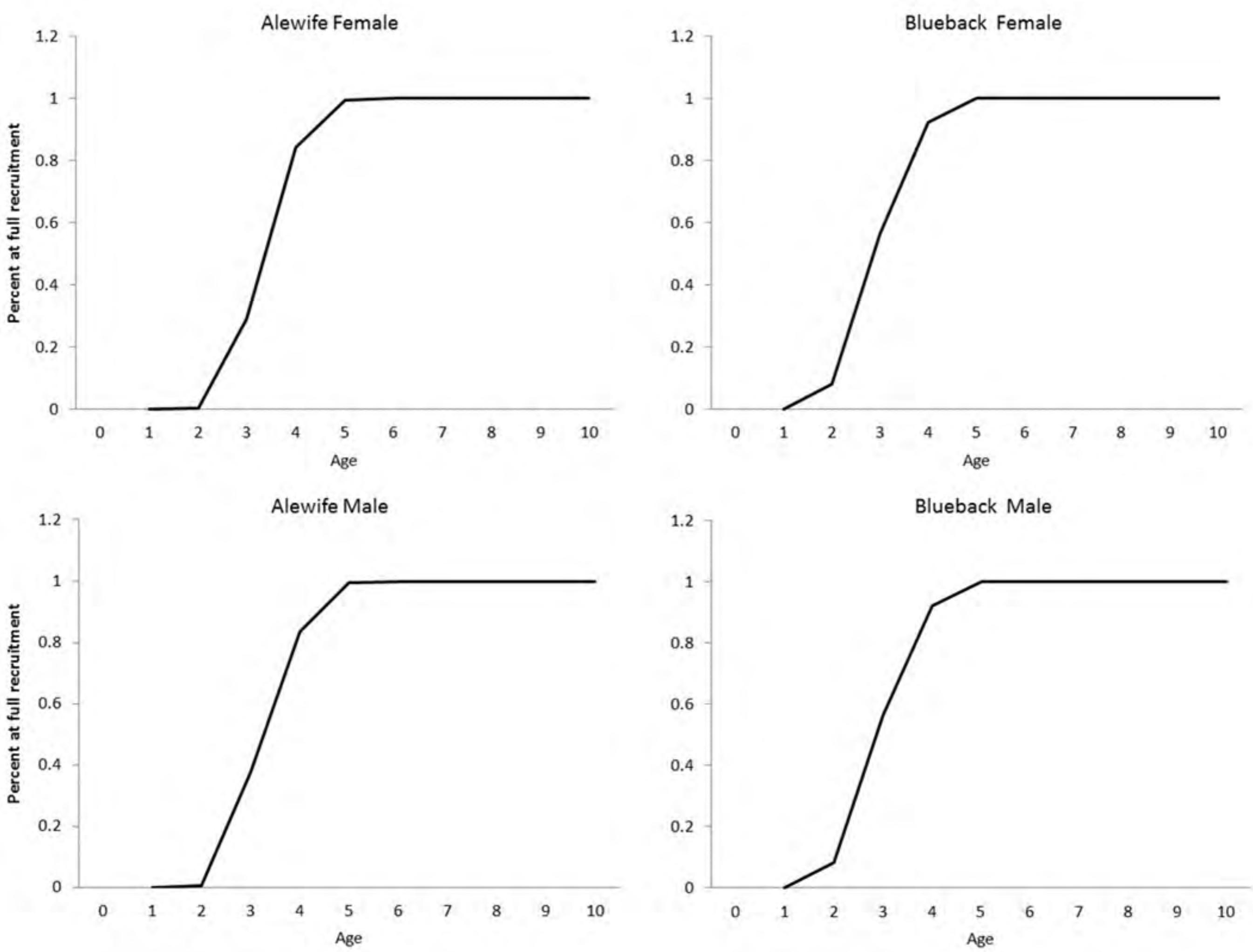

Figure 3. Maturity schedule for alewife and blueback herring derived from 2012-15 age data.

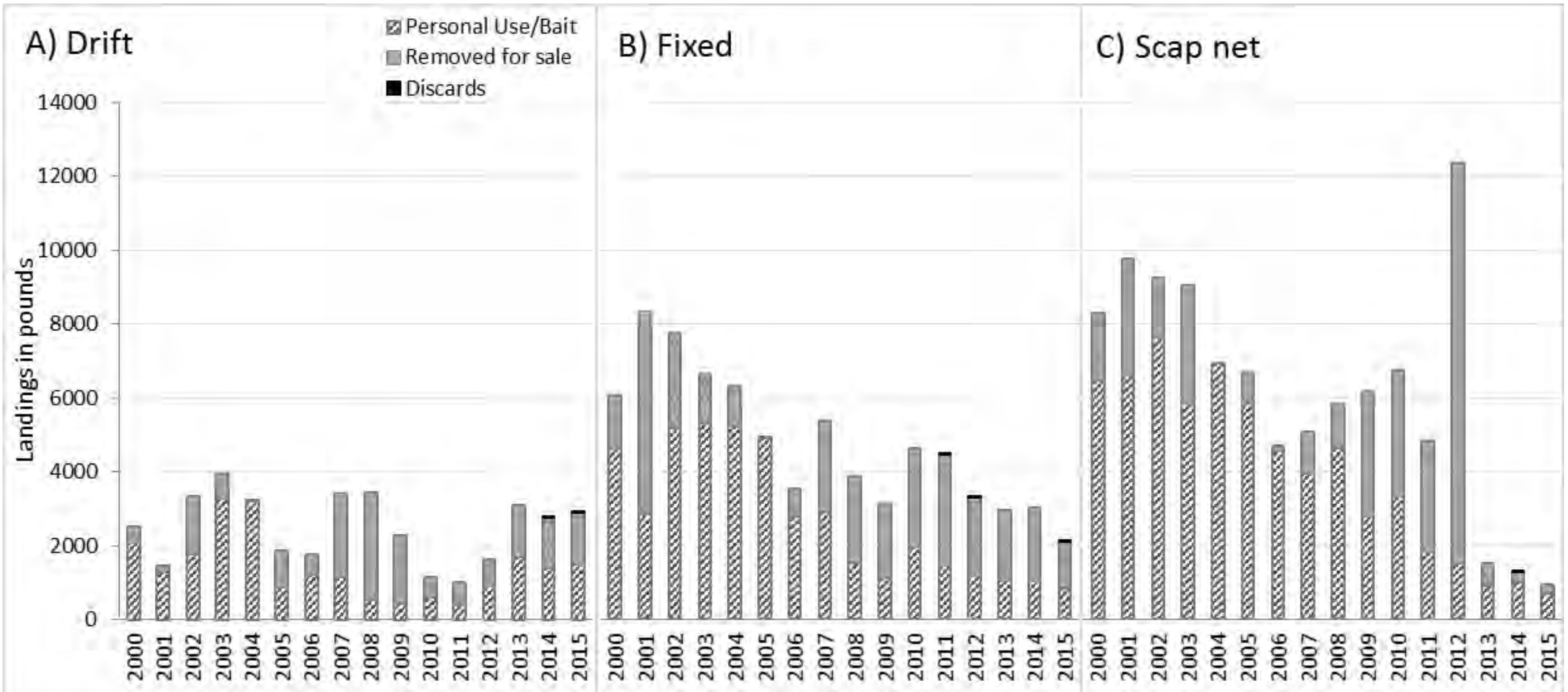

Figure 4. Dispositions of commercially caught river herring as reported in mandatory trip reports. Note very minimal discards in black.

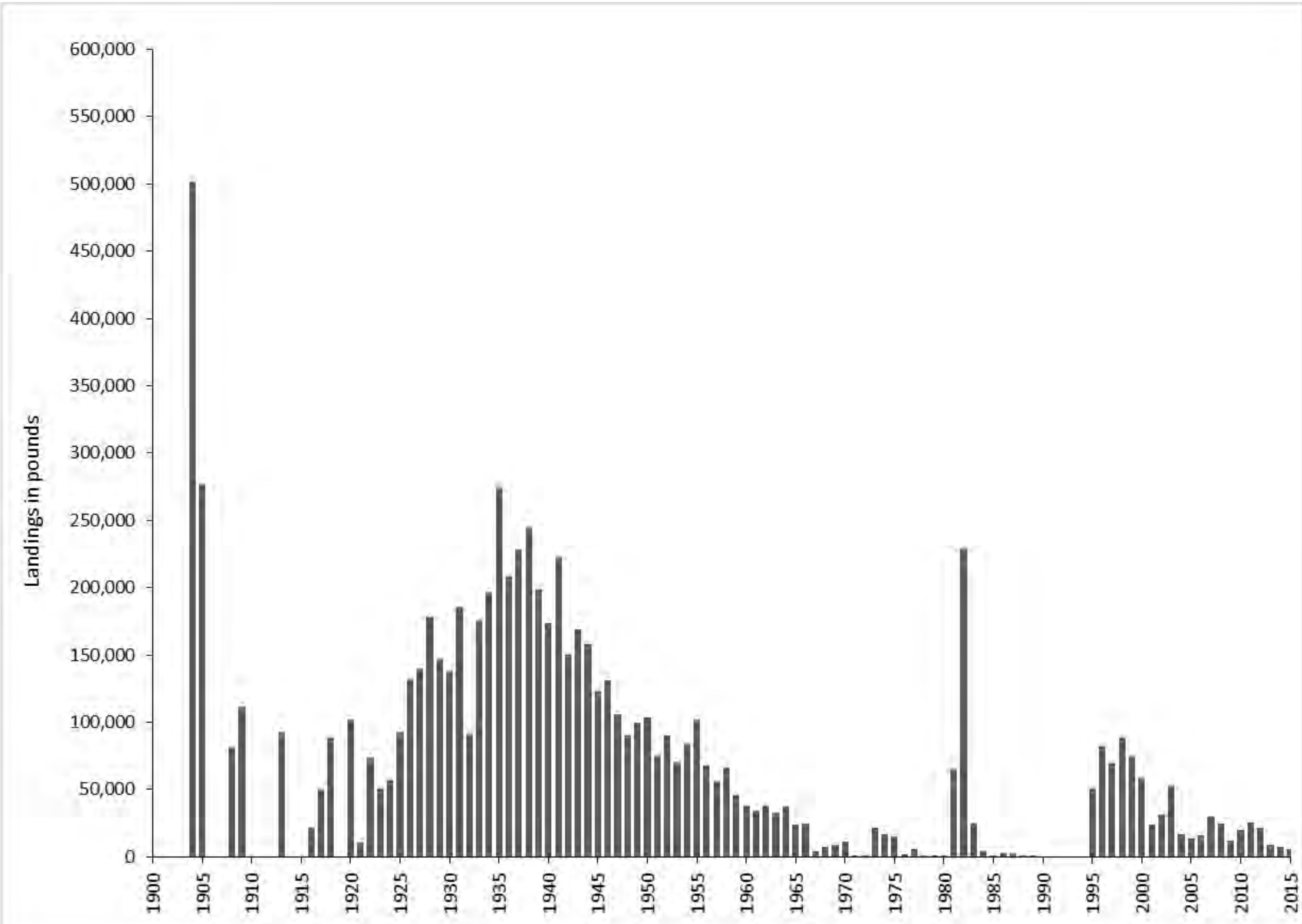

Figure 5. Pounds of river herring landed in New York waters. 1966 data point not included (see text).

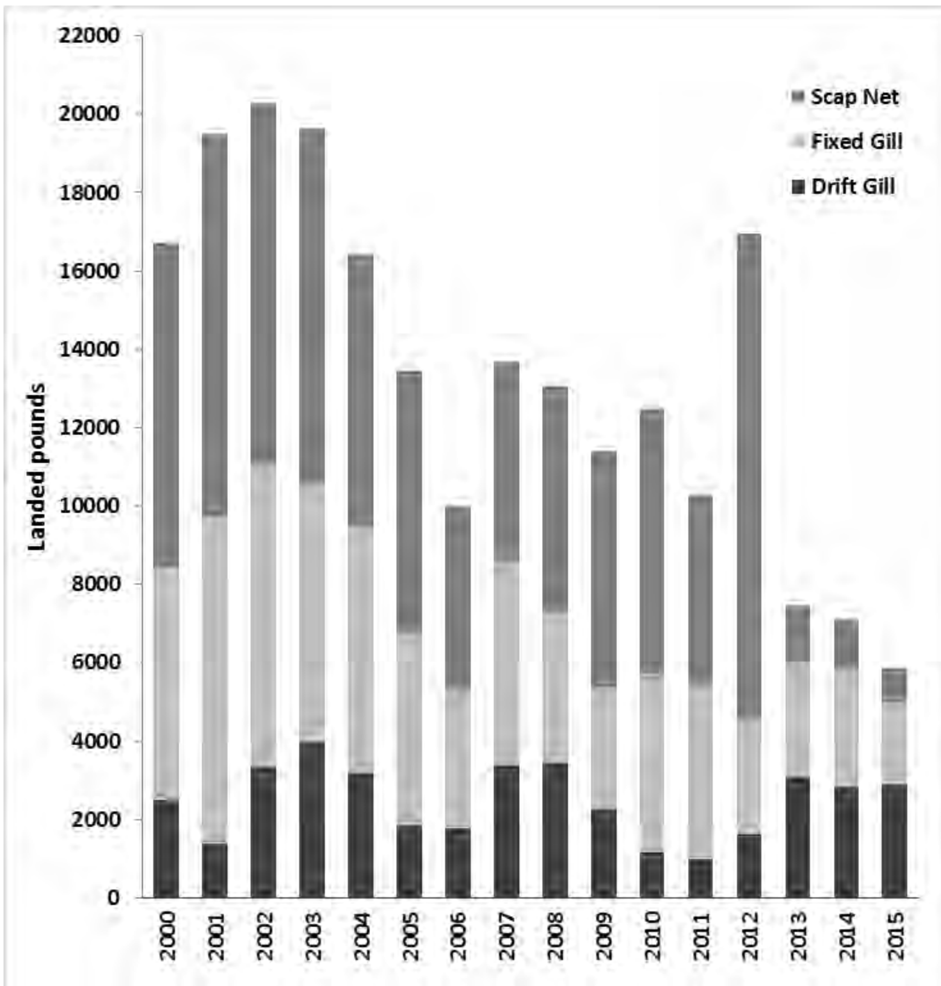

Figure 6. Annual total landed pounds of river herring separated by gear type. Catch includes targeted river herring trips only.

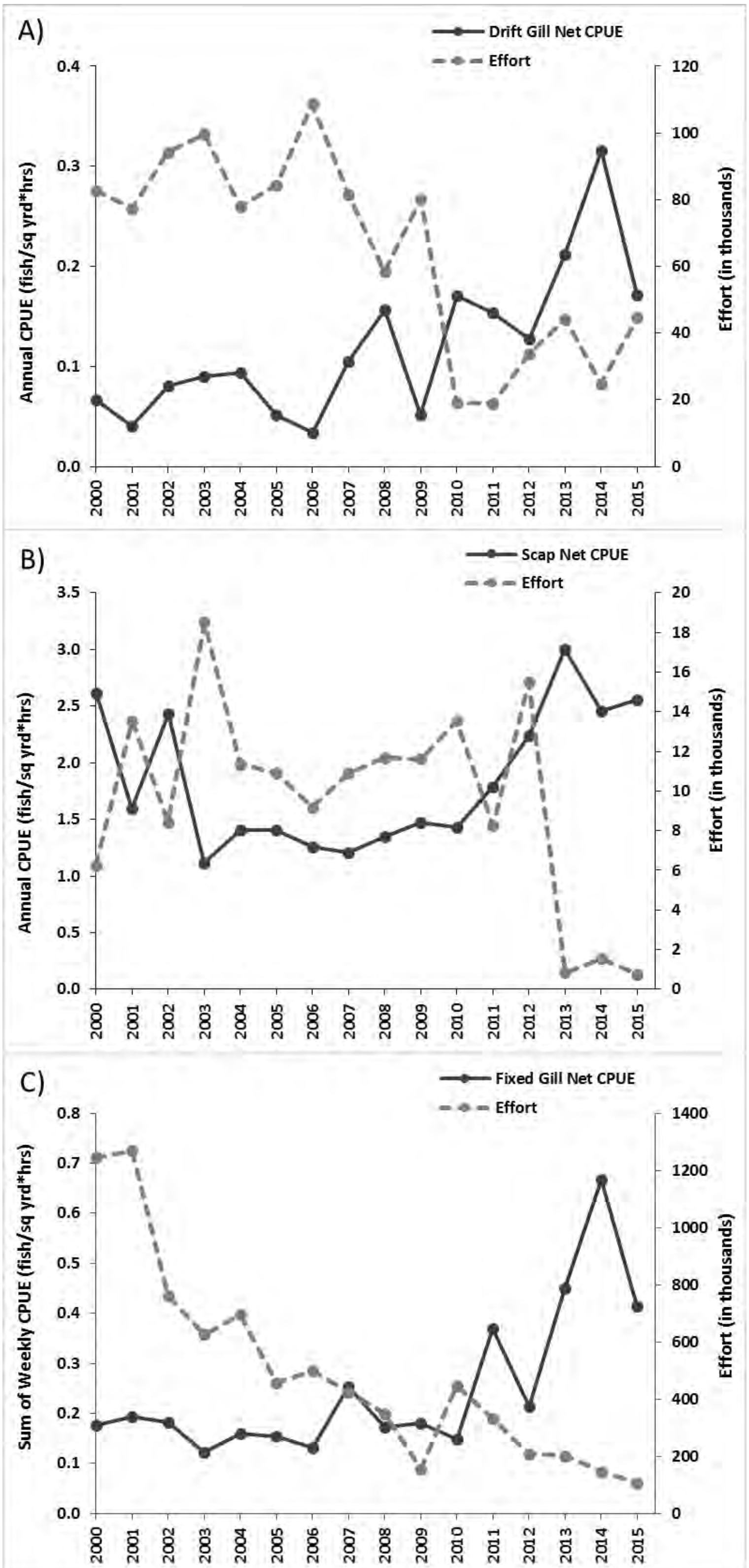

Figure 7. Efforts (sq yd net area * hours) and CPUEs from mandatory commercial reports. A) Drift gill net fishery above rkm 75; CPUE is total catch/total effort. B) Scap net fishery above rkm 75; CPUE is total catch/total effort. C) Fixed gill net fishery below rkm 75; CPUE is the sum of weekly catch/weekly effort.

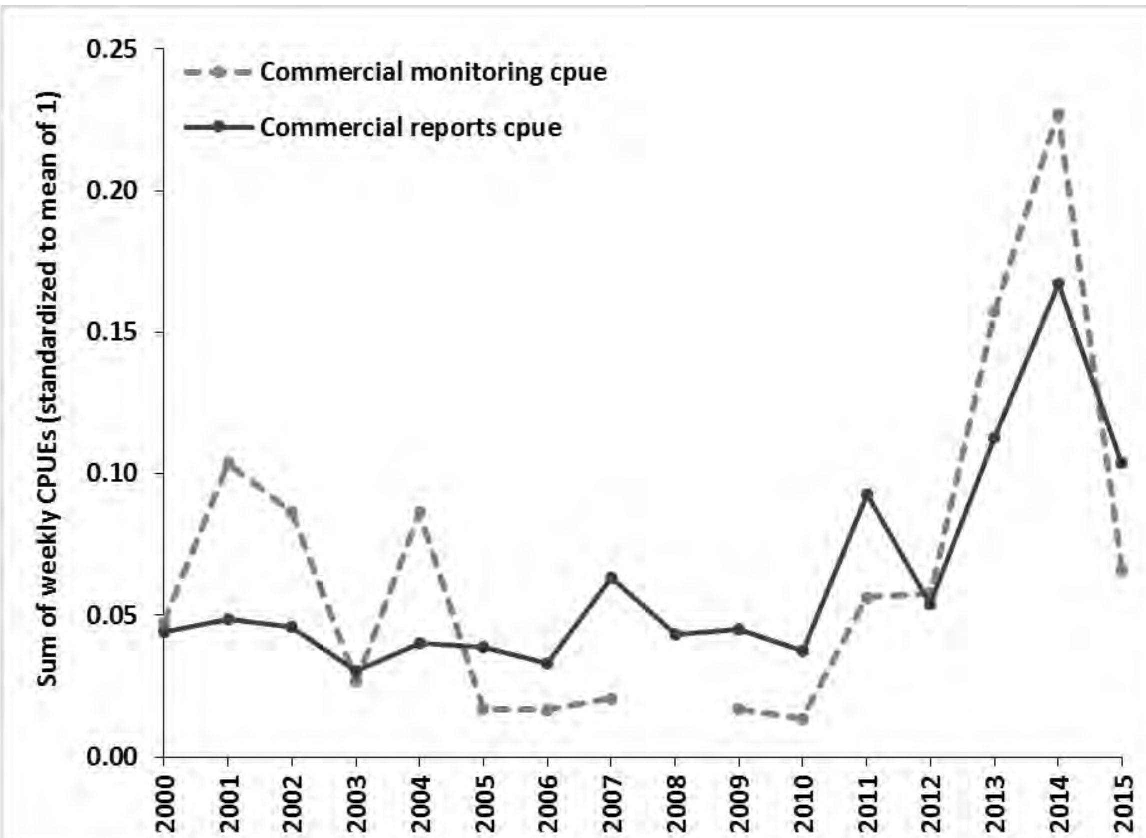

Figure 8. Comparison of the sum of weekly CPUEs calculated from commercial monitoring and mandatory commercial reports of the fixed gill net fishery below the Bear Mountain Bridge (rkm 75). Values are standardized to a mean of 1.

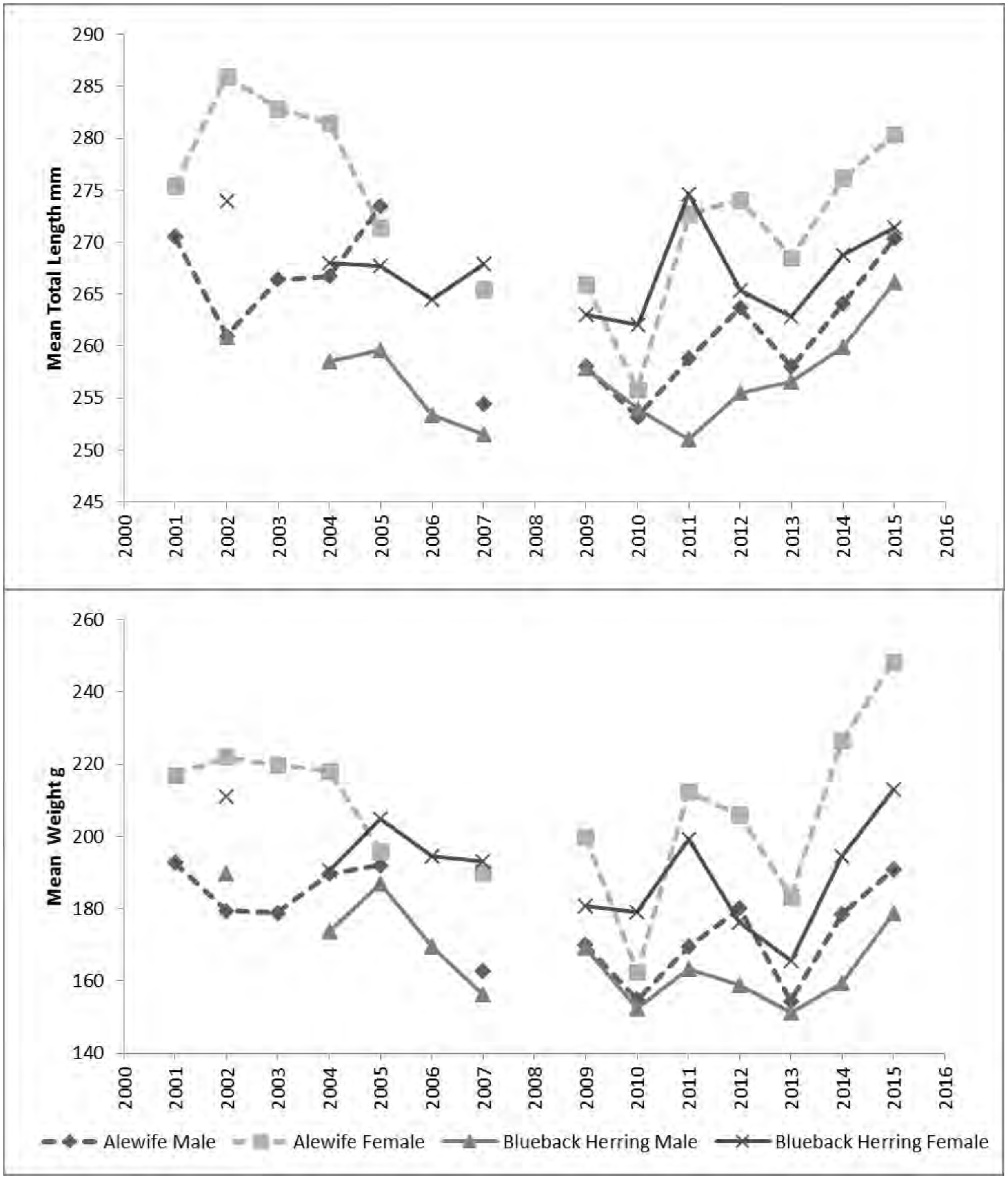

Figure 9. Mean length and weight of river herring collected in fishery dependent sampling in the commercial fishery in the Hudson River.

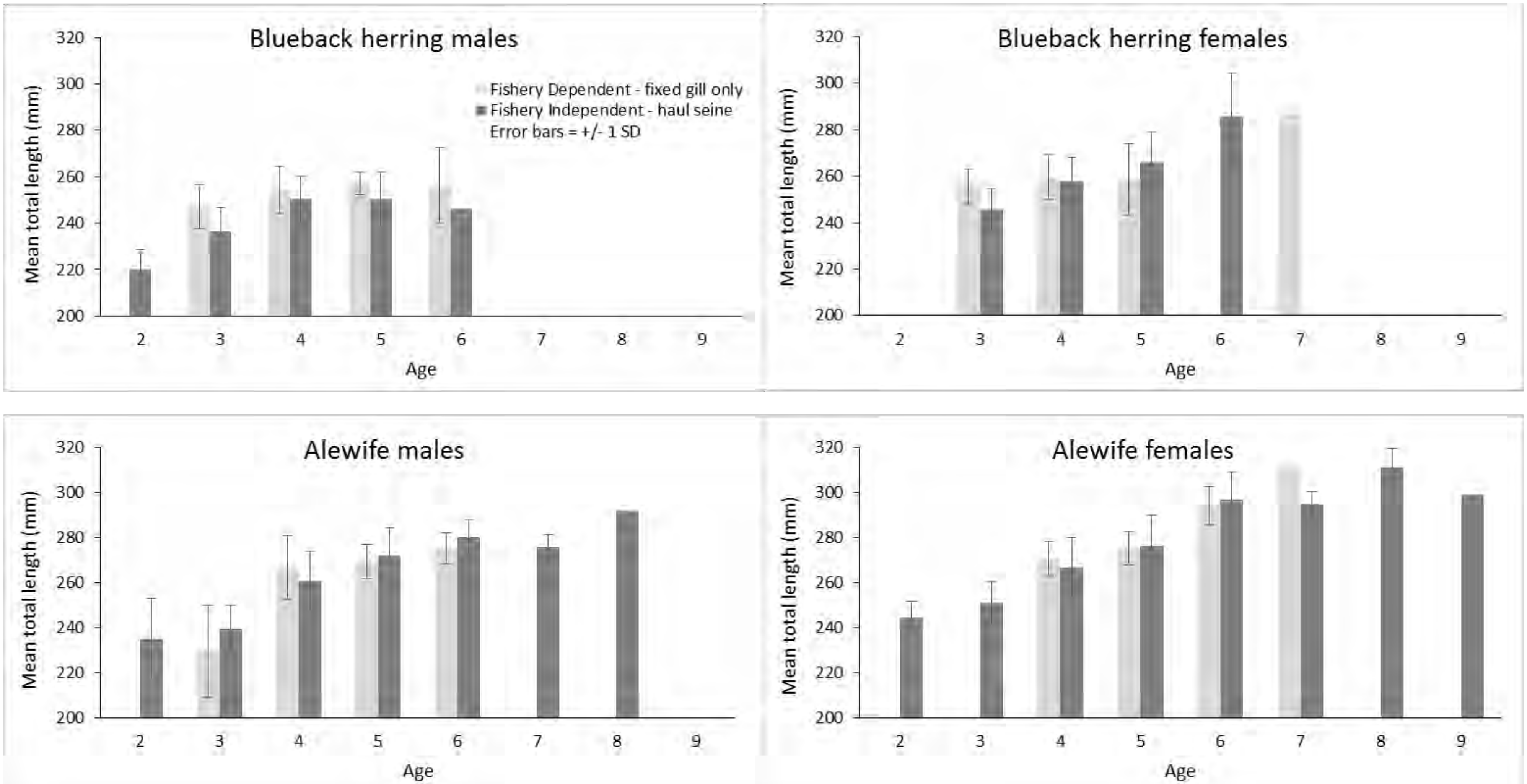

Figure 10. Comparison of length at age of river herring sampled in the lower-river fixed gill net commercial fishery versus the fishery independent survey.

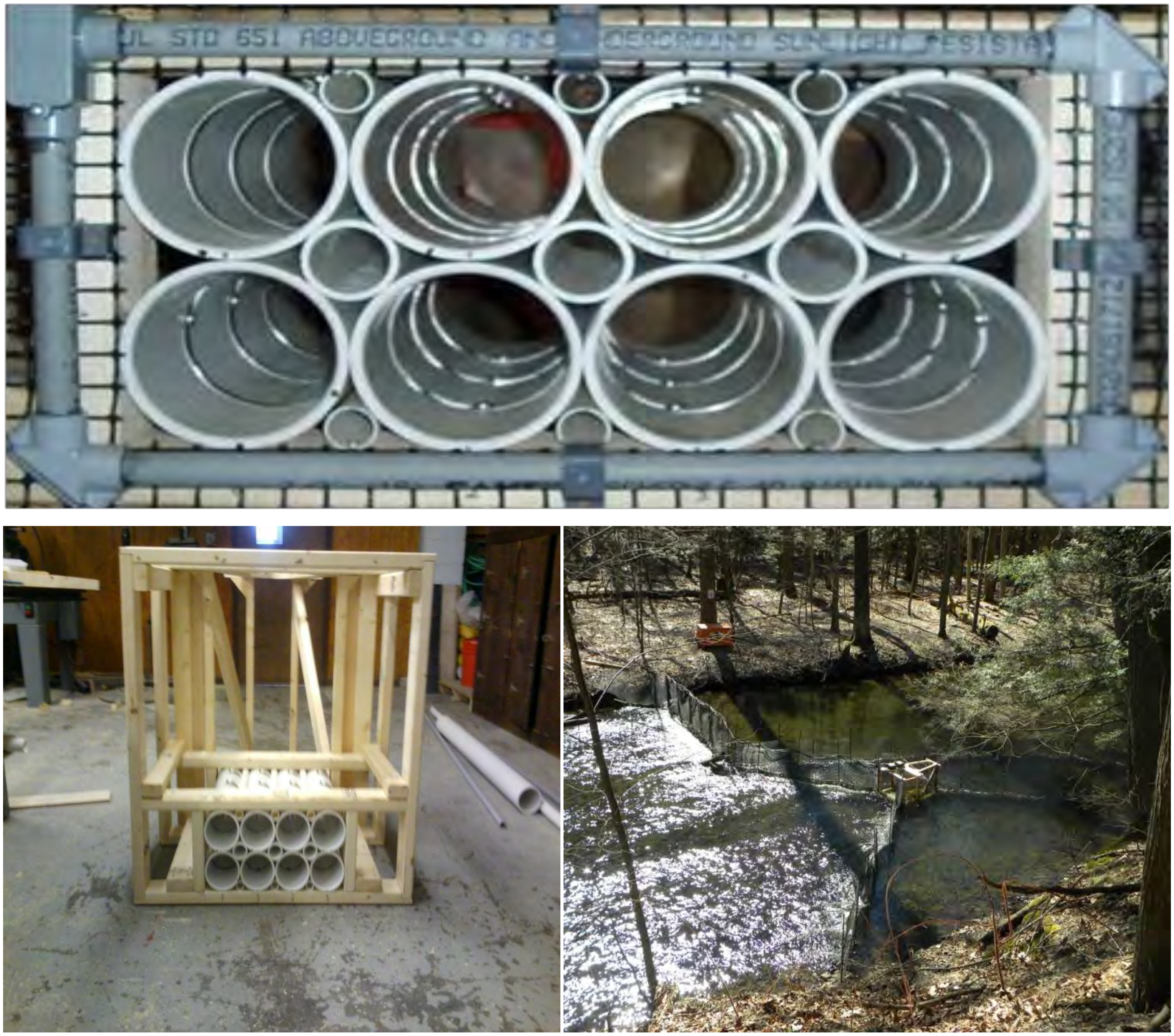

Figure 11. Top: Front view of the counter head that consists of eight four inch PVC tubes fitted with three stainless steel clamps, acting as sensors that measure water conductivity. Bottom left: View of fish counter head during construction. Bottom right: View of in-stream weir and fish counter.

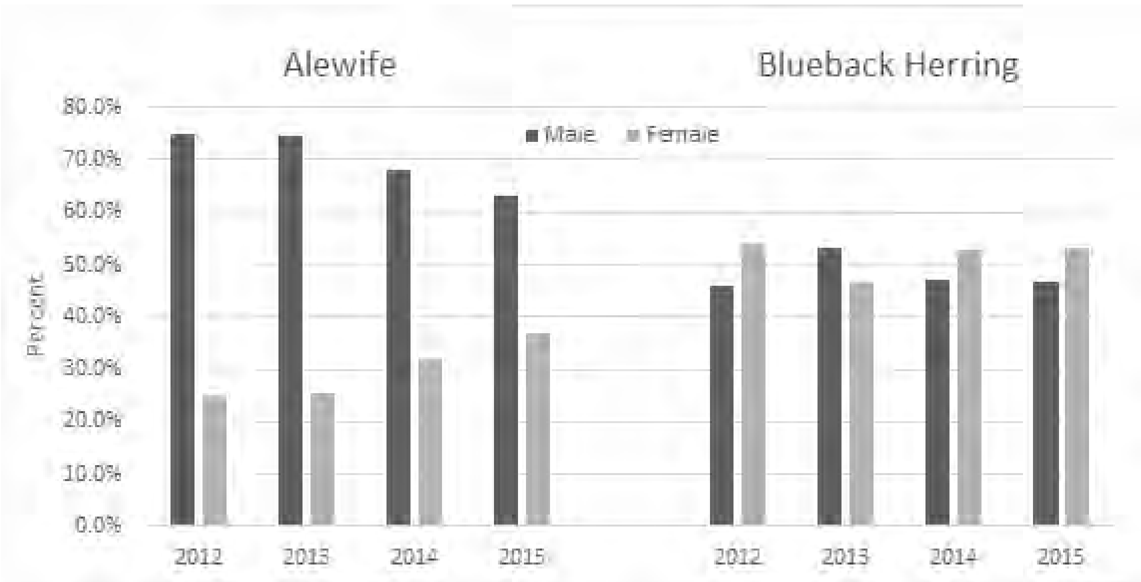

Figure 12. Annual sex ratios from river herring collected during the fisheries independent survey.

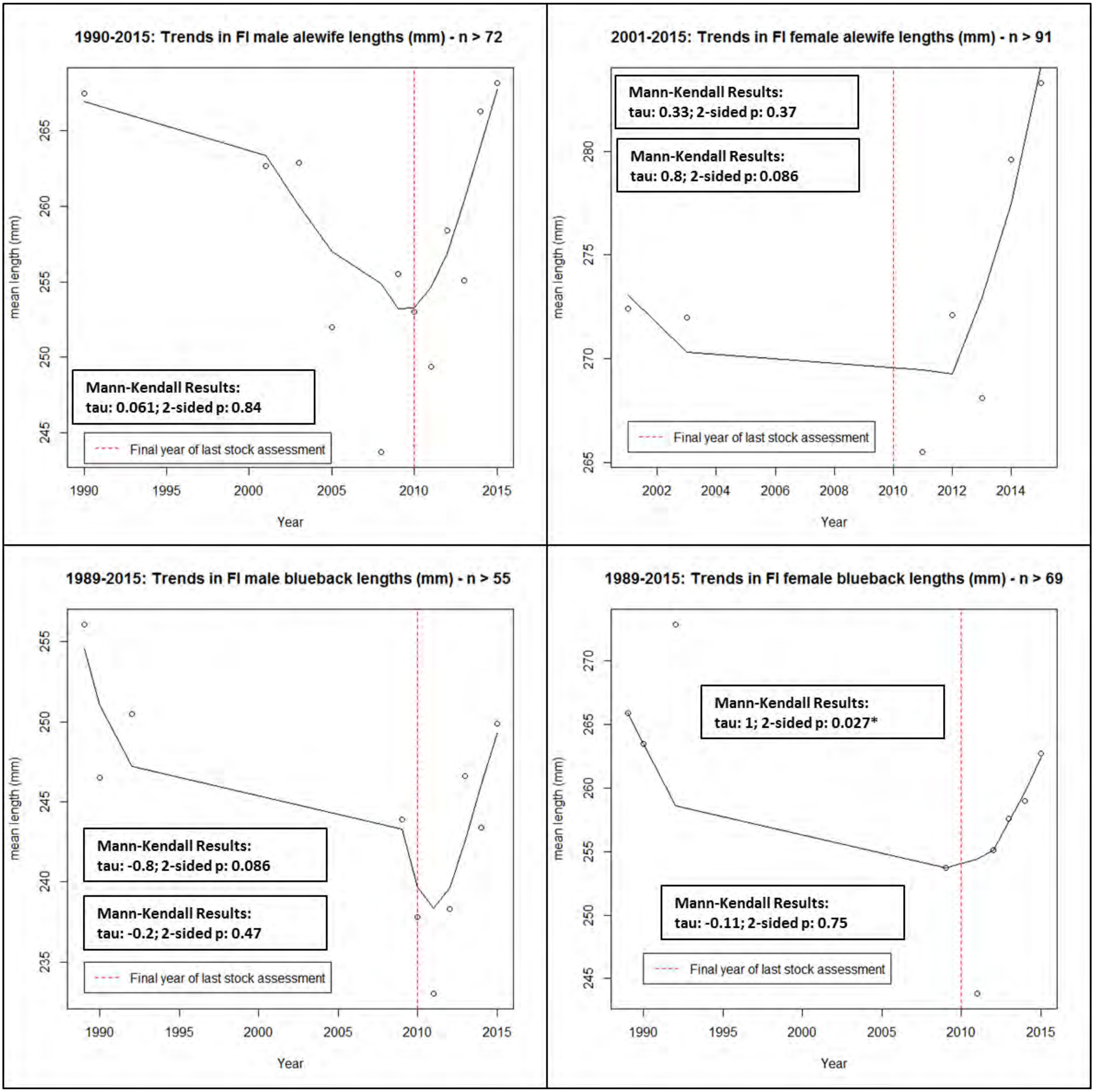

Figure 13. Trends in mean length for river herring by sex and species. Black lines are lowess smoothers (Cleveland 1981) and the red dotted lines indicate the terminal year for data included in the benchmark stock assessment.

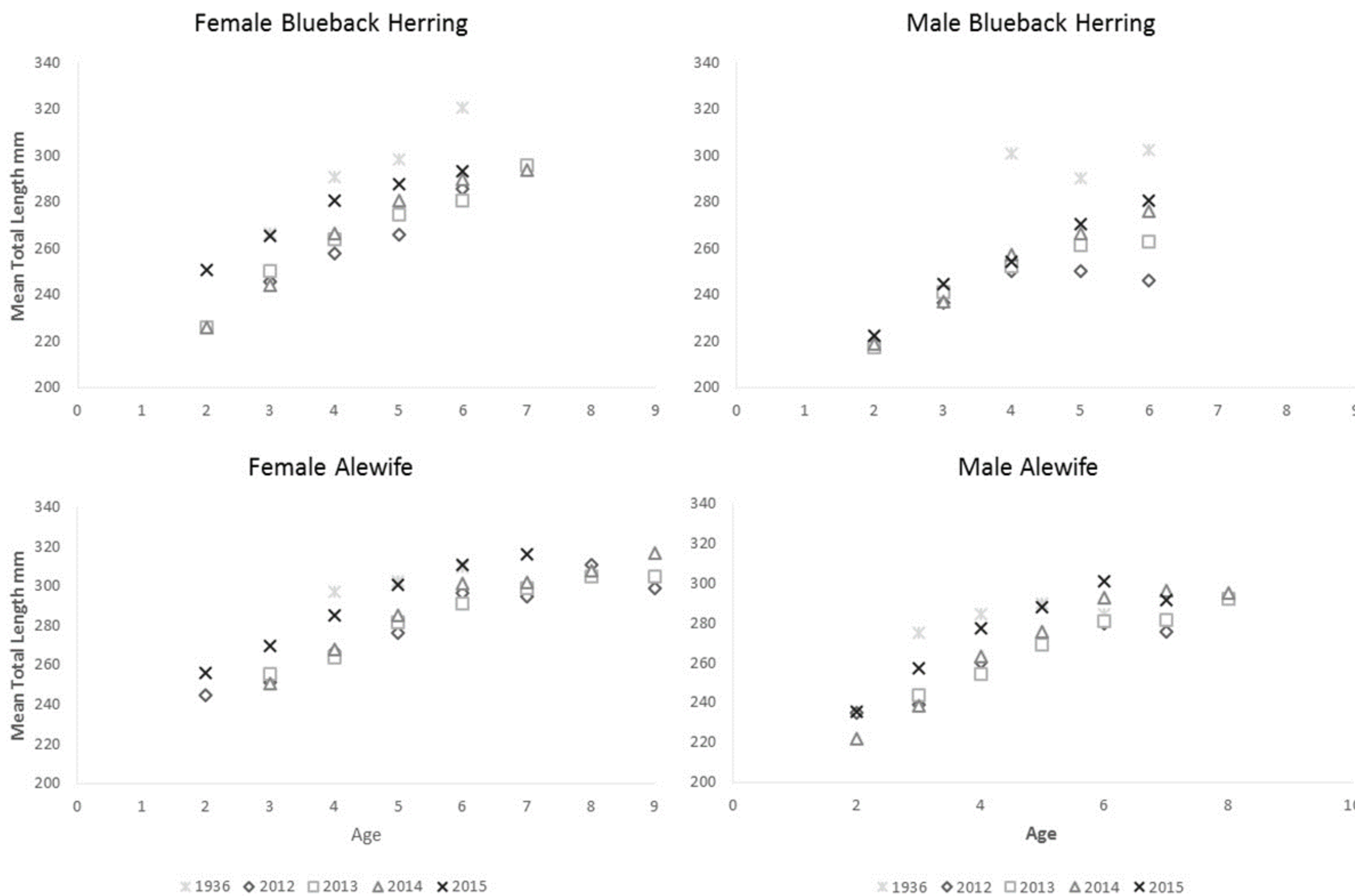

Figure 14. Mean length at age for river herring from fisheries independent sampling.

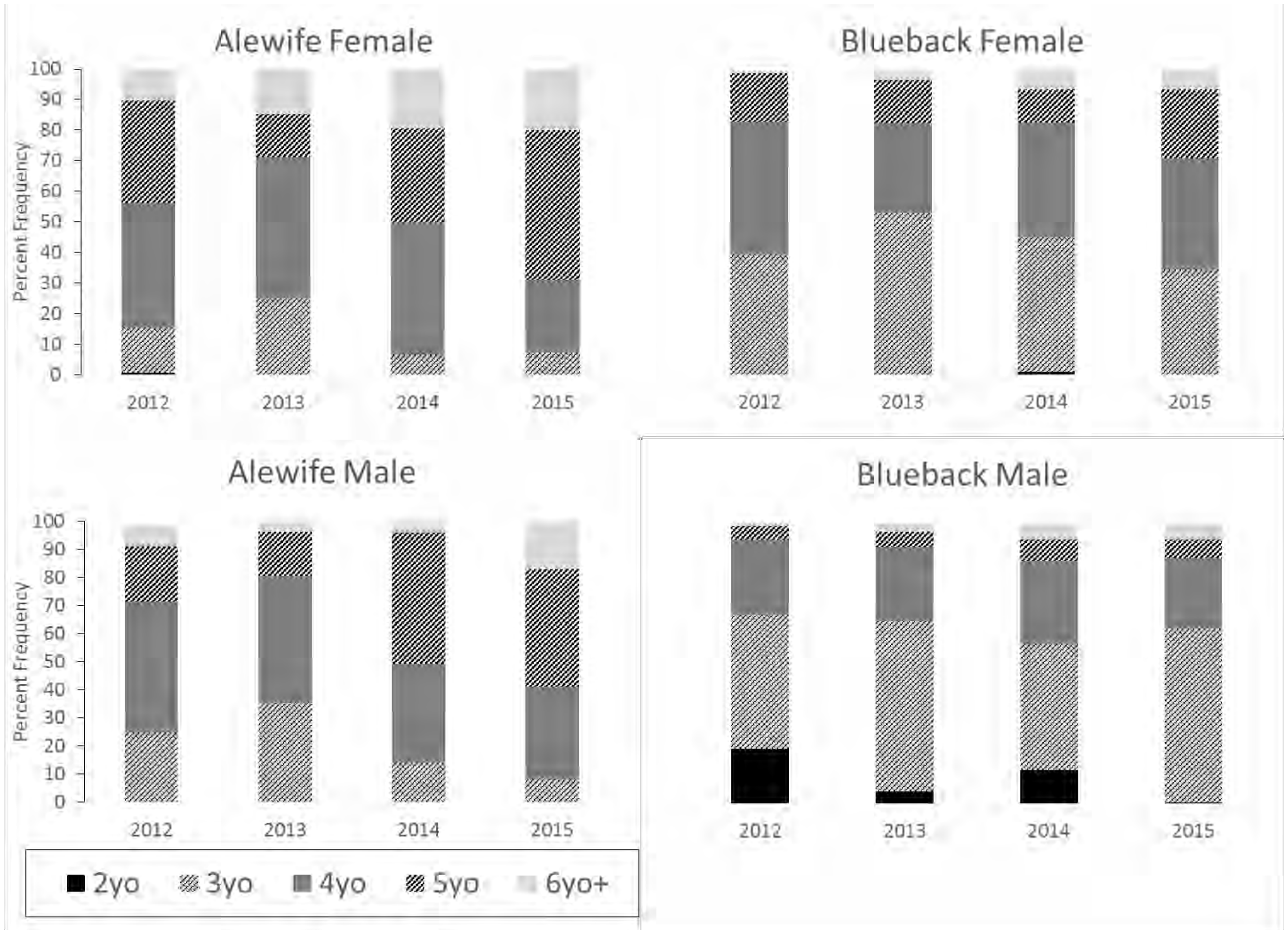

Figure 15. Proportion at age for both species of river herring collected during fisheries independent sampling.

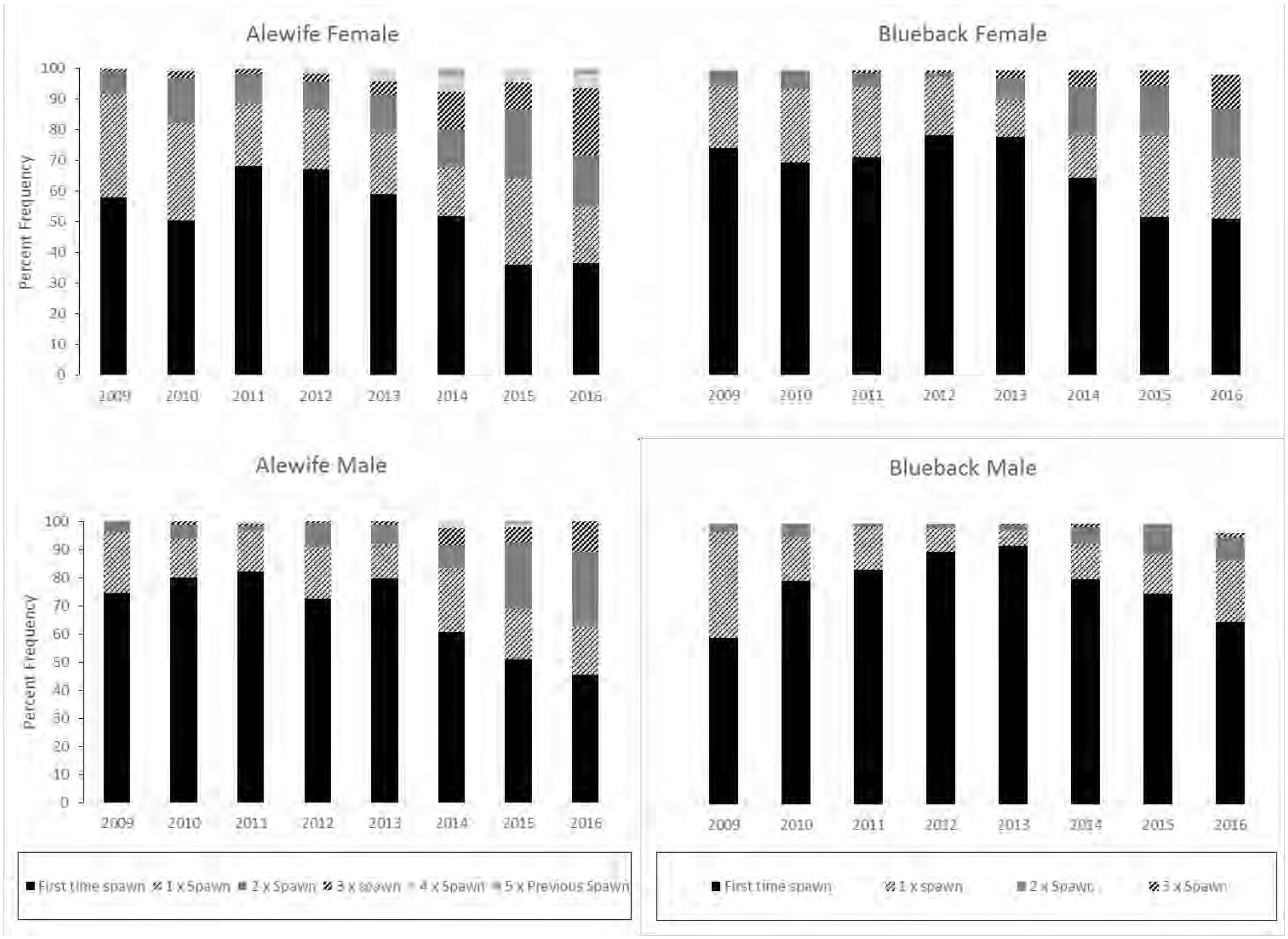

Figure 16. Frequency of repeat spawning occurrence for both species of river herring collected during fisheries independent sampling.

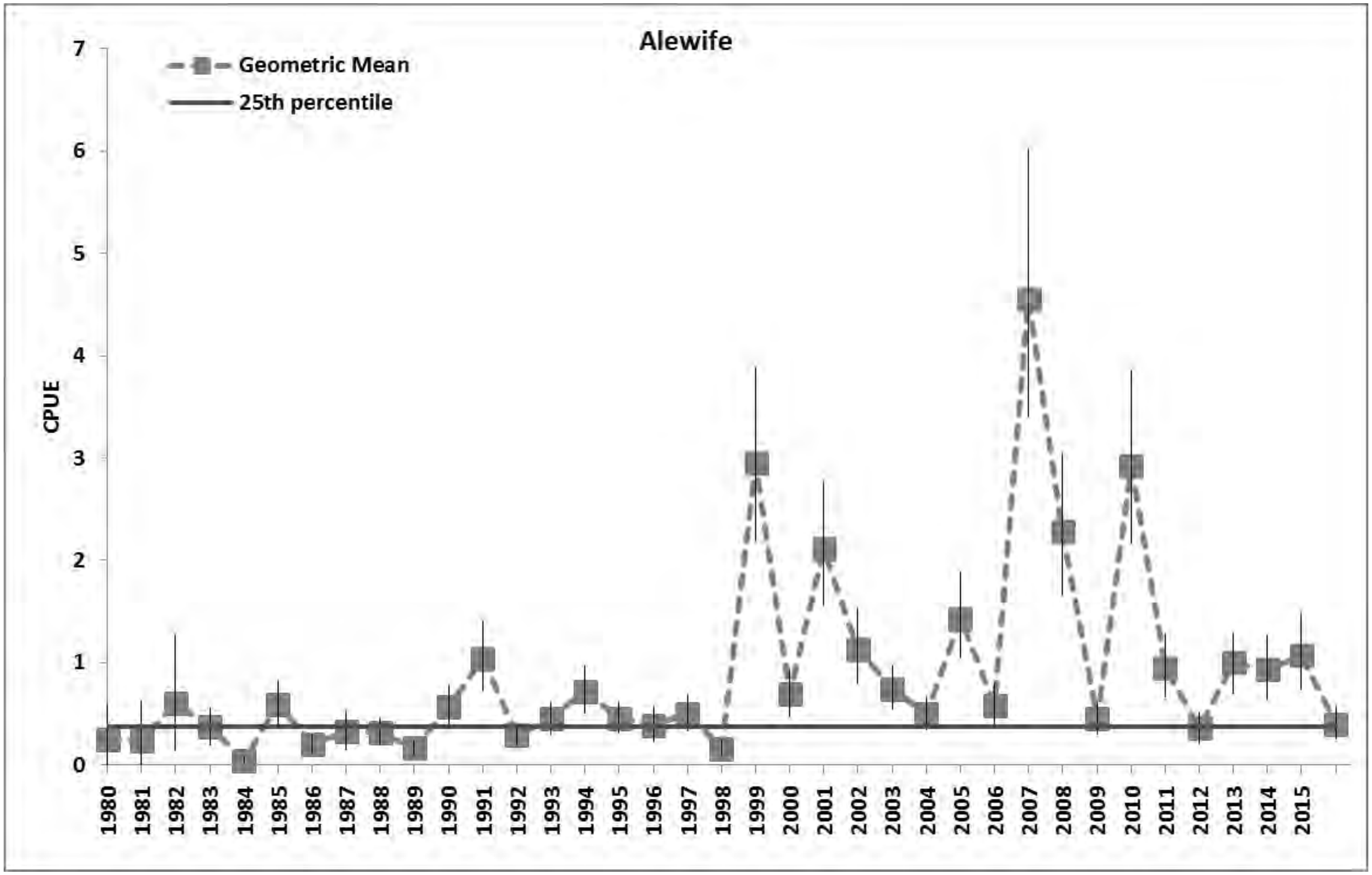

Figure 17. NYSDEC Young-of-year Alewife Index of Abundance. Solid line is the 25th percentile of the values from 1983-2015.

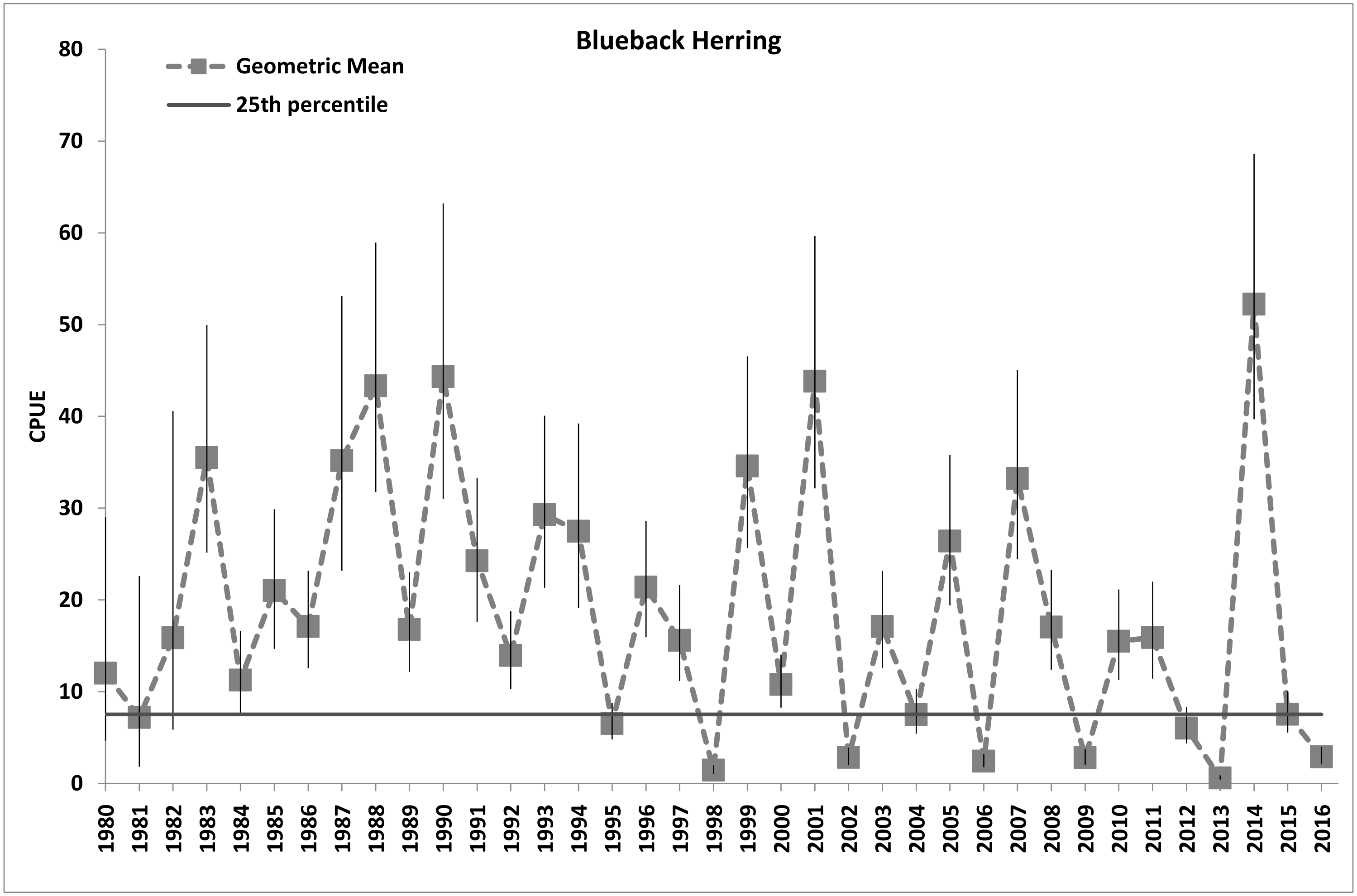

Figure 18. NYSDEC Young-of-year blueback herring index of abundance. Solid line is the 25th percentile of the values from 1983-2015.

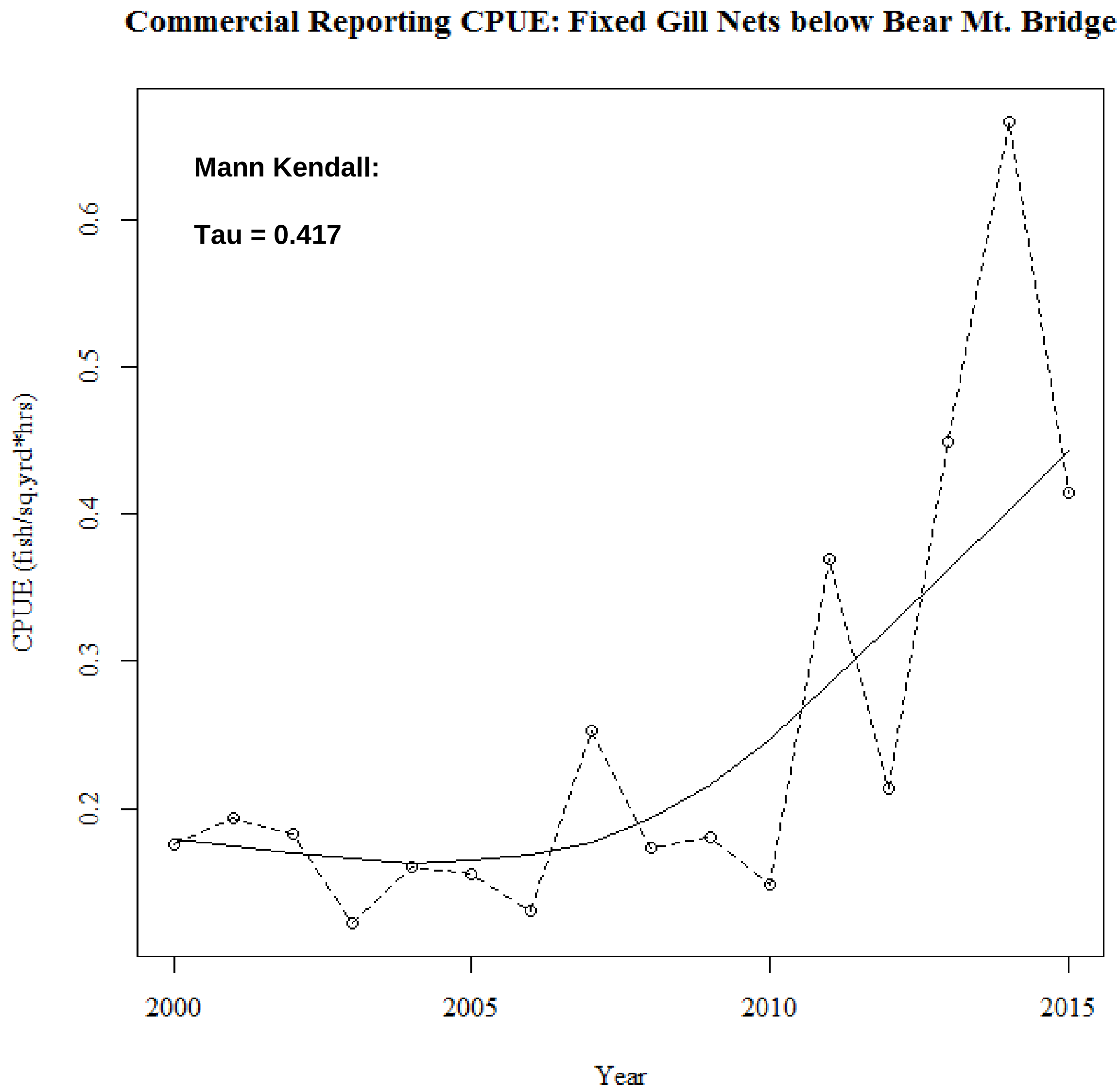

Figure 19. Trend analysis for CPUEs of commercial fixed gill net fishermen below Bear Mountain Bridge. CPUE is calculated as the sum of weekly CPUEs.

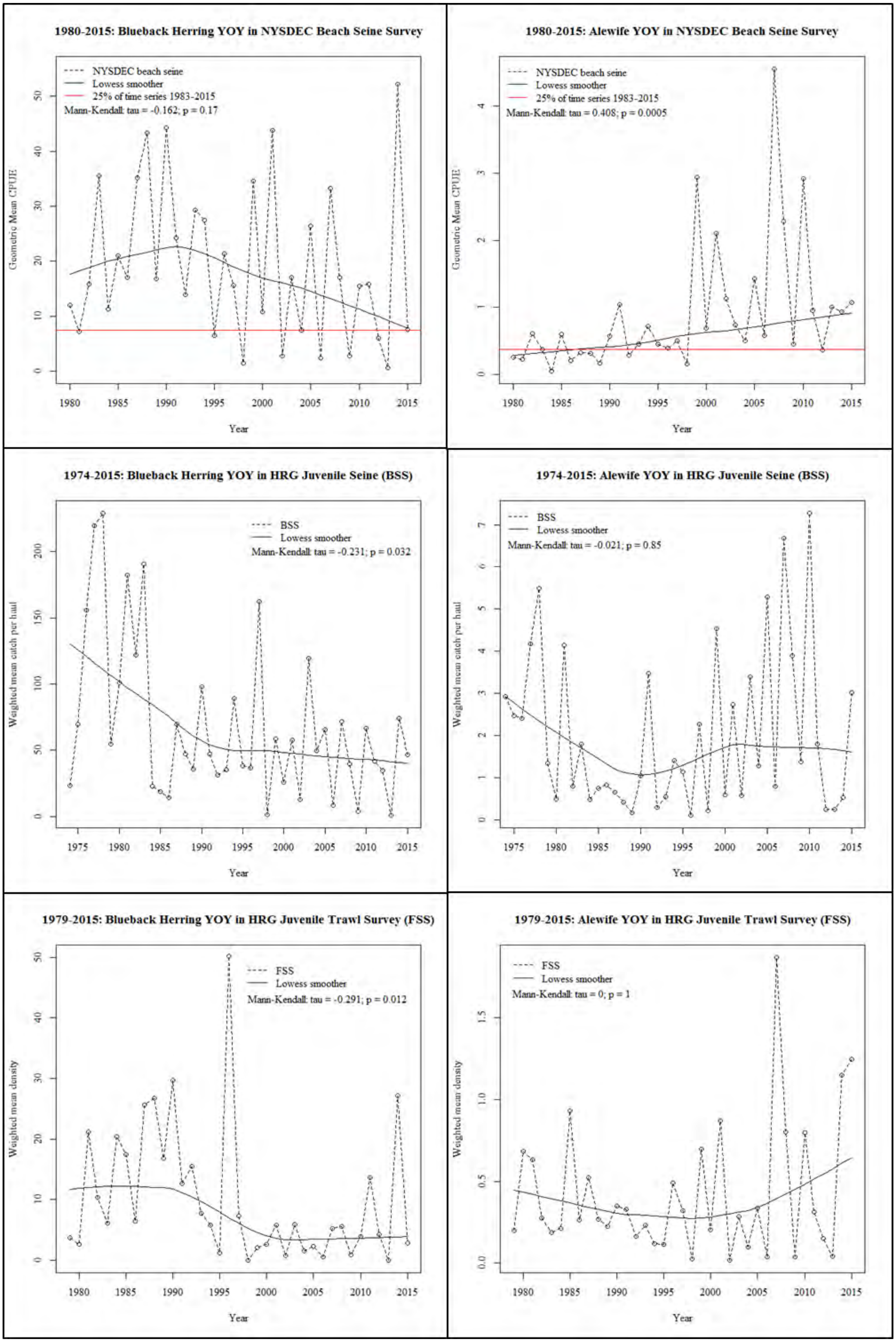

Figure 20. Trend analysis for Hudson River YOY surveys.

Appendix

Table A. Summary of historical and current commercial fishery regulations for alewife and blueback herring in New York State (2013 regulation changes in bold).

Regulation	2013 to Present	Regulation link
Season	Mar 15 – Jun 15	6 CRR-NY 36.3 (a)
Creel/ catch limits	None	
Commercial Gear (Marine permit)	Gill nets as commercial gear - 600 ft or less - 3.5 in stretch mesh or smaller - No fishing at night in HR above Bear Mt Bridge - **Drift gill nets only allowable gill nets above Bear Mt Bridge** - Gill nets above Bear Mt Bridge must be tended at all times	6 CRR-NY 36.3 (c) 6 CRR-NY 36.3 (b) 6 CRR-NY 36.3 (3)(i) 6 CRR-NY 36.3 (7) 6 CRR-NY 36.3 (2)(iv) 6 CRR-NY 36.3 (5)
	Seine as commercial gear - No size restrictions below Castleton/I90	6 CRR-NY 36.3 (c)
	Scoop/Dip/Scap net as commercial gear - **10' x 10' maximum**	6 CRR-NY 36.3 (c)
	Fyke/hoop/trap nets as commercial gear - No size restrictions	6 CRR-NY 36.3 (c)
Commercial Gear (Bait license)	Cast Net as bait collection gear - 10 ft maximum diameter	*To find the law* ***click here****, on ENV, find Article 11, click on Title 13, click* ***ECL 11-1315***
Closed areas	No gill nets above I90 - Castleton Bridge	6 CRR-NY 36.3 (2)(ii)
	No nets on Kingston Flats	6 CRR-NY 36.3 (2)(i)
	No nets in any tributary (including Mohawk River)	6 CRR-NY 36.3 (2)(i)
	All other waters of NY State closed to the take of anadromous river herring	6 CRR-NY 40.1(i)
Escapement (no fishing days)	36 hr lift period for **all commercial gears** Friday 6AM – Saturday 6PM	6 CRR-NY 36.3 (4)
Marine Permit Fees (established 1911)	Gill net $0.05/foot	6 CRR-NY 35.1
	Scap net <10 sq ft $1.00	
	Seine $0.05/foot	
	Trap nets $3 to $10	
	Fyke net $1 to $2	
Marine Permit Reporting	**Mandatory daily catch & effort; Vessel Trip Reports (VTRs) due monthly**	6 CRR-NY 36.1 (a)(1)

Transport and sale	- Commercially caught anadromous river herring must be sold and used in the Hudson River and tributaries to first impassable barrier and within the transport corridor - May also be sold or transferred to locations in the Marine District - Transport within DEC Reg. 3 requires a bait transport permit - Retail sale of live and frozen anadromous river herring requires o Fish health certification on premises o Receipt to purchaser (valid for 10 days) - Retail sale of dead packaged anadromous river herring requires o Preservation other than freezing o Each package must be labeled with ▪ Name of packager-processor ▪ Name of fish species ▪ Quantity of fish ▪ Means of preservation	6 CRR-NY 35.3 (d) 6 CRR-NY 35.3 (c)(1) 6 CRR-NY 35.3 (c)(2) 6 CRR-NY 35.3 (c)(3)(ii) 6 CRR-NY 35.3 (c)(3)(iii)(a) 6 CRR-NY 35.3 (c)(4)

Table B. Summary of historical and current recreational fishery regulations for alewife and blueback herring in New York State (2013 regulation changes in bold).

Regulation	**2013 to Present**	**Regulation link**
Season	Mar 15 – Jun 15	6 CRR-NY 10.10 (c)(2)
Creel/ catch limits (personal use)	**10 per day per angler or a maximum boat limit of 50 per day for a group of boat anglers (whichever is lower)**	6 CRR-NY 10.10 (c)(2)
Creel/ catch limits (party or charter)	- **10 per day per angler or a maximum boat limit of 50 per day for a group of boat anglers (whichever is lower)** - **Operator of party or charter north of Tappan Zee bridge may possess anadromous river herring in excess of individual recreational possession limit as long as** o **Register with Hudson River Fisheries Unit** o **Must display a valid Hudson River herring decal on port side of vessel**	6 CRR-NY 10.10 (c)(4)(i) 6 CRR-NY 10.10 (c)(4)(ii) 6 CRR-NY 10.10 (c)(4)(iii) 6 CRR-NY 10.10 (c)(4)(iii)(c)
Recreational gear (personal use)	Angling	6 CRR-NY 10.10 (c)(2)
	Seine – not exceeding 36 square feet	6 CRR-NY 10.10 (c)(3)(ii)(e)
	Scap net – - **Not exceeding 16 square feet** - Only one net	6 CRR-NY 10.10 (c)(3)(ii)(d) 6 CRR-NY 10.10 (c)(3)(ii)(b)
	Dip/Scoop – - Not exceeding 14 inches in diameter or 13 inches by 13 inches square - Only one net	6 CRR-NY 10.10 (c)(3)(ii)(c) 6 CRR-NY 10.10 (c)(3)(ii)(b)
	Cast net – not exceeding 10 feet in diameter	6 CRR-NY 10.10 (c)(3)(ii)(f)
Closed areas	- **No nets in any Hudson River tributary (including Mohawk R)** o **Nets must be stowed prior to entering a tributary** - **All other waters of NY State closed to the take of anadromous river herring**	6 CRR-NY 10.10 (c)(3)(i) 6 CRR-NY 10.10 (c)(3)(iii) 6 CRR-NY 10.10 (c)(2) 6 CRR-NY 40.1(f)
Transport restrictions	Herring taken in the Hudson River and tributaries (up to first impassable barrier) for personal use: - May only be used in the Hudson River and tributaries up to first impassable barrier - May only transported overland within the transportation corridor	6 CRR-NY 10.1 (f)(3)(iii) 6 CRR-NY 10.1 (f)(3)(iii)(c)
Escapement (no fishing days)	None	
License	Marine Registry	6 CRR-NY 10.10 (c)(1)(i)
Reporting	None	

11 Status of River Herring in New Jersey

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11.1 INTRODUCTION

In this report, river herring refers collectively to alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*). The river herring data presented within this report focuses on the coastal waters off of New Jersey. Data on river herring occurring within the Delaware River Drainage Basin (Basin) can be found in Section 12. Coastal areas are monitored through New Jersey's Stock Assessment Trawl Survey and the sampling area includes the near shore waters from the entrance of New York Harbor south, to the entrance of the Delaware Bay (Figure 11.20). The Raritan River fish ladder is located at the Island Farm weir just downriver of the Millstone-Raritan river confluence.

11.2 MANAGEMENT UNIT DEFINITION

New Jersey Division of Fish and Wildlife manages river herring populations occurring within New Jersey's sections of the Basin and the coastal waters from Cape May Point to Sandy Hook including Raritan Bay and River.

11.3 REGULATORY HISTORY

11.3.1 Commercial Fishery

As of January 1, 2012 landings of river herring in New Jersey have been prohibited. These regulations are in compliance with the Atlantic States Marine Fisheries Commission Amendment 2 to the Fisheries Management Plan for Shad and River herring.

Historically, no specific regulations have been adopted to reduce or restrict commercial landings of river herring in New Jersey, however there have been regulations which limited commercial fishing effort and had a direct impact on catch. New Jersey adopted general regulations that apply to the commercial fishery such as limited entry, limitations on the amount of gear, and gear restrictions in defined areas. Note these restrictions apply to all New Jersey waters and not just the coastal jurisdiction, unless otherwise noted. These restrictions included but were not limited to:

1. From November 1 to April 30, only haul seines with a mesh size ≥ 2 ¾ inch stretch and with a maximum length of 420 feet can be used in the Delaware River. This is currently limited to one commercial fishery based in Lambertville and rarely harvests river herring,
2. From February 1 through December 15, gill nets may be used in Delaware Bay and River. From

February 12 through May 15, the maximum net length allowed is 2400 feet; from May 16 through December 15, the maximum net length is 1200 feet,

3. Gill net small mesh exemption permit (GNSMEP) allows fishers to use gill nets between 2.75 inch stretched mesh to 3.25 inch stretched mesh within two nautical miles of the mean high water line between sunrise and sunset. Holders of these permits are required to report all landings and any weakfish discards.

4. Pound nets are allowed all year in Ocean waters and Sandy Hook/Raritan Bay. In Delaware Bay, pound nets are allowed only during February 15 to May 15

11.3.2 Recreational Fishery

As of January 1, 2012, the recreational fishery has been closed

Historically, the recreational fishery for river herring was very small with few participants and low retention rates. Those herring that were landed were typically frozen for bait, pickled, harvested for their roe, and other traditional uses. Recreational gear included hook and line, dip net, bait seine, cast net, and umbrella net.

Harvest of landlocked freshwater populations of river herring is permitted year round on lakes in select counties in New Jersey for bait purposes. Anglers are restricted to 35 fish per day with a six inch maximum size limit. Any unused herring must be returned to the water upon conclusion of the angler's fishing trip. Herring may not be transported away from the shoreline of these lakes by any mechanism. They may not be sold.

11.4 ASSESSMENT HISTORY

No stock assessments have been completed on river herring populations in New Jersey's coastal rivers and streams.

11.5 STOCK SPECIFIC LIFE HISTORY

Adult alewife and blueback herring will typical enter New Jersey streams to spawn beginning in early February. Peak spawning activity occurs during mid-April through May. Post-spawned adults will return to the ocean by mid-June. Larvae will hatch and juvenile will maintain freshwater residence through mid-November, although juvenile emigration can occur as early as July. Mature adults will return to their natal streams to spawn.

11.6 HABITAT DESCRIPTION

Many of New Jersey's rivers and streams contained spawning runs of river herring until pollution, overfishing and dams restricted the population and destroyed spawning habitat. It is estimated from 1953 to 1973, 61,678 acres of coastal wetlands and uncounted acreage of adjacent transitional wetlands were lost to filling and diking in New Jersey (Ferrigno et al 1973). Field investigations during the early to mid-1970s confirmed 132 river herring spawning runs (108 alewife and 24 blueback) in rivers and streams that were continuous with the marine environment (Zich 1977). The majority of these runs were river herring. Zich concluded that nine herring runs had already become extinct.

Also during these field investigations, 83 constructed barriers were found on streams where herring runs were reported or confirmed. These barriers were assessed to be blocking or limiting fish passage and therefore reducing spawning habitat. There is no current estimate as to whether or not this number has changed significantly since that time. Recent efforts have been undertaken to restore river herring runs in some of these systems by removing dams, installing fish ladders and/or trap and transport.

11.7 RESTORATION PROGRAMS

Restoration programs for river herring in New Jersey have been limited to the installation of fish ladders and occasional minor trap and transport programs or dam removal. The total amount of freshwater habitat opened up through these efforts has not been calculated. The only usable data available is from PSEG and represents fish ladder monitoring for both Delaware and New Jersey through 2016.

11.8 AGE

No age data has been reported for New Jersey. Otoliths have been collected during the January and April Ocean Stock Assessment trawls since 2009. Processing and aging of these samples will be completed as funding becomes available.

11.9 FISHERY DESCRIPTION

11.9.1 Commercial Fishery

New Jersey river herring landing estimates were obtained from two sources (Table 11.19; Figure 11.21 New Jersey Reported Commercial Landings 1950-2015). The NMFS estimates (1950 to 2009) are for the entire state, while mandatory logbooks of the GNSMEP (2000 to 2015) are from Delaware Bay. The average reported NMFS landings for the time period is estimated at 8,180 pounds. There are no estimates of underreporting, however it is assumed that the current data for river herring is underreported since some landings may be categorized as bait.

11.9.2 Recreational Fishery

Recreational surveys within the coastal jurisdictions have not been conducted.

11.9.3 Characterization of Other Losses

There are potential unknown sources of mortality from power plant intakes, commercial discards, and landings categorized as “bait”. Many of these could be significant according to some data points.

11.10 FISHERY-INDEPENDENT SURVEYS

11.10.1 Coastal waters

Ocean Trawl Survey

The New Jersey Ocean Trawl Survey is a multispecies survey that started in August 1988 and samples the near shore waters from the entrance of New York Harbor south, to the entrance of the Delaware Bay five times a year (January, April, June, August and October). There are 15 strata with five strata assigned to three different depth regimes; inshore (3 to 5 fathoms), mid-shore (5 to 10 fathoms), and off-shore (10 to 15 fathoms). Station allocation and location is random and stratified by strata size (Figure 11.20).

The survey net is a two-seam trawl with forward netting of 4.7 inch stretch mesh and rear netting of 3.1 inches stretch mesh. The codend is 3.0 inches stretch mesh and is lined with a 0.25 inch bar mesh liner. Each trawl is 20 minutes long and at the end of each tow, the total weight of each species is measured in kg and the length of all individuals, or a representative sample by weight for large catches, is measured to the nearest cm. A series of water quality parameters, such as surface and bottom salinity, temperature and dissolved oxygen, are also recorded at the start of each tow. New Jersey began collecting otoliths and other biological data in 2009 to develop age at length keys for both species. Processing and aging of these samples will be completed as funding becomes available.

River Herring Adult and Juvenile Abundance Survey

In 2015 the state of New Jersey began a river herring adult and juvenile abundance survey on the Great Egg Harbor River which has been known to have historical river herring populations. Gillnetting is performed once a week at two locations on the river representing brackish and freshwater environments. Adult river herring moving into spawning areas are collected by use of anchored sinking gill nets that measuring 141’ x 6’ x 3” and 171’ x 6’ x 3” stretch mesh set for 90 minutes. River herring collected are measured by fork and total length and are inspected for sex and ripeness. Water chemistry data (water temperature, salinity, dissolved oxygen, and pH) as well as atmospheric conditions (tidal stage, weather, wind directions and speed, cloud cover, moon phase, and air temperature) were recorded.

In the summer and fall juvenile river herring are collected at 7 sites along the river representing freshwater and estuarine environments utilizing a 100’ x 6’ x ¼ mesh bagged beach seine bi-weekly. Water chemistry data (water temperature, salinity, dissolved oxygen, and pH) as well as atmospheric conditions (air temperature, cloud cover and moon phase) were recorded. A total of 30 alewife and 30 blueback herring were subsampled from each haul and measured to fork length. All remaining alewife and blueback were counted and released.

This project is anticipated to continue as long as funding is available. As a longer time series is established, indices of abundance will be calculated to track adult returns and spawning success within the Great Egg Harbor River.

Raritan River Fish Passage

The Raritan River, which empties into Raritan/Sandy Hook Bay, historically supported a spawning run of river herring. A dam constructed at the confluence of the Millstone and Raritan rivers was equipped with a fish ladder that included an underwater viewing room. Data is available for 1996 to 2005 (except for 2000 and 2004) and 2011 to 2012. A CPUE was developed as the number of fish counted per day. Confidence that all herring are counted is low.

11.11 ASSESSMENT APPROACHES AND RESULTS

The purpose of this report is to assess the stock status of the New Jersey's coastal populations of blueback herring and alewife. It is obvious from historical data and anecdotal information that river herring populations statewide were much larger in the past and have declined drastically since the robust numbers of the late 1800s. The only data available for assessment is data from New Jersey's Ocean Trawl Survey and a fish ladder index from the Raritan River. The River Herring Adult and Juvenile Abundance Survey in the Great Egg Harbor River may prove to be a source of useable data in the future.

11.12 TRENDS IN SPAWNING STOCK SIZE

The majority of river herring are captured during the January and April trawls of the Ocean Trawl Survey so only those months are used for the geometric mean (Table 11.20 Ocean Trawl Survey river herring geometric mean per tow: 1989-2015; Figure 11.22). The trawl index for blueback herring showed a declining trend from 1993 to 2004 but has shown an increasing trend ever since. This includes the highest index of the time series in 2008. Since the previous stock assessment report there was a precipitous drop in the index in 2010 with an immediate recovery to the time series average in the following years. The alewife index has varied without much of a trend since the beginning, although there has been a slight increase since 2000 with a similar drop off in CPUE in 2010 and subsequent increase, although not as dramatic as in the case of bluebacks.

The Raritan fish ladder data is a very short term data set that was discontinued in 2005 and reinitiated for the 2011 and 2012 spring spawning runs. Regardless, the data showed a decreasing trend from 1997 to 2005 (Table 11.21; Figure 11.24).

The intermittent time series and uncertainty in count accuracy leaves this survey with little utility for management purposes.

11.13 BENCHMARKS

No benchmarks were developed for the coastal waters of New Jersey.

11.14 CONCLUSIONS AND RECOMMENDATIONS

Data for stock assessment of New Jersey's coastal rivers and streams is virtually non-existent. Additional data for New Jersey's portion of the Delaware Basin can be found in section 12. There are only two sources of river herring data from New Jersey's coastal waters, only one of which is currently ongoing._ The Ocean Trawl survey, which collects fishery independent data of mixed coastal stocks, showed an increase in blueback herring in recent years and a slight increasing trend for alewife since 2002. In contrast, the short data set from the Raritan fish ladder showed an overall decreasing trend. With so little data available, it is not possible to determine an accurate state of river herring stocks in New Jersey's coastal waters. It would be beneficial to undertake a more rigorous investigation of the population dynamics of these species within and outside the New Jersey coast.

For the New Jersey coast, this would include:

- Additional information on commercial and recreational landings
- Improved assessment of river herring adults at all fish ladder installations
- Improved assessment of river herring production in targeted tributaries
- Predator-prey relationships especially with striped bass, bluefish and white perch for yoy and striped bass, weakfish, bluefish, spiny dogfish for adults
- Habitat evaluations
- Development of age-length keys from samples collected during the Ocean Trawl Survey
- Revisit Raritan Bay fish ladder survey data

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Table 11.19 New Jersey commercial river herring (alewife and blueback herring) landings, in pounds: 1950 – 2015. NMFS landings are statewide; Logs are from the Delaware Basin.

Year	NMFS	Logs	Year	NMFS	Logs
1950	29,000	-	1983	2,200	-
1951	7,200	-	1984	3,100	-
1952	600	-	1985	4,800	-
1953	8,600	-	1986	4,200	-
1954	0	-	1987	5,200	-
1955	22,900	-	1988	700	-
1956	22,300	-	1989	800	-
1957	8,100	-	1990	42,494	-
1958	1,400	-	1991	9,994	-
1959	2,200	-	1992	3,069	-
1960	3,000	-	1993	2,659	-
1961	16,500	-	1994	328	-
1962	20,300	-	1995	795	-
1963	3,400	-	1996	4,449	-
1964	14,200	-	1997	4,515	9,221
1965	21,500	-	1998	7,371	2,430
1966	12,400	-	1999	1,377	3,880
1967	9,000	-	2000	0	5,410
1968	8,400	-	2001	1,034	1,900
1969	5,100	-	2002	3,366	552
1970	7,500	-	2003	228	2,127
1971	9,500	-	2004	2,548	3,192
1972	14,700	-	2005	1,079	2,402
1973	7,000	-	2006	469	2,793
1974	10,600	-	2007	0	-
1975	9,300	-	2008	631	1,551
1976	11,300	-	2009	0	177
1977	10,600	-	2010	1,004	409
1978	2,400	-	2011		1,634
1979	6,600	-	2012		18
1980	18,600	-	2013		0
1981	13,800	-	2014		1
1982	13,600	-	2015		0
			AVG	**7,541**	**2,094**

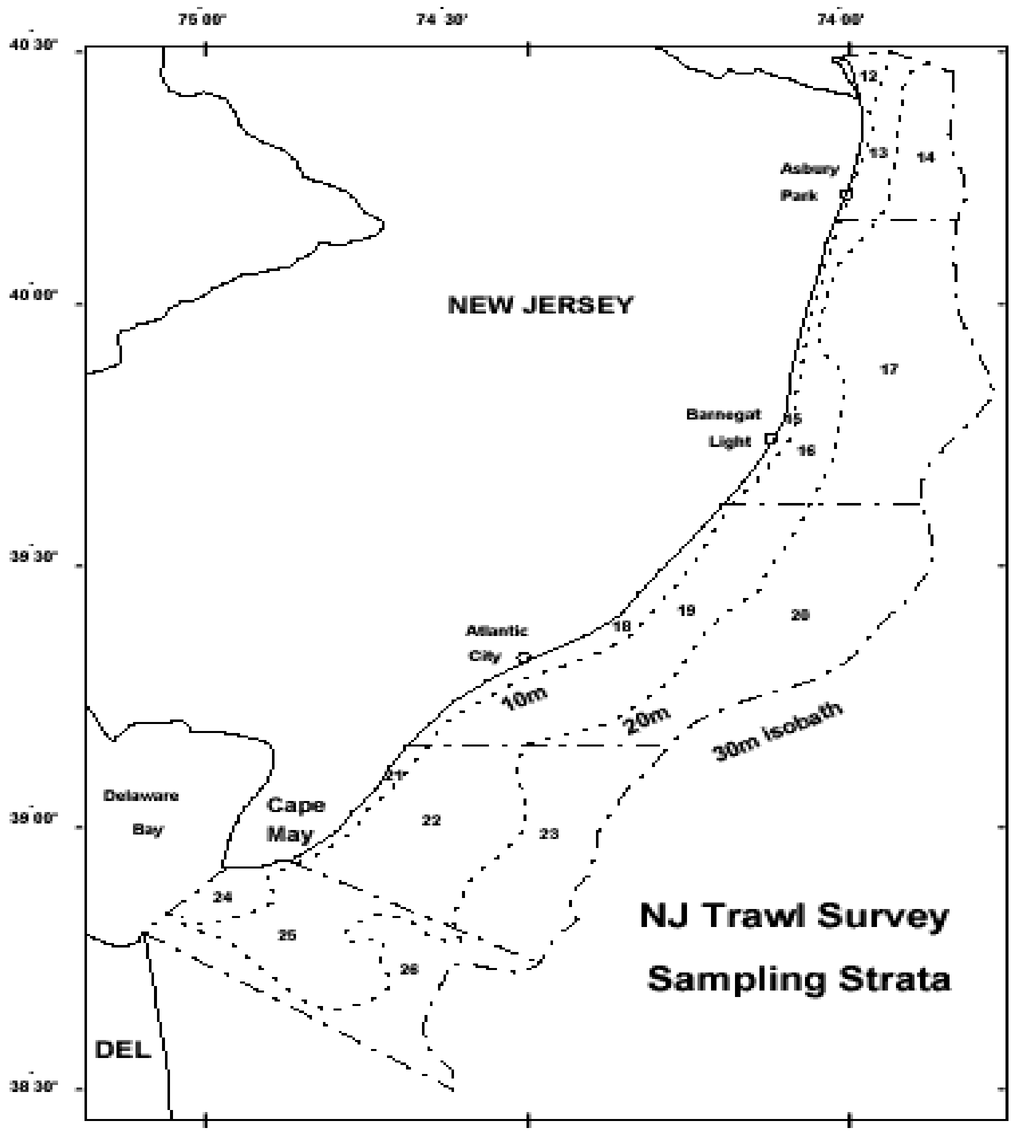
Table 11.20 Ocean Trawl Survey river herring geometric mean per tow: 1989-2015

Year	Blueback	Alewife
1989	4.45	3.01
1990	2.36	2.57
1991	3.42	5.01
1992	4.73	2.85
1993	4.34	7.03
1994	5.32	2.82
1995	3.20	5.01
1996	2.75	8.23
1997	4.01	3.97
1998	3.43	30.08
1999	4.26	11.85
2000	2.76	1.76
2001	2.30	1.79
2002	2.83	2.39
2003	4.42	4.69
2004	4.34	4.67
2005	4.51	3.92
2006	6.03	2.44
2007	4.70	4.63
2008	8.77	5.71
2009	6.21	4.89
2010	1.39	0.48
2011	2.07	2.02
2012	4.80	2.85
2013	4.22	2.20
2014	3.91	1.80
2015	4.60	2.74
AVG	**4.08**	**4.87**

Table 11.21 Raritan River Island Farm Weir fish ladder viewing CPUE (Herring per Day): 1996-2005, 2011-2012

Year	CPUE	Year	CPUE
1996	0.00	2002	0.29
1997	1.70	2003	0.15
1998	0.16	2004	-
1999	0.55	2005	0.00
2000	-	2011	1.45
2001	0.82	2012	0.35
		AVG	**0.55**

Figure 11.48 New Jersey Ocean Trawl Survey area: 2015



** Strata correspond to those of the National Marine Fisheries Service's spring and fall groundfish surveys*

Figure 11.21 New Jersey Reported Commercial Landings 1950-2015

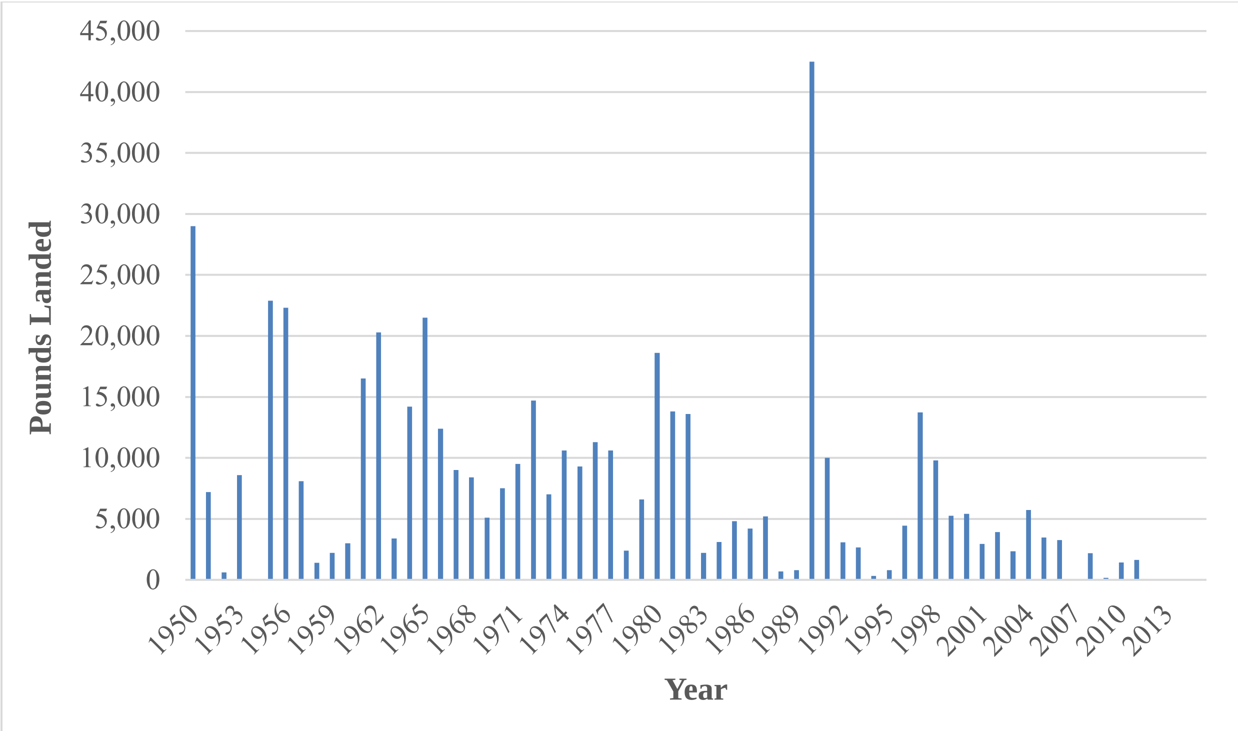


Figure 11.22 Ocean Trawl Survey river herring geometric mean per tow: 1989-2010

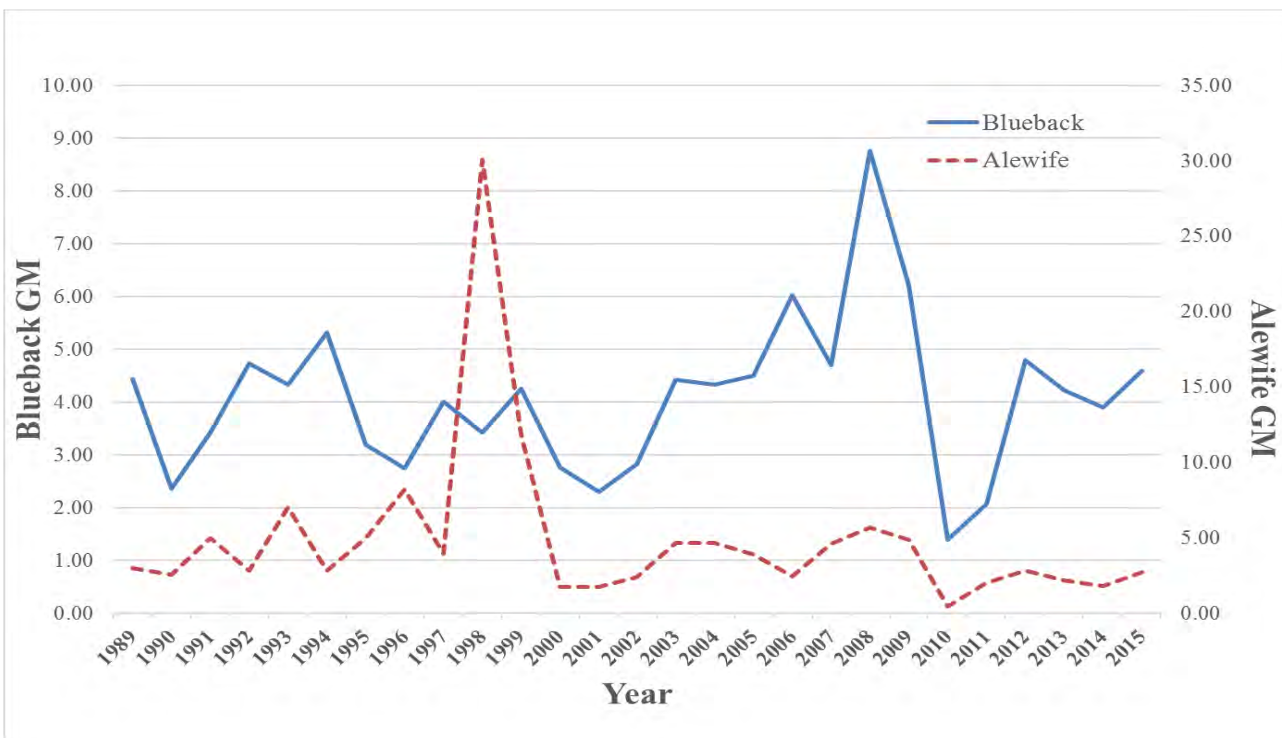


Figure 11.51 Ocean Trawl Survey percent length frequencies: 1989-2015

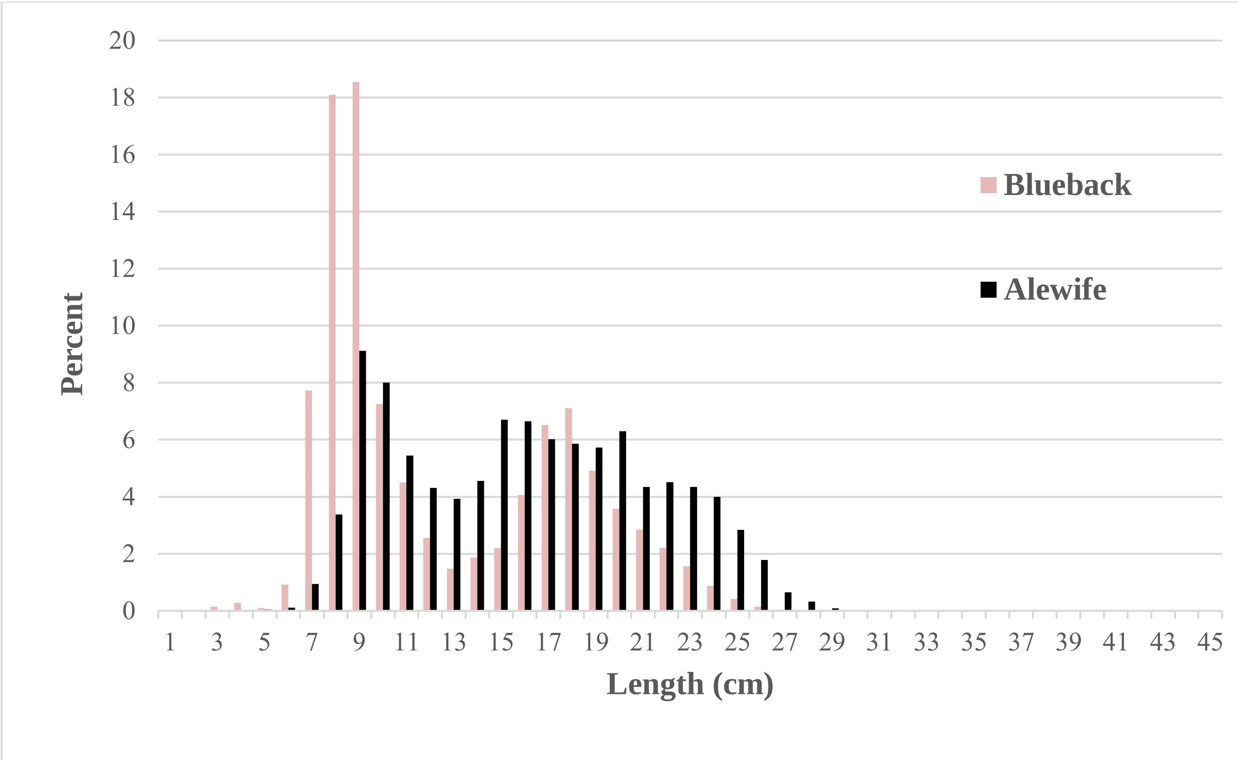
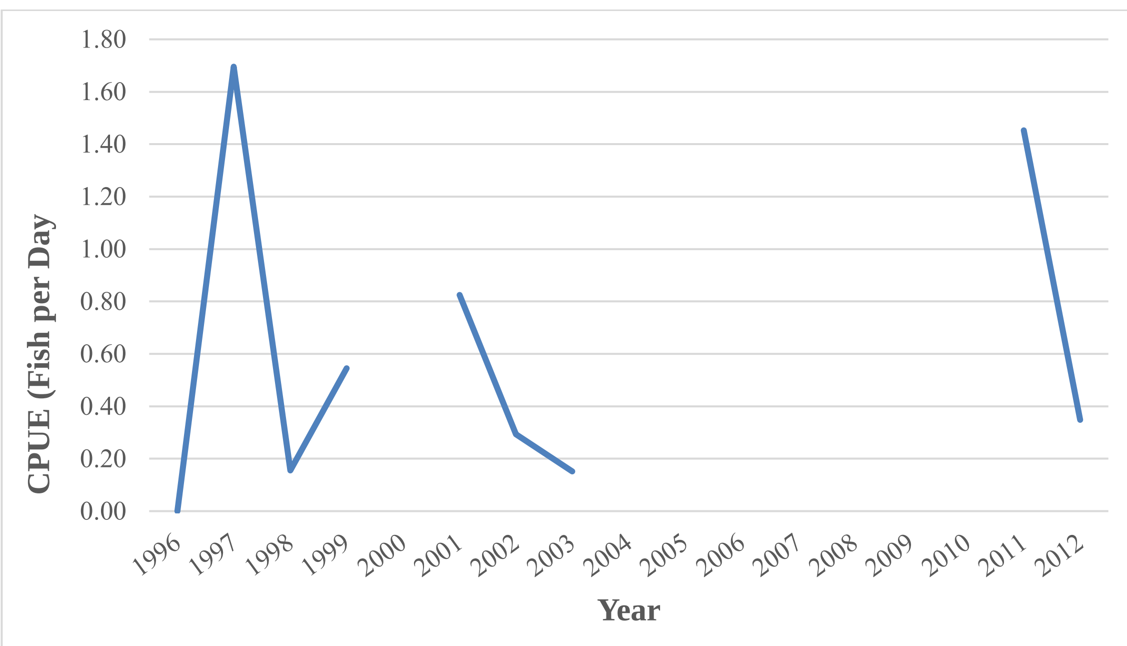


Figure 11.52 Raritan River Island Farm Weir fish ladder viewing CPUE (1996-2005, 2011-2012).



12 Status of River Herring in Delaware River and Bay

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12.1. INTRODUCTION

River herring populations in the state of Delaware, Pennsylvania and New Jersey consist of two species, alewife and the blueback herring. Both species occur throughout the Delaware River and Bay (Basin).

During the early 1900s the volume of herring in the Delaware River was so great that they often flipped onto the creek banks of the river each spring. The decline of river herring in the Basin began in the 1940's due to heavy organic loads around Philadelphia, Pennsylvania which caused severe declines in dissolved oxygen (DO). The ensuing "DO blocks" made parts of the lower Delaware River uninhabitable for fish during the warmer months of the year (Sykes and Lehman 1957). The contamination continued to worsen to such a degree that by 1951 it was advised that no one should go into the water. During the 1940s, commercial herring fisheries were mainly limited to the lower reaches of the River and Bay below Pennsylvania. By 1950, the urban reach of the Delaware River was one of the most polluted stretches of river in the world.

A remnant of the herring runs in the upper Basin survived by migrating upstream early in the season, when water temperatures were low and flows were high, before low DO ensued. These fish, because of their early arrival, migrated farther up the Delaware to spawn. Runs in the lower Basin survived by spawning below the DO block. Out-migrating juveniles survived by moving downriver late in the season during high flows and low temperatures, thus avoiding the low oxygen waters present around Philadelphia earlier in the fall. Pollution continued to be a major factor until passage of the Federal Clean Water Act in 1972. This Act was instrumental in the elimination of the pollution block in the region around Philadelphia.

12.2. MANAGEMENT UNIT DEFINITION

The Delaware River Drainage Basin consists of the Delaware River, including the East and West branches above Hancock, New York, and its tributaries to the mouth of Delaware Bay, encompassing some 13,539 square miles and 216 tributaries. The Basin includes the states of Delaware, New Jersey, New York, and Pennsylvania. Management authority lies with the New York Department of Environmental Conservation (NYDEC), Pennsylvania Fish and Boat Commission (PFBC), New Jersey Division of Fish and Wildlife (NJDFW) and Delaware Division of Fish and Wildlife (DFW)

The main-stem of the Delaware River is the longest un-dammed river east of the Mississippi and stretches for 330 miles. There are individual runs of river herring in nearly all of Delaware Basin's larger streams and rivers to at least river-mile 155. The Delaware River north of Port Jervis, NY is a shared water body between the states of New York and Pennsylvania. River herring have not been documented to occur in this section of the Delaware River and will not be discussed in this chapter.

12.3. REGULATORY HISTORY

12.3.1. Commercial Fishery

As of January 1, 2012 landings of river herring in systems without an approved sustainable fisheries management plan are prohibited. These regulations are in compliance with the Atlantic States Marine Fisheries Commission Amendment 2 to the Fisheries Management Plan for Shad and River herring.

As of January 1, 2012 the commercial fishery in Delaware, New Jersey and Pennsylvania waters has been closed. No harvest of river herring is permitted.

Within Delaware's waters of the Basin, DFW restrictions historically included:

1. The spring gill net season is from February 15- May 31, and the fall season for any remaining quota

not caught in the spring season extends from November 15-December 31.
2. Drift gill nets only from February 15-February 28 with a stretch mesh > 4” and from May 10-May 31.
3. Drift gill nets are prohibited from Saturday through 1600 hours Sunday or on legal state holidays from May 10 through September 30.
4. No fixed gill net more than one-half nautical mile from the beach of the Delaware River and Bay to the north of Beach Plum Island Nature Preserve between and including May 11 and September 30, and no more than 200 feet of net from May 11 through September 30.
5. No fixed gill nets from May 10 through September 30 in Delaware Bay.
6. The use of any type of net within 300 feet of any dam is prohibited on any tributary.
7. The striped bass spawning grounds which include the Nanticoke, Delaware River and C&D Canal are closed to all gill nets from April 1 to May 31.

Within New Jersey’s waters of the Basin, NJDFW restrictions historically included:

5. From November 1 to April 30, only haul seines with a mesh size ≥ 2 ¾ inch stretch and with a maximum length of 420 feet can be used in the Delaware River. This is currently limited to one commercial fishery based in Lambertville and rarely harvests river herring,
6. From February 1 through December 15, gill nets may be used in Delaware Bay and River. From February 12 through May 15, the maximum net length allowed is 2400 feet; from May 16 through December 15, the maximum net length is 1200 feet,
7. Gill net small mesh exemption permit (GNSMEP) allows fishers to use gill nets between 2.75 inch stretched mesh to 3.25 inch stretched mesh within two nautical miles of the mean high water line between sunrise and sunset. Holders of these permits are required to report all landings and any weakfish discards.
8. Pound nets are allowed all year in Ocean waters and Sandy Hook/Raritan Bay. In Delaware Bay, pound nets are allowed only during February 15 to May 15

A robust commercial river herring fishery existed near Philadelphia in the late 1800’s and early 1900’s. This fishery was eliminated by the “DO block” in the mid 1900’s. No commercial fishery has existed for river herring within New York’s shared portion of the Delaware River

12.3.2. Recreational Fishery

Historically, the recreational fishery for river herring was very small with few participants and low retention rates. Those herring that were landed were typically frozen for bait, pickled, kept for their roe or other traditional uses.

As of January 1, 2012 the recreational fishery in Delaware, New Jersey and Pennsylvania waters has been closed. No harvest of river herring is permitted.

Delaware

In the Delaware portion of the Basin, the recreational fishery took place at the various low-head dams that form mill ponds on the majority of Delaware's tidal rivers where herring concentrated during the spring spawning season. Some recreational fishermen used hook and line, but most herring were landed using lift nets (umbrella nets) or dip nets at the peak of the run. Prior to 2005, no recreational limit for river herring existed in the State of Delaware. The catch and effort for river herring increased as striped bass stocks rebounded and the popularity of using live river herring for bait escalated. In an effort to prevent over exploitation of these small herring runs, a 25 fish per day limit was adopted in 2005. The popularity of this fishery continued to increase and consequently a 10 fish per day possession limit was adopted in spring of 2008 to help conserve remaining spawning stocks and to prevent stock-piling fish in net pens or live cars. In addition, in 2008, Delaware's General Assembly approved legislation that prohibits the use of any net by any fisherman within 300 feet of any dam on any tidal tributary. The 10 fish possession limit and the prohibited use of any net immediately below any dam greatly reduced both catch and effort by forcing recreational fishermen to use only hook and line and to limit landings to the possession limit. **As of January 1, 2012 the recreational fishery in Delaware waters has been closed. No harvest of river herring is permitted.**

New Jersey

Historically, the recreational fishery for river herring was very small with few participants and low retention rates. Those herring that were landed were typically frozen for bait, pickled, harvested for their roe, and other traditional uses. In the freshwater areas of New Jersey, the limit was historically 10 fish per angler per day, while the marine section was 35 fish. Recreational gear included hook and line, dip net, bait seine, cast net, and umbrella net. **As of January 1, 2012 the recreational fishery in New Jersey waters has been closed. No harvest of river herring is permitted.**

Pennsylvania

Historically, the sport fishery for river herring in Pennsylvania was almost exclusively a bait fishery which was limited to hook and line fishing, open year-round, with no minimum length limit. Since the mid-1980's, the daily creel limit for river herring in the Delaware River and Estuary was a total of 35 fish. Beginning in 2010, the Pennsylvania Fish and Boat Commission adopted regulations in coordination with New Jersey and later coordinated with New York reducing the daily creel limit from the historic limit to a limit of 10 river herring from the confluence of the East and West Branches downriver to the Commodore Barry Bridge. The remaining 2.9 river miles below the Commodore Barry Bridge remained at the historic daily limit of 35 herring, in cooperation with New Jersey's Marine Council. **As of January 1, 2012 the recreational fishery in Pennsylvania waters has been closed. No harvest of river herring is permitted.**

12.4. ASSESSMENT HISTORY

In 2012 a river herring benchmark stock assessment was completed and found that of the 52 stocks of alewife and blueback herring assessed, 23 were depleted relative to historic levels, one was increasing, and the status of 28 stocks could not be determined because the time-series of available data was too short. Estimates of abundance and fishing mortality could not be developed due to lack of data. The "depleted" determination was used instead of "overfished" and "overfishing" to indicate factors other than fishing have contributed to the overall population decline, including habitat loss, predation and climate change (ASMFC 2012).

12.5. STOCK SPECIFIC LIFE HISTORY

Adult alewife and blueback herring will typically enter the Basin to spawn beginning in early February. Peak activity for alewife occurs during April and the beginning of May, while peak spawning activity for blueback typically occurs during April and through the end of May. The adults emigrate downstream soon after spawning although a minority remains in the ponds through the summer. Larvae will hatch and juvenile will maintain freshwater residence through November, although juvenile emigration can occur as early as the water temperatures decline through the fall. Once mature, adults will return to their natal streams to spawn.

12.6. HABITAT DESCRIPTION

Many of the Basin tributaries contained spawning runs of river herring until pollution, overfishing, and dams restricted the population and destroyed spawning habitat.

On the Delaware side of the Basin all of the major tributaries contained spawning runs of river herring through 1990. At that time, there were 13 tidal streams that had either confirmed runs from a variety of adult and juvenile monitoring activities, or the collection of eggs and early life stages during the spring spawning season. All of the tidal streams have reduced amounts of available spawning habitat due to the construction of low-head dams that formed mill ponds dating to the 1800's or earlier 1900's. No new dams have been constructed since the 1960's that interfere with river herring spawning. Although all of Delaware's tidal rivers have been dammed to some extent, there was some suitable spawning and nursery habitat available in each system to sustain at least a remnant spawning stock. All of the tidal streams are relatively short in length, resulting in a fairly steep salinity gradient, especially in those rivers that terminate in the lower Bay where the ambient salinity is high. Subsequently, all spawning is usually restricted to a short distance of freshwater near the dam and immediately downstream. In northern Delaware, where springtime salinities in the adjacent Delaware River are very low, the spawning areas are more dispersed, and eggs and larvae are found throughout much of each system. The Christina River is the longest of the Delaware tidal tributaries and is approximately 15 miles from the Bay to the first dam. Age-0 River herring use these tributaries for nursery habitat from spring through early fall and then migrate to the mainstem Delaware River and Bay. Those adults (typically blueback herring) that use the ladders generally do so during the peak of the run and all spawning occurs in the impoundment; no movement into upstream tributary streams has been documented. The adults emigrate downstream soon after spawning although a minority remains in the ponds through the summer. The ladders are kept opened for a period of time throughout the summer and fall to allow the juvenile year class that generally congregates in the deeper waters near the dam to leave the system via the ladder, rather than swimming over the face of the dam.

On the New Jersey side of the Basin, it is estimated from 1953 to 1973, 61,678 acres of coastal wetlands and uncounted acreage of adjacent transitional wetlands were lost to filling and diking (Ferrigno et al 1973). Field investigations during the early to mid-1970s confirmed 132 river herring spawning runs (108 alewife and 24 blueback) in rivers and streams that were contiguous with the marine environment (Zich 1977). Zich concluded that nine herring runs had already become extinct. Also during these field investigations, 83 constructed barriers were found on streams where herring runs were reported or confirmed. These barriers were assessed to be blocking or limiting fish passage and therefore reducing spawning habitat. There is no current estimate as to whether or not this number has changed significantly since that time. Recent efforts have been undertaken to restore river herring runs in some of these systems by removing dams, installing fish ladders and/or trap and transport.

12.7. RESTORATION PROGRAMS

Efforts in Delaware and New Jersey have been undertaken to restore river herring runs in some of these systems by installing fish ladders. Twelve tidal streams located within the Delaware River/Bay watershed have fish ladders installed (eight in Delaware and four in New Jersey) at the first upstream dam to allow for river herring passage into the non-tidal impoundments above the dams. The fish ladders are all of Alaskan Steeppass design and are operated to allow for increased spawning activity and nursery habitat. All of the ladders have been monitored at some level to determine passage rates and develop species use following construction. All fish using the ladder were trapped in a fish ladder exit trap, identified, counted and released. Only target species were released into the impoundment. A target passage rate of 5 adults per surface acre was established for all ladders as a threshold for successful river herring passage. Once the target rate was achieved, annual monitoring was suspended. Annual monitoring has continued at those ladders that have not met the 5 fish per surface acre target. Some engineering modifications to the entrance to the ladders have been done to enhance passage. Monitoring at the ladders was discontinued at those sites that achieved their target for two consecutive years to avoid potentially impacting spawning behavior. Monitoring resumes at these sites every third year to determine trends in abundance and continued use. A supplemental stocking program for river herring was initiated in some impoundments as part of their restoration efforts (Table 12.5). This stocking element was dependent on the availability of adult river herring in hopes of increasing spawning run size in subsequent years. No stocking has occurred since 2004 due to the limited availability of adult herring for trap and transfer.

Within Pennsylvania, restoration efforts have also focused on dam removal and installation of fish passage. Fishways have been constructed in the Schuylkill River at Fairmount Dam (rebuilt in 2008), Flat Rock Dam (2007), Norristown Dam (2007), and Black Rock Dam (2009), which, along with dam removals have opened up 100 river miles to migratory fish. Fishways have been built on the Lehigh River at Easton Dam (rebuilt in 2001), Chain Dam (rebuilt in 2001), and Hamilton Street Dam (1983), opening up 24 river miles to migratory fish. Dam removals have occurred in Ridley Creek (2 dams), Chester Creek (2 dams), Neshaminy Creek (2 dams), Darby Creek (4 dams, 10.5 miles opened), and Pennypack Creek (7 dams, 22 miles opened).

12.8. AGE

No age data has been reported from the Delaware Basin.

12.9. FISHERY DESCRIPTION

Fisheries data, with some exceptions, is reported and compiled by state. **As of January 1, 2012 there has been no commercial fishery within Pennsylvania, New Jersey, and Delaware waters.**

12.9.1. Commercial Fishery

Delaware

Delaware's commercial landings were determined annually from mandatory commercial catch reports under the provisions enacted by the Delaware General Assembly in 1984. Every fisherman holding a commercial food-fishing license was required to submit a monthly report specifying what general area gear was deployed at within the estuary, the type and amount of fishing gear deployed, and the pounds landed of each species taken for each day fished. The reported commercial gill net landings and the kilograms of fish landed per meter of gill net for Delaware's portion of the Delaware Estuary are found in Table 12.1 and Figure 12.3. The effort data reflects days that fishermen actually landed river herring and does not account for days when the species was not landed.

The commercial fishery for river herring was relatively small but highly variable in Delaware, ranging from 500 lbs to 36,000 lbs annually since 1985. Commercial landings occurred from February through May with peak landings in March and April. Landings occurred from all of the broader regional areas of Delaware but the Nanticoke River has traditionally yielded the majority of landings and it also has the largest herring runs of any of the tidal streams in the state (see Section 13 for more information on the fishery in the Nanticoke River). Both species are represented in the catch but the majority is probably blueback herring based on observations of relative abundance and temporal distributions within state waters.

Adult river herring in Delaware have not been sampled for any biological characteristics such as size, sex, and age structure or species composition. In the past there has been concern over the misidentification of river herring by commercial watermen in the Delaware Estuary. Analysis of past data has resulted in a cutoff date of June 1 for reported herring landings. Landings were reported monthly until 1989, after which they were reported on a daily basis. There has been no commercial fishery for river herring in Delaware since 2011, when the total estimated dockside value for all species landed was $1.3 million with river herring contributing $682 to that total value.

New Jersey

New Jersey river herring landing estimates were obtained from two sources (Table 12.5 and 12.8). The NMFS estimates (1950 to 2010) are for the entire state, while mandatory logbooks of the GNSMEP (2000 to 2015) are from Delaware Bay. The average reported NMFS landings for the time period is estimated at 7,541 pounds. There are no estimates of underreporting, however it is assumed that the current data for river herring is underreported since some landings may be categorized as bait.

The GNSMEP is primarily directed towards white perch and other species with river herring being a harvestable bycatch when they could still legally be harvested. The gear is not standardized and therefore the data should only be used for potential trends and not absolute numbers. Harvest was only categorized as herring and could include some Atlantic herring landings. A CPUE developed for this data shows a declining trend since 2000 (Table 12.1 and 12.8).

12.9.2. Recreational Fishery

As of January 1, 2012 there has been no recreational fishery within Pennsylvania, New Jersey, and Delaware.

Delaware

There are over 500 'recreational' gill net permits issued to Delaware fishermen. The permit stipulates that a fisherman is entitled to set up to 200 feet of anchored or fixed gill net with a minimum mesh size of 3.25 inches. Many commercial crabbers hold these permits which allow them to catch bait, primarily Atlantic menhaden. River herring were also reported as discards from this fishery but were highly variable ranging from 6 fish per year to over 1,000. All recreational gill net fishermen abided by the same seasons, size and creel limits for foodfish that applied to recreational anglers except the harvest of certain species (such as striped bass) was not allowed. From 1996 through 2003 annual total harvest estimates ranged from 4,400 fish in 1996 to 297 in 2002 (Table 12.2). The number of river herring harvested per trip declined steadily from 1998 through 2004 (Table 12.2). **As of January 1, 2012 the recreational fishery in Delaware waters has been closed. No harvest of river herring is currently permitted.**

New Jersey

The only survey of the recreational fishery for river herring within the Delaware Basin was an access point survey in conjunction with an aerial effort survey conducted by Versar, Inc. during 2002 (Volstad et al 2003). The study area included all tidal and non-tidal waters from the Delaware Memorial Bridge to Downsville, NY.

A total of 7,553 river herring were estimated to be caught and 4,916 were harvested by recreational anglers in the Delaware River for 2002. Angler catch rate was estimated 0.0189 per angler hour and the harvest rate was estimated at 0.0123 per angler hour.

12.9.3. Subsistence Fishing

There is no known or recorded subsistence fishery for river herring within the Basin.

12.9.4. Characterization of Other Losses

There are many potential unknown sources of mortality from power plant intakes, commercial discards, and landings categorized as "bait". Many of these could be significant.

12.10. FISHERY-INDEPENDENT SURVEYS

12.10.1. Spawning Stock Surveys

The Delaware Estuary is monitored annually by DFW to document the relative abundance and distribution of a number of important finfish species. A 30-foot bottom trawl was used to sample nine fixed stations in the Delaware Bay from March through December (Greco 2015). Tow duration was 20 minutes with a minimum tow time of 10 minutes required for the data to be considered valid. A global positioning system (GPS) was used to determine exact vessel position at the start and conclusion of each tow. Odometer readings from the

GPS unit were used to determine distance towed (nautical miles). Adult densities were calculated for blueback herring and alewife by dividing the number of individuals for a species by the distance towed (N/NM) at each station sampled, then calculating arithmetic means and standard errors in the typical fashion.

Length frequencies have been determined for blueback herring (Figure 12.9) and alewife (Figure 12.10) resulting from collections during the adult finfish surveys conducted on the Delaware Bay. Species represented by less than 50 individuals were measured for fork length to the nearest half-centimeter. Species with more than fifty individuals were randomly sub-sampled (50 measurements) for length with the remainder being enumerated for each tow.

One of the area utilities Public Service Electric and Gas (PSEG) constructed and maintained fish ladders on Delaware River Estuary tributaries for spawning run restoration of alewife and blueback herring (Table 12.3). Alaska Steeppass fish ladders have been installed at twelve sites: Sunset Lake, Stewart Lake, Newton Lake, and Cooper River Lake in New Jersey, and Noxontown Pond, Silver Lake (Dover), Silver Lake (Milford), McGinnis Pond, Coursey Pond, McColley Pond, Garrisons Lake and Moores Lake in Delaware. Adult passage monitoring typically occurred from March to early June. Sampling was performed using a fish ladder exit trap net. Sites were not sampled every year. Sampling was stopped when a fish ladder consistently passed adult herring, to avoid potentially impacting spawning behavior.

12.10.2. Juvenile Surveys

The Delaware Estuary is monitored annually by DFW to document the relative abundance and distribution of a number of important juvenile finfish species encountered in the estuary from April through October at 38 fixed stations using a 16' trawl seine. Tow duration was 10 minutes for the 16-foot trawl survey. A global positioning system (GPS) was used to determine exact vessel position at the start and conclusion of each tow. Odometer readings from the GPS unit were used to determine distance towed (nautical miles). JAIs were determined for yoy and age 1 blueback herring and alewife resulting from collections during juvenile finfish surveys. Fish densities were calculated by dividing the number of individuals for a species by the distance towed (No/NM) at each station sampled, then arithmetic means and standard errors were calculated. Length frequencies have been determined for blueback herring and alewife resulting from collections during juvenile finfish surveys conducted on the Delaware River and Delaware Bay. A representative subsample of 30 juvenile specimens per species was measured for fork length to the nearest millimeter; the remainder were enumerated.

Another juvenile survey includes the use of a 150' haul seine is used to generate juvenile indices of abundance for the Christina River, a tributary of the Delaware River (Park, I, A. 2015). Haul seine sampling was fully implemented in 2014 and continued annually to assess reproduction and recruitment of all alosines. Sampling in 2015 was conducted biweekly at five locations on the Christina River from July through the first week of November during ebb or slack tides. All captured fish were identified to species and enumerated.

The reproductive success of YOY river herring was assessed, prior to assumed out-migration, in Delaware ponds using a boat-mounted pulsed-DC electrofisher by DFW staff during 1995-96 and from 2000 to the present (Stetzar 2015). Fall samples were obtained to determine spawning success, recruitment and relative abundance between impoundments. Most of these impoundments are small, averaging less than 64 acres, and the entire pond can be surveyed relatively quickly. Young river herring are either counted individually or size of the schools is estimated. Subsamples are taken to determine species composition and size ranges. The CPUE was calculated using the total river herring observed which included estimates of larger schools. Estimates of total production are not determined. Careful analysis of the juvenile electrofishing data is warranted since not all impoundments were equally sampled throughout the time period. This work was discontinued in February of 2014.

PSEG also conducted electrofishing twice a month from September through November to gauge juvenile river herring presence and relative abundance at the impoundments discussed earlier in this document (Table 12.6). Fish were counted each time the foot switch was pressed. The count of small numbers of fish was an exact count. Estimates of larger numbers of fish were made in 10, 25, 50, 100, 150, and 200 fish increments. Sampling frequency and locations varied. Additionally, when herring were encountered in considerable numbers, electroshocking was briefly interrupted to limit the stress on fish. The survey was discontinued in 2005.

New Jersey has conducted a juvenile abundance survey for striped bass in the Delaware River from Trenton to Artificial Island since 1980. The program utilizes a 100-foot bagless beach seine during the months of August, September, and October at representative stations. A juvenile abundance index (JAI) is calculated for alewife and blueback herring using a geometric mean. Since river herring are not collected at all stations, those farthest downriver stations (below the Delaware Memorial Bridges) have been removed from analysis to give a more accurate picture of juvenile production in the lower Delaware River. Length frequencies of juvenile blueback herring and alewife have been determined from collections since 2002 (Table 12.9). A representative subsample of 30 juvenile specimens per species was measured for fork length to the nearest half centimeter; the remainder was enumerated. No trends were discernible from this time series of data.

12.11. ASSESSMENT APPROACHES AND RESULTS

The purpose of this report is to document and update the stock status of river herring in the Delaware River and Estuary. It is obvious from historical data and anecdotal information that river herring populations were much larger in the past and have declined drastically since the late 1800s.

12.11.1. Spawning Stock Abundance

Adult river herring commercial landings were typically the result of bycatch from other fisheries like the white perch fishery. Overall landings data in both New Jersey and Delaware showed that landings have declined in the years prior to the basin wide harvest moratorium. The best indicator of the commercial fishery was the CPUE from mandatory commercial catch reports. In Delaware, the commercial CPUE for the Delaware Estuary declined since the mid-1990's and the lowest CPUE in the time series for the Delaware River occurred in 2010. The New Jersey commercial CPUE, except for 2000, decreased since 1997 up until the harvest moratorium. The recreational gill net CPUE for Delaware peaked in 1998 with no data between 2004- 2006, then a slight incline with data collected in 2007. The declines seen in the commercial and recreational data could be a result of declining stocks, declining effort, or regulatory changes.

Adult data from Delaware's finfish trawl survey indicate the greatest recent increase in alewife abundance occurred from 1996-1998 (Figure 12.8). After 1998 alewife relative abundance decreased and has remained at substantially depressed levels since 2002, however since 2008 alewife levels have been trending somewhat upwards (Figure 12.8). Blueback herring varied without trend throughout the 1990's prior to good year classes in 1999 and 2000. Blueback herring abundance has trended downward from 2001-2003 and has remained stable at low levels without trend since 2003.

The aggregate PSEG fish ladder passage CPUE (#/Hr) has trended downward since 1996 in Delaware and New Jersey ponds (Table 12.4). This index has declined throughout the time series from the highest value of 0.5 in

1996 to the lowest value of 0.001 in 2014 (PSEG 2015). Blueback herring have been the primary users of the fish ladders and river herring runs in the Basin are dominated by blueback herring overall. Alewife use of the ladders increases slightly in the northern part of the Basin. These numbers need to be considered with certain caveats however. For blueback herring, ladders that had high usage are no longer sampled every year. Likewise, newer ladders have yet to see any significant usage but are monitored 24 hours per day. The increase in alewife usage comes mainly from the Sunset Lake (NJ) fish ladder where restoration seems to be going well for alewife while all other fish ladders have yet to see the same results.

12.11.2. Juvenile Abundance

The annual abundance (geometric mean catch per tow) from 16-foot otter trawl sampling for YOY alewife in the Delaware River and Bay varied without trend throughout the time series with peak years in 1996, 2000, 2003, 2007, and 2015 (Figure 12.13). However, the time series does demonstrate improvement since 2012. The Age 1 alewife index declined since the highest value was reached in 1997 (Figure 12.15). The YOY index for blueback herring increased slightly from 1990 through 2003, but substantial declines were noted since then (Figure 12.14). The Age 1 blueback herring index has varied substantially since 1991 with no discernible trend (Figure 12.16). It is unknown if these changes in the trawl index are actual trends or more a function of gear inefficiency. A bottom trawl is not the most efficient gear for capturing alosines, and can result in low sample numbers. Environmental conditions may have also played a factor in the number of river herring captured.

In 2015, the annual abundance (geometric mean catch per haul) of river herring from haul seining on the Christina River was 2.11 for alewife and 1.34 for blueback herring. The geometric mean increased substantially from 2014 for both species (Table 12.10).

The PSEG electrofishing survey for YOY alewife fluctuates wildly but shows an increasing trend. The blueback herring index shows an increasing trend from 1996 to 2001 before declining through 2005 when sampling was discontinued (PSEG 2009).

Overall CPUE (catch per minute) of YOY river herring collected during electrofishing efforts throughout seven Delaware impoundments by DFW staff exhibited the highest values in 1999, 2004 and 2007. However, the overall CPUE is often driven by a single pond's catch and does not represent an overall trend in use or reproductive success. For example the 1999 and 2004 CPUE were driven by high numbers sampled primarily in one pond (Wagamon's Pond). The 2007 value was driven by a high number of river herring caught in McColley Pond as well. This work was discontinued in February of 2014.

Juvenile production was very low for both species in the early years of the NJDFW striped bass survey (Table 12.9). Since that time, the blueback herring index was varied with a fairly steady increase in blueback herring production from 1980 through the first real high year class in 1993. From 1993 through 2001, the survey included two additional large year classes (1996 and 2001) with some production years below average. Since 2001 the production of blueback herring has decreased. Abundance of YOY alewife has fluctuated without trend with years of high abundance (1988, 1996, 2001 and 2005) mixed with years of low abundance (1992, 1998, 2002, and 2006, and 2008-2015). More recent alewife trends are similar to blueback herring, although 2007 was considered a good year. It should be noted that environmental conditions in 2002 (drought) and 2006 (floods) were not conducive for good spawning or survival of either species.

12.12. BENCHMARKS

No benchmarks were developed at this time for river herring fisheries in the Basin.

12.13. CONCLUSIONS AND RECOMMENDATIONS

The data that is presented here is a stock status report update of the original stock status report of 2008, and is not intended as a full assessment of river herring within the Delaware River Basin. Additional assessment techniques and data should be used in an attempt to determine why these stocks have declined in recent years. This would include comparisons to data from other east coast river systems, predation, fishing mortality estimates if available, and offshore harvest and discards.

Overall river herring landings in the Delaware Basin have declined since 1992. Although fish passage may have been considered fair to good in some years, reproduction in these freshwater impoundments has been poor overall. The installation of fish ladders in Delaware ponds have resulted in little success and it appears that to date this effort has been ineffective in restoring river herring populations. However, alewives in New Jersey have increased in recent years due to an increase in passage at the Sunset lake fish ladder.

The overall assessment of data from these stocks suggest stocks have declined since the beginning of data collection. There are no estimates of mortality for the Delaware Basin stocks of river herring so it is not possible to determine the cause or causes of this decline. In order to update our current understanding of the population dynamics associated with both species of river herring within the Delaware River Basin, the following research areas should be further considered, including, but not limited to:

- Improved assessment of river herring adults at all fish ladder installations such as tagging studies below the ladders to estimate population numbers and ladder passage rates.
- Evaluation of fish ladders to determine the effectiveness of attraction flow at each ladder, with priority given to those ladders that are under performing.
- Improved assessment of river herring production in targeted tributaries within the basin.
- Predator-prey relationships especially with striped bass, bluefish and white perch for yoy and striped bass, weakfish, bluefish, spiny dogfish for adults require evaluation.
- Habitat condition and usage continue to require evaluation and consistent monitoring.

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Table 12.1 Delaware Estuary Gill Net Landings and CPUE. Discontinued after 2011. (Source: DE DFW).

Year	Kgs Landed	CPUE (kgs/net meter)
1985	2158	0.044
1986	643	0.015
1987	496	0.010
1988	1263	0.009
1989	1560	0.112
1990	746	0.046
1991	3305	0.070
1992	307	0.018
1993	2568	0.102
1994	170	0.043
1995	110	0.019
1996	679	0.071
1997	44	0.014
1998	181	0.017
1999	128	0.042
2000	223	0.028
2001	562	0.053
2002	38	0.012
2003	196	0.029
2004	231	0.023
2005	8	0.003
2006	579	0.016
2007	85	0.005
2008	886	0.064
2009*	Confidential	
2010*	Confidential	
2011	341	0.362

Table 12.2 Recreational fishery for river herring in Delaware, 1996 – 2003, and 2007. (Source DE DFW).

					Effort		Catch	Harvest
	Harvested	Released Alive	Total	# of		Net Yard	per	per
Year	N	N	N	Fishers	Trips	Days	Trip	Trip
1996	4399	.	4399	391	3,808	196,381	1.16	1.16
1997	2247	.	2247	274	2,291	111,659	0.98	0.98
1998	2835	.	2835	269	1,161	55,453	2.44	2.44
1999	460	14	474	27	948	49,342	0.50	0.49
2000	1134	6	1140	197	1,560	84,396	0.73	0.73
2001	502	1028	1530	198	1,686	82,301	0.91	0.30
2002	297	48	345	179	1,615	83,022	0.21	0.18
2003	370	43	413	173	1,390	65,779	0.30	0.27
2004	No Data	.	.	.	.	.	.	.
2005	No Data	.	.	.	.	.	.	.
2006	No Data	.	.	.	.	.	.	.
2007	341	495	836	144	878	43,096	0.95	0.39

Table 12.3 Fish ladder information from PSEG

	Ladder Date	Size (acres)	Length (miles)	Perimeter (miles)	Lake Watershed (acres)
New Jersey					
Cooper River Lake	1998	190	4.53	9.57	23,680
Newtown Lake	2004	41	2.87	6.03	2,332
Stewart Lake	2004	38	1.17	4.39	2,897
Sunset Lake	1997	94	0.67	2.1	29,248
Delaware					
Coursey Pond	1997	58	0.72	2.48	14,579
Garrison Lake	1999	86	0.76	2.19	10,752
McColley Pond	1996	49	1.14	3.34	6,080
McGuiness Pond	1996	31	0.76	2.16	7,040
Moores Lake	1999	27	0.76	1.87	11,776
Noxontown Pond	2004	162	1.99	7.03	6,110
Silver Lake (Dover)	1996	171	1.71	4.52	20,480
Silver Lake (Milford)	2004	27	0.49	1.56	17,326

Table 12.4 PSEG river herring fish passage CPUE for Delaware and New Jersey Ponds. Source: NJ DFW.

Year	Effort	BB	AW
1996	239	0.490	0.013
1997	593	0.312	0.002
1998	3501	0.196	0.006
1999	7384	0.176	0.031
2000	12242	0.118	0.007
2001	14684	0.134	0.006
2002	14552	0.181	0.019
2003	14928	0.059	0.013
2004	17679	0.065	0.054
2005	16053	0.022	0.002
2006	12232	0.016	0.002
2007	13102.67	0.008	0.025
2008	17986.61	0.138	0.010
2009	19941.96	0.010	0.028
2010	13165	0.010	0.060
2011	14019.87	0.025	0.051
2012	20469.38	0.039	0.008
2013	16347.98	0.007	0.000
2014	12111	0.001	0.001
2015	0	-	-
2016	22567	0.117	0.005

Table 12.5 PSEG river herring stocking for Delaware and NJ Ponds (1996-2004). Discontinued after 2004. Source: NJ DFW.

Bluebacks										
Impoundment	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total
Cooper River Lake (NJ)	N/A	N/A	766	1,069	964	1,071	840	197	0	4,907
Coursey Pond	N/A	0	156	0	0	0	0	0	0	156
Garrisons Lake	N/A	N/A	N/A	318	48	473	432	0	17	1,288
McColley Pond	8	0	7	11	0	0	0	0	0	26
McGinnis Pond	32	0	211	166	0	241	0	22	11	683
Moore's Lake	N/A	N/A	N/A	271	70	0	0	0	0	341
Newton Lake (NJ)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Noxontown Pond	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	23	23
Silver Lake (Dover)	84	0	713	687	419	993	865	201	0	3,962
Silver Lake (Milford)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Stewart Lake (NJ)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sunset Lake (NJ)	N/A	50	1,045	892	430	1,337	756	969	126	5,605
Alewife										
Impoundment	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total
Cooper River Lake (NJ)	N/A	N/A	0	0	0	0	0	0	0	0
Coursey Pond	0	0	0	0	0	0	0	0	0	0
Garrisons Lake	N/A	N/A	N/A	0	0	0	0	0	0	0
McColley Pond	0	0	0	0	0	0	0	0	0	0
McGinnis Pond	0	0	0	5	0	0	0	0	0	5
Moore's Lake	N/A	N/A	N/A	0	0	0	0	0	0	0
Newton Lake (NJ)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Noxontown Pond	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	0
Silver Lake (Dover)	0	0	0	0	0	0	0	0	0	0
Silver Lake (Milford)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Stewart Lake (NJ)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sunset Lake (NJ)	N/A	0	0	3	71	0	254	0	0	328

Table 12.6 PSEG river herring electrofishing CPUE for Delaware and New Jersey Ponds. Discontinued after 2005 Source: NJ DFW.

Year	Effort	Blueback	Alewife
1996	707.4	0.062	0.000
1997	470.8	0.520	0.002
1998	618.6	4.470	0.000
1999	493.6	26.244	0.063
2000	433.1	12.136	0.028
2001	499.5	49.215	0.212
2002	434.9	8.533	0.000
2003	433.9	15.266	0.364
2004	720	5.819	0.013
2005	720	6.639	0.554

Table 12.7 New Jersey commercial river herring (alewife and blueback herring) landings, in pounds (1950 – 2015). NMFS landings are statewide; Logs are from the Delaware Basin. Source: NJ DFW.

Year	NMFS	Logs	Year	NMFS	Logs
1950	29,000	-	1983	2,200	-
1951	7,200	-	1984	3,100	-
1952	600	-	1985	4,800	-
1953	8,600	-	1986	4,200	-
1954	0	-	1987	5,200	-
1955	22,900	-	1988	700	-
1956	22,300	-	1989	800	-
1957	8,100	-	1990	42,494	-
1958	1,400	-	1991	9,994	-
1959	2,200	-	1992	3,069	-
1960	3,000	-	1993	2,659	-
1961	16,500	-	1994	328	-
1962	20,300	-	1995	795	-
1963	3,400	-	1996	4,449	-
1964	14,200	-	1997	4,515	9,221
1965	21,500	-	1998	7,371	2,430
1966	12,400	-	1999	1,377	3,880
1967	9,000	-	2000	0	5,410
1968	8,400	-	2001	1,034	1,900
1969	5,100	-	2002	3,366	552
1970	7,500	-	2003	228	2,127
1971	9,500	-	2004	2,548	3,192
1972	14,700	-	2005	1,079	2,402
1973	7,000	-	2006	469	2,793
1974	10,600	-	2007	0	-
1975	9,300	-	2008	631	1,551
1976	11,300	-	2009	0	177
1977	10,600	-	2010	1,004	409
1978	2,400	-	2011		1,634
1979	6,600	-	2012		18
1980	18,600	-	2013		0
1981	13,800	-	2014		1
1982	13,600	-	2015		0
			AVG	**7,541**	**2,094**

Table 12.8 New Jersey Commercial CPUE for Delaware Bay (1997-2015). Source: NJ DFW.

Year	Hr*Ft/100	Lbs	CPUE
1997	15,248	9,221	0.60
1998	8,100	2,430	0.30
1999	22,608	3,880	0.17
2000	6,846	5,410	0.79
2001	12,696	1,900	0.15
2002	17,872	552	0.03
2003	12,160	2,127	0.17
2004	43,348	3,192	0.07
2005	40,176	2,402	0.06
2006	45,288	2,793	0.06
2007	-	-	-
2008	49,176	1,551	0.03
2009	29,808	177	0.01
2010	26,688	409	0.02
2011	43,992	1,634	0.04
2012	49,884	18	0.00
2013	0	0	0.00
2014	144	1	0.01
2015	0	0	0.00

Table 12.9 Delaware River index of relative abundance, geometric mean, for juvenile river herring collected during New Jersey's striped bass young of year survey (1980-2015). Source: NJ DFW.

YEAR	Alewife	Rank	Blueback	Rank
1980	0.00	32	30.30	2
1981	0.00	32	0.26	35
1982	0.10	22	3.19	25
1983	0.28	11	46.15	1
1984	0.00	32	16.99	8
1985	0.06	25	7.17	17
1986	0.52	6	18.13	6
1987	0.23	15	10.72	10
1988	3.17	1	9.03	13
1989	0.26	13	17.90	7
1990	0.26	12	4.63	21
1991	0.47	7	9.84	11
1992	0.03	27	6.91	18
1993	0.35	9	19.78	5
1994	0.19	17	2.38	28
1995	0.11	21	1.84	29
1996	1.96	2	24.97	4
1997	0.15	19	2.58	27
1998	0.03	28	4.36	22
1999	0.41	8	5.34	20
2000	0.14	20	12.33	9
2001	0.83	4	26.33	3
2002	0.00	32	0.62	33
2003	0.30	10	7.50	16
2004	0.24	14	8.15	14
2005	0.95	3	9.79	12
2006	0.00	32	0.15	36
2007	0.52	5	4.29	23
2008	0.01	29	1.37	30
2009	0.06	24	3.55	24
2010	0.05	26	1.37	31
2011	0.19	16	7.97	15
2012	0.01	31	0.42	34
2013	0.01	30	1.21	32
2014	0.18	18	5.46	19
2015	0.10	23	2.76	26
1980-2015	**0.34**		**9.33**	
2006-2015	**0.30**		**2.85**	
2011-2015	**0.13**		**3.56**	

Table 12.10 The geometric mean number taken per haul of river herring (2014-2015). Source: DE DFW.

Year	Alewife	Blueback herring
2014	0.02	0.61
2015	2.11	1.34

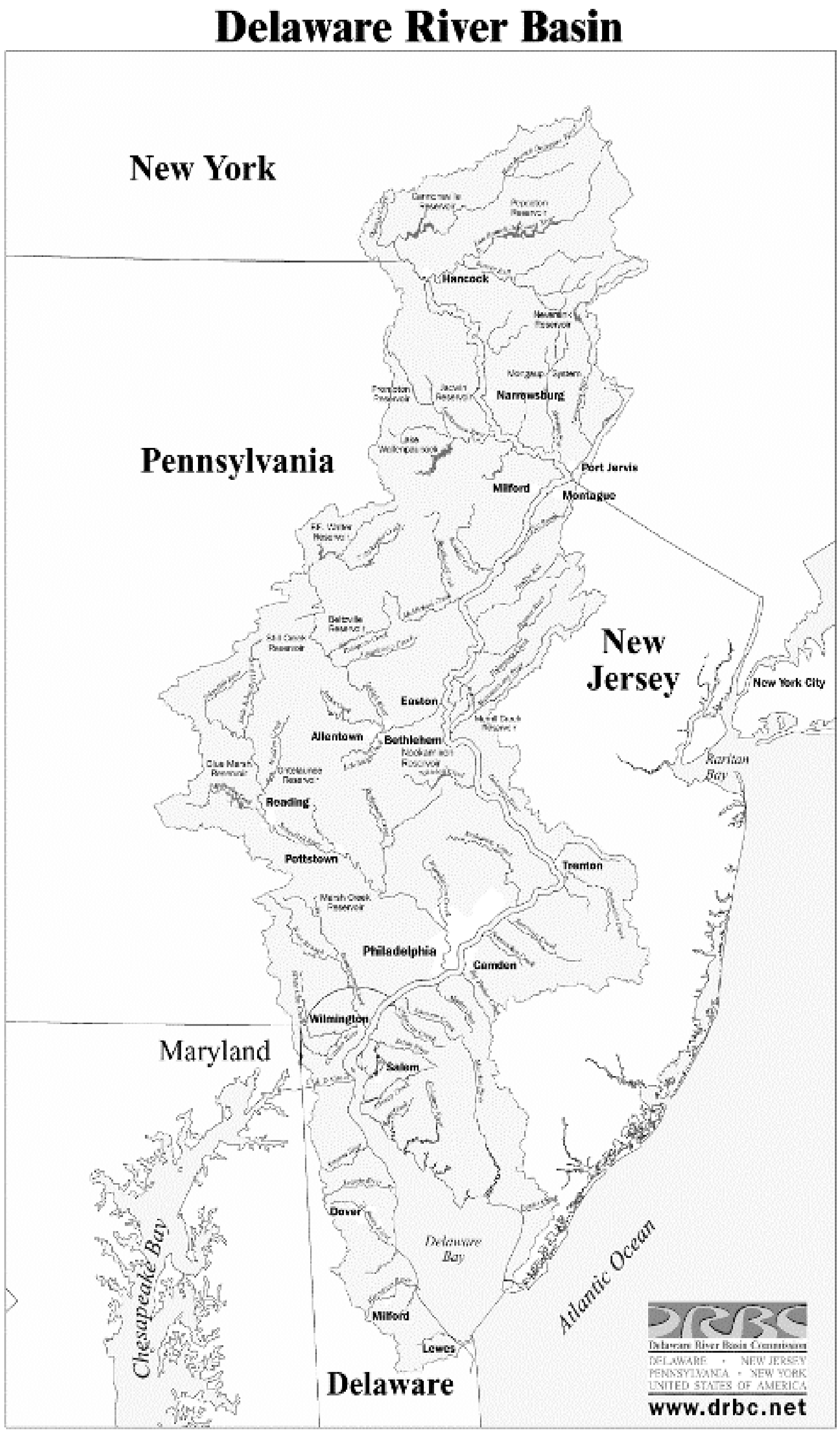

Figure 12.1 Map of the Delaware River/Bay Watershed.

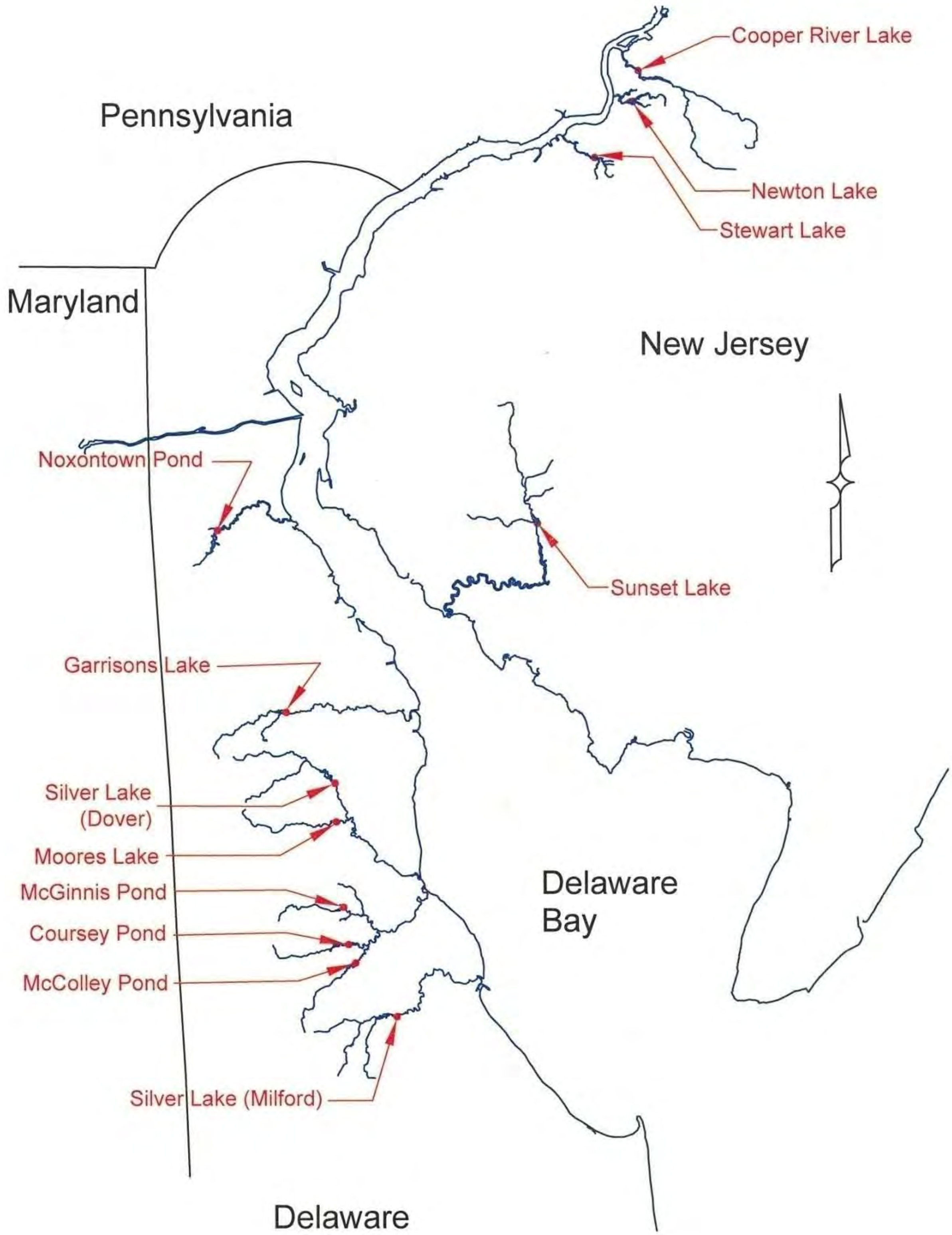

Figure 12.2 Locations of PSEG fish ladders within the Delaware River Basin (2009).

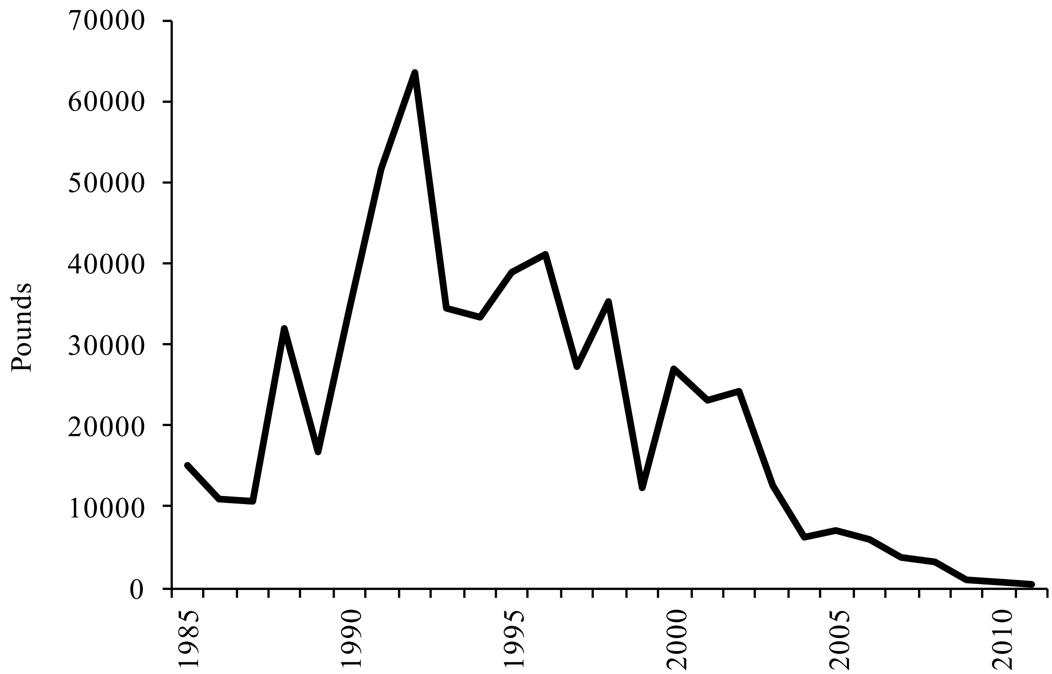

Figure 12.3 The reported **statewide** river herring commercial landings for Delaware, all gears combined. Discontinued after 2011. Source: DE DFW

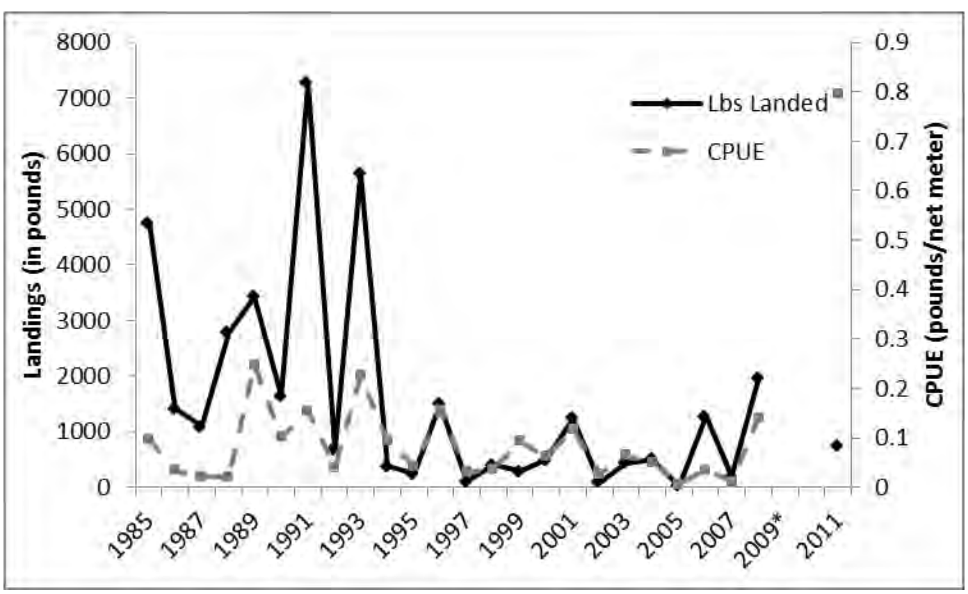

Figure 12.4 The reported commercial gill net landings and the pounds of fish landed per meter of gill net for Delaware's portion of the **Delaware Estuary**. *** Data from 2009 and 2010 are confidential.** Discontinued after 2011. Source: DE DFW

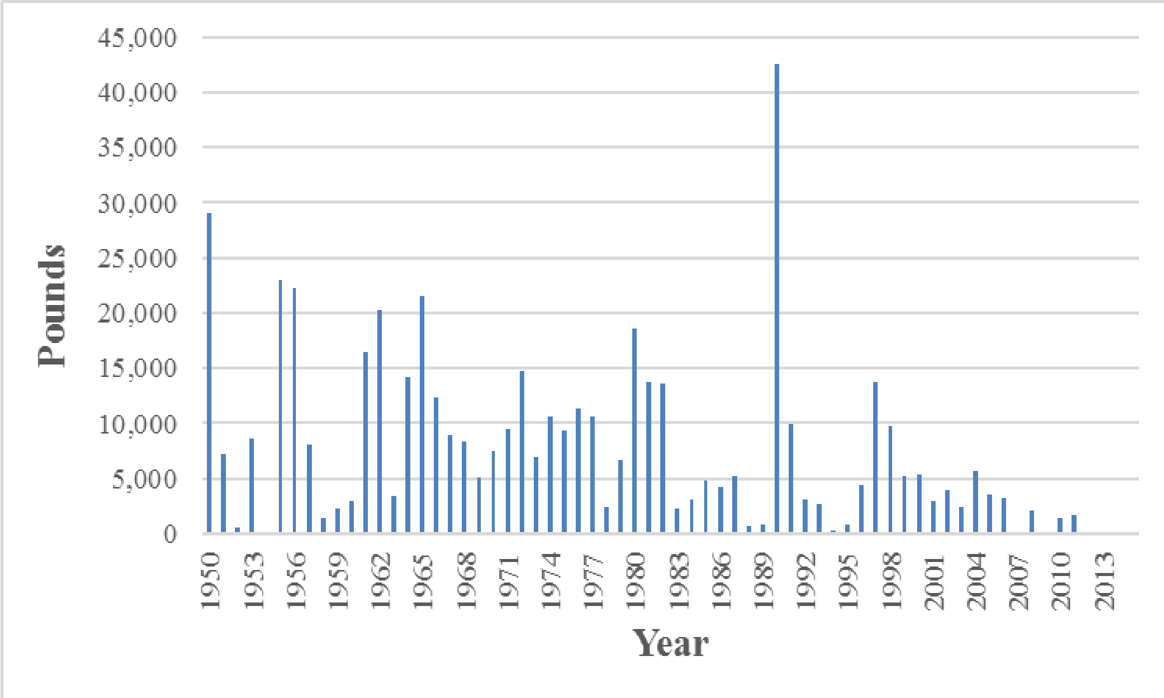

Figure 12.5 New Jersey Reported Commercial Landings (1950-2015). Source: NJ DFW

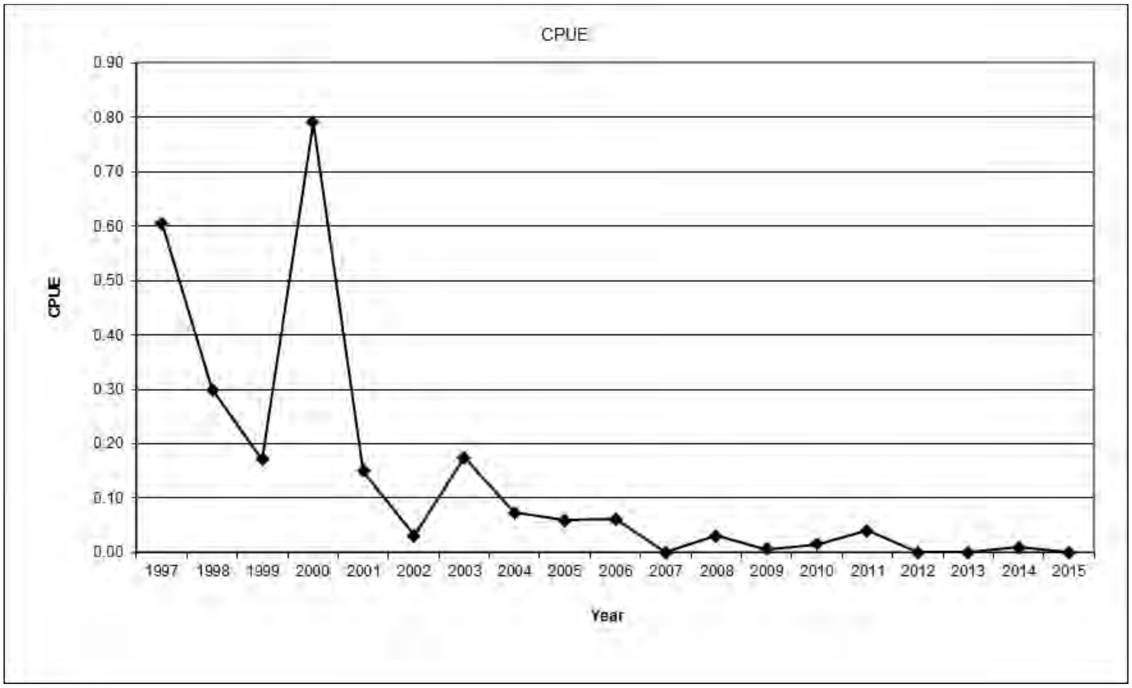

Figure 12.6 New Jersey Commercial CPUE for lower Delaware Bay (1997-2015). Harvest is bycatch in small mesh weakfish/perch fisheries during February to May. Source: NJ DFW

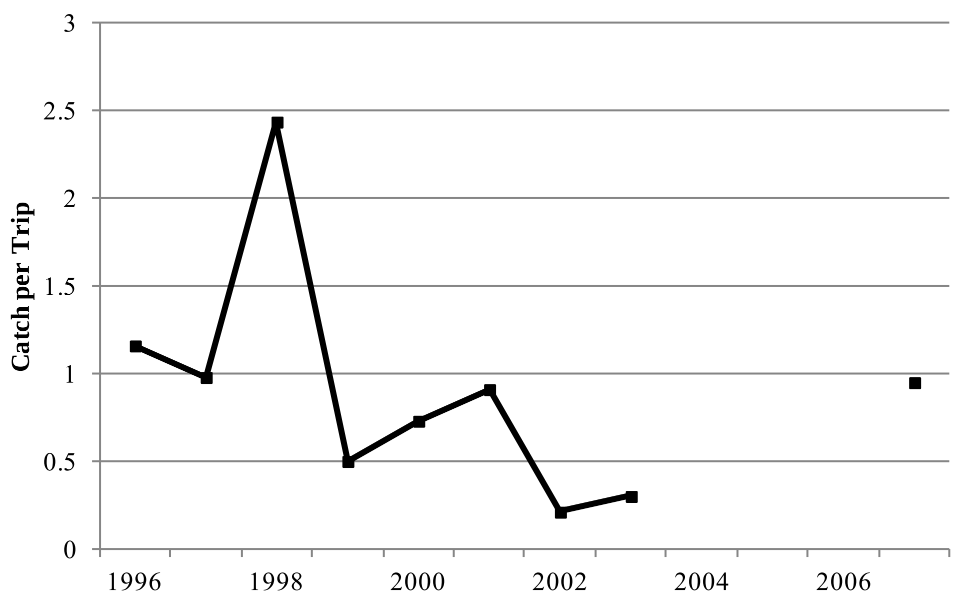

Figure 12.7 The recreational gill net fishery annual catch per trip for river herring in Delaware (1996 – 2003 and 2007). Source: DE DFW

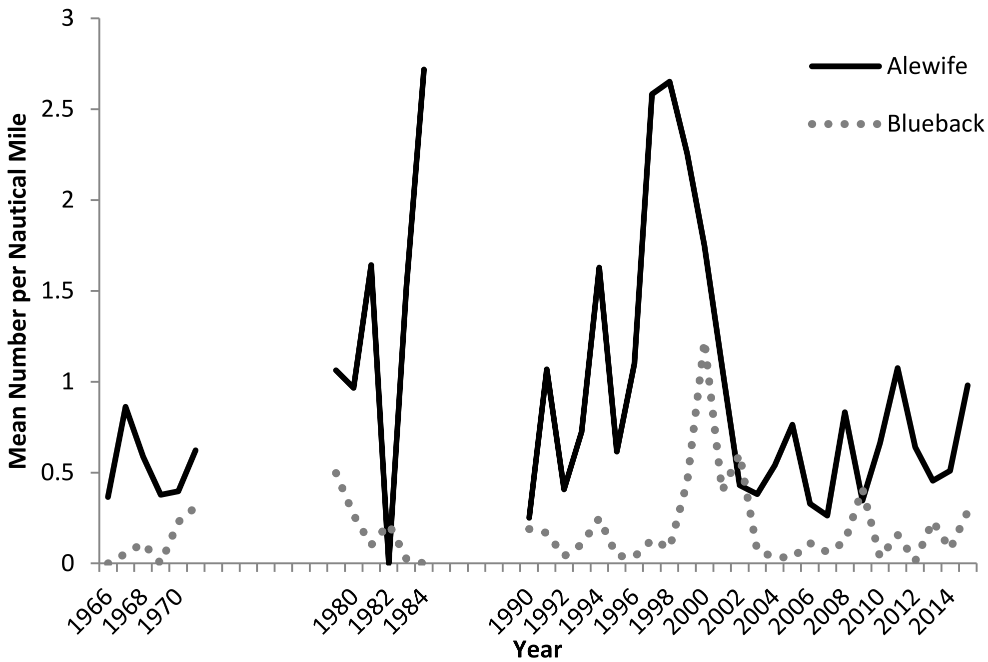

Figure 12.8 Adult River Herring indices for the Delaware Bay 30 foot trawl: 1966 – 2015. There is no data for 1972-1978 and 1985-1989. Source: DE DFW.

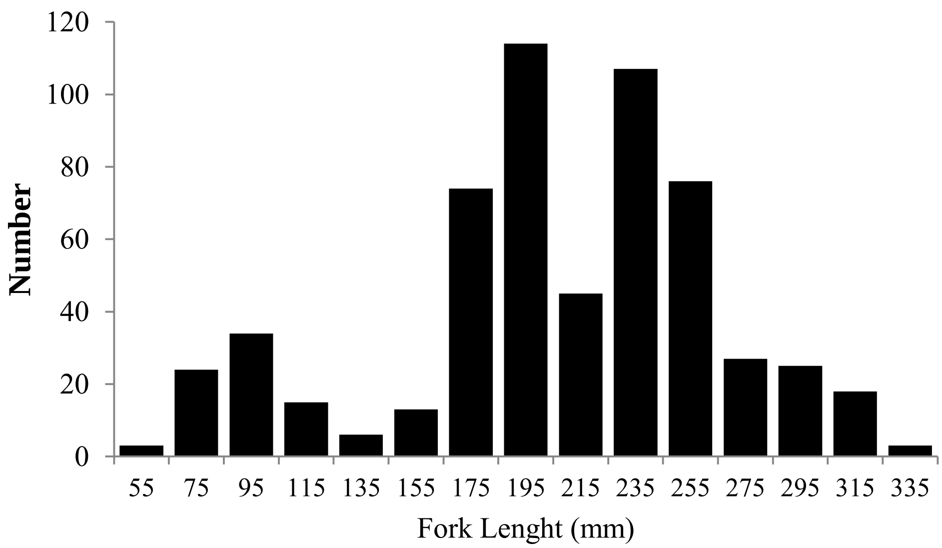

Figure 12.9 Adult Blueback Herring length frequencies for the Delaware River/Bay 30 foot trawl: 1966 – 2015. There was no data for 1972-1978 and 1985-1989. Source: DE DFW.

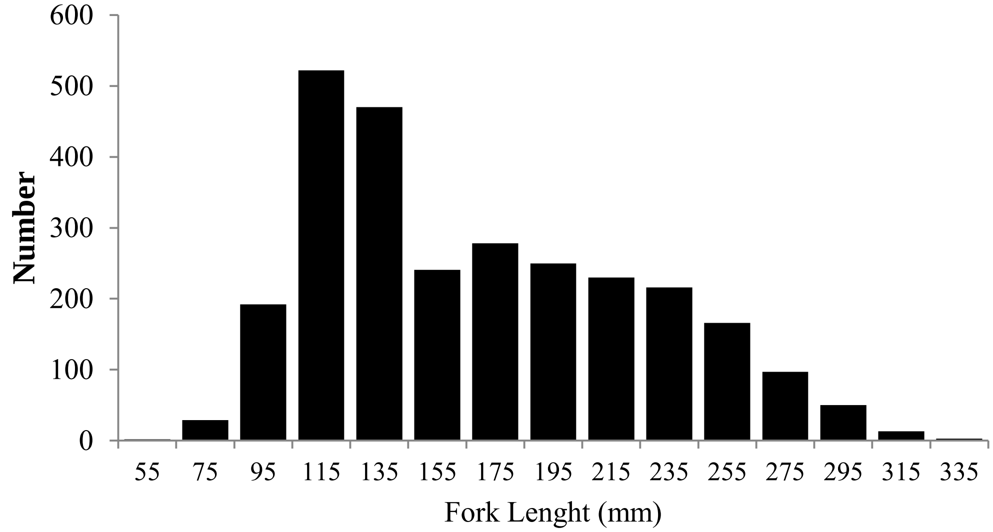

Figure 12.10 Adult Alewife length frequencies for the Delaware River/Bay 30 foot trawl: 1966 – 2015. There was no data for 1972-1978 and 1985-1989. Source: DE DFW.

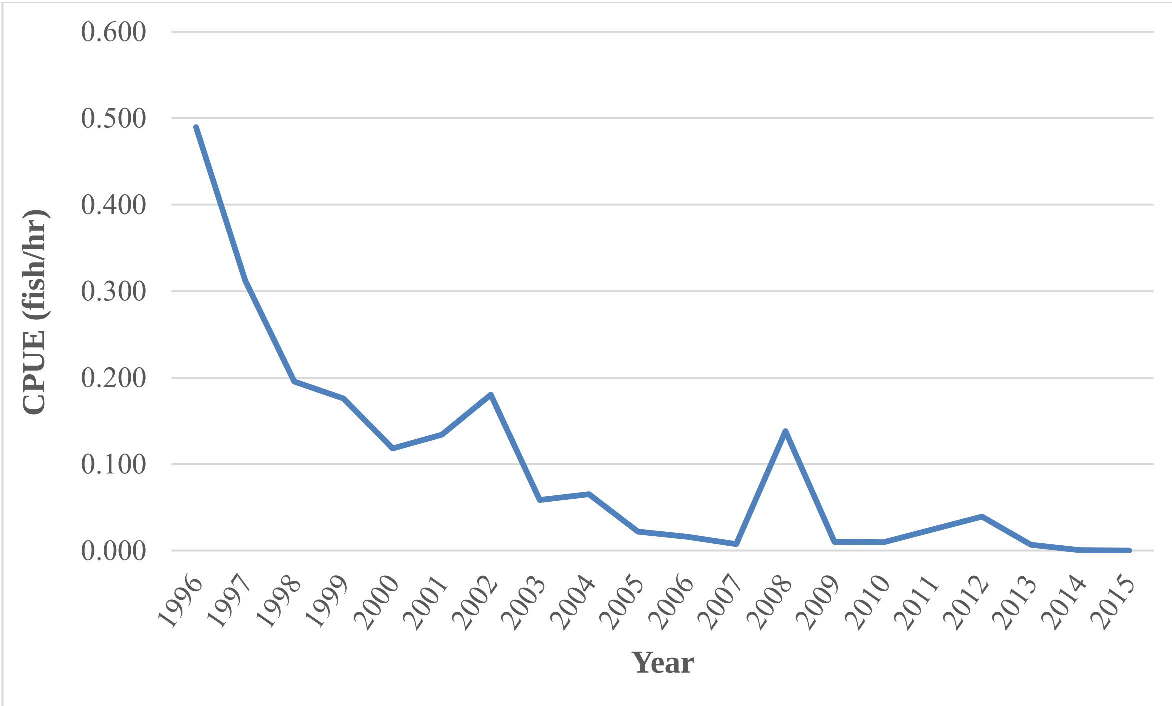

Figure 12.11 PSEG blueback herring fish passage CPUE (fish per hour) for Delaware and New Jersey Ponds. Source: NJ DFW.

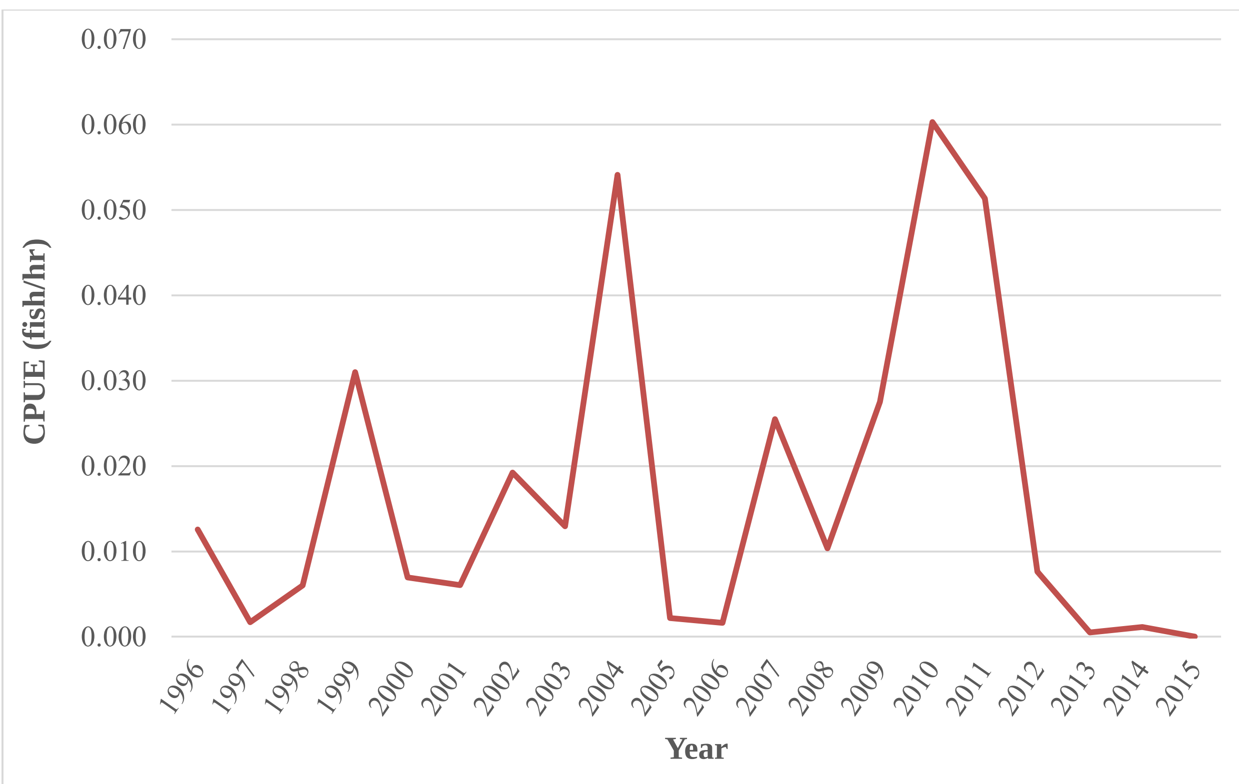

Figure 12.12 PSEG alewife fish passage CPUE (fish per hour) for Delaware and New Jersey Ponds. Source: DE DFW.

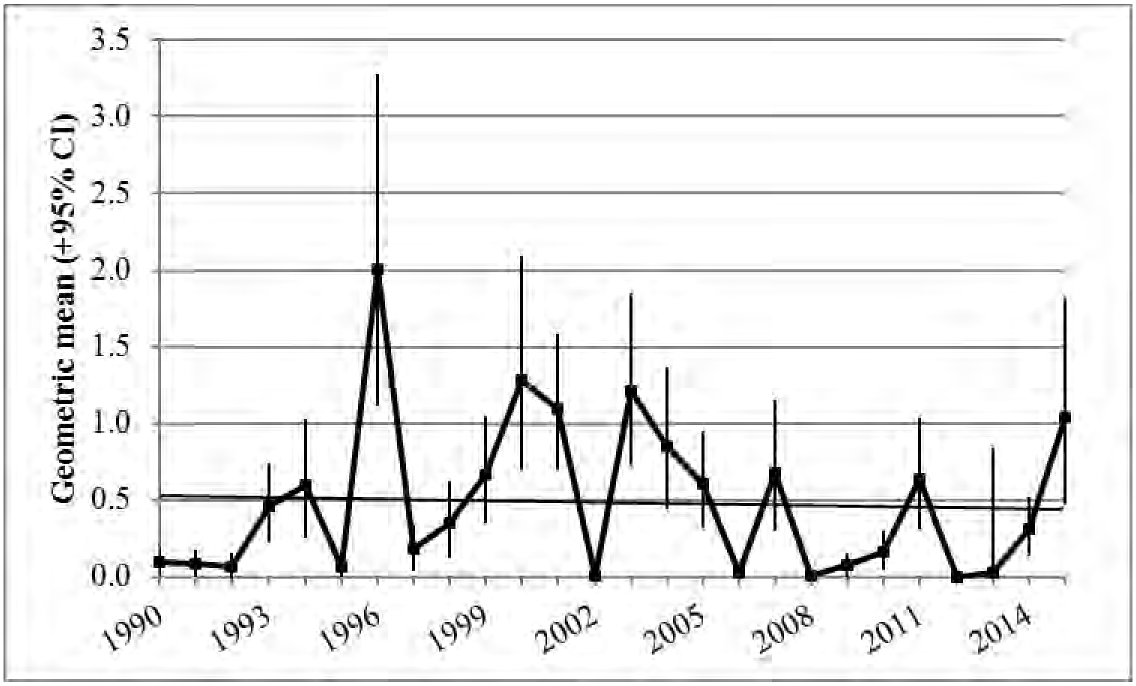

Figure 12.13. Annual YOY alewife relative abundance index (geometric mean catch per tow) and trend from the 16 foot otter trawl survey in the Delaware Estuary. Source: DE DFW.

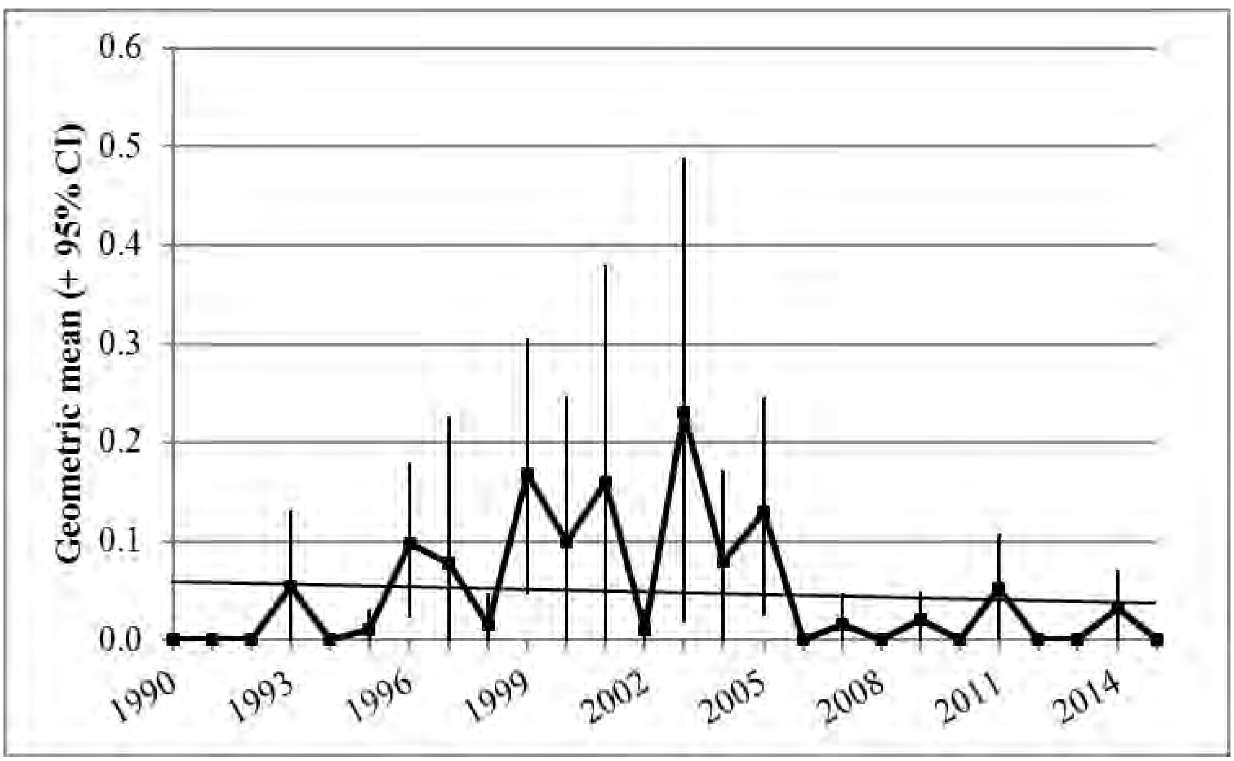

Figure 12.14 Annual YOY blueback herring relative abundance index (geometric mean catch per tow) and trend from the 16 foot otter trawl survey in the Delaware Estuary. Source: DE DFW.

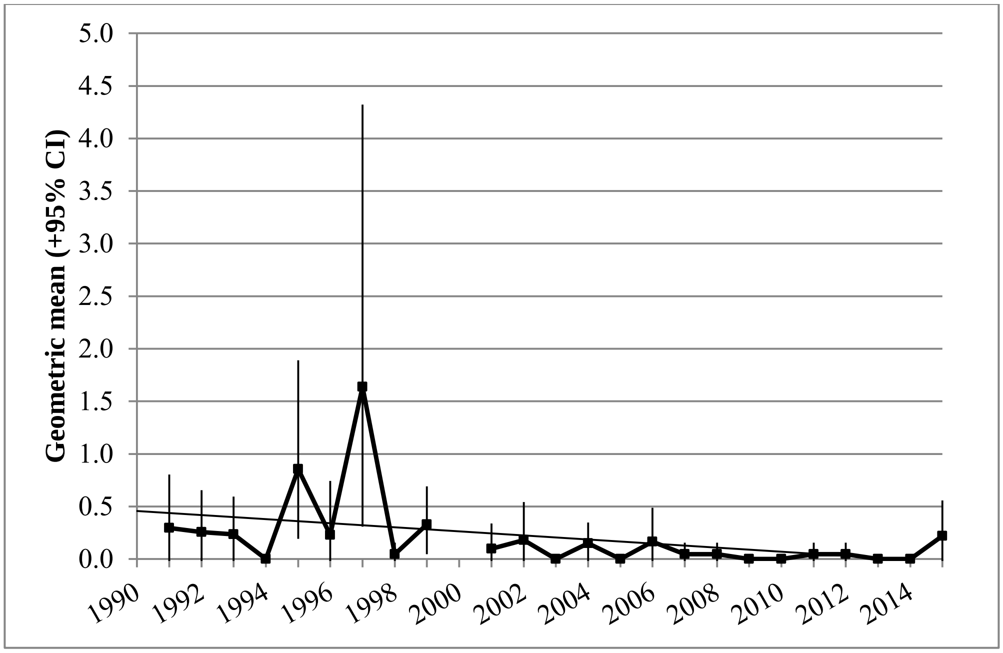

Figure 12.15 Annual Age 1 alewife relative abundance index (geometric mean catch per tow) from the 16-foot otter trawl survey in the Delaware Estuary. The 2000 age 1 annual abundance estimate was not available due to sampling missed in April of that year. Source: DE DFW.

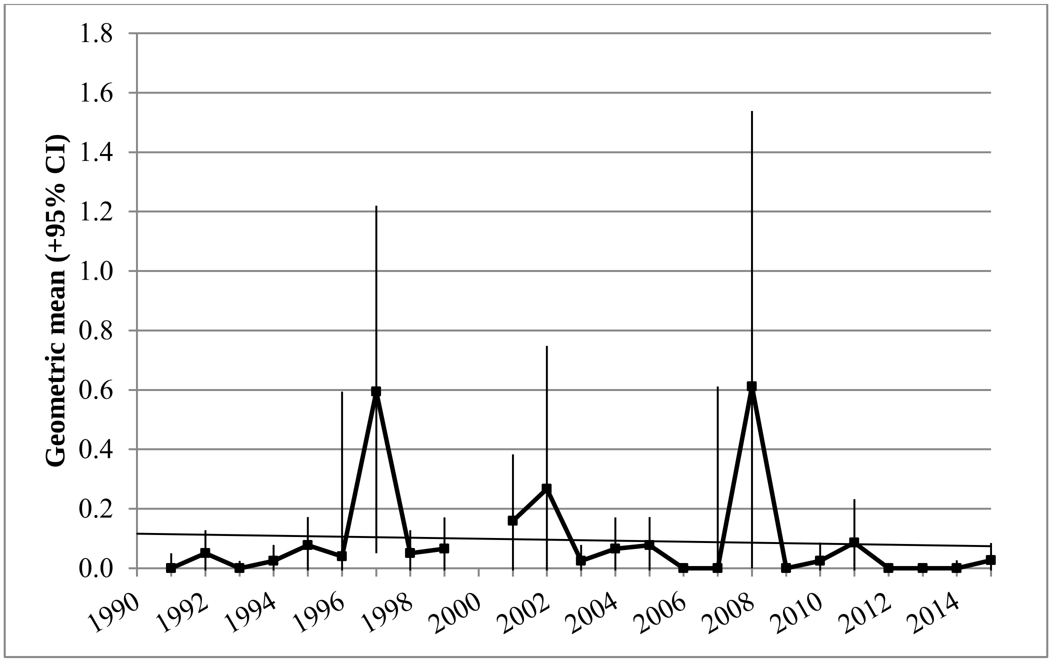

Figure 12.16 Annual age 1 blueback herring relative abundance indices (geometric mean catch per tow) from the 16 foot otter trawl survey in the Delaware Estuary. The 2000 age 1 annual abundance estimate was not available due to sampling missed in April of that year. Source: DE DFW.

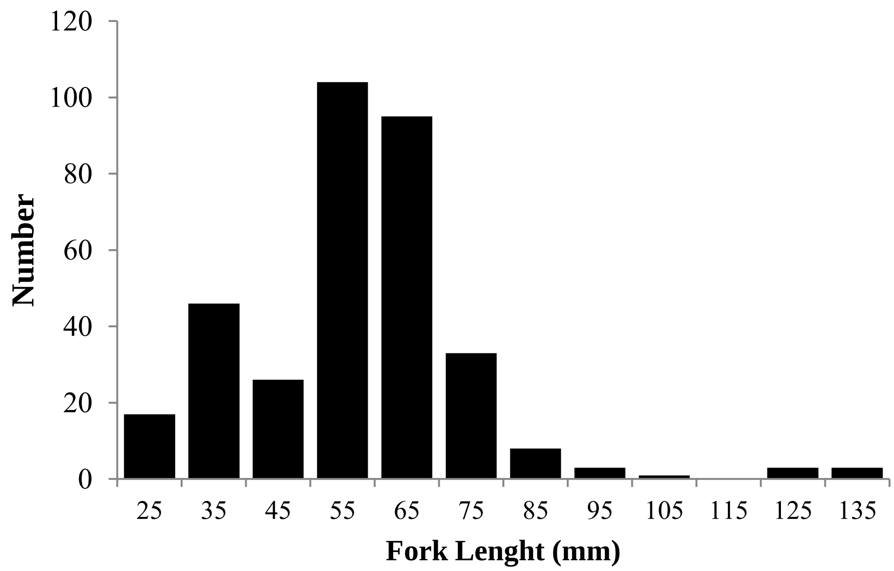

Figure 12.17 Delaware River length frequencies for YOY blueback herring collected during Delaware's 16 foot otter trawl survey in the Delaware Estuary from 1981-2015. Source: DE DFW.

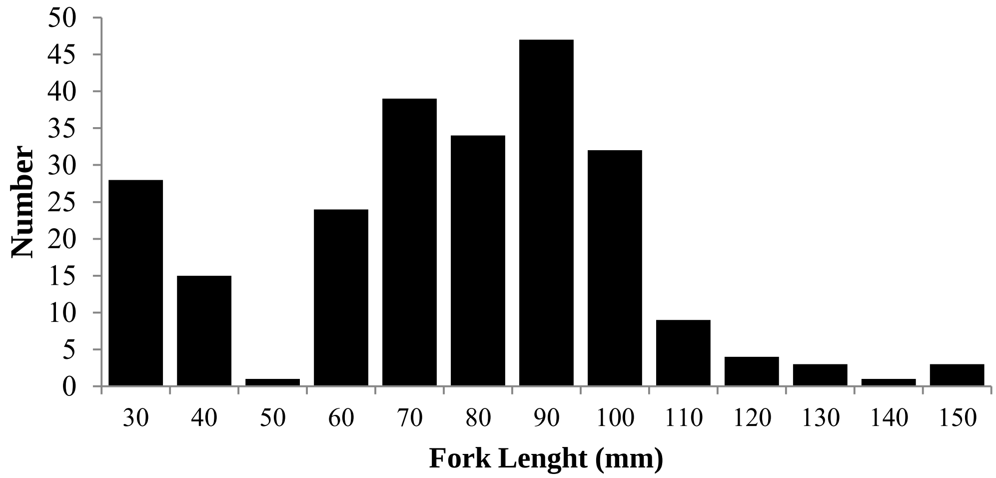

Figure 12.18 Delaware River length frequencies for Age 1 blueback herring collected during Delaware's 16 foot trawl survey in the Delaware Estuary from 1981-2015. Source: DE DFW.

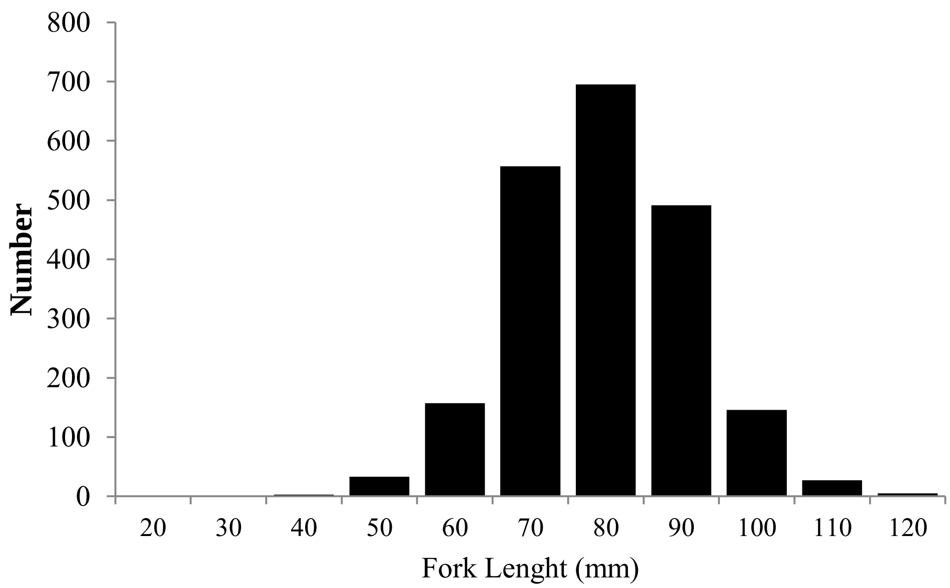

Figure 12.19 Delaware River length frequencies for YOY alewife collected during Delaware's 16 foot trawl survey in the Delaware Estuary from 1981-2015. Source: DE DFW.

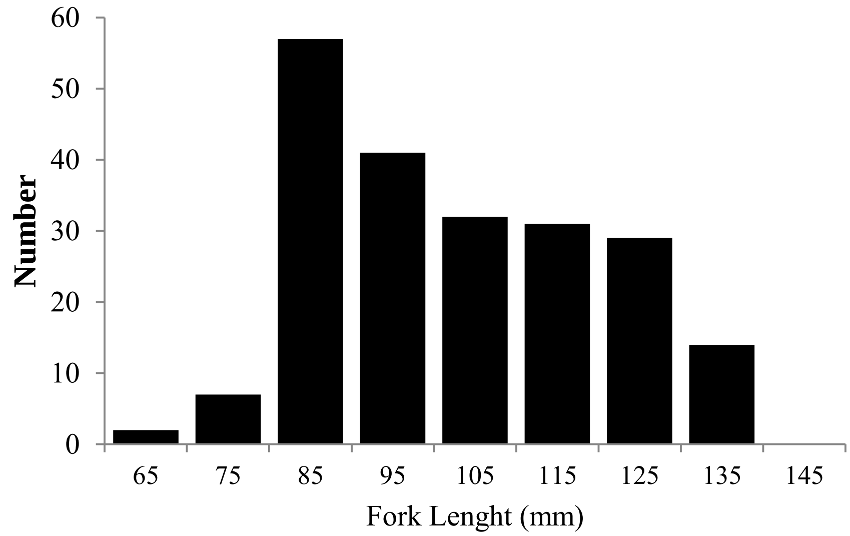

Figure 12.20 Delaware River length frequencies for Age 1 alewife collected during Delaware's 16 foot trawl survey in the Delaware Estuary from 1981-2015. Source: DE DFW.

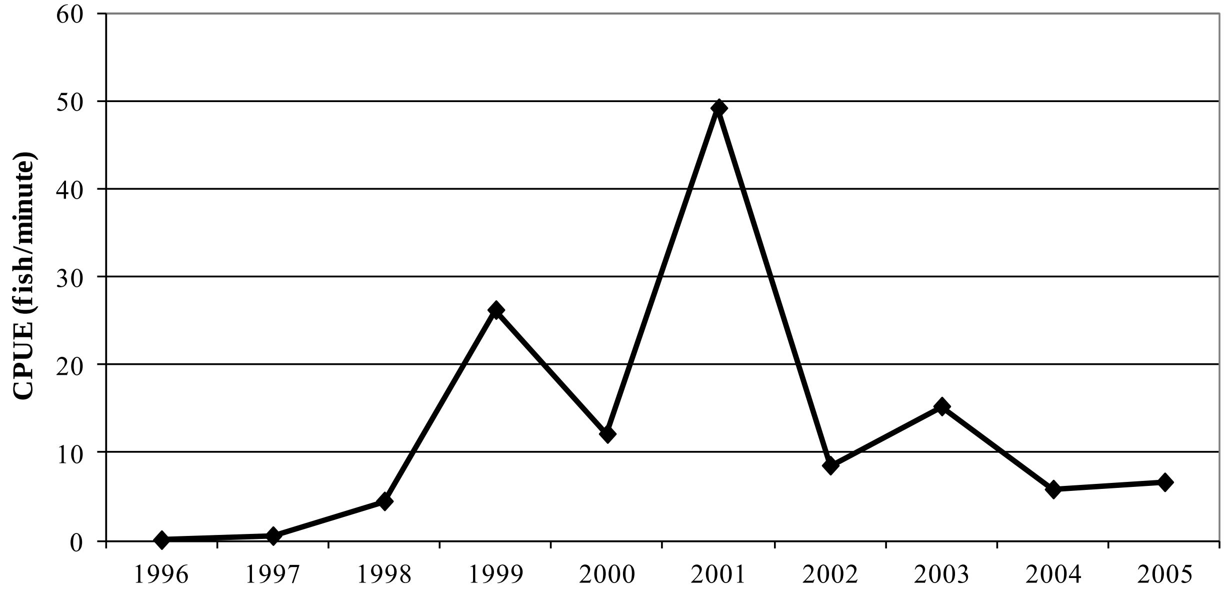

Figure 12.21 PSEG blueback herring electrofishing CPUE for Delaware and New Jersey Ponds (1996 – 2005). Discontinued after 2005. Source: NJ DFW.

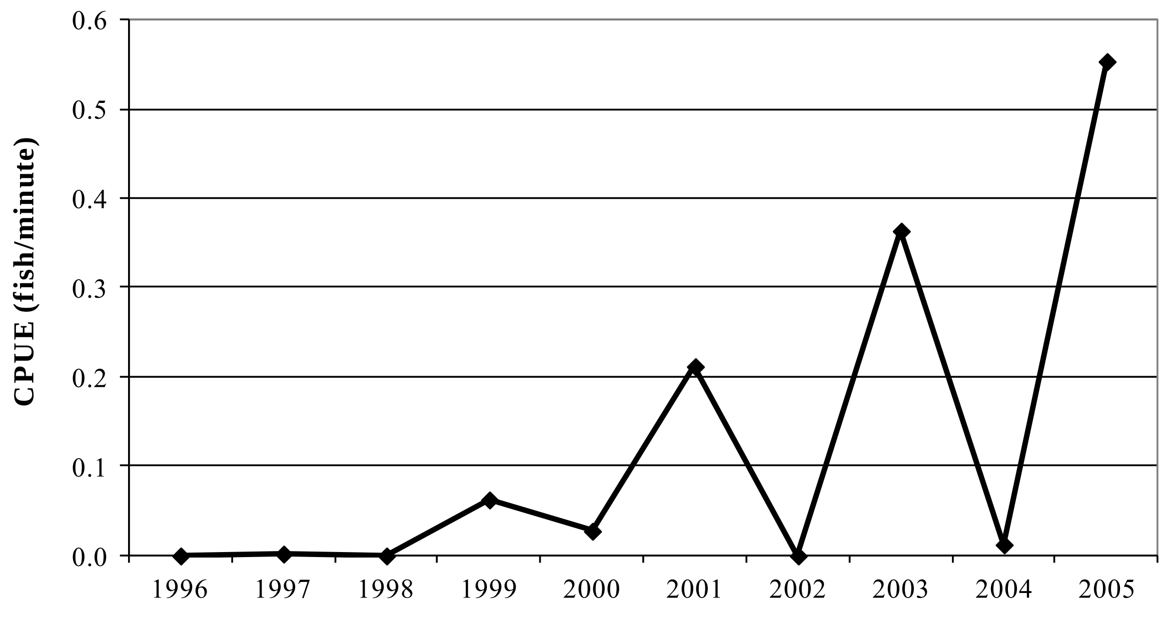

Figure 12.22 PSEG alewife electrofishing CPUE for Delaware and New Jersey Ponds (1996 – 2005). Discontinued after 2005. Source: NJ DFW.

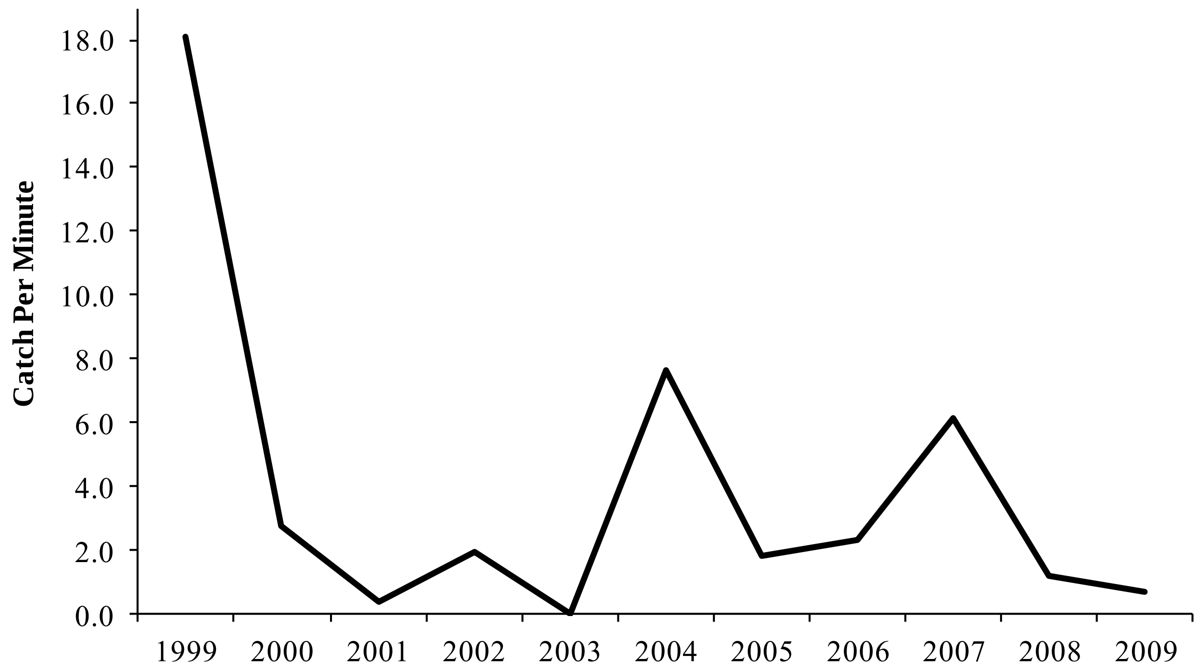

Figure 12.23 Overall CPUE (catch per minute) of YOY river herring collected during electrofishing at seven Delaware impoundments equipped with Alaskan Steeppass fish ladders, 1999-2009. Each pond was not sampled annually. These values reflect an aggregate CPUE calculated from those ponds sampled during that specific year. Source: DE DFW.

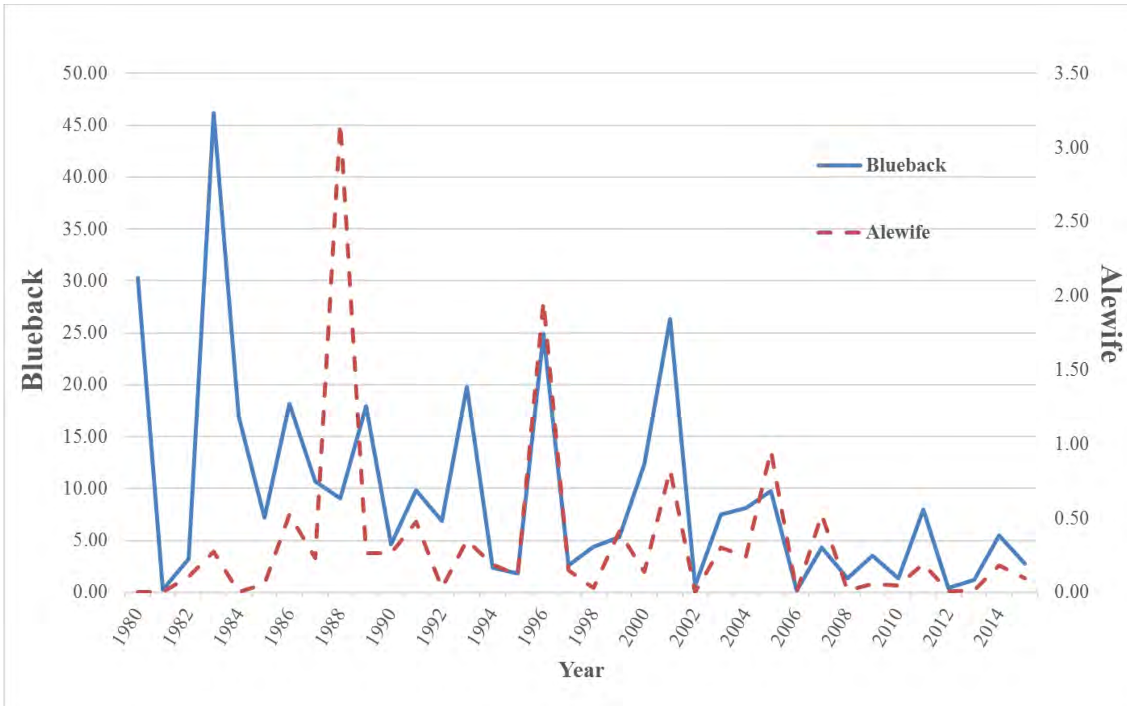

Figure 12.24 Delaware River index of relative abundance, geometric mean, for juvenile river herring collected during New Jersey's striped bass young of year survey (1980-2015). Source: NJ DFW.

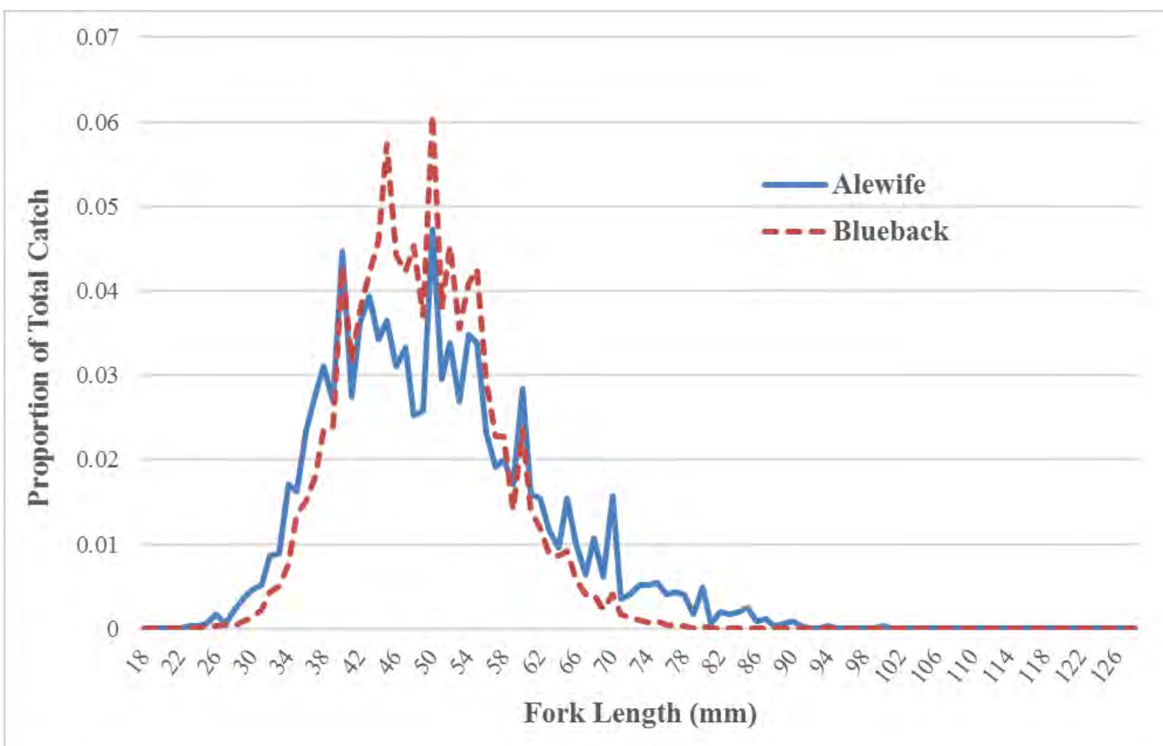

Figure 12.25 Delaware River juvenile river herring (alewife and blueback herring) length frequency (proportion at length) collected during New Jersey's striped bass young of year survey (2000-2015). Source: NJ DFW.

13 Status of River Herring in Maryland and the Upper Chesapeake Bay

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13.1. INTRODUCTION

Alewife and blueback herring are synonymous with the term river herring. Both species historically occur in significant numbers in the Chesapeake Bay with pre-spawn alewife herring appearing in the tributaries during late February followed by blueback herring in April. Evidence suggests that Native Americans depended partially on fish for food and caught shad and herring in large quantities long before European colonists arrived in North America (Meehan, 1897; Gay, 1892). Herring were likely caught for subsistence since colonial days, Radoff (1971) noted that herring were first exported from Maryland in 1753 but the fishery was more local and seasonal because salt was limited.

Documented landings from Maryland's portion of the Chesapeake Bay and tributaries date back to the 1800's. This serves as one of the best sources of data for river herring in the Upper Chesapeake Bay. Commercial landings are also available from Delaware's portion of the Nanticoke River. The fishery in this area was an important local resource for commercial fishermen in the past. The commercial and recreational fisheries in the Upper Chesapeake Bay were closed in 2012.

13.2. Management unit definition

In general, since most river herring in the Chesapeake Bay will return to their natal rivers to spawn, each river is considered a separate stock. The Maryland portion of the Chesapeake Bay begins at the Virginia line, at the mouth of the Pocomoke River, and continues north, ending at the Susquehanna Flats.

While distinct geographic areas divide the Chesapeake Bay into two or three zones, the divisions were not consistent in the literature. The Upper Chesapeake Bay area designated for this assessment is defined as the area from the Susquehanna River to the Nanticoke River and analyzes data from Maryland, Pennsylvania and Delaware. The management authorities in the Upper Chesapeake Bay include the Maryland Department of Natural Resources (MD DNR), the Delaware Division of Fish and Wildlife (DFW) and the Pennsylvania Fish and Boat Commission (PFBC).

There are a few minor tributaries of the Bay on Maryland's western shore that have small runs of river herring, but the two major Chesapeake Bay tributaries in the Upper Chesapeake are the Susquehanna and Nanticoke Rivers. The Susquehanna River watershed is located in Maryland, Pennsylvania and New York; however the New York portion will not be discussed in this report because river herring cannot access this portion. The Nanticoke River watershed originates in southwest Delaware and flows through Maryland before emptying into the Chesapeake Bay along Maryland's eastern shore. In addition to the mainstem of the Nanticoke River, herring runs primarily occur in Deep Creek and Broad Creek, two main tributaries to the Nanticoke River in Delaware.

13.3. Regulatory History

Since the Upper Chesapeake Bay is under the jurisdiction of four separate states, there have been differing regulations pertaining to river herring within the Bay. As of January 1, 2012 landings of river herring in systems without an approved sustainable fisheries management plan are prohibited. These regulations are in compliance with the Atlantic States Marine Fisheries Commission Amendment 2 to the Fisheries Management Plan for Shad and River herring (2009). Regulations below may apply state-wide unless otherwise noted.

13.3.1. Commercial

Maryland

Maryland's commercial river herring fishery historically has been seasonally restricted, closed from June 5th to Jan 1st of the next year. Since migrations occur in the spring, this law has little, if any, management consequences. Up until 2005, it was primarily a directed fishery using drift gill nets with meshes ranging from 3 ⅛ to 3 ¼ inches. A limited pound and fyke net bycatch fishery also existed. After 2005, the directed fishery reported few fish and little effort, and many commercial gill netters no longer targeted river herring. A directed commercial river herring fishery developed in 2006 in a select Chesapeake Bay tributary (based on landing records) and was the result of new spring regulations allowing river herring as live bait to target striped bass in the upper Chesapeake Bay. There were no state limits on total river herring catch or the amount of gear utilized. Individual rivers may have distinct gill net area restrictions. As of January 1, 2012 possession of river herring is prohibited in Maryland.

Delaware

No specific regulations were ever adopted to reduce or restrict commercial landings of river herring, however there are regulations that applied to the commercial fishery that limited commercial fishing effort and have a direct impact on catch and effort. In Delaware, these restrictions include a limited entry license system, limitations on the amount of gear allowed to be fished, and season and area closures. Examples include:

8. Drift nets are prohibited from Saturday through 1600 hours Sunday.
9. No fixed gill nets from January 1 through May 31, and not more than 200 feet of net from June through September in the Delaware River.
10. No fixed gill nets from May 10 through September 30 in Delaware Bay.
11. The use of any type of net within 300 feet of any dam is prohibited on any tributary.
12. The striped bass spawning grounds which include the Nanticoke , Delaware River and C&D Canal are closed to all gill nets from April 1 to May 31

Additionally, since 1985, every fisherman holding a commercial food-fishing license was required to submit a monthly report specifying where he fished, the type and amount of fishing gear deployed, and the pounds landed of each species taken for each day fished. Those herring that were landed were typically frozen for bait, pickled, kept for their roe and other traditional uses. As of January 1, 2012 possession of river herring are prohibited in Delaware.

Pennsylvania

Harvest of river herring is prohibited in Pennsylvania waters of the Susquehanna River.

13.3.2. Recreational

Maryland

Maryland's recreational river herring fishery historically was seasonally restricted, closed from June 5th to Jan 1st of the next year. There were no size or creel limits on river herring. Maryland has no recreational landings data. Limited data indicated that catches were minimal but there may be small incidental catches of river herring used for striped bass bait that are not documented. Historically, anglers used dip nets to catch river herring and very few herring were caught by hook and line, usually when fishing for other species. Dip nets may not be used within 50 yards of the mouth of any river or tributary or the base of a dam and may not be used in any waters of the state stocked with trout. In non-tidal waters an individual can only use hook and line to take herring. Dip nets may not be used in the Susquehanna River upstream of Deer Creek. Nets, other than a landing net, cannot be used in Deer Creek. As of January 1, 2012 the recreational fishery was closed.

Delaware

The recreational fishery in Delaware often occurred at the various low-head dams that form mill ponds on the many of Delaware's tidal rivers where herring concentrated during the spring spawning season. Recreational fishermen used hook and line and t lift nets (umbrella nets) or dip nets during the peak of the run to catch herring. Prior to 2005, no recreational limit for river herring existed in the State of Delaware. Anecdotal reports indicated the catch and effort for river herring has increasing as striped bass stocks rebounded and the popularity of using live river herring for bait escalated. In an effort to prevent over exploitation of these small herring runs, a 25-fish limit was adopted in 2005. The popularity of this fishery continued to increase and consequently a 10-fish possession limit was adopted in spring of 2008 to help conserve remaining spawning stocks and to prevent "stock-piling" in net pens or live cars. In addition during 2008, Delaware's General Assembly approved legislation that prohibits the use of any net by any fisherman within 300 feet of any dam on any tidal tributary. The 10-fish possession limit and the prohibited use of any net immediately below any dam greatly reduce both catch and effort by forcing recreational fishermen to use only hook and line and to limit landings to the possession limit. As of January 1, 2012 the recreational fishery was closed.

Pennsylvania

> ***There has been no sport fishery for river herring in Pennsylvania waters of the Susquehanna River since the 1920's when the Conowingo Dam was built. As of January 1, 2012 the recreational fishery was closed.***

13.4. Assessment History

River herring assessments in Maryland waters have been conducted sporadically during the last fifty years, and were generally regionally specific. The most comprehensive collection of data by Mowrer et al (1984) summarized river-specific data and stock status of river herring. This study concluded that:

- Commercial landings had declined since the 1930's and was due to exploitation
- Recreational river herring fishery in the 1980s was less than 1% of the reported commercial landings
- Stock levels were at historically low levels

Mowrer et al (1984) also provided a 1980 population estimate of 57,628 blueback herring in the Susquehanna River. In the Choptank River, a tributary of the Chesapeake Bay on the Delmarva Peninsula, he estimated river herring (species combined) abundance of 570,543 in 1972 and 305,794 in 1973 (Speir et al. 2008). Ogburn et al. (2016) estimated run counts of alewife and blueback herring in the Choptank River using DIDSON technology paired with weekly electrofishing. This study, which occurred just upstream of where abundance was estimated in 1972 and 1973, estimated the run count in 2014 of alewife herring at 581,275 ± 31,970 and 726,450 ± 39,955 for blueback herring.

The Nanticoke River was included in the 1990 ASMFC coastwide stock assessments of river herring from selected Atlantic coast rivers (ASMFC 1990). Nanticoke River alewife were not overfished ($u < u_{msy}$) but have experienced a stock decline in recent years. The current or historical u values for Nanticoke alewife were within 75% of the u_{msy} levels, and therefore were considered by the criteria to be fully exploited. Abundance from these river herring stocks has exhibited a significant decline in recent years. The Nanticoke River blueback herring were considered to be partially exploited, since the current and historical fishing rates for these stocks were less than 75% of the river-specific u_{msy} levels.

Of the 15 river herring stocks examined in the 2012 ASMFC coastwide stock assessment, nine stocks were judged by the criteria to be either overfished ($u > u_{msy}$) or severely depleted (ASMFC 2012). These overfished stocks were confined to the northern and mid-southern end of the geographic range for river herring and included the Nanticoke stock of alewife. There are substantial weir fisheries on the river herring stocks within the north and south, whereas river herring from mid-southern rivers, such as the Nanticoke, were harvested primarily by pound nets that were set in or just outside these river systems (ASMFC 1985).

13.5. Stock-specific life history

Alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) are anadromous clupeids and members of the herring family which include the two shad species. These two species collectively known as river herring, mature between two and five years of age in the Chesapeake Bay, and peak catch-at-age is from four to six years. Some fish may return to spawn for four consecutive years (repeat spawning; Sadzinski and Jarzynski. 2007). Hatching occurs one week after fertilization. Young-of-the-year begin leaving the Chesapeake Bay in late fall. Juveniles remain in the ocean until sexual maturity, most returning to their natal rivers to spawn. There appears to be annual overwintering of both species of herring in the Chesapeake (Dovel 1971 and Carter 1973).

13.5.1. Growth

Dovel (1971) estimated young-of-the-year growth rates for blueback herring at six months old to be 65.0 mm total length (TL) with an estimated hatching date of 15 April. One-year old TL was estimated to be 80.0 mm. Preliminary review of the literature has not revealed adult river herring growth studies in the Chesapeake Bay.

Mowrer et. al 1980 also estimated young-of-the-year growth from beach seine samples and noted the larger size of alewife as compared to blueback herring; however both species were comparable in length by September. Their growth curves quickly flattened, indicating outward migration of larger fish.

13.5.2. Maturity Schedule

Using Speir and Mowrer’s (1987) maturity schedule calculation, 84% of male alewife and 100% of male blueback herring were mature by age 4 in 2010. The percentages of female alewife and blueback herring mature by age 4 in 2010 were 66% and 93%, respectively.

13.5.3. Natural Reproduction

Dovel (1971) collected egg and larval fish throughout the Chesapeake Bay in the late 1960’s and early 1970’s and noted significant numbers of Alosa species in his samples, including river herring.

O’Dell et al (1984) surveyed anadromous fish species in Maryland streams from 1979-1982. They concluded that river herring successfully spawned in each major river system through the capture of pre-spawned adults and later by fertilized eggs or larval fish. Natural reproduction of river herring did occur in all major tributaries and likely still occurs in every major river system.

13.6. Habitat Descriptions

Carter et. al (1982) surveyed more than 700 streams in Maryland from 1970 to 1980 and documented anadromous species in 323 of these streams. The report defines spawning and nursery areas by river system and is species specific. Natural or man-made barriers to migration were also noted. Based on his data and juvenile indices, river herring were a prolific species in Maryland tributaries and spawning and nursery habitat was not limiting.

The first major hydroelectric plant on the Susquehanna River was constructed at York Haven, PA (river km 90) in 1904. In 1910, Holtwood Dam (river km 39) was built with two fishways that were later shown to be ineffective. Commercial fishing continued below Holtwood until 1924 (Kotkas and Robbins 1977) but soon disappeared because of the absence of American shad. Conowingo Dam (river km 16) was constructed in 1928 and Safe Harbor Dam (river km 52) was completed in 1931. These dams permanently cut off river herring from their historical spawning areas in the Susquehanna River until 1972 when the Conowingo Dam was retrofitted with a fish elevator and fish were trucked above the upper most mainstream dam.

The Nanticoke River is a major tributary of the Chesapeake Bay. It begins in Delaware and flows 64 miles, including 37 miles through Maryland, before emptying into the Bay. It is a free-flowing river originating near Greenwood, Delaware. Delaware Division of Fish and Wildlife staff reported river herring caught by recreational anglers as far upstream as Bridgeville, Delaware. River herring spawn within two primary tributaries that flow into the Nanticoke River within Delaware boundaries as well. Deep Creek begins at the dam below Concord Pond and flows into the Nanticoke proper at Seaford, DE. Broad Creek extends from the dam below Records Pond in Laurel, DE and flows into the mainstem of the Nanticoke just upstream of the Maryland state line. Although the dams on Deep Creek and Broad Creek inhibit upstream passage, there is sufficient spawning habitat below the structures to maintain a stable run. Smaller tributaries, many of which are tidal freshwater, also contribute to the total amount of spawning and rearing habitat available. These tributaries include Marshyhope Creek and Barren Creek on the Maryland side.

13.7. Restoration Programs

There are no dedicated restoration programs for river herring in the Upper Chesapeake Bay. There has been some experimental stocking in select rivers, but numbers of larval fish stocked (less than 500,000) were likely not significant enough to impact the stock and stocking was not consistent over time. Stocking was primarily done as mitigation for construction projects and to evaluate fish passage effectiveness. No evaluation of stocked fish survival or how the stocking contributed to populations was conducted. Adult river herring were captured from the west fish lift at Conowingo Dam, transported upstream and stocked in Pennsylvania waters during 1990 to 2001.

As part of the Chesapeake 2000 Agreement, several fish passage commitments were developed that are important for anadromous fish, especially shad and river herring. The commitments include: 1) identify the final initiatives necessary to achieve the existing goal of restoring fish passage to more than 1,357 miles of currently blocked river habitat and establish a monitoring program to assess outcomes; 2) set a new goal with implementation schedules for additional migratory and resident fish passages; 3) determine tributary-specific target population sizes; and, 4) revise fish management plans. The fish passage goal was met at the end of 2004 with approximately 1,400 miles of habitat reopened for anadromous fish. A new goal was established in 2005. To date, MDNR's Fish Passage Program has completed 79 projects, reopening a total 457 miles of upstream spawning habitat in Maryland since 2005. The current goal is to expand to 3,500 miles (Bay wide) by 2025. MD DNR Fish Passage is making progress towards the removal of Bloede Dam on the Patapsco River. An ecosystem-based management plan for alosines was developed and includes population and habitat strategies.

On the Susquehanna River, the Policy Committee of the Susquehanna River Anadromous Fish Restoration Cooperative (SRAFRC) approved an "Alosine Management and Restoration Plan for the Susquehanna River Basin" in 2010. The restoration goal is:

> *"By 2025, produce self-sustaining annual populations of 2 million American shad and 5 million river herring, reproducing in the free-flowing Susquehanna River above York Haven Dam, and in suitable tributaries, and provide 500,000 angling days annually throughout the Basin for these species."*

13.7.1. Upstream Fish Passage Efficiency

Fishway counts at the four dams along the Susquehanna River (from south to north: Conowingo (MD), Holtwood (PA), Safe Harbor (PA) and York Haven (PA)) are provided in Tables 13.1 and 13.2. River herring passage was episodic prior to 2002 and has plummeted since then. The fish lifts at Conowingo, the lower most dam, target operation and attraction flow for American shad passage, which likely excludes river herring. Operation of these lifts begins in April annually, and therefore misses the peak of the alewife run in most years.

Few river herring have passed upstream of Holtwood Dam except in 2000 and 2001 when river herring were transported to the Conestoga River, a tributary of the Susquehanna River. The transported river herring left the Conestoga River and moved up the mainstem Susquehanna River and were observed at the Safe Harbor Dam. In 2001, transports to the Conestoga River included 2,983 blueback herring in 2000 and 4,200 blueback herring and 1,820 alewives. Other reports of alewife upstream of Holtwood Dam are largely attributed to movement of individuals from landlocked populations in several lakes in the drainage. Transport of river herring above Holtwood Dam ceased in 2001, when the East Fish Lift at Conowingo Dam became an automated flow through system.

The operating license for Conowingo Dam expired in 2014. Exelon Generation, LLC has been operating the dam under a temporary license while a new is being reviewed by the Federal Energy Regulatory Commission (FERC), resource agencies for Maryland and Pennsylvania and US Fish and Wildlife Service.

The US Fish and Wildlife Service and Exelon Generation, LLC signed a settlement agreement in April 2016 which will allow for adaptive management and fish passage improvements geared towards migratory fish restoration at Conowingo Dam (over the term of its next FERC Operating License). Initial improvements will encompass: enhanced attraction flows for the East Fish Lift, reduction in fish lift cycle time and added capacity; tailrace modifications (zone of passage) for

river herring; a Trap and Transport program to move adult shad and river herring from below Conowingo to above York Haven Dam; fish passage efficiency target of 85% substantiated through radio telemetry monitoring every five years through the term of the FERC operating license; along with other operational and structural modifications should performance targets not be met.

Fish passage improvements at the Holtwood Hydroelectric Station (i.e. construction of zones of passage in the tailrace and spillway, dedicated attraction water flow to spillway, increased attraction flow and replacement of flashboards with Obermeyer crest gates) were near completion prior to the 2015 spring passage season. The 401 Water Quality Certification at the York Haven Hydroelectric Project, requires the construction of a nature-like fishway along the main dam to be constructed by 2021. The planning and design phases of the nature-like fishway were well underway in 2015, with several pre-permit application meetings being held.

Smaller fish ladders have been installed on a number of dams throughout the Upper Chesapeake Bay region allowing river herring to pass, but fish counts and efficiency have not been assessed for any of these structures.

13.8. Age

MD DNR has collected scale samples from river herring through fishery dependent sampling in the Nanticoke River since 1989 and the North East River since 2013. Scales were removed below the insertion of the dorsal fin. A minimum of four scales per fish were cleaned, mounted between two glass slides and read for age and spawning history using a Bell and Howell MT-609 microfiche reader. The scale edge was counted as a year-mark since it was assumed that each fish had completed a full year's growth at the time of capture. Annuli were identified using Cating’s (1953) method and the same reader aged river herring in Maryland from 1989 - 2010. Since 2010, two new readers began ageing river herring from Maryland one beginning in 2011, and the other in 2014. Following the recommendation from the “2013 River Herring Ageing Workshop” (ASMFC 2014), ages have been assigned to river herring utilizing the methods outlined in “Massachusetts Division of Marine Fisheries Age and Growth Laboratory: Fish Aging Protocols” (Elzey et al., 2015). The number of repeat spawning marks, defined as the freshwater spawning mark on the scale was recorded for each fish.

Since 2011, the PFBC and MD DNR, through their membership in the SRAFRC and contracts with the contractor responsible for operating the west fish lift and American Shad tank spawning operation at Conowingo Dam, requested that the first 50 river herring of each species be sampled for biological data collection (i.e. length, weight, scales and otoliths), annually. Additionally, one of every 25th additional river herring species collected will also be sacrificed for biological data collection. Age determinations of any collected river herring were made by the PFBC following the “Massachusetts Division of Marine Fisheries Age and Growth Laboratory: Fish Aging Protocols” (Elzey et al., 2015). However, the identification of repeat spawning marks were not identified due to the inexperienced nature of the scale reader

13.9. Fishery Descriptions

13.9.1. Commercial Fisheries

Prior to the 2012 stock assessment, river herring populations had declined to such low levels that most commercial fishermen were no longer targeting them, but instead caught them as bycatch while targeting white perch. Maryland enacted a moratorium on river herring that took effect January 1, 2012.

Maryland

Evidence suggests that Native Americans depended partially on fish for food and caught shad and herring in large quantities long before European colonists arrived in North America (Meehan, 1897; Gay, 1892). The earliest commercial fisheries were initiated in the late 1800s and with the introduction of the pound net into Maryland waters, herring catches likely peaked. During the 20th century, pound and fyke nets were extensively used to catch river herring. After the 1980's the fishery was in decline and it evolved more into a bycatch fishery. In addition, commercial fishermen could target river herring on their spawning grounds using small mesh gill nets. The commercial river herring landings for the Nanticoke River showed declines while the fishery was monitored from 1989-2011. The commercial fishery has been closed since January 1, 2012.

Delaware

Commercial Landings and Catch Rates

Since 1985, Delaware's commercial landings were determined annually from mandatory commercial catch reports. Landings occur from all of the broader regional areas of Delaware but the upper Nanticoke River has traditionally yielded the majority of landings and it also has the largest herring runs of any of the tidal streams in the state. In 2010, 84% of river herring landings reported in Delaware came from the Nanticoke. Commercial landings occurred from January through May with peak landings occurring in March. Both species are represented in the catch but the majority is probably blueback herring based on observations of relative abundance and temporal distributions within state waters. Additional sampling is not performed.

In Delaware's portion of the Nanticoke River the CPUE has been in decline since the mid 1990's and the lowest CPUE in the time series occurred in 2010 (Table 13.3). The effort data reflects days that fishermen actually landed river herring and does not account for days when the species was not landed.

13.9.2. Recreational Fisheries

Maryland

MD DNR has conducted a roving creel survey below Conowingo Dam on the Susquehanna River since 2001. In general, few anglers (less than one percent) target river herring in the spring because most anglers are targeting American or hickory shad and walleye. In most river systems, river herring are not targeted and are caught as bycatch.

Delaware

There are over 500 'recreational' gill net permits issued to Delaware fishermen statewide. Mostly commercial crabbers hold these permits which allow them to catch bait, primarily Atlantic menhaden. River herring were also reported as discards from this fishery but were highly variable ranging from 6 fish per year to over 1,000. From 1996 through 2003 annual total harvest estimates ranged from 4,400 fish in 1996 to 297 in 2002 (Table 13.4).

13.9.3. Subsistence Fisheries

Herring were likely caught for subsistence since colonial days Radoff (1971) noted that herring were first exported from Maryland in 1753 but the fishery was more local and seasonal because salt was limited. No additional information on subsistence fishing is available.

13.9.4. Bycatch losses

Bycatch losses were typically minimal because the commercial fisheries were allowed to harvest and land river herring. As of January 1, 2012 no landings of river herring are allowed in Maryland or Delaware. Currently, there are no means for reporting river herring bycatch in the Maryland reporting system.

<u>Bycatch Monitoring</u>

River herring are captured as bycatch primarily in the spring pound and fyke net commercial fishery targeting perch and catfish species. This fishery occurs in the Chesapeake Bay and various Maryland tributaries in the spring. Maryland was monitoring this fishery in the Nanticoke River prior to the moratorium on river herring, and following the moratorium has continued to sample river herring as bycatch from this fishery.

Alewife and blueback herring in Maryland's portion of the Nanticoke River were collected from commercial pound nets and fyke nets, and the number of nets and locations were fished at the discretion of the commercial watermen. These nets were generally sampled at least one to two times per week from early March to late April. Fish were sorted according to species and transferred to the survey boat for processing. Monitoring began in 1989, when it was still legal for commercial fishermen to harvest river herring, but has continued since the fishery closed as bycatch monitoring. In 2015, there was extensive ice coverage late into the spring on the Nanticoke River that prohibited commercial fishermen from setting their gear, therefore analyses utilizing data from this monitoring have a terminal year of 2014.

A minimum of ten alewife and ten blueback herring selected at random from unculled commercial catches were counted, sexed, fork length measured and scales removed for age analysis. The total number of herring harvested was estimated by multiplying the number of bushels harvested by the number of fish per bushel from sampled nets on that particular day or by direct counts.

Beginning in 2014, if random scale samples taken during the sampling season exceeded 300 samples per species, then a randomly chosen subset of 300 scales were aged. Ages where then assigned to the total catch using an age length key. This was a necessary change to accommodate large catches and limited available staff time for processing.

13.9.5. Other losses

Prior to the moratorium, herring were used as bait in eel and crab pots in Maryland. Some of the herring used as bait were females that had their roe removed for market. As of January 1, 2012 possession of river herring is not be allowed in Maryland, unless a bill of sale is provided from a state with a river herring fishery.

13.10. Fishery-Independent Surveys

13.10.1. Adult catch data

Fishery-independent data for river herring comes from the fish lifts at Conowingo Dam in the Susquehanna River and a multi-panel anchored gill net survey in the North East River. There are two lifts (west and east) operating at the lowest dam on the Susquehanna River. The lifts are operated to give priority to American shad passage and may exclude other species, including river herring. The two fish lifts are operated each spring beginning in April, which may eliminate alewife herring because their peak spawning period is likely prior to the opening of the lifts.

The west fish lift at Conowingo Dam has been used to monitor adult abundance since 1972. This lift operates in the traditional manner except that fish collected are dumped into a large steel trough where the catch is hand sorted by biologists. Target species are enumerated, sampled and then released back into the Conowingo Dam tailrace, used for tank-spawning, or transported upstream, as dictated by restoration plan requirements. Since 2011, the operators of the west fish lift have been instructed to collect the first 50 river herring of each species, followed by one of every 25th additional river herring species collected.

The Conowingo east fish lift is constructed with a viewing window where a trained biologist counts all fish species as they exit the fishway and enter the upstream reservoir. This lift has been operating since 1991 but prior to 1997, fish were manually trucked upriver. It is also worth noting that flows have been increased since the late 1990’s to maximize American shad catches in the east lift, which may decrease river herring catches.

MD DNR has conducted a gill net survey targeting river herring in the North East River since 2013. A multi-panel sinking monofilament gill net is set perpendicular to the channel at four randomly chosen sites once a week for 10 weeks in mid-March to mid-May. For the 2013 and 2014 sampling years, the gill net had three separate panels each 100ft x 6ft with mesh sizes of 2 ½, 2 ¾, and 3”. In 2015, the 3” mesh panel was replaced with a 2 ¼” mesh panel, as there was evidence the current mesh size selection was not successful in capturing smaller sized blueback herring. Four sites are randomly chosen for each day, along with four alternate sites, from a grid of 1000ft x 1000ft squares overlaid on a map of the North East River. Determination of whether to set the net shallow or deep is also randomly chosen. The net is soaked for 30 min at each site prior to retrieval. All fish are identified and enumerated to species per gill net mesh size. All alewife and blueback herring are sexed and measured to the nearest mm FL and TL. Scales are taken from a subsample of alewife and blueback herring per panel (i.e. first 20 fish encountered of each species per panel) to determine age and spawning history.

The North East River Gill Net Survey is successful in capturing a relative sample of both alewife and blueback herring spawning stock in the North East River. This survey captures the weekly temporal differences in these species spawning runs, and provides a relative index of abundance. Since this survey has a short-time series and was not initiated prior to the previous assessment, the group determined it would not be used for determining stock status at this time.

13.10.2. Juvenile Catch Data

Maryland's river herring juvenile indices are derived annually from seine sampling at 22 fixed stations within the Chesapeake Bay. A 30.5-m x 1.24-m bagless beach seine of untreated 6.4-mm bar mesh was set by hand. One end was held on shore. The other was fully stretched perpendicular from the beach and swept with the current (Durell et. al 2007).

Stations have been sampled continuously since 1954, with changes in some station locations (see http://dnr.maryland.gov/fisheries/PublishingImages/sitemap.jpg). They are divided among four of the major spawning and nursery areas: seven each in the Potomac River and Head of Bay areas and four each in the Nanticoke and Choptank Rivers. Sampling is monthly, with rounds occurring during July, August, and September.

Replicate seine hauls, a minimum of thirty minutes apart, are taken at each site on each sample round. This produces a total of 132 samples from which bay-wide means are calculated. In 1962, stations were standardized and a second sample round was added for a total of 88 samples. A third sample round, added in 1966, increased sample size to 132. Auxiliary stations have been sampled on an inconsistent basis and are not included in survey indices.

A 150' haul seine is used to generate juvenile indices of abundance for the upper Nanticoke River stock in Delaware (Stangl 2010). Haul seine sampling was initiated in 1999 and continued annually to assess reproduction and recruitment of all alosines. Sampling in 2010 was conducted at four locations using a haul seine from July-October. Samples were obtained once every two weeks at ebb or low slack tide. The geometric mean was calculated using the number taken per haul and utilized as an index of relative abundance for each species. Alosine samples with more than 90 individuals per species were randomly sub-sampled for lengths with the remainder being enumerated.

13.11. Assessment Approachs and Results

13.11.1. Spawning Stock Abundance

As was described in Section 13.9, commercial landings in the Upper Chesapeake Bay decline leading up to the moratorium. Alewife geometric mean CPUEs for the lower Nanticoke River have varied without trend, while those for blueback herring have significantly decreased (Figure 13.1 and 13.2, respectively). River herring lift catches at the Conowingo Dam (Tables 13.1 and 13.2) were erratic for the time series. Flows have been increased in recent years to encourage American shad to use the lift. Although high flow precludes river herring usage of the lifts this may not explain the wide range of annual values.

13.11.2. Juvenile Abundance

Beach seine sampling conducted by MD DNR since 1959 in the lower Nanticoke has fluctuated without trend for both alewife and blueback herring (Figure 13.3 and 13.4). The highest index value in a decade was recorded for blueback herring in 2011 (0.98), followed by the 2015 index (0.82), although both were still below the time-series mean (1.09). The highest alewife index value in a decade was recorded in 2010 (0.80), followed by the 2015 index (0.60), and both were above the time-series mean (0.36).

Haul seine sampling conducted in the Upper Nanticoke River by DFW has seen no long-term trend from 1999-2015 in juvenile blueback herring relative abundance. However, juvenile blueback herring relative abundance decreased to the sixth highest value in the 17-year time series during 2015 (Figure 13.5). Anecdotal information from Delaware electrofishing surveys indicated the majority of river herring in the upper Nanticoke system consisted of blueback herring. As a result, alewife relative abundance has been calculated from small sample sizes. No long-term trend for alewife relative abundance has been observed from 1999-2015 however the 2015 alewife geometric mean CPUE was the highest in the time series (Figure 13.6).

Baywide juvenile alewife and blueback herring indices are presented in Figure 13.7 and 13.8, respectively.

13.11.3. Trends in Mean Age and Length

The river herring data for Maryland is based on the bycatch monitoring in the lower Nanticoke River. Sample bias is likely minimum because of the very small mesh sizes used in both the pound and fyke nets (1.5 inch stretched mesh). Therefore, changes in mean age and length of fish over time is likely due to population changes, especially since the same gear and mesh sizes have been used during our sampling efforts.

Data from MD DNR indicated that in the recent years, fewer fish over the age of 7 for both alewife and blueback herring have been observed (Tables 13.5 and 13.6, respectively). Mean length has declined over the time series for blueback herring, and varies without trend for alewife (Figure 13.9). Age four and five fish were most prevalent in the samples, but river herring were generally not fully recruited to the spawning population until age five. Number of alewife and blueback herring sampled by sex and age class from bycatch monitoring in the lower Nanticoke River is presented in Tables 13.6 and 13.7 respectively. Mean length-at-age for alewife and blueback herring sampled from the Nanticoke River is presented in Tables 13.7 and 13.8 respectively.

River herring data from the West Fish Lift collections at Conowingo Dam is likely biased, as sampling begins in mid-April or early May, following the peak spawning periods for alewife. Further, operations of the West Fish Lift, like the East Lift, have traditionally been operated at flows to maximize American Shad catch/passage, thereby further hindering river herring catch. However, between 2012 and 2015, 85 blueback herring were collected at the West Fish Lift, in addition to 43 alewife between 2014 and 2015.

Catch-by-age data are presented in Tables 13.9 (alewife) and 13.10 (blueback herring). Tables 13.11 and 13.12 summarize mean length at age for alewife and blueback herring, respectively.

13.11.4. Trends in Repeat Spawning

The arcsine-transformed proportion of alewife repeat spawners (sexes combined) from bycatch monitoring in the lower Nanticoke River indicated no trend (1989-2014; $r^2 = 0.078$ $P = 0.18$), while blueback herring repeat spawning showed a decreasing trend (1989-2014; $r^2 = 0.63$, $P < 0.001$; Figure 13.10).

13.11.5. Trends in Z-estimates

Total instantaneous mortalities (Z) were estimated from bycatch monitoring in the lower Nanticoke River by the Chapman-Robson method utilizing age data (Citation needed). Following methodology from the previous assessment, the first age-at-full recruitment was the age with the highest frequency and estimates were only made when data was available from three or more age-classes (including first fully-recruited age). Mortality rates for alewife and blueback herring by sex are presented in Figures 13.11 and 13.12, respectively.

13.12. BENCHMARKS

NO BENCHMARKS HAVE BEEN DEVELOPED FOR MARYLAND AT THIS TIME.

CONCLUsIONS

Commercial landings in Maryland and Delaware showed a decline leading up to a moratorium being established in 2012. The expectation is that this regulatory change will help protect the remaining spawning populations and aid in reversing the declining trend in river herring abundance.

Maryland's best estimate of adult relative abundance comes from the Nanticoke River and shows that both alewife and blueback herring populations have remained low for the time series, and blueback herring have continued to decline following the closure of the fishery. In general, ages four and five were the most prevalent fish in adult samples from pound and fyke nets on the Nanticoke River, but river herring were generally not fully recruited to the spawning population until age five, as shown with the freshwater spawning mark not present on all five year-old fish. Fewer older aged fish (>7 years) have been observed for both alewife and blueback herring from the Nanticoke River, and mean length of blueback herring from this system has continued to decline.

Juvenile alewife abundance shows a decreasing trend in the upper Nanticoke, but higher values were seen during sampling efforts in 2010 in both the upper and lower portions of the river. Blueback herring juvenile relative abundance increased to the third highest value in 2009 and to the highest value in 2010 during the 12-year time series.

Data from the Conowingo Dam fish lifts on the Susquehanna River are highly influenced by flow and likely do not reflect the abundance of river herring in the system. Therefore, trends in abundance for this system are relatively unknown.

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Table 13.1. Blueback herring passage at Susquehanna River Dams.

Year	Conowingo (rm 10.0)	Holtwood (rm 24.6)	Safe Harbor (rm 32.2)	York Haven (rm 56.1)
1997	242,815	1,042	534	no fishway
1998	700	62	20	no fishway
1999	130,625	73	30	no fishway
2000	14,963	27	816	0
2001	284,921	1,300	710	4
2002	2,037	13	0	0
2003	530	3	0	0
2004	101	0	0	0
2005	4	0	0	0
2006	0	0	0	0
2007	460	0	0	0
2008	1	0	0	0
2009	71	0	0	0
2010	4	0	0	0
2011	17	0	0	0
2012	25	0	0	0
2013	7	0	0	0
2014	25	0	0	0
2015	3	0	0	0
Total	677,309	2,520	1,290	4

Table 13.2. Alewife passage at Susquehanna River Dams.

Year	Conowingo (rm 10.0)	Holtwood (rm 24.6)	Safe Harbor (rm 32.2)	York Haven (rm 56.1)
1997	63	0	0	no fishway
1998	6	0	0	no fishway
1999	14	1	1	no fishway
2000	2	0	0	2
2001	7,458	1	0	0
2002	74	0	0	1
2003	21	2	0	0
2004	89	2	1	0
2005	0	0	0	0
2006	0	0	0	0
2007	429	0	0	0
2008	4	0	0	0
2009	160	1∗	0	0
2010	1	0	0	0
2011	2	0	0	0
2012	27	0	0	0
2013	0	0	0	0
2014	111	0	0	0
2015	10	0	0	0
Total	8,471	6	2	3

∗ *Landlocked populations of alewives are present in Susquehanna River Basin impoundments and some of those recorded at the fishways may not be anadromous in origin.*

Table 13.3 Nanticoke River Gill Net Landings and CPUE

Year	Kgs Landed	CPUE (kgs/ net meter)
1985	1271	0.165
1986	1862	0.162
1987	1759	0.163
1988	5901	0.175
1989	1706	0.097
1990	6818	0.315
1991	6824	0.458
1992	13495	0.410
1993	4541	0.211
1994	6950	0.547
1995	8056	0.800
1996	8378	0.810
1997	5445	0.282
1998	7627	0.397
1999	2490	0.089
2000	5188	0.133
2001*	confidential	
2002*	confidential	
2003*	confidential	
2004*	confidential	
2005*	confidential	
2006*	confidential	
2007*	confidential	
2008*	confidential	
2009*	confidential	
2010*	confidential	

Table 13.4 Recreational fishery for river herring in Delaware (statewide).

Year	Harvested N	Released Alive N	Total N	# of Fishers	Effort Trips	Net Yard Days	Catch per Trip	Harvest per Trip
1996	4399	.	4399	391	3,808	196,381	1.16	1.16
1997	2247	.	2247	274	2,291	111,659	0.98	0.98
1998	2835	.	2835	269	1,161	55,453	2.44	2.44
1999	460	14	474	27	948	49,342	0.50	0.49
2000	1134	6	1140	197	1,560	84,396	0.73	0.73
2001	502	1028	1530	198	1,686	82,301	0.91	0.30
2002	297	48	345	179	1,615	83,022	0.21	0.18
2003	370	43	413	173	1,390	65,779	0.30	0.27
2004	No Data	.	.	.	.	.	.	.
2005	No Data	.	.	.	.	.	.	.
2006	No Data	.	.	.	.	.	.	.
2007	341	495	836	144	878	43,096	0.95	0.39

Table 13.5 Annual catch-by-age and sex for alewife herring sampled from the Nanticoke River, 1989-2014.

Males

Year	Catch-by-Age									
	2	3	4	5	6	7	8	9	10	11
1989		14	76	79	20	3				
1990		53	94	142	75	12	1			
1991		18	249	123	54	12	1			
1992		29	99	135	27	6				
1993		15	73	93	48	7	1			
1994		29	77	94	31	7				
1995		8	18	10	6	2				
1996	1	62	81	40	11	1				
1997		18	53	32	5	0	1			
1998		9	52	27	11	2				
1999		21	36	53	39	5				
2000		13	72	19	1					
2001		16	48	40	2					
2002		5	42	48	26	4				
2003		5	19	24	16	1				
2004		12	37	22	11	3				
2005		6	39	19	5	1				
2006		4	13	22	11					
2007		13	49	19	7					
2008		5	24	26	10	1				
2009		5	33	15	5					
2010		2	14	4	5					
2011		6	18	14	11					
2012		12	24	21	8					
2013		5	12	17	8	1				
2014		3	59	61	14	1				

Table 13.5 Continued

Females

Year	Catch-by-Age									
	2	3	4	5	6	7	8	9	10	11
1989		6	85	87	50	13	2			
1990		12	78	141	93	26	21	1		
1991		8	158	102	77	35	7	6		
1992		13	116	244	70	30	7	2		
1993		1	78	151	129	30	11			
1994		8	75	135	90	34	3			
1995		4	23	12	15	11				
1996		25	61	68	28	19	7	1		
1997		6	67	48	19	3	4			
1998		2	69	65	28	5	0	1		
1999		7	31	75	48	1	1			
2000		2	62	30	23	6				
2001		1	38	62	24	7	1			
2002		1	21	54	75	19	2			
2003		2	13	35	43	10				
2004			26	40	31	15	6			
2005			28	24	27	17	3			
2006		2	15	56	24	4	4			
2007		2	38	40	35	12	3			
2008		2	26	56	17	13	2	1		
2009		4	50	61	33	10				
2010			5	19	16	4				
2011		2	48	37	35	9	2			
2012		8	22	34	27	10				
2013		3	19	31	20	11	1			
2014		2	35	84	20	3	1			

Table 13.6 Annual catch-by-age and sex for blueback herring sampled from the Nanticoke River, 1989-2014.

Males

Year	Catch-by-Age								
	2	3	4	5	6	7	8	9	10
1989		10	110	122	76	15	6	1	
1990		15	69	131	110	79	29	11	
1991		11	101	82	101	54	19	2	1
1992		10	43	54	49	36	14	4	
1993		5	39	74	73	40	15	3	
1994		24	91	102	41	9			
1995		2	13	11	10	4			
1996	1	13	67	63	12	1	2		
1997		10	18	53	82	11	2		
1998		7	22	23	22	15			
1999		7	14	20	14	3			
2000		8	59	31	10	5			
2001		7	23	17	4				
2002		8	24	25	7				
2003		2	17	27	12				
2004		16	29	19	4	1			
2005		3	3	2	0				
2006		1	6	15	3	1			
2007		11	17	7	1				
2008		5	19	11					
2009		9	17	5					
2010		2	8	0	1				
2011		8	30	13	5				
2012	1	14	30	19	4				
2013		4	22	17	11	1			
2014		21	75	38	5	1			

Table 13.6 Continued

Females

Year	Catch-by-Age								
	2	3	4	5	6	7	8	9	10
1989		3	112	126	76	37	6	1	
1990		0	43	78	75	64	18	5	4
1991		6	76	68	106	54	24	14	
1992		2	34	44	50	31	20	5	
1993		1	29	90	72	43	18	6	1
1994		3	42	70	46	19	4	1	
1995		3	11	7	5	1	3		
1996		2	57	63	24	3	3		
1997		3	33	50	67	14	3	1	
1998		0	38	39	41	22	3		
1999		1	9	36	14	5			
2000		4	41	20	11	7	2		
2001		1	24	20	7	2			
2002		1	27	41	15	1			
2003		1	22	26	15	5	1		
2004		0	20	25	8	9	1		
2005		1	6	1	2				
2006		1	13	22	6				
2007		8	13	11	4	2			
2008		3	23	14	3	3	1		
2009		5	20	8	1	1			
2010			7	6	2				
2011		1	37	20	7	1			
2012		6	21	31	7	3			
2013		1	11	7	4	1	3		
2014		15	45	47	13	1			

Table 13.7 Mean length-at-age by sex for alewife herring sampled from the Nanticoke River, 1989-2010.

Males

Year	Age									
	2	3	4	5	6	7	8	9	10	11
1989		230	236	243	256	261				
1990		221	231	244	250	263	264			
1991		224	234	240	251	260	243			
1992		216	228	238	247	254				
1993		208	225	239	246	248	246			
1994		207	219	231	239	246				
1995		214	226	238	246	251	244			
1996	212	219	228	238	242	263				
1997		213	228	233	240		252			
1998		217	225	238	243	254				
1999		211	222	233	238	244				
2000		220	228	238	258					
2001		225	234	240	247					
2002		225	233	241	244	248				
2003		228	239	245	251					
2004		228	242	251	250					
2005		214	226	236	252	252				
2006		219	223	235	242					
2007		219	227	235	248					
2008		216	217	229	235	278				
2009		221	224	231	241					
2010		221	224	232	248					
2011		215	230	233	244					
2012		215	217	230	242					
2013		204	222	232	243	245				
2014		222	222	229	240	230				

Table 13.7 Continued.

Females

Year	Age									
	2	3	4	5	6	7	8	9	10	11
1989		229	244	253	267	277	286			
1990		225	238	253	261	274	283	286		
1991		227	243	251	263	270	273	286		
1992		223	240	248	256	265	276	279		
1993		225	233	247	256	265	277			
1994		219	228	243	254	258	270			
1995		221	235	252	263	268	274		280	
1996		219	231	250	257	267	268	260		
1997		228	234	242	253	267	271			
1998		224	235	245	255	264		277		
1999		220	229	242	250	260	272			
2000		237	237	250	257	270				
2001		239	243	249	256	266	270			
2002		226	238	248	255	260	263			
2003		240	239	250	260	263				
2004		235	249	259	262	270				
2005			233	243	257	267	272			
2006		228	240	247	256	264	277			
2007		220	236	247	256	265	269			
2008		217	231	238	248	256	276	279		
2009		215	231	242	252	261				
2010			234	245	257	251				
2011		226	241	247	255	266	275			
2012		218	233	249	260	263				
2013		233	232	240	249	262	269			
2014		233	229	240	253	263	263			

Table 13.8 Mean length-at-age by sex for blueback herring sampled from the Nanticoke River, 1989-2014.

Males

Year	Age								
	2	3	4	5	6	7	8	9	10
1989		218	227	234	245	259	262	279	
1990		218	232	239	249	258	263	270	
1991		217	229	237	247	258	260	273	
1992		212	224	235	245	251	260	256	
1993		205	224	237	247	256	262	261	
1994		213	223	238	250	256			
1995		220	226	233	247	256			
1996	205	219	230	240	244	270	261		
1997		212	225	238	241	247	257		
1998		212	225	233	245	253			
1999		200	222	232	239	251			
2000		219	225	235	246	249			
2001		218	231	235	250				
2002		217	229	234	243				
2003	215	230	240	238					
2004	216	231	234	245	250				
2005		222	226	238					
2006		209	224	235	236	270			
2007		207	221	227	266				
2008		206	216	220					
2009		214	219	231					
2010		219	227		228				
2011		206	220	226	234				
2012	212	208	217	228	229				
2013		216	222	225	231	226			
2014		214	226	232	239	236			

Table 13.8 Continued.

Females

Year	Age								
	2	3	4	5	6	7	8	9	10
1989		227	236	244	257	271	279	297	
1990			241	252	262	271	281	286	291
1991		228	238	251	260	264	273	285	
1992		230	230	250	260	264	272	281	
1993		220	236	246	259	269	277	290	296
1994		215	226	245	260	272	282	277	
1995		228	235	248	260	264	270		
1996		218	238	249	257	275	278		
1997		226	242	247	254	268	276	290	
1998			233	246	257	265	281		
1999		219	236	244	253	273			
2000		227	231	243	260	269	275		
2001		219	242	248	260	273			
2002		220	235	246	257	260			
2003	224	235	248	252	264	283			
2004		236	245	254	262	262			
2005		241	236	248	264				
2006		204	235	242	246				
2007		217	221	246	247	266			
2008		213	227	234	252	251	261		
2009		227	232	242	260	278			
2010			243	238	247				
2011		201	240	238	251	262			
2012		213	230	243	250	256			
2013		232	226	240	244	233	256		
2014		217	232	245	256	275			

Table 13.9 Annual catch-by-age and sex for alewife herring sampled from the West Fish Lift, Conowingo Dam, Susquehanna River, 2014 - 2015.

Males

Year	Catch-by-Age									
	2	3	4	5	6	7	8	9	10	11
2014		6		1						
2015		1	9	7	1					

Females

Year	Catch-by-Age									
	2	3	4	5	6	7	8	9	10	11
2014		4	2							
2015			5	7						

Table 13.10 Annual catch-by-age and sex for blueback herring sampled from the West Fish Lift, Conowingo Dam, Susquehanna River, 2012 - 2015.

Males

Year	Catch-by-Age									
	2	3	4	5	6	7	8	9	10	11
2012		4	3							
2013			1	1						
2014		12	29	8	2	1				
2015		3	6	4						

Females

Year	Catch-by-Age									
	2	3	4	5	6	7	8	9	10	11
2012			2							
2013										
2014			4	1						
2015	1	1	1	1						

Table 13.11 Mean length-at-age by sex for alewife herring sampled from the West Fish Lift, Conowingo Dam, Susquehanna River, 2014 - 2015.

Males

Year	Mean Length at Age									
	2	3	4	5	6	7	8	9	10	11
2014		255		278						
2015		259	266	264	260					

Females

Year	Mean Length at Age									
	2	3	4	5	6	7	8	9	10	11
2014		263	287							
2015			268	279						

Table 13.12 Mean length-at-age by sex for blueback herring sampled from the West Fish Lift, Conowingo Dam, Susquehanna River, 2012 - 2015.

Males

Year	Mean Length at Age									
	2	3	4	5	6	7	8	9	10	11
2012		231	249							
2013			254	250						
2014		237	253	262	260	292				
2015		252	252	264						

Females

Year	Mean Length at Age									
	2	3	4	5	6	7	8	9	10	11
2012			255							
2013										
2014			264	273						
2015		251	272	284	280					

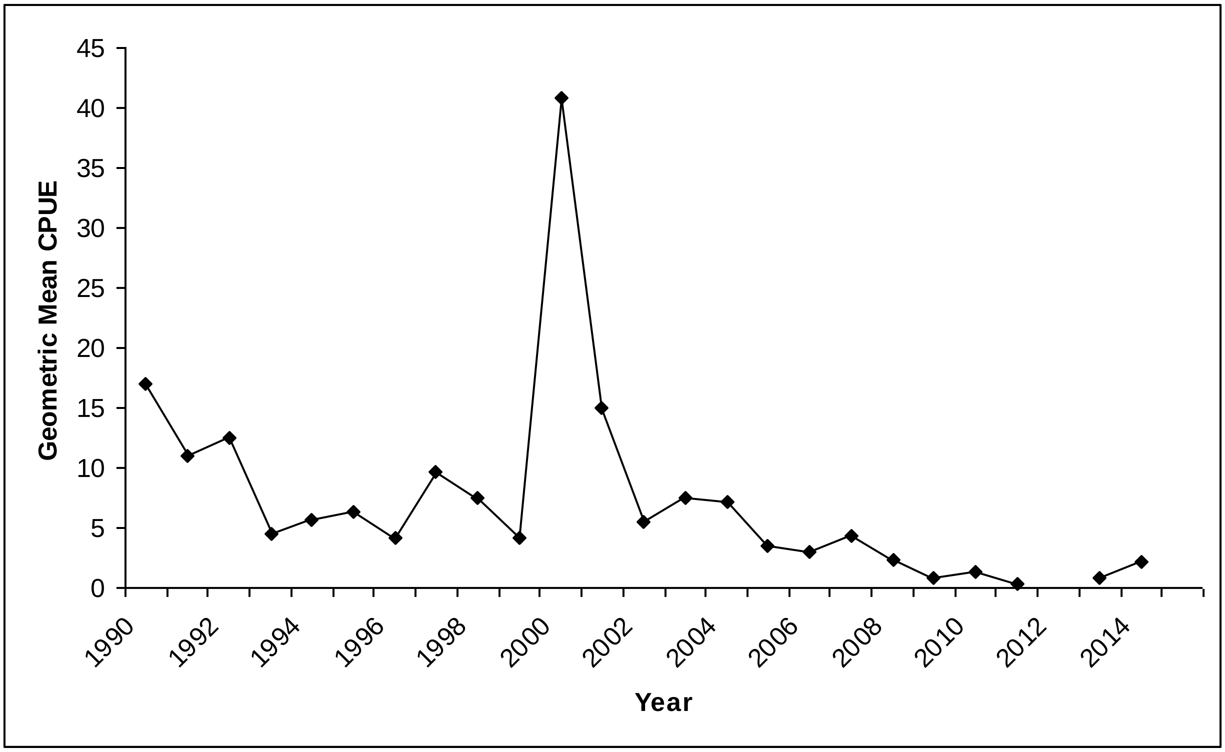

Figure 13.1 Geometric mean CPUEs of adult alewife herring from the Nanticoke River fyke nets, 1989-2014.

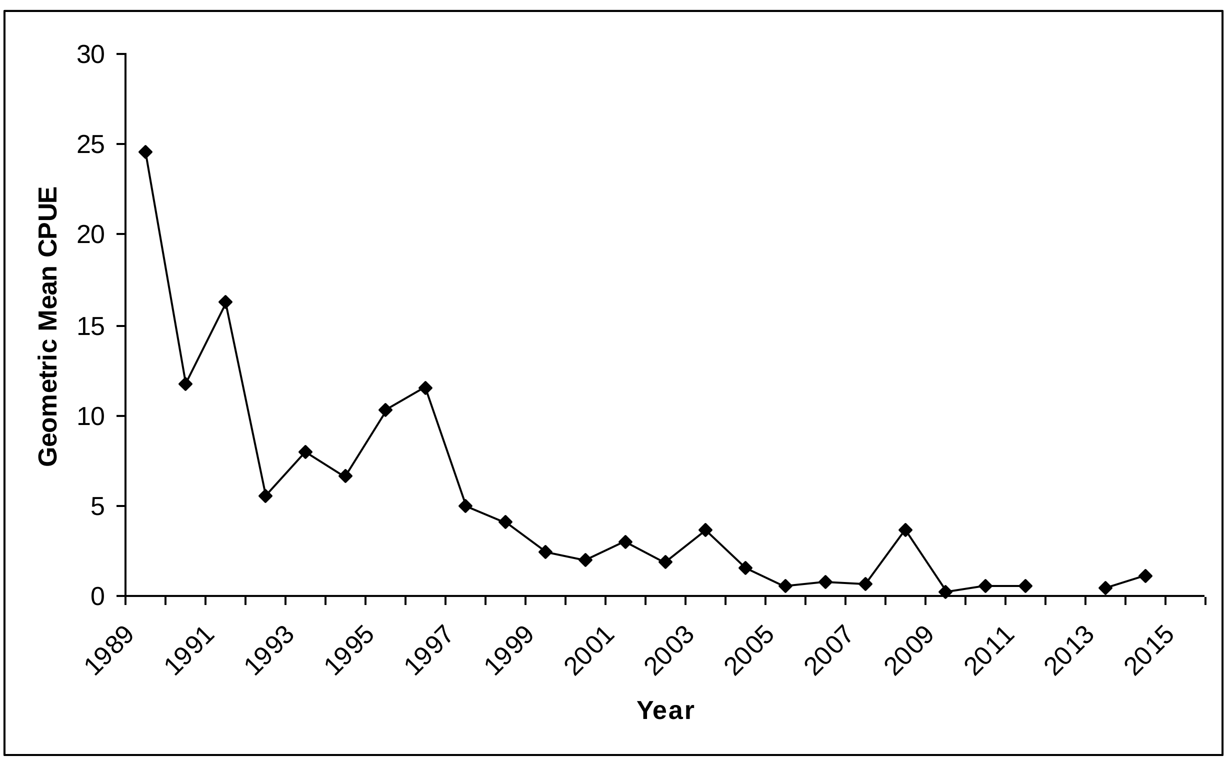

Figure 13.2 Geometric mean CPUEs of blueback herring from the Nanticoke River fyke nets, 1989-2014.

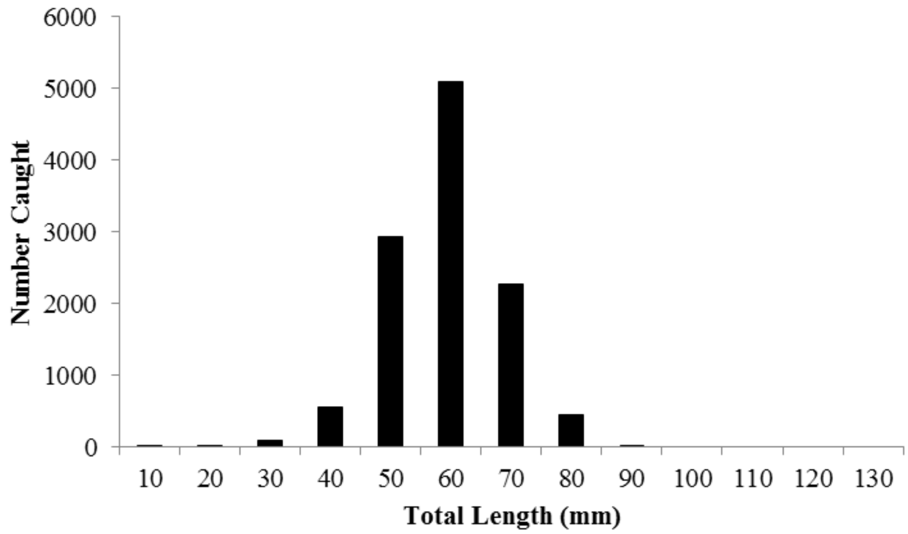

Figure 13.? Length frequency of YOY blueback herring from the haul seine survey on the Nanticoke River in Delaware 1999-2016.

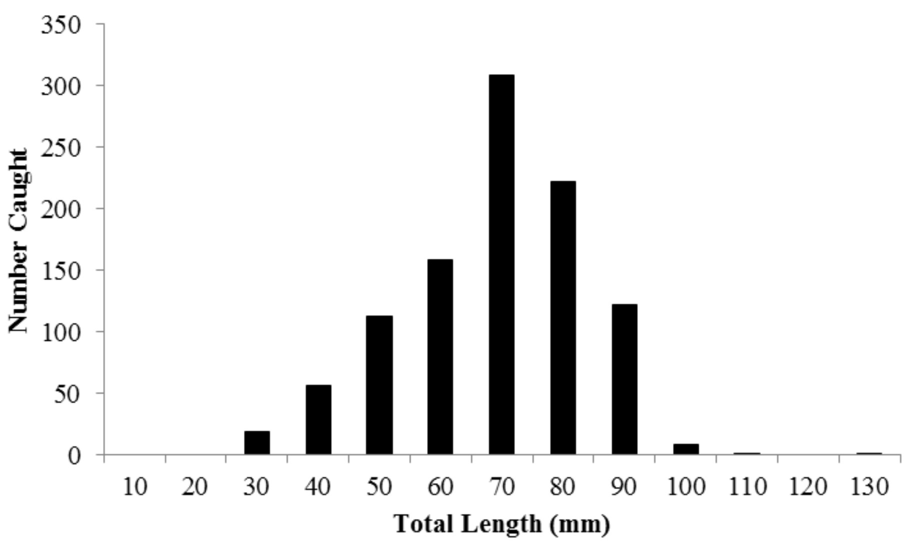

Figure 13.? Length frequency of YOY alewife from the haul seine survey on the Nanticoke River in Delaware 1999-2016.

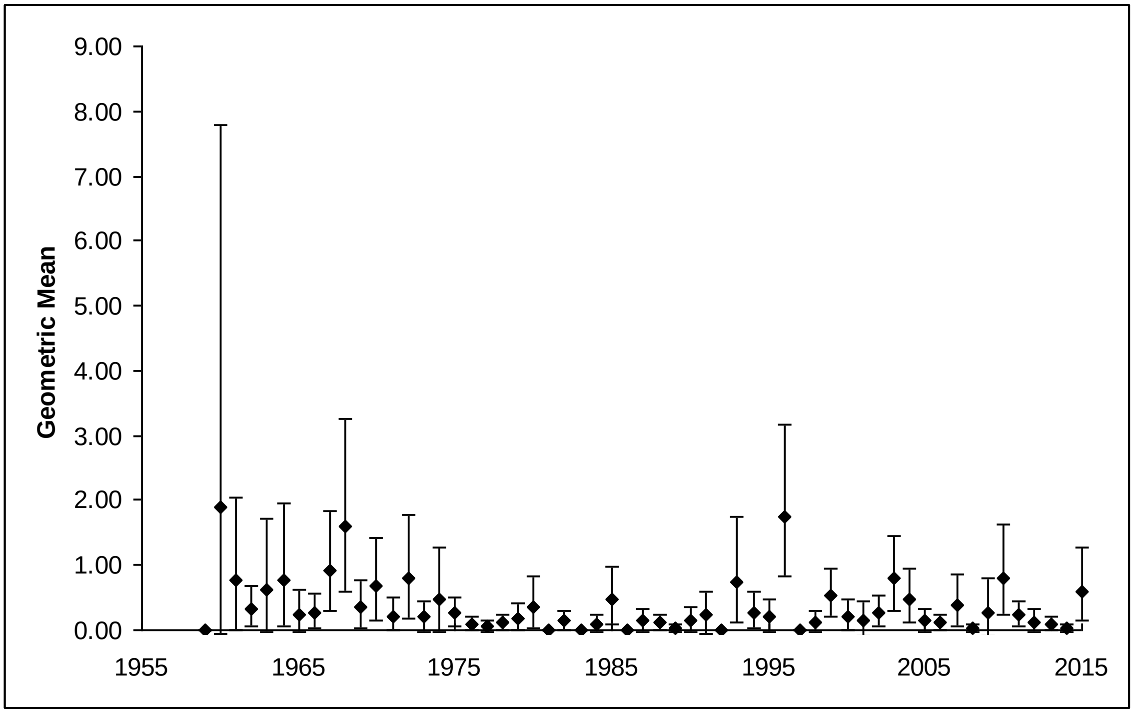

Figure 13.3 Nanticoke River juvenile alewife herring geometric mean CPUEs with 95% confidence intervals, 1959-2015.

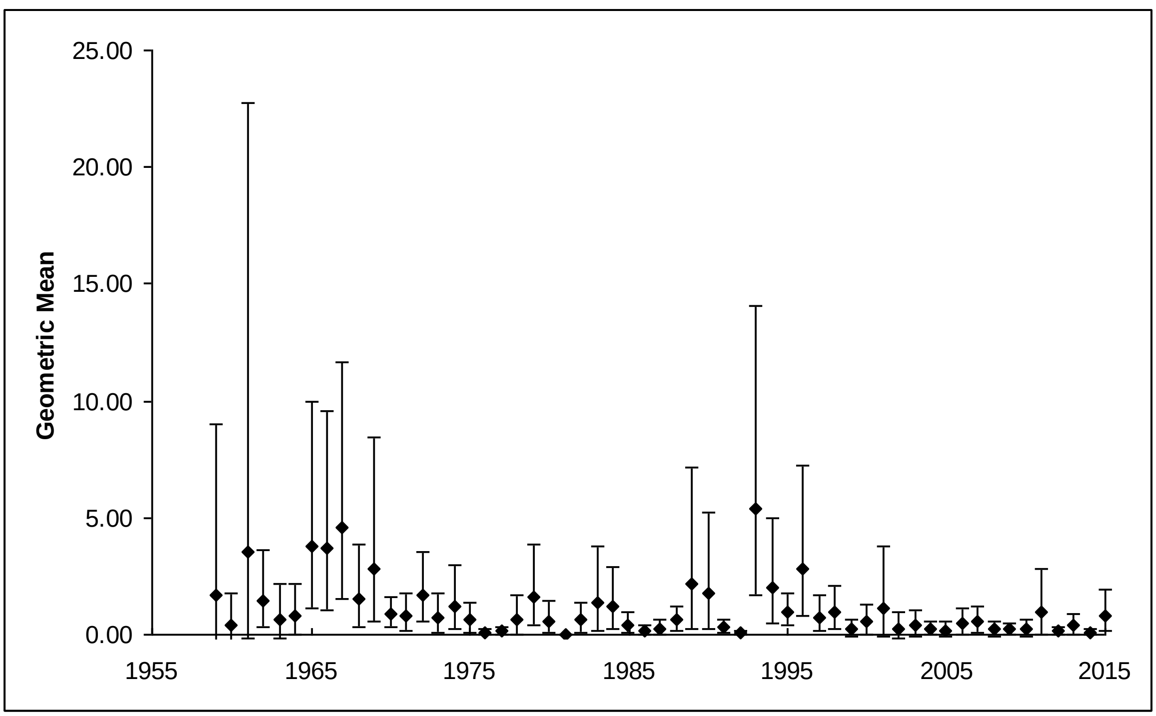

Figure 13.4 Nanticoke River juvenile blueback herring geometric mean CPUEs with 95% confidence intervals, 1959-2015.

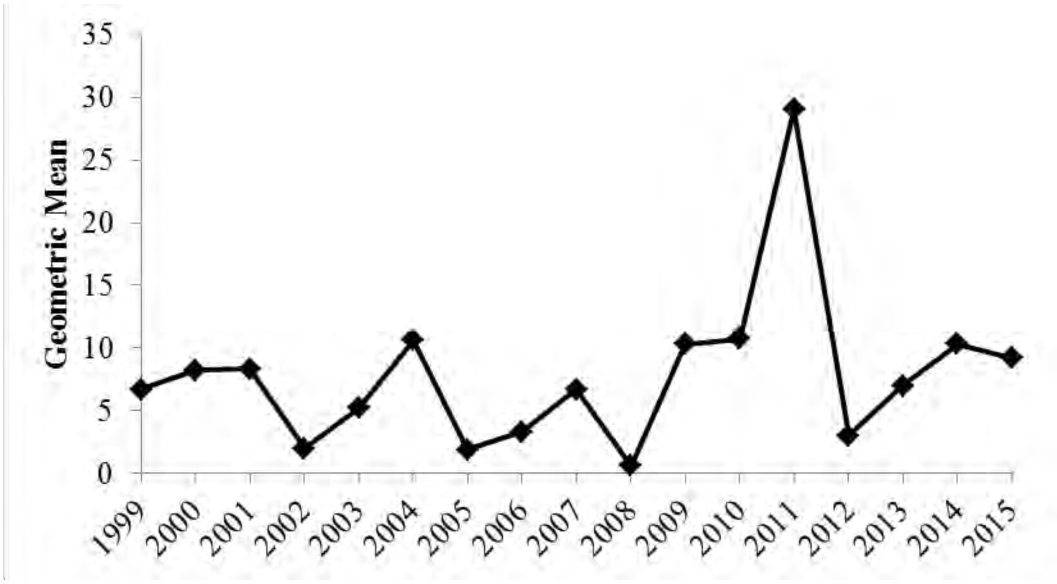

Figure 13.5 The geometric mean for juvenile blueback herring caught with the haul seine from the upper Nanticoke River and Broad Creek from 1999 through 2015.

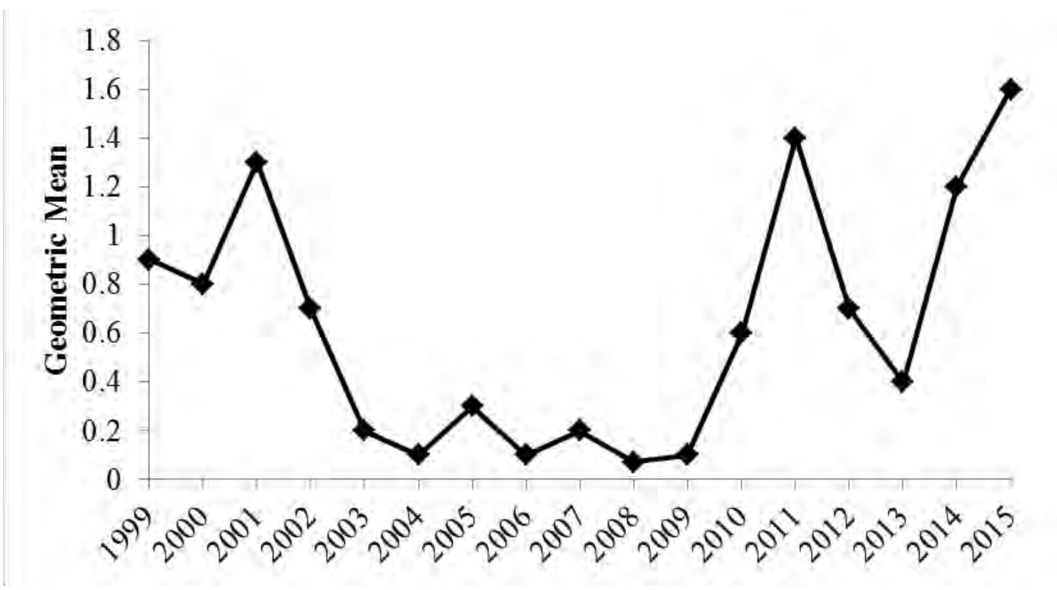

Figure 13.6 The geometric mean for juvenile alewife caught with the haul seine from the upper Nanticoke River and Broad Creek from 1999 through 2015.

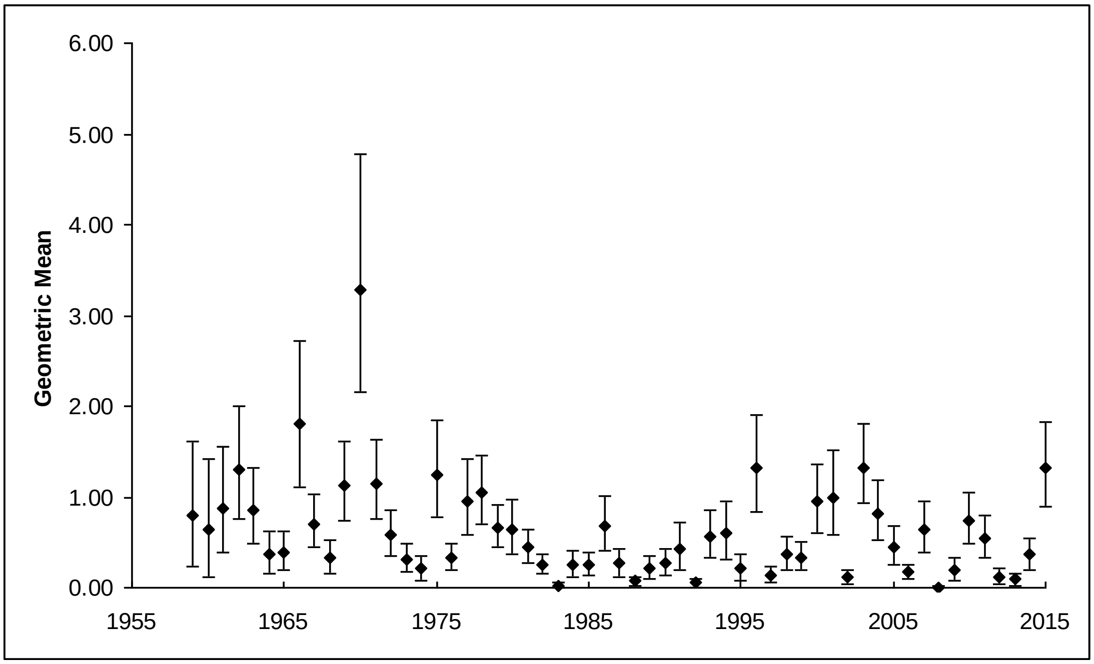

Figure 13.7 Baywide juvenile alewife herring geometric mean CPUEs with 95% confidence intervals, 1959-2015.

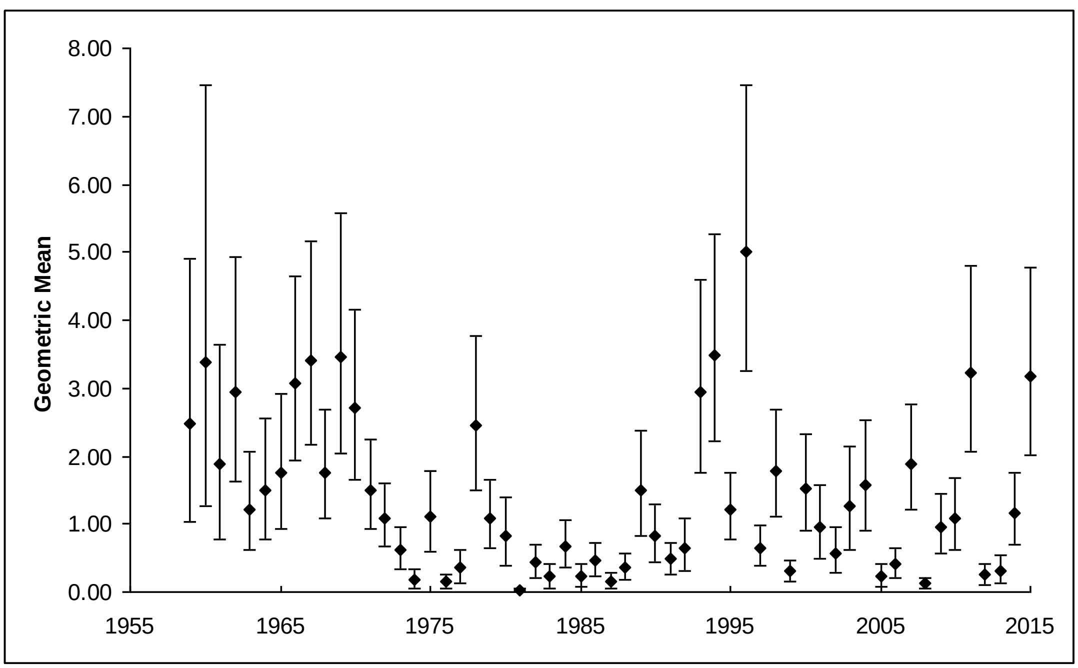

Figure 13.8 Baywide juvenile blueback herring geometric mean CPUEs with 95% confidence intervals, 1959-2015.

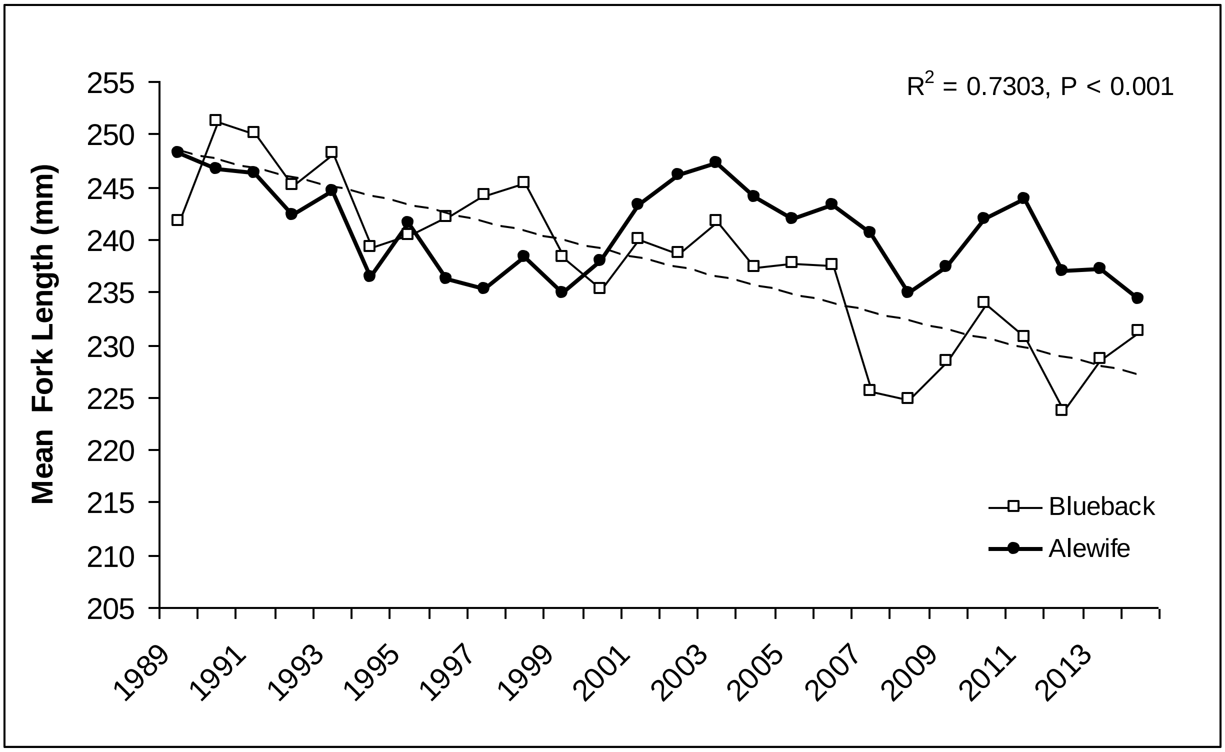

Figure 13.9 Mean length (FL mm) of adult alewife and blueback herring from the Nanticoke River, 1989-2014.

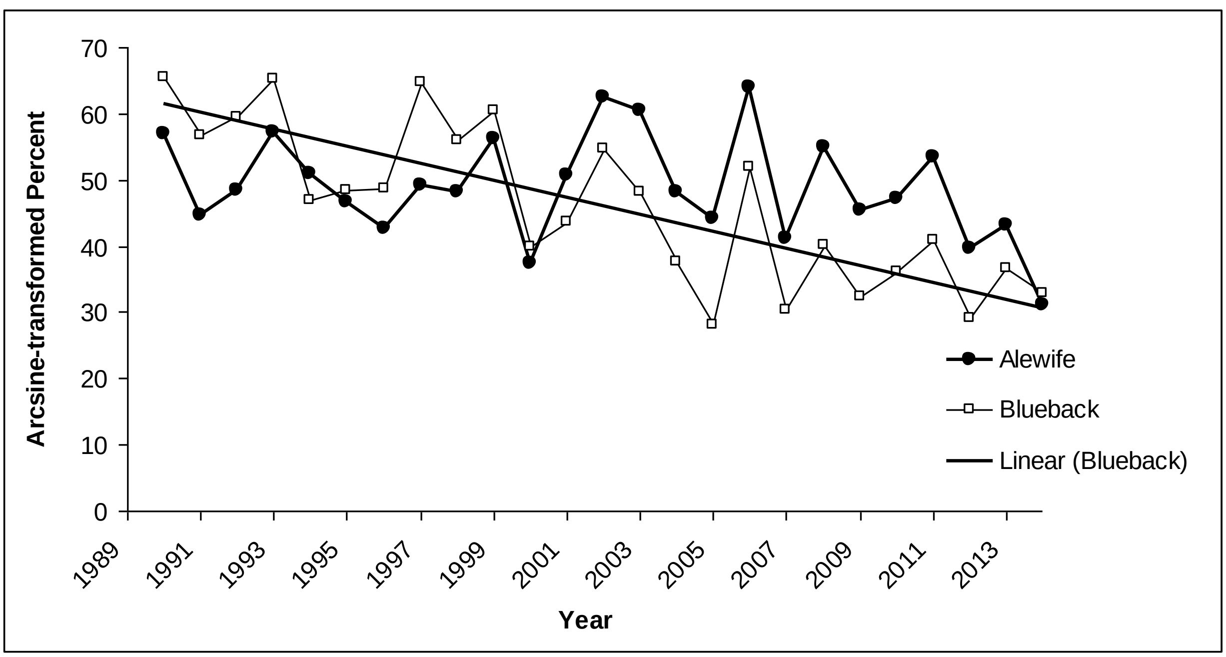

Figure 13.10 Trends in the arcsine-transformed percentage of repeat spawning alewife and blueback herring (sexes combined) from the Nanticoke River, 1989-2014.

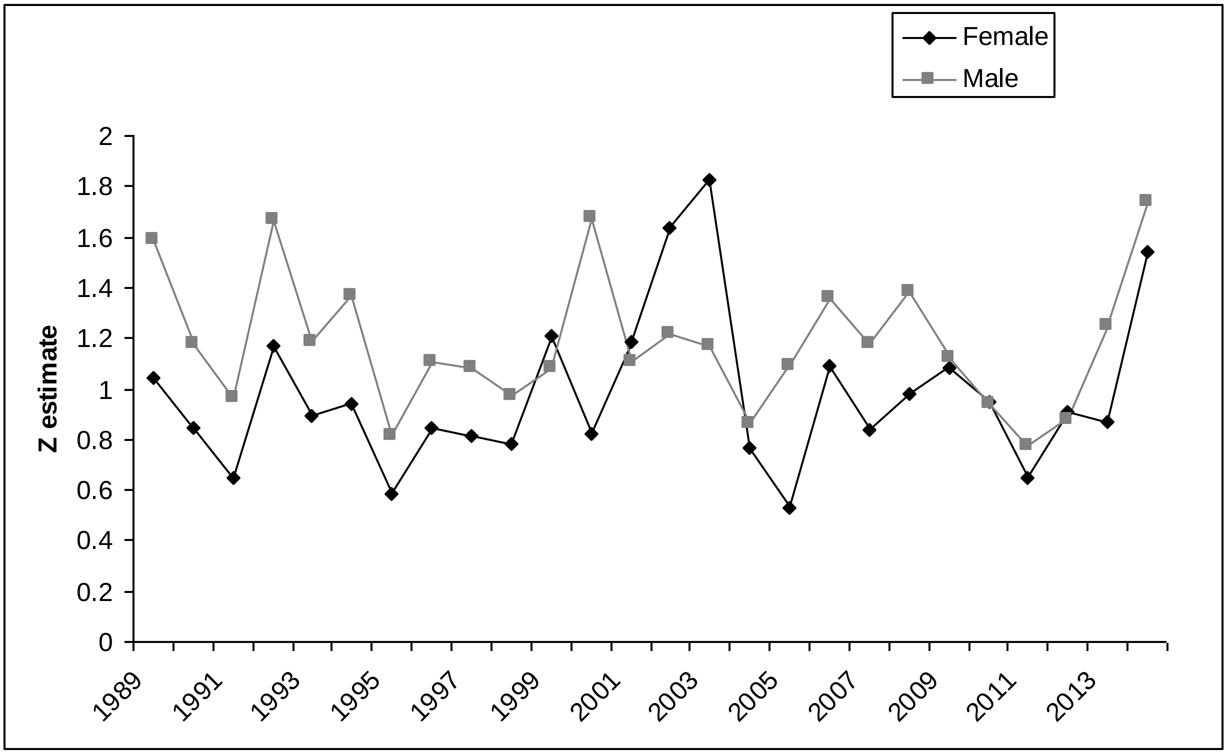

Figure 13.11 Alewife mortality rates for males and females from the Nanticoke River, 1989-2014.

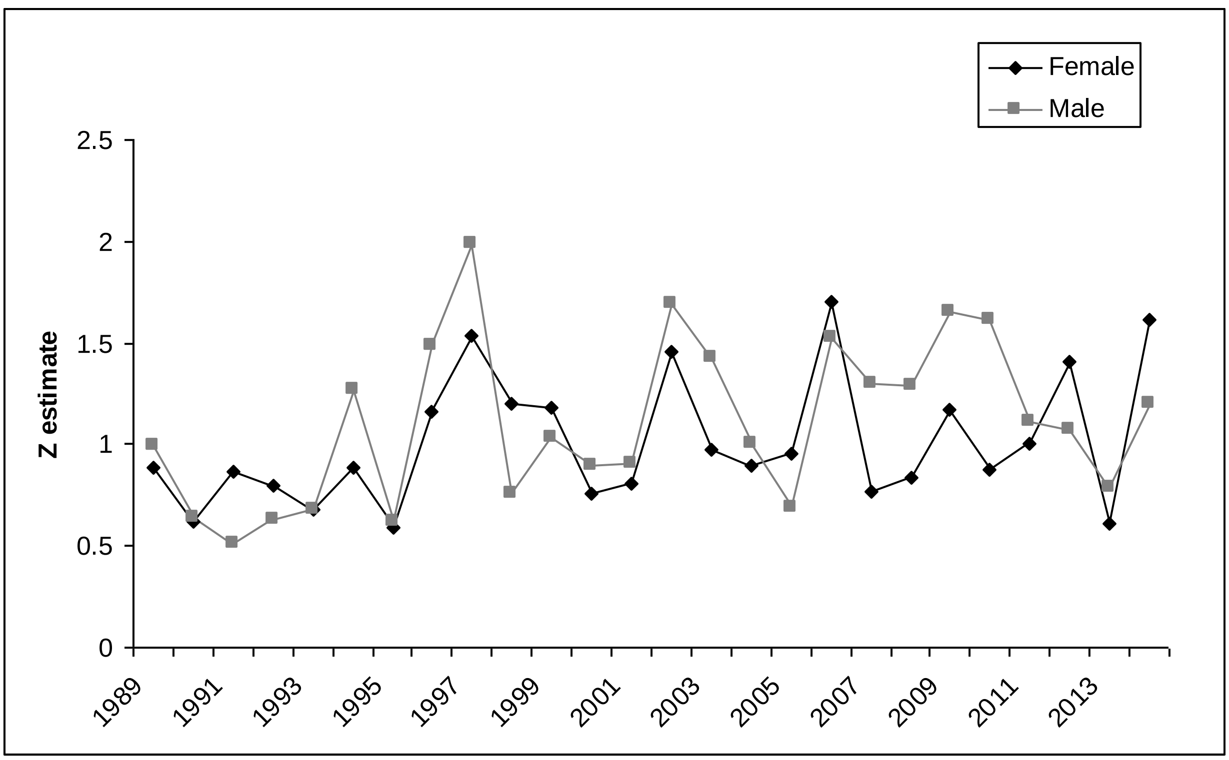

Figure 13.12 Blueback herring mortality rates for males and females from the Nanticoke River, 1989-2014.

14 Status of River Herring in the Potomac River

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Executive Summary

The following report will give a brief overview of the work done by the District Department of Energy and Environment (DOEE) and the Potomac River Fisheries Commission (PRFC) as it relates to river herring (alewife and blueback herring) management and monitoring. PRFC manages and tracks commercial landings of river herring in the Potomac River. In 2010, the commercial harvest of river herring was closed to all gear with the exception of a limited pound net by-catch of 50 pounds per fishermen per day, and a moratorium was established on river herring for recreational and charter fishing. In 2012, all commercial fisheries were closed to the taking and/or possession of river herring. Surveys conducted by DOEE include fisheries independent electrofishing for adults and seining and push net sampling for juveniles. There has been a drastic decline in CPUE of alewife and blueback herring in the DDOE adult electrofishing survey from the late 1990s to early 2000s. However, size structure trends from the electrofishing survey have remained relatively stable from 2005-2016. Maryland Department of Natural Resources (MD DNR) conducts a juvenile survey in the Potomac River, and a striped bass spawning stock survey which encounters river herring. The population of blueback herring appears to be more abundant in the Potomac River than alewife herring.

14.1 INTRODUCTION

River herring (*Alosa psuedoharengus* and *Alosa aestivalus*) are important anadromous species that frequent the waters of the Potomac River. There was a significant abundance of river herring caught in the Potomac

River from the Colonial Period through the 19th Century. Historically, the primary gear for harvesting river herring in the Potomac River was the haul seine. The large haul seine fisheries of the 18th and 19th centuries are now gone and replaced today by much smaller, shorter seines (2,400 ft. maximum).

Sexually mature river herring return each spring to spawn in the Potomac River. Locally and historically, the “herring run” was an anticipated fishing event as eager anglers, birds, and other opportunists took advantage of these nutrient rich visitors. Adult herring are normally present in the Potomac River for about three months each year from March through May. In addition to the annual run of adult river herring, the juveniles that were spawned use the region as a nursery to grow and develop. Each year clouds of juvenile river herring consume zooplankton during the summer months before migrating out of our region by autumn.

River herring are monitored by DOEE and MD DNR each year to assess the status of the local populations and determine how that may affect the overall coastal stock. Because of the two distinct life stages (adult and juvenile) that are represented in the Potomac River, sampling efforts are designed to target each group specifically. Data is analyzed annually and compared by year to determine significant trends in population structure and size.

14.2 DEFINITION OF MANAGEMENT UNITS

The low water mark of the southern shore Potomac River, exclusive of the tributaries, is the boundary line between the states of Maryland and Virginia, with Maryland being the owner of the river. Maryland and Virginia first entered into a compact in 1785 (before the adoption of the U.S. Constitution) to regulate, among other things, the fisheries of the Potomac. After the adoption of the U.S. Constitution and the formation of a Federal Government, Maryland ceded the area, including that part of the Potomac River, which is now the District of Columbia.

There are five fishery management authorities on the Potomac River. The Potomac River Fisheries Commission (PRFC) is the Maryland / Virginia bi-state Commission with fisheries management authority for the main stem of the river, exclusive of the tributaries on either side, from the Chesapeake Bay to the southern Maryland / District of Columbia boundary line; the District Department of Energy and Environment (DOEE) with authority for the Potomac River to the Virginia shore and other waters within D.C.; the Maryland Department of Natural Resources (MD DNR) with authority for the tributaries of the Potomac on the Maryland side of the river and the fluvial portion of the river upstream of D.C.; the Virginia Marine Resources Commission (VMRC) with authority for commercial fisheries in all tidal Virginia tributaries and for recreational fisheries in the saltwater portions of the tidal Virginia tributaries below the Route 301 Bridge; and the Virginia Department of Game and Inland Fisheries (VDGIF) with authority for recreational fisheries in the freshwater portions on the Virginia tributaries. Additionally the Federal government controls much of the shoreline, and therefore access, of the Potomac through several military bases and the National Park Service.

14.3 REGULATORY HISTORY

During colonial times, the fisheries were essentially unregulated. In 1785 Maryland and Virginia adopted a compact to regulate the fisheries by requiring all fishery laws for the Potomac River to be enacted jointly by the legislatures of both states. In 1963 the PRFC was created and charged with the establishment and maintenance of a program to conserve and improve fishery resources. While PRFC has never had any specific regulations regarding river herring, there have been prohibitions against certain gears such as purse nets, trawls, trammel nets, troll nets, or drag nets have been in place which has limited commercial harvest of river herring such that river herring harvest in the Potomac is almost exclusively taken by pound nets. The District of Columbia does not allow commercial harvest of river herring from their portion of the Potomac River.

The pound net fishery shifted from a shad and herring fishery in the 1960's and early 1970's, when those species began declining, to primarily a menhaden fishery in the late 1970's and early 1980's. The deep water in-line pound nets were replaced by shallow water singly-set pound nets, and as a result shad and river herring became by-catch species in pound nets. The PRFC adopted a commercial fishery moratorium for river herring in 2010, with a minimal by-catch provision of 50 pounds per licensee per day for pound nets. A pound net by-catch provision was put in place to enable monitoring of river herring runs. In 2012, all fisheries were closed to the taking and/or possession of river herring. The PRFC now has no commercial or recreational fisheries for river herring.

The PRFC adopted the mandatory use of fish cull panels in all pound nets in the Potomac River, effective January 1, 2011. Fish cull panels are specially designed and manufactured by-catch reduction devices that have been tested and used (prior to 2011) voluntarily in Potomac River pound nets. They were effective in the safe release of sublegal flounder, weakfish, spot, croaker and bluefish when installed in the bottom corners of the sides of the pound nets. The regulation requires that four panels be installed in the bottom corners of the upriver and downriver sides of the net, and two additional panels be installed closer to the surface for the purpose of releasing river herring. It is expected that this conservation measure will greatly reduce the by-catch of small fish in pound nets.

Prior to 2010, no river herring were reported as discarded because it was an open fishery and the fishermen kept their entire catch. The fishermen are now adding data for the discard/release of river herring, and in 2015 there were 715 pounds of river herring that were reported as discarded. However, an unknown amount of river herring are released each year from pound nets as a result of the mandatory use of the fish cull panels.

The Potomac River recreational fishery for river herring under the jurisdiction of PRFC was closed in 2010 in the main stem of the river below the District of Columbia. Recreational anglers have historically been permitted to harvest river herring within the District of Columbia's portion of the Potomac River by way of hook and line fishing, dip netting, and snagging, with no size or creel limit. As of January 1, 2012 recreational harvest of river herring was prohibited within the District's waters.

Note that the PRFC regulates and records harvest for only the main stem of the river, while the tributaries on either side are under Maryland or Virginia jurisdiction. Harvest records for alewife and blueback herring in the Potomac River have been historically combined as river herring.

14.4 ASSESSMENT HISTORY

A stock assessment on selected river herring stock was conducted in 1990 by ASMFC. This assessment included both alewife and blueback herring populations in the Potomac River. Stock-recruitment (S-R) analyses were originally planned for the Potomac River, but the river herring S-R data were considered to be unreliable because recruitment estimates were either missing for certain years, were of unacceptably short duration (<15 years), or yielded imprecise and implausible S-R parameters.

The assessment found that Potomac River alewife populations were or were being overfished ($u > u_{msy}$ or u_{coll}) to the extent that recruitment failure was apparent in the late 1980's. The Potomac River blueback herring stocks were not overfished ($u < u_{msy}$) but were experiencing a stock decline. The 1990 or historical u values for Potomac River blueback herring were within 75% of the u_{msy} levels, and therefore were considered by the criteria to be fully exploited. The time series of alewife and blueback herring abundance exhibited a pronounced downward trend during the 1980's which is consistent with excessive fishing mortality.

The assessment also concluded that the highest fishing mortality rates ($u>0.60$) on river herring occurred mainly near the northern (St. John and Damariscotta Rivers) and southern (Potomac, Rappahannock, Chowan Rivers) end of the distribution, where there are directed riverine fisheries. In order to rebuild the spawning population and stabilize recruitment in these river herring stocks, additional conservation measures were recommended to be imposed to reduce the fishing mortality rates below the u_{msy} levels. The results strongly suggested that heavy fishing pressure by the states of Maine, Virginia and North Carolina is primarily responsible for the continued decline of river herring stocks in the Damariscotta, Potomac, Rappahannock and Chowan Rivers.

14.5 STOCK-SPECIFIC LIFE HISTORY

Alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) are anadromous clupeids. Adult river herring usually appear in the Potomac River waters in March, and spawn through May. Approximately 44 to 65 percent of blueback herring in Chesapeake Bay tributaries are repeat spawners (Joseph and Davis 1965), as well as 30 to 72 percent of alewife (Weinrich et al. 1987; Howell et al. 1990). Alewife usually spawn three to four weeks earlier than blueback herring, giving juvenile alewife a relative size advantage over juvenile blueback herring, and thus access to a larger variety of prey (Jessop 1990); however, there may be considerable overlap in the spawning period (Loesch 1987). Hatching usually occurs within three to five days after fertilization (Edsall 1970). In addition to the annual run of adult river herring, the juveniles that were spawned use this tidal freshwater area as a nursery to grow and develop (Warriner et al. 1970). Michael Odom (U.S. Fish and Wildlife Service, personal communication) has observed that in the Potomac River, juvenile blueback herring are found in the pelagic main channel portion of tidal waters, while American shad juveniles seek shallower nearshore flats adjacent to and among SAV beds. Juvenile river herring in the Potomac River are abundant at the surface during daylight in the summer; however they shift to mid-water and bottom depths in the fall until they begin their seaward migration in November (Warriner et al. 1970). There appears to be some overwintering annually of both species of herring in the Chesapeake Bay (Dovel 1971; Hildebrand 1963).

14.6 HABITAT DESCRIPTION

The Potomac River is a major tributary of the Chesapeake Bay, the area of its watershed ranking fourth on the East Coast (Figure 14.26). The estuary extends 113 miles from its mouth to the head of tide. On the outskirts of the District of Columbia at Little Falls, a low head dam for water withdrawal has a fish passage facility that allows river herring to extend their spawning range an additional 10 to 12 miles upstream to Great Falls, a natural barrier to all anadromous species. Alosine fishes (American shad, hickory shad, alewife, and blueback herring) utilize that reach of the Potomac extending from Ragged Point to the fall line near Washington, D.C. (Warriner et al. 1970; Lippson and Moran 1974). The primary spawning grounds of alosine fishes include mainstream and tributaries from Mathias Point to the fall line. River herring also utilize the freshwater portions of downriver tributary streams in Maryland and Virginia as spawning sites.

Within District of Columbia, spawning herring are typically found congregating adjacent to man-made sea walls and rip rap barriers which account for much of the shoreline habitat. They can also be found “staging” in deeper holes and pools prior to significant rain events which trigger upstream migration and subsequent spawning. The larvae and juveniles spread throughout the tidal freshwater portion of the estuary (Warriner et al., 1970) and remain there until water temperatures drop in the fall; at that time they proceed seaward. Juvenile river herring tend to remain in clusters or schools moving along various types of shoreline cover, SAV beds, and open water.

Within the District of Columbia, there have been no significant losses of habitat over the past twenty years while potential habitat has been made available in Rock Creek. In 2007, DOEE installed a fish ladder at Pierce Mill in Rock Creek in conjunction with the removal of all of the remaining man-made obstructions to fish passage. These habitat improvements were designed to expand potential spawning habitat for river herring and other anadromous species. Electrofishing efforts in Rock Creek have been expanded to include this additional habitat, but have so far failed to confirm the utilization of the fish ladder by river herring.

14.7 RESTORATION

DOEE and PRFC currently have no restoration programs for river herring.

14.8 AGE

PRFC provided a bushel sample of pound net caught river herring to the Chesapeake Biological Laboratory for age analyses in 2011 and 2013. Results included in appendix. DOEE currently has no age data for river herring.

14.9 FISHERY DESCRIPTIONS

14.9.1 Commercial Permits

In 1964, the first year that the PRFC collected harvest data, there were 138 pound nets licensed. Pound net licenses have fluctuated from a high of 181 in 1969 to a low of 69 in 1974. The pound net fishery shifted from a shad and river herring fishery in the 1960's and early 1970's, when those species began declining, to primarily a menhaden fishery in the late 1970's and early 1980's with shad and river herring as bycatch species. After Maryland and Virginia established limited entry fisheries in the 1990's, the PRFC responded to industry's request and capped the Potomac River pound net fishery at 100 licenses in 1995. The 100 pound net licenses are held by 18 fishermen in 2017, and the PRFC only requires that one net be set; consequently the number of pound nets being fished in the Potomac is at a very low level.

14.9.2 Commercial Landings

With the total moratorium in place in 2012, the only reports of river herring are discards or releases.

14.9.3 Recreational Fishery

As of January 1, 2010 recreational landings were prohibited in the Potomac River water's under the jurisdiction of PRFC. As of January 1, 2012 recreational landings were prohibited in the Potomac River water's under the jurisdiction of the DOEE.

14.10 FISHERY INDEPENDENT SURVEYS

The DOEE Fisheries Research Branch conducts three main surveys in which river herring are regularly encountered. These surveys include boat electrofishing, seining, and push net.

MD DNR conducts an annual juvenile survey for YOY in the Potomac River, and a spring striped bass spawning stock survey in which river herring are encountered.

14.10.1Spawning Stock Survey

A standardized electrofishing survey is conducted throughout the District of Columbia's waters from March–November. This survey is conducted on a monthly basis at eight standard sites located throughout the District's jurisdiction. Four alternate sites were added in 1995; alternate sites are only visited every other month during May–November. Transects are run at each site for 600 seconds with 2 repetitions conducted at each site. This survey targets all species of fish located in the District and allows biologist to track population trends of both resident and anadromous fish species occurring in the District. In the spring, typically from April – June, adult river herring appear in this survey. The data collected from the herring include species and the length and sex of each herring netted. For large samples, data from 50 fish are recorded and the remaining fish are counted. The DOEE uses this survey to monitor trends in run sizes and the size structure of adults. CPUE is calculated by number of fish captured per hours of shock time; because the survey is conducted March – November only the data collected from March-June is used for the calculation of the adult herring CPUE (Table 14.3).

MDNR has conducted a spring striped bass spawning stock survey since 1959 in which river herring are encountered. The survey occurs above the Rt. 301 Bridge and the samples are collected using a drift gill net (Figures 14.6 and 14.7).

14.10.2Juvenile Surveys

A beach seining survey was initiated by DOEE in 1990. During June through October, a single haul is made at each of six fixed locations. Prior to 2010, sampling sites were visited once a month; as of 2010, the frequency of visits to the sites was increased to twice a month. This survey targets all YOY finfish occurring within the District of Columbia. The data that are recorded includes species and length. For large samples, data from 50 fish are recorded and the remaining fish are counted. Juvenile river herring show up in this survey typically from June – October.

The push net survey is conducted in the District of Columbia's Potomac River waters from July to September. This survey has been in effect from 2005 – present. The push net consists of a 4'x 3' frame with a 1/8" mesh bag attached. The frame pivots out over the bow of the boat and the net is then allowed to skim just below the surface of the water. A total of six fixed transects are run. The boat is kept at a constant speed of five mph for 10 min. Each site is sampled once a week for 11 consecutive weeks. This survey is designed to capture YOY alosine species. When samples are examined all fish are identified to species and counted; lengths are taken from a subset of 50 individuals.

A previous push net juvenile survey was conducted by the Interstate Commission on the Potomac River Basin (ICPRB) and U.S. Fish and Wildlife Service (USFWS) from 1997 to 2002 . This survey was generally upstream of the area of the river sampled by the MDNR YOY survey (described below). The purpose of the USFWS survey was to capture juvenile American shad to determine proportion of hatchery fish. Identification of river herring to species was not done by technicians all of the time, but blueback herring were encountered. Data from 1997 is not considered reliable because the sampling protocol and sites had not been standardized. Additionally data from 2002 was not processed. Funding for the ICPRB/USFWS survey ended in 2002.

MDNR has been annually sampling for juvenile/YOY river herring within the Chesapeake Bay since 1959. Durell and Weedon (2015) described the sampling protocol. Seine sampling occurs at 22 fixed stations using a 30.5 x 1.24 meter bagless beach seine of untreated 6.4 mm bar mesh which is set by hand. One end is held on shore while the other is fully stretched perpendicular from the beach and swept with the current. Stations have been sampled continuously since 1954, with changes in some station locations. The sampling is divided among four of the major spawning and nursery areas: seven each in the Potomac River and Head of Bay areas and four each in the Nanticoke and Choptank Rivers. Sampling is monthly, with rounds occurring during July, August, and September. Replicate seine hauls, a minimum of thirty minutes apart, are taken at each site on each sample round. This produces a total of 132 samples from which bay-wide means are calculated. In 1962, stations were standardized and a second sample round was added for a total of 88 samples. A third sample round, added in 1966, increased sample size to 132. Auxiliary stations have been sampled on an inconsistent basis and are not included in survey indices. The river herring juvenile indices for the Potomac River are derived from the MDNR juvenile survey (Figures 14.8 and 14.9).

14.11 ASSESSMENT APPROACHES AND RESULTS

There is very little data available to conduct an assessment of the population of river herring in the Potomac River.

14.11.1 Trends in Spawning Stock

Trends in spawning stock can be observed in data collected from the electrofishing survey in which a CPUE is generated. CPUE (fish captured per hour of shock time) indices derived from this survey show a drastic decline for both alewife and blueback herring from the late 1990s to early 2000s (Figure 14.28).

14.11.2 Trends in Length

The electrofishing survey provides data to observe trends in size structure of adult river herring. Size structure trends have remained relatively stable from 2005-2016; however data prior to 2005 is unavailable. During this time period average annual adult alewife lengths were between 259 and 270 mm for males and 283 to 290 for females. For blueback herring, average annual adult lengths were between 239 and 251mm for males and 258 and 270 mm for females.

Limited data is available from the pound net sample analyses conducted at CBL in 2011 and 2013 (See appendix).

14.11.3 Trends in Juvenile Abundance

The beach seining and push net surveys conducted by DOEE provide relative abundance data for juvenile river herring. Due to the differences in survey design and species identification it is difficult to draw trends between the USFWS/ICPRF and DOEE push net surveys. Geometric means (average number of fish per haul) derived from the beach seining survey show a dramatic decline in alewife numbers from the early 1990's until present day. By comparison, geometric means derived for blueback herring appear to have followed a cyclical pattern since 1994 (Figure 14.4). The push net survey show similar trends for both alewife and blueback. Since 2005, when the push net survey was started, the geometric means seem to follow a cyclical pattern (Figure 14.5).

The MD DNR juvenile/YOY river herring survey catches blueback herring in higher proportions. The 2016 geometric mean CPUE for alewife was 0.00, a decrease from the 0.24 value in 2015. The 2016 geometric mean CPUE for blueback was 0.17, compared to 4.00 in 2015. There are no apparent trends in the YOY indices. The geometric mean CPUEs for the Potomac River YOY alewife and blueback herring are presented in Figures 14.8 and 14.9.

14.11.4 Trends in Sex

Trends in sex are available from the DDOE electrofishing survey. In the DOEE electrofishing survey male alewives have consistently occurred more frequently than females, while there is no apparent trend for blueback herring.

Limited data is available from the pound net sample analyses conducted at CBL in 2011 and 2013 (See appendix).

14.11.5 Trends in Age

Limited data is available from the pound net sample analyses conducted at CBL in 2011 and 2013 (See appendix).

14.11.6 Trends in Repeat Spawning

No data is available for trends in proportion of repeat spawners.

14.11.7 Trends in Mortality

No data is available for trends in mortality.

14.12 BENCHMARKS

There are no benchmarks established for river herring fisheries in the Potomac River.

14.13 CONCLUSIONS

The YOY indices have fluctuated widely without trend. The population of blueback herring appears to be more abundant in the Potomac River than alewife herring.

PRFC and DOEE recognize that invasive species such as blue catfish potentially pose a threat to the river herring populations within the Potomac River. DOEE is currently establishing sampling protocol to investigate blue catfish populations and diet within the waters of the District of Columbia. PRFC has encouraged more commercial fishing to target blue catfish and the market for blue catfish has become stronger, especially in Maryland.

The PRFC and DOEE will continue to use surveys and YOY indices to track relative health of the river herring stock. The PRFC and DOEE will continue to communicate with the other management authorities on the Potomac River for additional data that may become available for the assessment of river herring.

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Table 14.10 Commercial Landings of River Herring in the Potomac River. A moratorium on the harvest of river herring was enacted in 2010, except for the limited pound net by-catch* of 50 lbs per day. A total moratorium was established in 2012. Source: PRFC.

Year	Landings	Year	Landings
1960	5,788,600	1986	1,198,669
1961	6,234,900	1987	1,164,854
1962	11,013,600	1988	182,656
1963	8,037,800	1989	97,047
1964	8,162,444	1990	49,734
1965	9,959,891	1991	365,966
1966	11,127,487	1992	162,885
1967	8,580,234	1993	144,752
1968	7,477,581	1994	80,258
1969	3,433,438	1995	113,504
1970	6,184,858	1996	80,447
1971	5,858,125	1997	59,949
1972	5,720,951	1998	18,501
1973	2,005,057	1999	26,656
1974	3,529,221	2000	33,370
1975	5,758,824	2001	35,723
1976	1,308,222	2002	55,086
1977	473,531	2003	20,132
1978	1,467,743	2004	19,739
1979	997,360	2005	8,507
1980	1,686,203	2006	6,819
1981	84,143	2007	6,011
1982	493,039	2008	5,476
1983	1,728,810	2009	8,925
1984	899,275	2010	898*
1985	261,675	2011	1,672*

Table 14.11 Adult alewife and blueback herring length frequency caught by electrofishing by year in Potomac River. Source: DOEE.

	Blueback herring - male											Blueback herring - female										
Bin	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<200											1											
200-209																						
210-219	1							1														
220-229	5	3	1			5	7		2		1											
230-239	25	24	3	3	10	5	22	11	25	21	13						1	1		1		
240-249	18	49	9	14	22	12	8	45	7	96	67		2		3	2	1	2	2	6	4	5
250-259	18	51	22	26	22	20	6	34	35	83	143		6	4	7	3	8		8	3	8	4
260-269	18	27	19	22	11	7	1	3	22	55	77		15	21	20	1	7		16	11	15	13
270-279	4	8	12	4	6	1			3	11	15		8	34	25	4	6		4	12	9	15
280-289	2	1	6	1					1	2	2	1	5	11	14	2	2			4	5	8
290-299			1										4	3	9		1				1	2
300-309														4	1							3
310-319																						
320-329																						
330-339																						
340-349																						
>350																						
Total	91	163	73	70	71	50	44	94	95	268	319	1	40	77	79	12	26	3	30	37	42	50

Table 14.12 Continued   Adult alewife and blueback herring length frequency caught by electrofishing by year in Potomac River. Source: DOEE.

	Alewife - male															Alewife - female						
Bin	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<200						1	1				7												
200-209																							
210-219																							
220-229						2	3				3												
230-239			1		9	10	9		14		21												
240-249	2	6	1	3	19	36	32	7	22	1	51						1	2	2				3
250-259	2	11	5	4	20	77	14	14	31	15	59		1	1	1		2	5	3	2			1
260-269	5	13	5	10	14	37	24	17	24	20	96			4	2		6	9	3	11	3		9
270-279	17	24	2	13	11	17	9	10	23	17	54		2	4		1	8	7	1	15	4	1	10
280-289	22	9	3	15	6	2		1	5	8	12		3	6	2	2	8	3	12	19	6	4	3
290-299	8	2	2	2	6	2	1	1		1	6		3	3	1	5	7	2	4	19	1	11	5
300-309	2			1			1	1		1	2		2	6		1	3			7	1	5	2
310-319				1									5	2		6				1		1	1
320-329															1		1					2	
330-339																							
340-349																							
>350																							
Total	58	65	19	49	85	184	94	51	119	63	311		16	26	7	15	36	28	25	74	15	24	34

Figure 14.26 The Potomac River Basin.

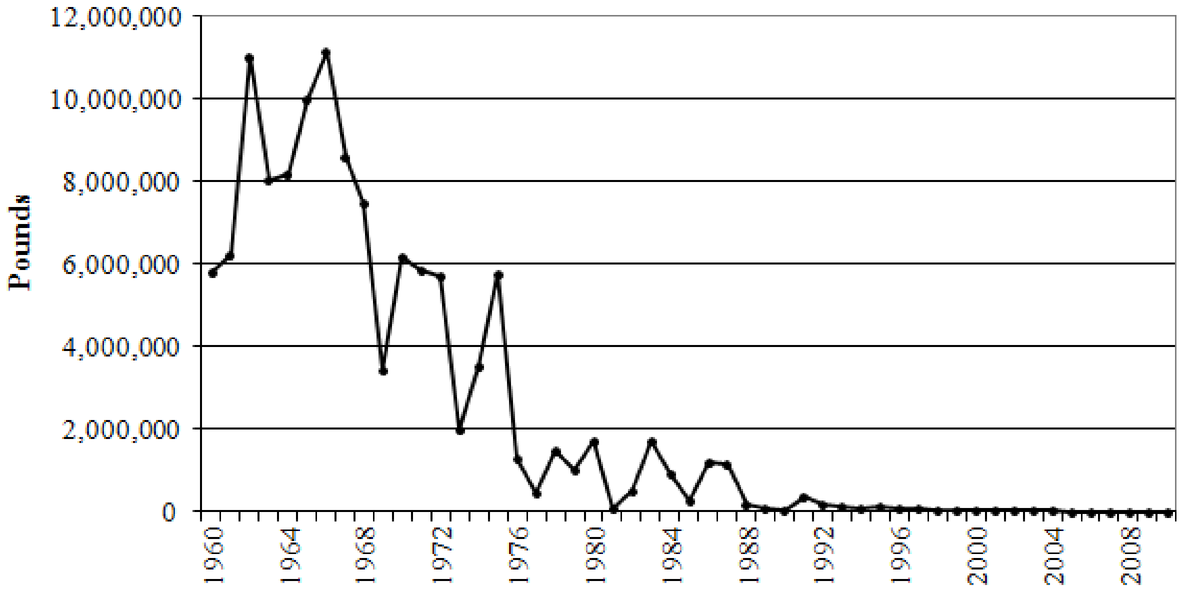

Figure 14.79 River Herring Harvested (pounds) in the Potomac River from 1960 – 2010. Source: PRFC

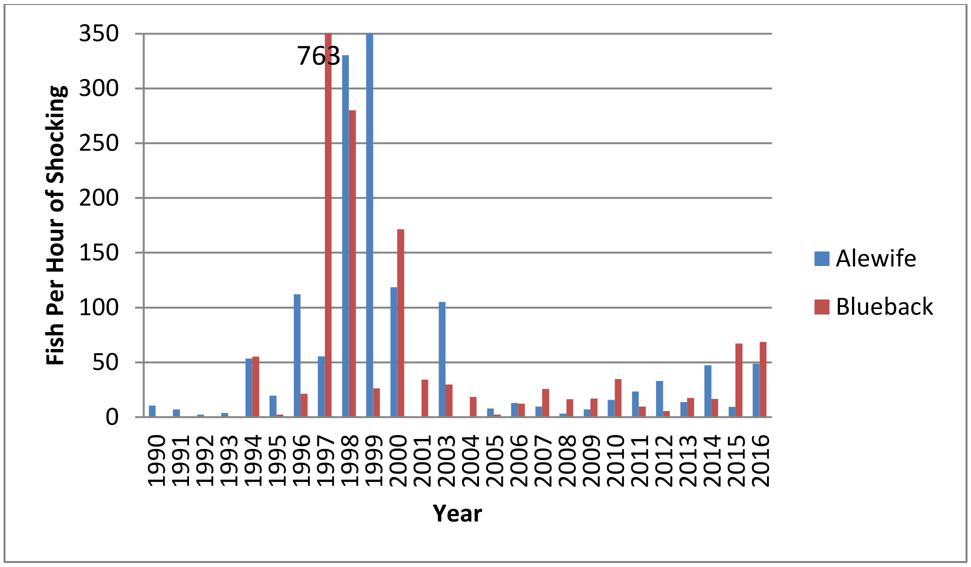

Figure 14.28 CPUE (fish per hour of shocking) of adult alewife and blueback herring during boat electrofishing survey in the Potomac River, 1990-2016. Source: DOEE.

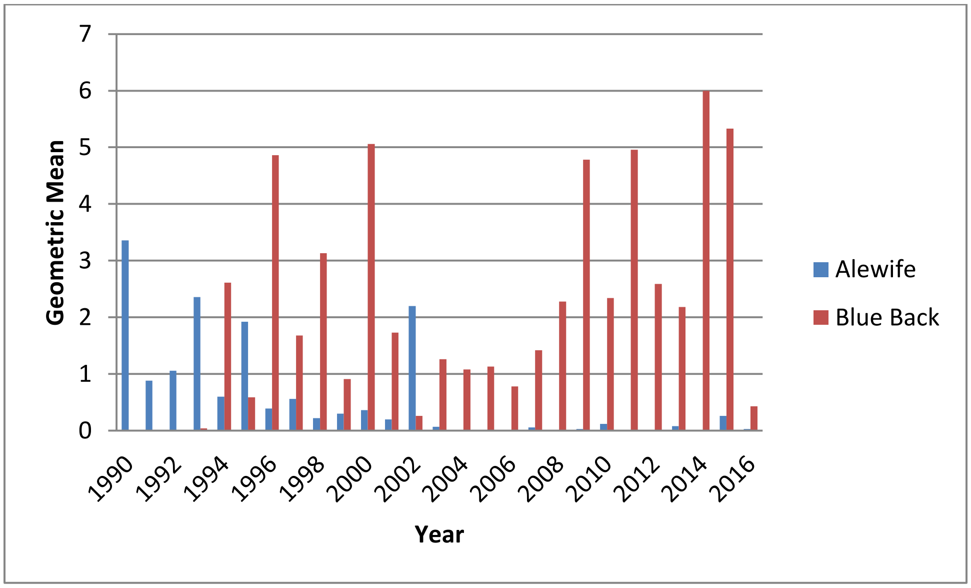

Figure 14.81 Geometric mean (average number of fish per haul) of YOY alewife and blueback herring caught during 100ft beach seining survey, 1990-2016

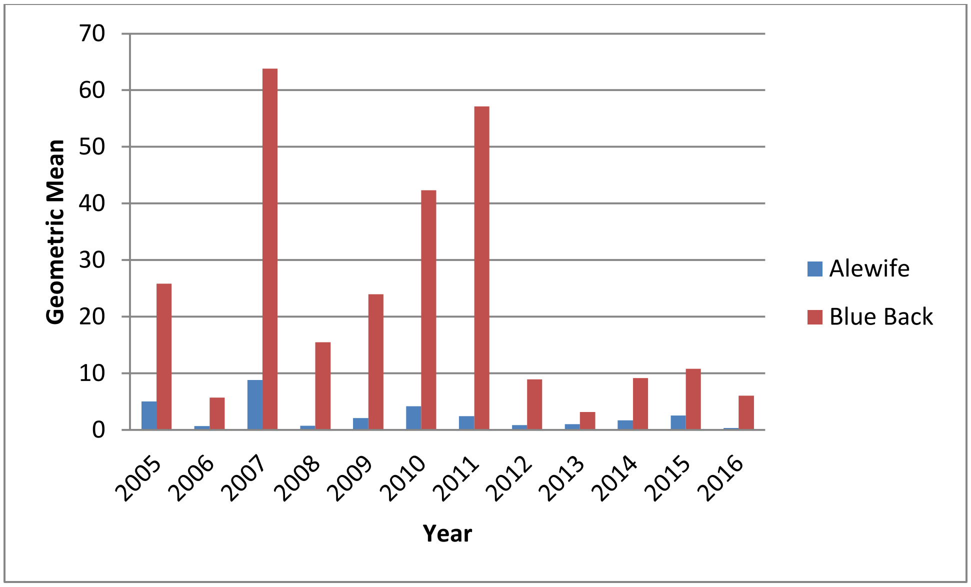

Figure 14.82 Geometric mean (average number of fish per haul) of YOY alewife and blueback herring caught during 10 minute push net survey, 2005-2016.

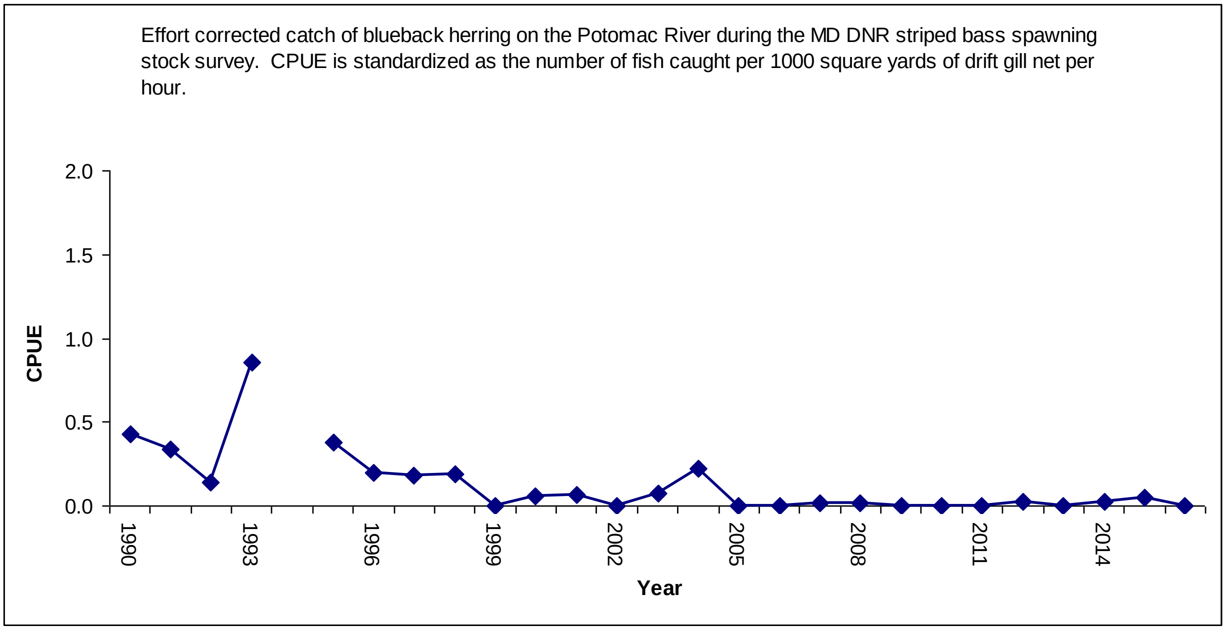

Figure 14.6 MD DNR striped bass spawning survey

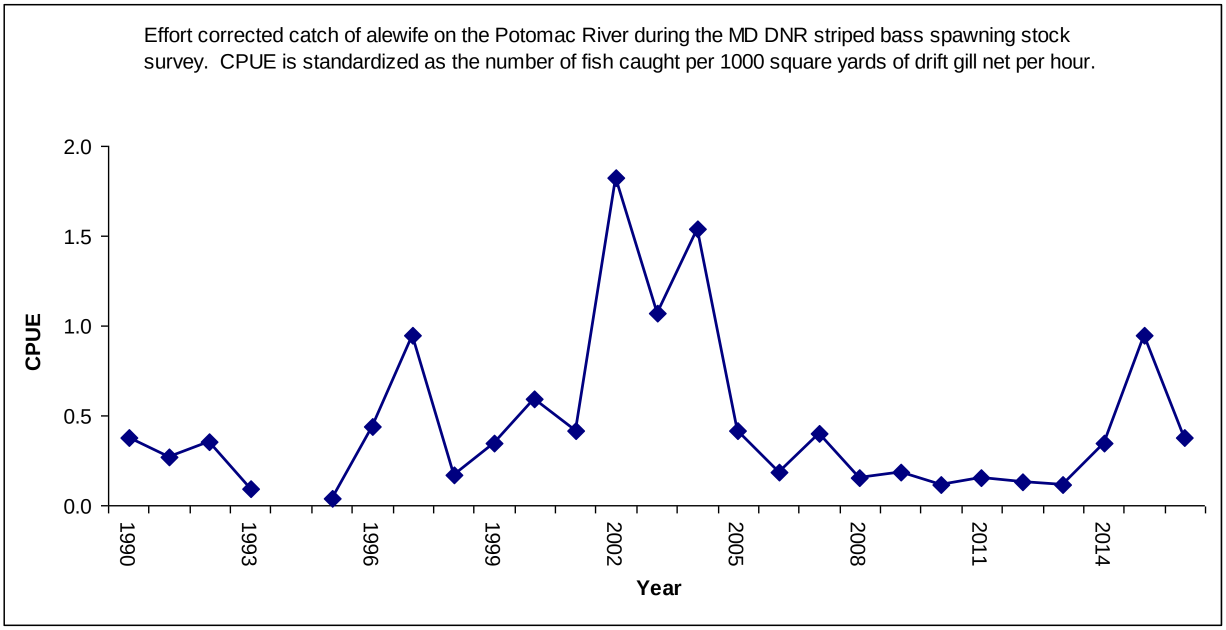

Figure 14.7 MD DNR striped bass spawning survey

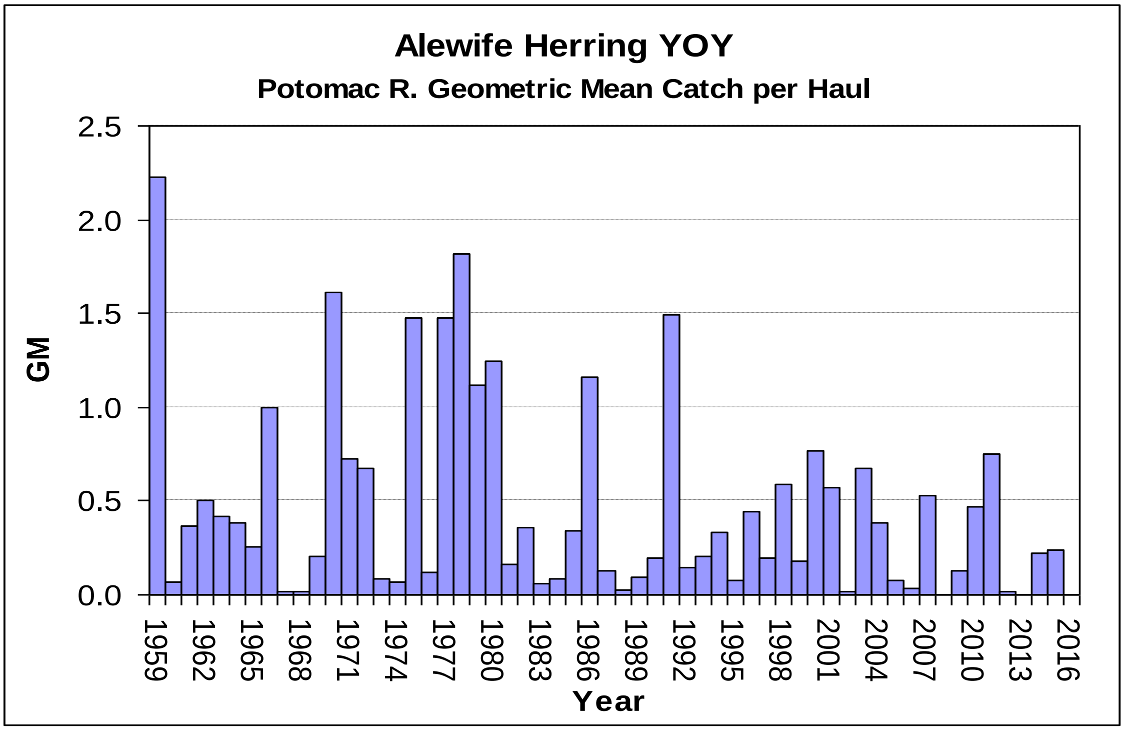

Figure 14.8 Juvenile alewife geometric mean (catch per haul) in the Potomac River (1959 – 2017). Source: Maryland Department of Natural Resources.

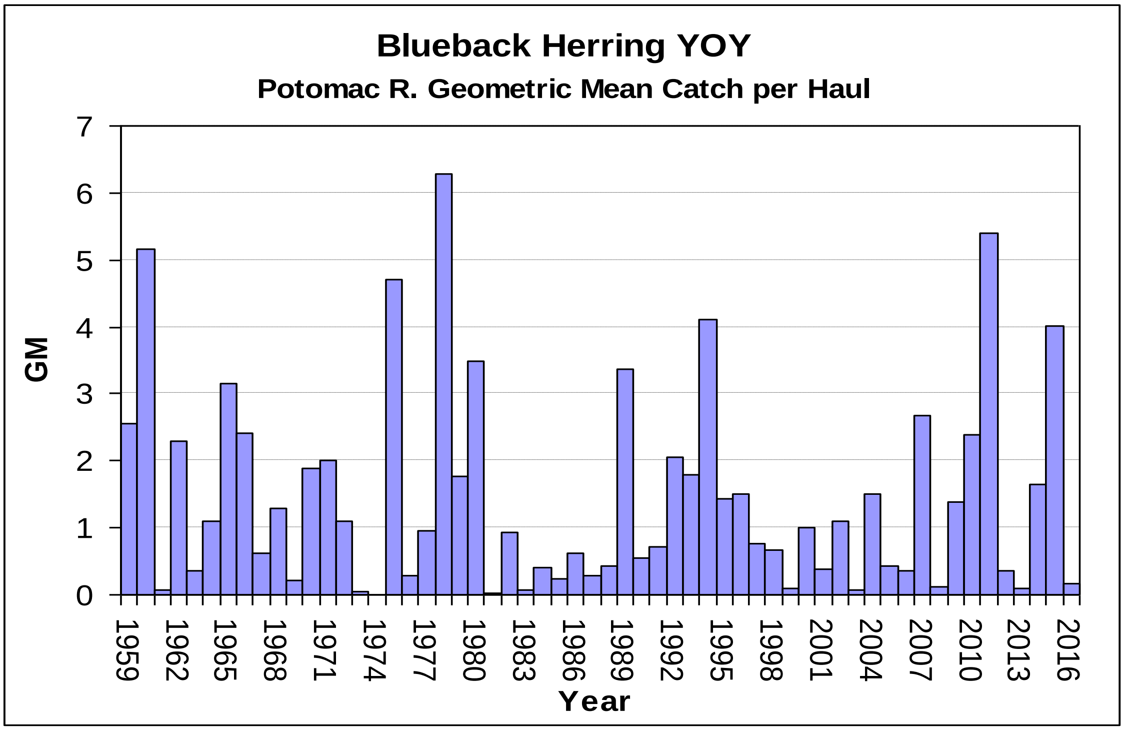

Figure 14.9 Juvenile blueback herring geometric mean (catch per haul) in the Potomac River (1959 – 2017). Source: Maryland Department of Natural Resources.

APPENDIX

Ref. No. [UMCES]CBL-11-040

The Biological Characteristics of River Herring Caught in Potomac River Pound Nets

Final Report Submitted to:

Potomac River Fisheries Commission

by

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September 2011

Technical Report Series No. TS-625-11 of the University of Maryland Center for Environmental Science.

1. Background.

River herring is a term used to describe two similar congeneric species of fish, blueback herring (*Alosa aestivalis*) and alewives (*Alosa pseudoharengus*). These two species display anadramous behavior, meaning that they live as adults in estuarine and ocean habitats but migrate to spawn in freshwater rivers. These two species will migrate into tributaries of the Chesapeake Bay to spawn each spring. Alewives may spawn a few weeks earlier than blueback herring in areas where they overlap (Jones et al. 1978). Upon spawning, adults will leave freshwater rivers and return to estuarine and ocean habitats (Jones et al. 1978). Eggs hatch in freshwater and larvae and juveniles spend the first year of their lives in fresh and brackish waters (Hildebrand 1963, Street et al. 1975). As adults, they feed primarily on zooplankton (Janssen and Brant 1981). They are preyed upon by a variety of other species and may play an important role in food web dynamics (Blackwell et al. 1997, Bowen and Harrison 1996, Buckel and Conover 1997, Buckel et al. 1999, Dew 1988). Historically, they supported large, valuable fisheries, but catches have declined significantly as damming of rivers has blocked access to spawning habitat.

Blueback herring range from Nova Scotia to Florida (Hildebrand 1963, Scott and Crossman 1973), whereas alewives range from Labrador to South Carolina (Berry 1964, Winters 1973). In areas where their ranges overlap, such as the mid-Atlantic Bight and Chesapeake Bay, these schooling species are often found together (Raney and Massman 1953, O'Dell and Mowrer 1984). They can be difficult to distinguish without close examination. There are several distinguishing characteristics between the two species. Blueback herring have a dusky, mottled peritoneum (the lining of the body cavity), while alewives have a pale, pink colored peritoneum. They are also distinguished by the diameter of the eye, which is significantly larger for alewives (Murdy et al. 1997).

Here we report the results of sampling of migrating river herring from the Potomac River in spring 2011 to determine the distribution and characteristics of both species.

2. Methods.

Fish were collected from Potomac River pound nets in May and delivered fresh, on-ice to the Chesapeake Biological Laboratory where they were frozen for future dissection and analysis. Fish were thawed in batches, weighed to the nearest 0.01 g. and measured for total length and fork length to the nearest 1 mm. Total length is a measure of the fish from snout to the end of the tail. Fork length is a measure of the fish from the snout to the shortest of the tail fin rays (the fork in the tail). Total length is preferred, but may not always be a representative measure of fish length because the longest fin rays may be subject to damage.

Fish were then dissected by making an incision from the anal pore to the pectoral fins in order to examine the body cavity. The peritoneum was visually inspected to determine the species of fish (Murdy et al. 1997). The gonads were then visually inspected to determine the sex of the fish. The next incision was made by removing the fish's head along the operculum followed by turning the head so that it was oriented with the snout vertically upwards. An incision was then made into the skull that was along a tangent following the upper portion of the eye socket. This sufficed to open the skull of the fish so that sagittal otoliths could be removed. Fish have two sagittal otoliths which can be prepared in a way that will show annual growth rings. Otoliths were rinsed and placed in a labeled vial for future ageing analysis.

Otoliths were aged using standard procedures (Secor et al. 1991). Briefly, otoliths were mounted in a clear epoxy resin (Epofix, Struers Company, www.struers.com). First, a layer of epoxy was poured into a tray of molds such that each mold was filled approximately half way. After the epoxy was allowed to cure, otoliths were placed into the molds and then covered with another layer of epoxy which was then allowed to cure for 24 hours. The embedded otoliths were then removed from the molds and thin-sectioned using a low-speed diamond wafering saw (South Bay Technology, www.southbaytech.com). The saw was outfitted with 2 parallel blades with a .3mm thick aluminum spacer between them. The embedded otolith was oriented in a manner that would allow for a transverse section and aligned so that the core of the otolith was in lined up with the spacer between the two blades. The thin-section was then mounted on a microscope slide using crystal bond as a mounting medium. The slide was placed under a standard bright field compound microscope and annuli were counted and recorded. Each otolith was read by two readers on two separate occasions. If the readers disagreed by more than two years, then that otolith was considered unreadable and removed from the analysis.

Disagreements in ageing may be a result of improper alignment of the otolith before sectioning or poor transmission of light through the thin-section. Additionally, these species may have marks that appear on their otoliths as a result of spawning events. These marks are often different in appearance and out of pattern relative to the annular marks, so care was taken to avoid counting these bands.

3. Results.

A total of 143 fish were sampled. 12 (8.3%) were identified as alewives and the remaining 131 were identified as blueback herring. All fish appeared to be gravid adults and preparing to spawn. 74 of the 131(56%) blueback herring were male, while 57 (44%) were female. Among the 12 alewives, 8 (66%) were male and 4 (33%) were female. Table 1 displays the size characteristics of the fish that were sampled. The alewives were slightly larger than the blueback herring. There were minimal differences in size between males and females.

A frequency distribution of the total lengths for both species reveals that blueback herring sampled lengths approximate a normal distribution except that there were two modes in the length distributions at 245 and 265mm (Figure 1). This same feature is found when looking at males and females separately (Figure 2). The distribution of sizes amongst males and females is very similar, except that females were encountered in a narrower range of sizes than males. The length and weight relationship for blueback herring is shown in Figure 3. There was no difference in the relationship (p=.7468) between male and females as tested by Analysis of Covariance using SAS (SAS version 9.2, Cary, NC). The model for this relationship is:

$$\text{Log}_{10}(\text{Total Length}) = 0.258(\text{Log}_{10}(\text{Weight}))+1.841$$

We note that alewives were not found in sufficiently high enough numbers to make any size- and sex-based inferences.

Otoliths were recovered and aged from 104 of the 143 fish. In 12 instances, readers disagreed on age while in 27 instances otoliths were not recovered or broken during dissection. The length at age for both species was consistent with previous studies (Joseph and Davis 1965, Pardue 1983) that examined fish from the mid-Atlantic region and Chesapeake Bay. Figure 4 shows the length at age for both species. Larger fish tended to be older, although there was a substantial amount of variation in length at age. Age 7 fish were the most common followed by Age 6 and Age 8. The younger age-classes are not well represented, but age of first spawning in these species is variable, as previous research has shown that less than 50% of age 4 fish may spawn.

Figure 5 shows the data for just blueback herring with each sex displayed separately. There is no difference in the relationship between length at age between males and females. As tested by ANCOVA. When examining the distribution of ages between species and sexes, the median age was 7 for both species and both sexes of blueback herring. The distribution of ages approximates a normal distribution around this age, with a minimum age of 4 for male blueback herring, 5 for female blueback herring, and 6 for alewives. The maximum ages recorded were 9 for alewives and 10 for both sexes of blueback herring.

4. Discussion.

The biological characteristics of blueback herring and alewives caught in Potomac River pound nets agrees with previous research on these species. Their migratory and spawning behavior indicate that these fish were moving into the Chesapeake Bay and Potomac River in advance of their spawning season. These fish were gravid and appeared ready to spawn. The difference in relative abundance between the species, with blueback herring representing the majority of fish encountered, has been previously documented in the Chesapeake Bay and mid-Atlantic regions (Joseph and Davis 1965), and also may be related to differences in the time of spawning between these two species.

Previous studies of spawning-aged river herring in this region (Joseph and Davis 1965, Street et al. 1975, O'Dell and Mowrer 1984) found fish of spawning age from 3 to 8 years old. This study found fish that were from 4 to 9 years of age with the majority of fish being 6 to 8 years of age. It is difficult to say if these changes are a reflection of the population or if there are artifacts in the spatial and temporal differences the sampling methods between studies. O'Dell and Mowrer (1984) found that blueback herring ages 5, 6, and 7 comprised 96% of the blueback herring spawning population as opposed to 57% in this study where there were significant numbers of 8 and 9 year old fish. River herring spawning migration behavior is not the same between species and sexes so a shift in sampling relative to the spawning run will result in a different portion of the population being characterized. This may influence the age, sex, and species composition of the sampled fish.

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Table 1. Summary of morphometric information on river herrings collected in the Potomac River in 2011.

	Blueback Herring		Alewife	
	Male	Female	Male	Female
Number	74	57	8	4
Average Total Length (mm)	254.0	250.6	264.1	266.0
Maximum Total Length (mm)	285	275	306	283
Minimum Total Length (mm)	214	223	242	245
Average Fork Length (mm)	225.7	222.4	234.9	234.8
Maximum Fork Length (mm)	263	246	260	247
Minimum Fork Length (mm)	188	198	219	215
Average Weight (g)	145.2	136.5	172.7	175.9
Maximum Weight (g)	196.4	203.7	266.6	223.9
Minimum Weight (g)	77.8	96.1	124.9	144.4

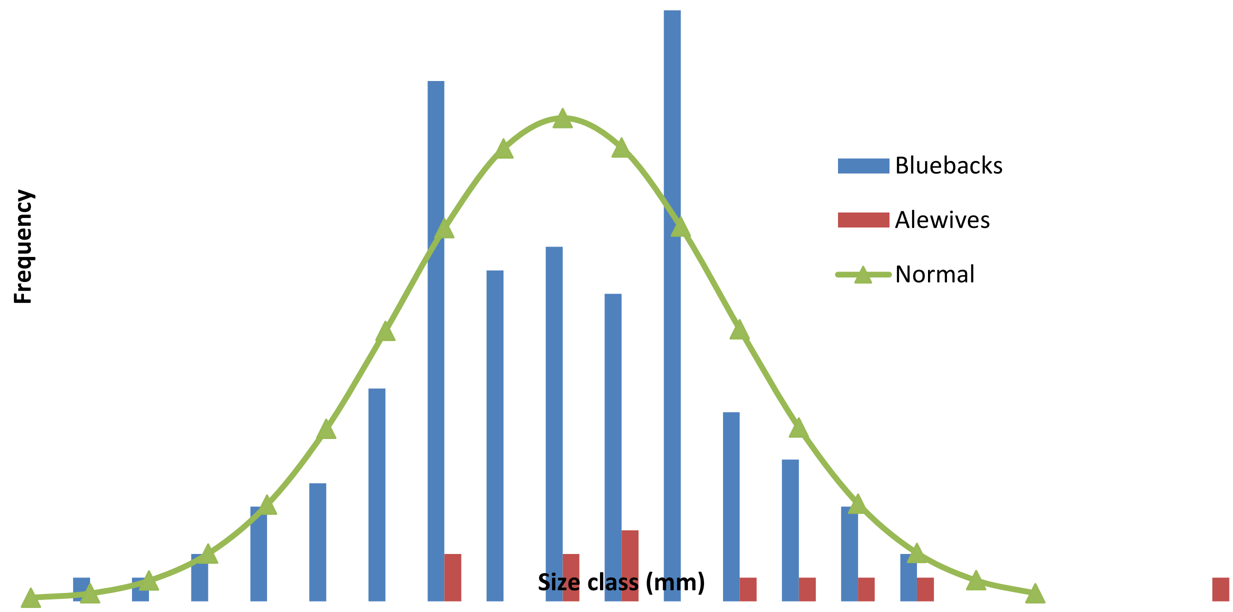

Figure 1. Size frequency distribution of blueback herring (blue) and alewife (red). A normal distribution of the predicted length frequency given the mean and variance is shown in green.

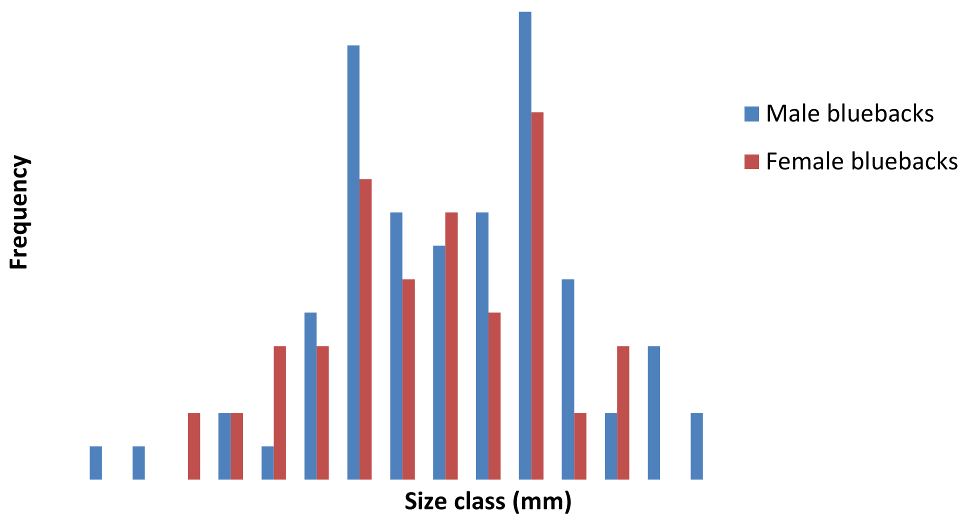

Figure 2. Size frequency distribution of male (blue) and female (red) blueback herring.

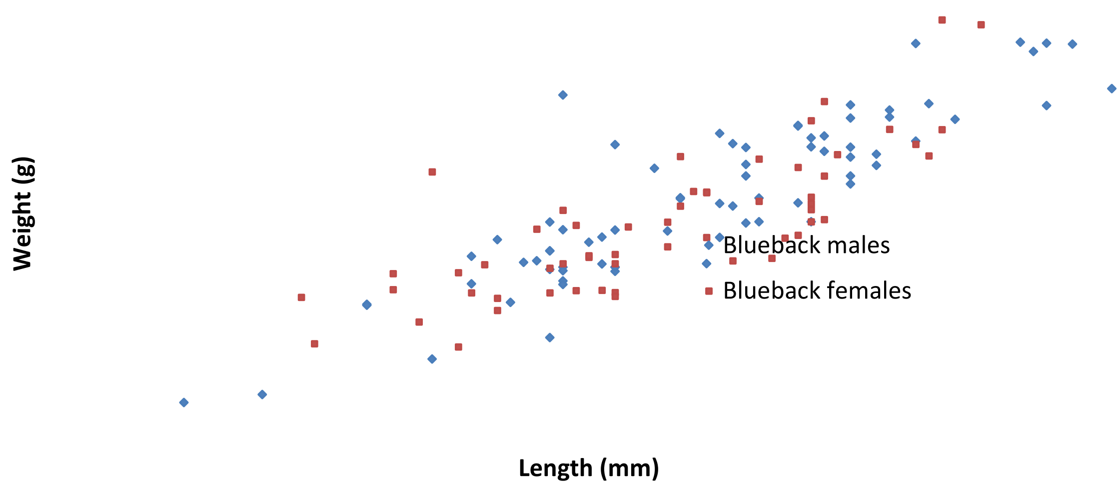

Figure 3. Length weight relationship of blueback herring. Males are show in blue. Females are shown in red.

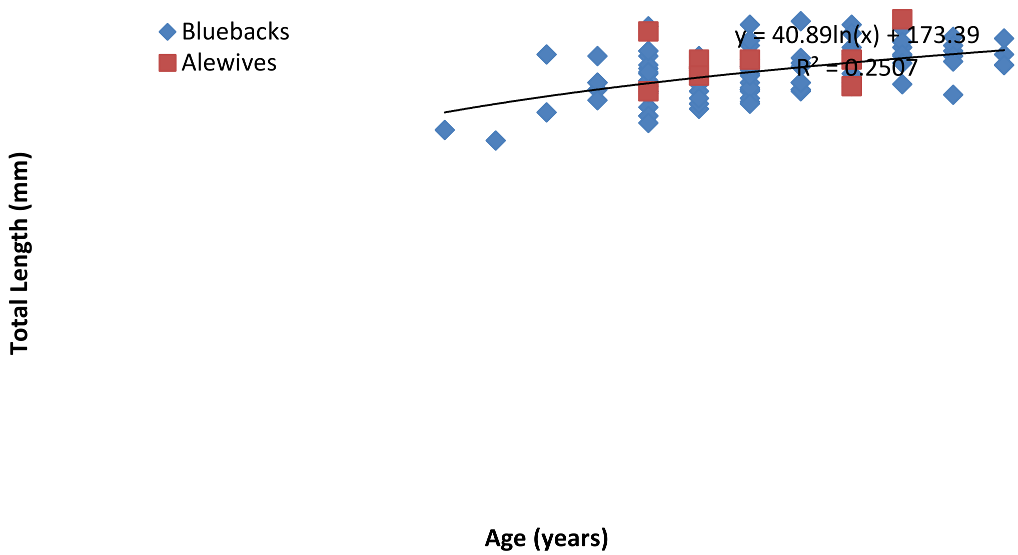

Figure 4. Total length at age for blueback herring (blue) and alewives (red).

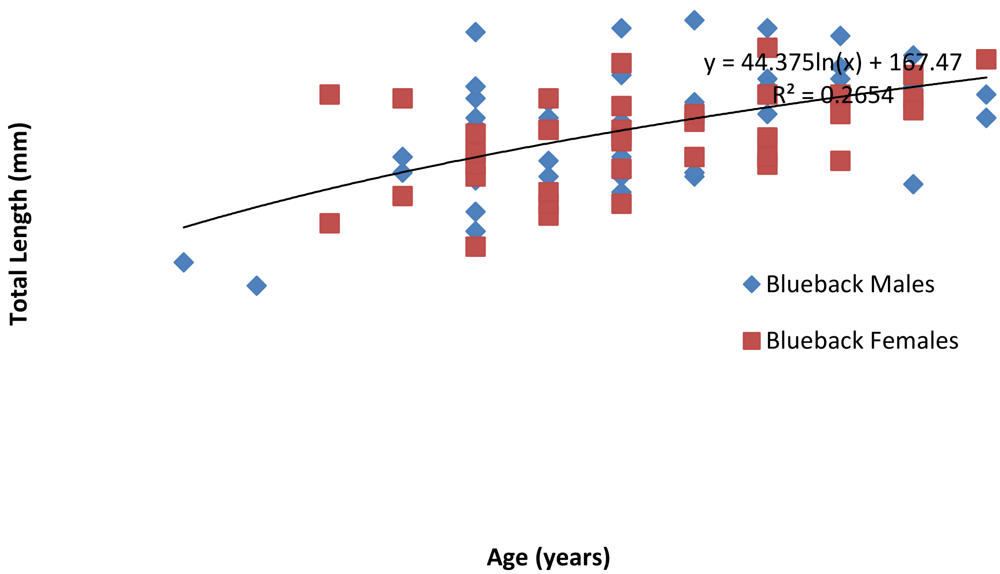

Figure 5. Total length at age for blueback herring by sex. Males are show in blue. Females in red.

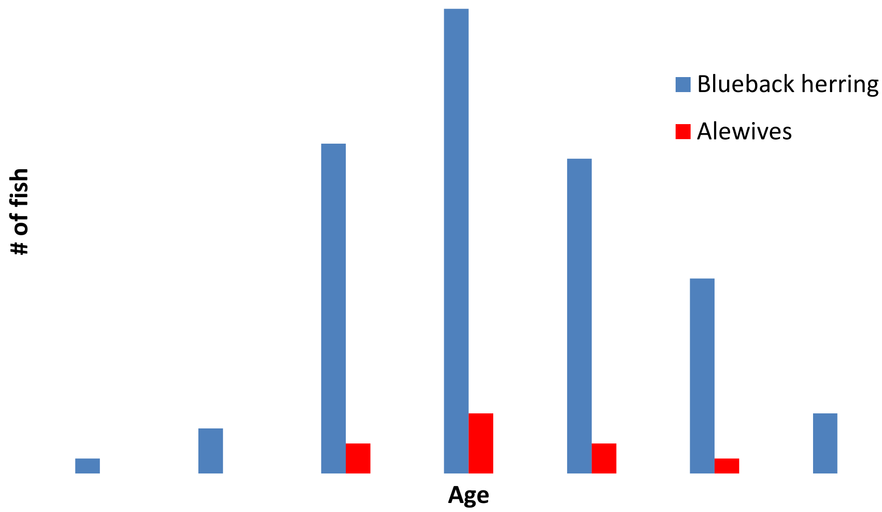

Figure 6. Frequency distribution of ages for blueback herring (blue) and alewvies (red).

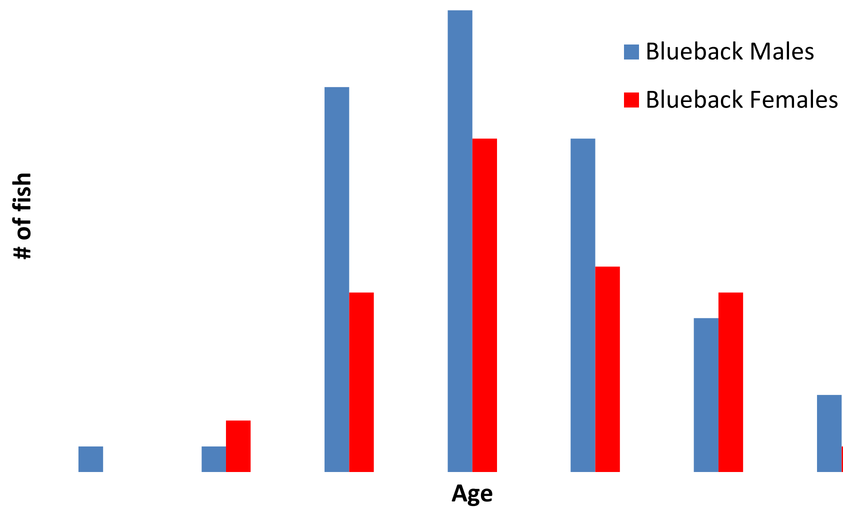

Figure 7. Frequency distribution of ages for blueback herring by sex. Males are shown in blue. Females are shown in red.

Ref. No. [UMCES]CBL 2013-045

The Biological Characteristics of River Herring Caught in Potomac River Pound Nets, 2013

Final Report Submitted to:

Potomac River Fisheries Commission

by

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Technical Report Series No.TS-649-13 of the University of Maryland Center for Environmental Science.

1. Background.

River herring is a term used to describe two similar congeneric species of fish, blueback herring (*Alosa aestivalis*) and alewives (*Alosa pseudoharengus*). These two species display anadramous behavior, meaning that they live as adults in estuarine and ocean habitatsbut migrate to spawn in freshwater rivers. These two species will migrate into tributaries of the Chesapeake Bay to spawn each spring.Alewives may spawn a few weeks earlier than blueback herring in areas where they overlap (Jones et al. 1978). Upon spawning, adults will leave freshwater rivers and return to estuarine and ocean habitats(Jones et al. 1978). Eggs hatch in freshwater and larvae and juveniles spend the first year of their lives in fresh and brackish waters (Hildebrand 1963, Street et al. 1975). As adults, they feed primarily on zooplankton (Janssen and Brant 1981). They are preyed upon by a variety of other species and may play an important role in food web dynamics (Blackwell et al. 1997, Bowen and Harrison 1996, Buckel and Conover 1997, Buckel et al. 1999, Dew 1988). Historically, they supported large, valuable fisheries, but catches have declined significantly as damming of rivers has blocked access to spawning habitat.

Blueback herring range from Nova Scotia to Florida (Hildebrand 1963, Scott and Crossman 1973), whereas alewives range from Labrador to South Carolina (Berry 1964, Winters 1973). In areas where their ranges overlap, such as the mid-Atlantic Bight and Chesapeake Bay, these schooling species are often found together (Raney and Massman 1953, O'Dell and Mowrer 1984). They can be difficult to distinguish without close examination. There are several distinguishing characteristics between the two species. Blueback herring have a dusky, mottled peritoneum (the lining of the body cavity), while alewives have a pale, pink colored peritoneum. They are also distinguished by the diameter of the eye, which is significantly larger for alewives (Murdy et al. 1997).

Here we report the results of sampling of migrating river herring from the Potomac River in spring 2013 to determine the distribution and characteristics of both species. This work replicates analyses of river herrings in the Potomac River conducted in 2011 (Loewensteiner et al. 2011).

2. Methods.

Fish were collected from Potomac River pound nets in May and delivered fresh, on-ice to the Chesapeake Biological Laboratory where they were frozen for future dissection and analysis. Fish were thawed in batches, weighed to the nearest 0.01 g. and measured for total length and fork length to the nearest 1 mm. Total length is a measure of the fish from snout to the end of the tail. Fork length is a measure of the fish from the snout to the shortest of the tail fin rays (the fork in the tail). Total length is preferred, but may not always be a representative measure of fish length because the longest fin rays may be subject to damage.

Fish were then dissected by making an incision from the anal pore to the pectoral fins in order to examine the body cavity. The peritoneum was visually inspected to determine the species of fish (Murdy et al. 1997). The gonads were then visually inspected to determine the sex of the fish. The next incision was made by removing the fish's head along the operculum followed by turning the head so that it was oriented with the snout vertically upwards. An incision was then made into the skull that was along a tangent following the upper portion of the eye socket. This sufficed to open the skull of the fish so that sagittal otoliths could be removed. Fish have two sagittal otoliths which can be prepared in a way that will show annual growth rings. Otoliths were rinsed and placed in a labeled vial for future ageing analysis.

Otoliths were aged using standard procedures (Secor et al. 1991). Briefly, otoliths were mounted in a clear epoxy resin (Epofix, Struers Company, www.struers.com). First, a layer of epoxy was poured into a tray of molds such that each mold was filled approximately half way. After the epoxy was allowed to cure, otoliths were placed into the molds and then covered with another layer of epoxy which was then allowed to cure for 24 hours. The embedded otoliths were then removed from the molds and thin-sectioned using a low-speed diamond wafering saw (South Bay Technology, www.southbaytech.com). The saw was outfitted with 2 parallel blades with a .3mm thick aluminum spacer between them. The embedded otolith was oriented in a manner that would allow for a transverse section and aligned so that the core of the otolith was in line with the spacer between the two blades. The thin-section was then mounted on a microscope slide using crystal bond as a mounting medium. The slide was placed under a standard bright field compound microscope and annuli were counted and recorded. Each otolith was read by two readers on two separate occasions. If the readers disagreed by more than two years, then that otolith was considered unreadable and removed from the analysis. Disagreements in ageing may be a result of improper alignment of the otolith before sectioning or poor transmission of light through the thin-section. Additionally, these species may have marks that appear on their otoliths as a result of spawning events. These marks are often different in appearance and out of pattern relative to the annular marks, so care was taken to avoid counting these bands.

3. Results.

A total of 229 fish were sampled. 29 (12.6%) were identified as alewives and the remaining 200 were identified as blueback herring. All but 3 of the fish (blue back herring, sex undetermined, 183-187mm TL) appeared to be gravid adults and preparing to spawn. 96 (48%) blueback herring were male, while 101 (51%) were female. Among the 29 alewives, 8 (28%) were male and 21 (72%) were female. Table 1 displays the size characteristics of the fish that were sampled. The alewives were slightly larger than the blueback herring. Blueback herring and alewife females were longer than their male counter parts.

A frequency distribution of the total lengths for both species reveals thatblueback herring sampled lengths approximate a normal distribution except that there were two modes in the length distributions at 245 and 265mm (Figure 1). This same feature corresponds with the different sizes that were observed between sexes (Figure 2). Alewives, although fewer in number, appear to have a similar pattern of sizes between sexes with modes of 260mm and 270mm for males and females, respectively (Figure 3). The length and weight relationship for blueback herring and alewives is shown in Figure 4. It should be noted that lower end of this relationship is represented primarily by male blueback herring and that the higher end of this relationship is represented primarily by female blueback herring.

Otoliths were randomly selected and aged from 62 of the 229 fish. The length at age for both species was consistent with previous studies (Joseph and Davis 1965, Pardue 1983) that examined fish from the mid-Atlantic region and Chesapeake Bay. Figure 5 shows the length at age for both species. Larger fish tended to be older, although there was a substantial amount of variation in length at age. The younger age-classes were not well represented, but age of first spawning in these species is variable, as previous research has shown that less than 50% of age 4 fish may spawn.

Figure 5 shows the data for length at age data for blueback herring with each sex and alewives in aggregate. Age 6 fish were the most common followed by Age 7. There is no difference in the relationship between length at age between male and female blueback herring as tested by ANCOVA. Upon examining the distribution of ages between species and sexes, the median age was 6 for both sexes of blueback herring and age 8 for alewives (Figure 6). The maximum ages recorded were 11 for alewives and for both sexes of blueback herring.

4. Discussion.

The biological characteristics of blueback herring and alewives caught in Potomac River pound nets agrees with previous research on these species. Their migratory and spawning behavior indicate that these fish were moving into the Chesapeake Bay and Potomac River in advance of their spawning season. These fish were gravid and appeared to be preparing to spawn. The difference in relative abundance between the species, with blueback herring representing the majority of fish encountered, has been previously documented in the Chesapeake Bay and mid-Atlantic regions (Joseph and Davis 1965), and also may be related to differences in the time of spawning between these two species.

In analyses of fish collected in the Potomac River, Loewensteiner et al. (2011) reported that 12% of 143 river herrings sampled were alewife, with the remainder being blueback herring. Blueback herring sampled varied from 214-285 mm TL and alewife varied from 242-306 mm TL. All sampled fish appeared to gravid adults preparing to spawn. The modal age of both species in the sample was 7 years. Blueback herring varied in age from 4-10 years and alewife from 6-9 years. The proportion of the overall river herring abundance comprised by alewife remained unchanged from 2011 in this year's sample at 12%. Size and age information for river herrings collected this year were very similar. Blueback herring sizes were more variable (172-314 mm TL) and alewife appeared slightly smaller (235-295 mm TL)this year compared to 2011. Age composition was also similar among the two years, with both blueback herring and alewife in the sample varying from 4-11 years

Previous studies of spawning-aged river herring in this region (Joseph and Davis 1965, Street et al. 1975, O'Dell and Mowrer 1984)found fish of spawning age from 3 to 8 years old. This study found fish that were from 4 to 11 years of age with the majority of fish being 6 to 8 years of age. It is difficult to say if these changes are a reflection of the population or if there are artifacts in the spatial and temporal differences of the sampling methods between studies. O'Dell and Mowrer(1984) found that blueback herring ages 5, 6, and 7 comprised 96% of the blueback herring spawning population as opposed to 58% in this study where there were significant numbers of 8 and 9 year old fish. River herring spawning migration behavior is not the same between species and sexes so a shift in sampling relative to the spawning run will result in a different portion of the population being characterized. This may influence the age, sex, and species composition of the sampled fish.

Overall, our results indicate that alewife collected in pound nets in the Potomac River remains a small proportion of the total river herring catch, and that the biological characteristics of both species in the catch suggest the fishery is removing mature adult fish capable of spawning.

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Table 1. Summary of morphometric information on river herrings collected in the Potomac River in 2013.

	Blueback Herring		Alewife	
	Male	Female	Male	Female
Number	96	101	8	21
Average Total Length (mm)	246.5	258.0	258.5	266.2
Maximum Total Length (mm)	314	290	285	295
Minimum Total Length (mm)	227	172	243	235
Average Fork Length (mm)	216.8	226.8	227.8	234.2
Maximum Fork Length (mm)	270	257	251	263
Minimum Fork Length (mm)	200	151	215	204
Average Weight (g)	131.7	160.4	155.1	171.4
Maximum Weight (g)	256.6	241.2	215.5	237.6
Minimum Weight (g)	101.2	35.3	131.3	107.2

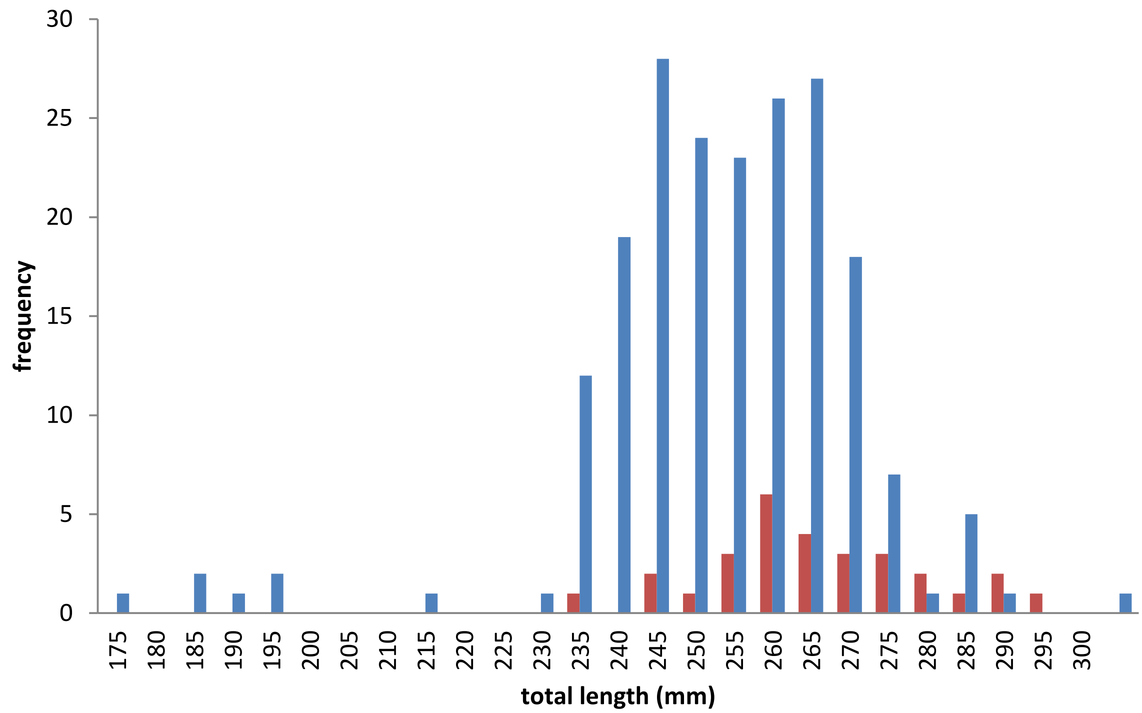

Figure 1.Size frequency distribution of blueback herring (blue) and alewife (red).

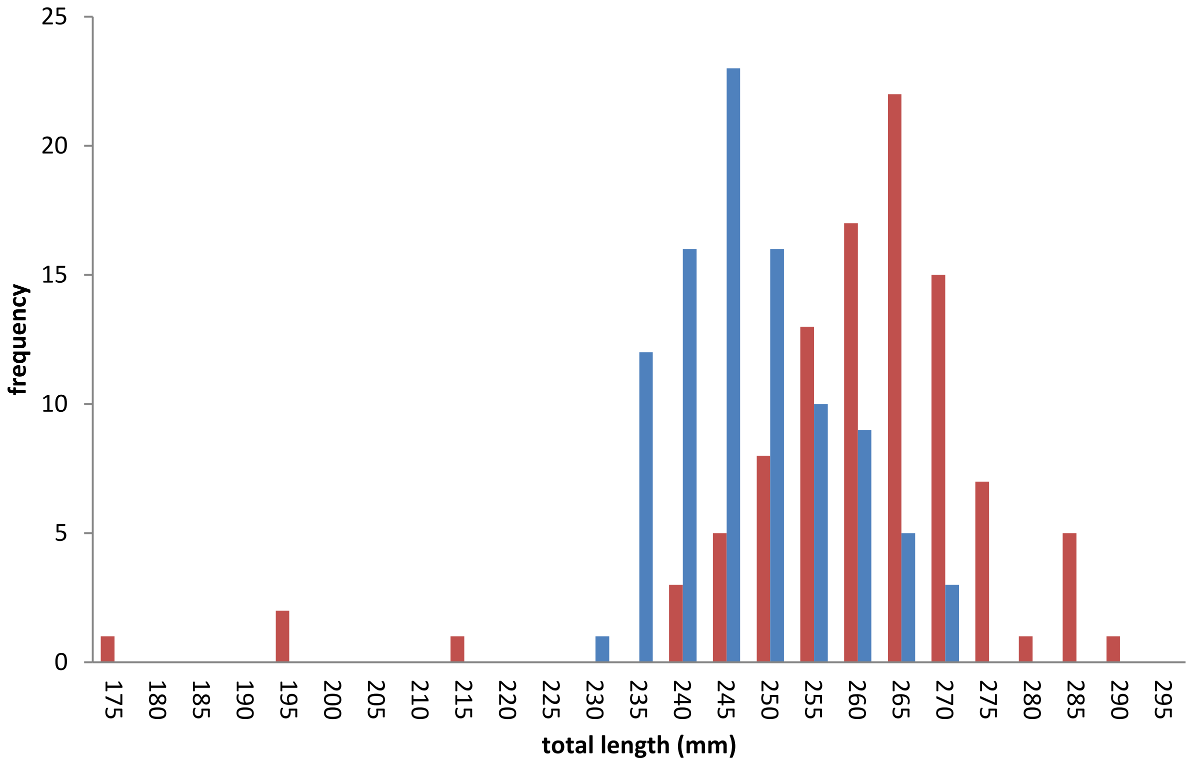

Figure 2.Size frequency distribution of male (blue) and female (red) blueback herring.

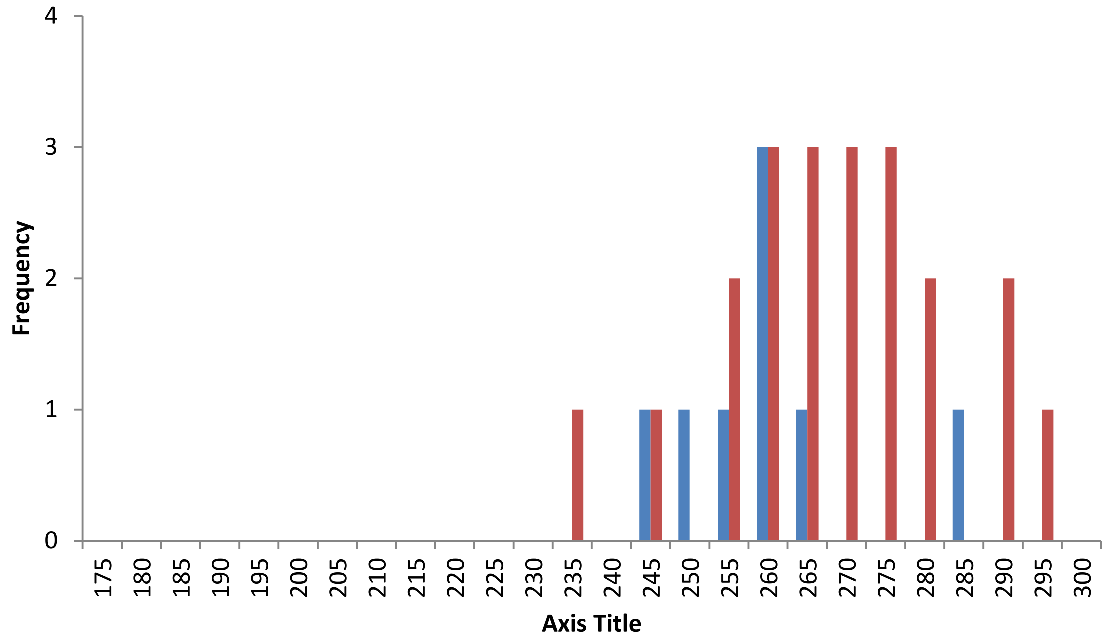

Figure 3.Size frequency distribution of male (blue) and female (red) alewives.

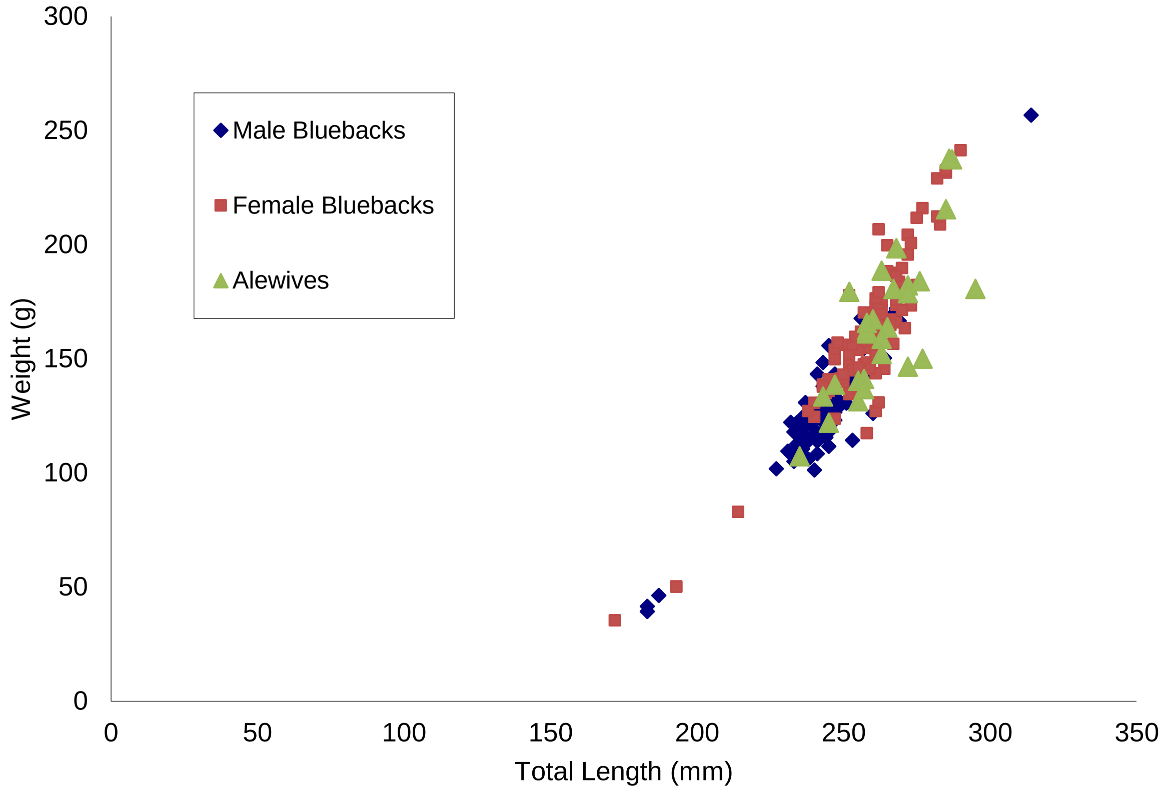

Figure 4. Length weight relationship for male blueback herring shown in blue, female blueback herring shown in red, and alewives shown in green.

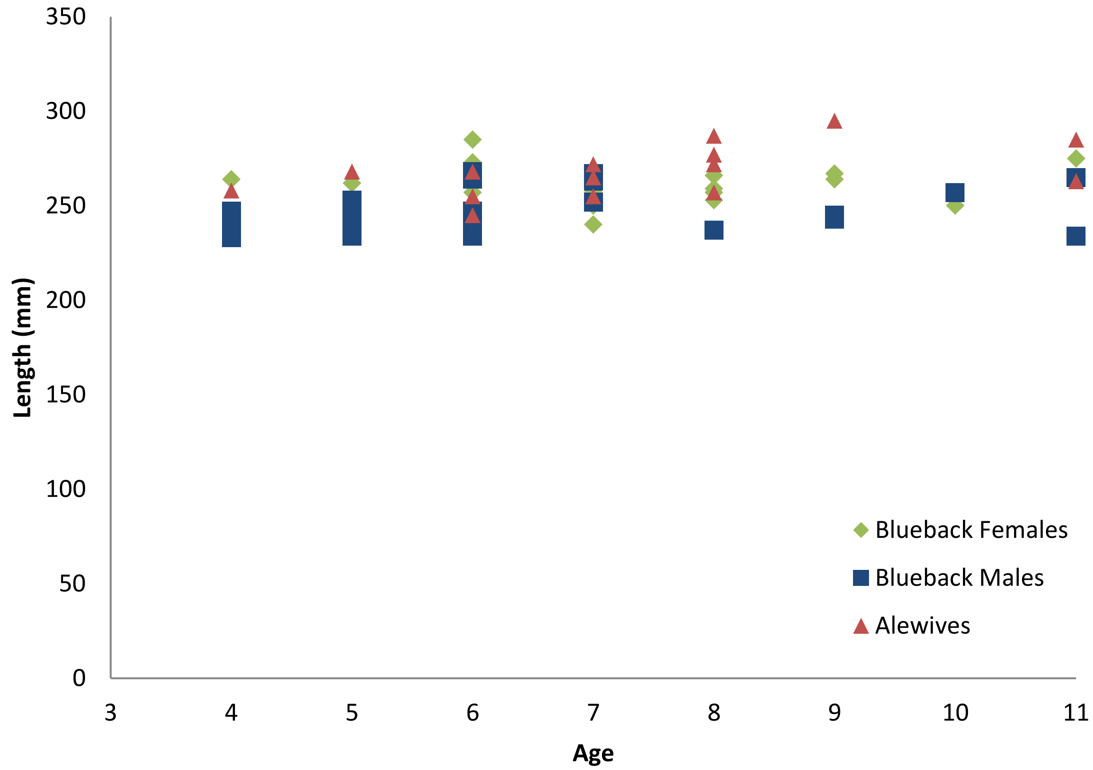

Figure 5. Total length at age for alewives (red) and blueback herring by sex (females in green, males in blue).

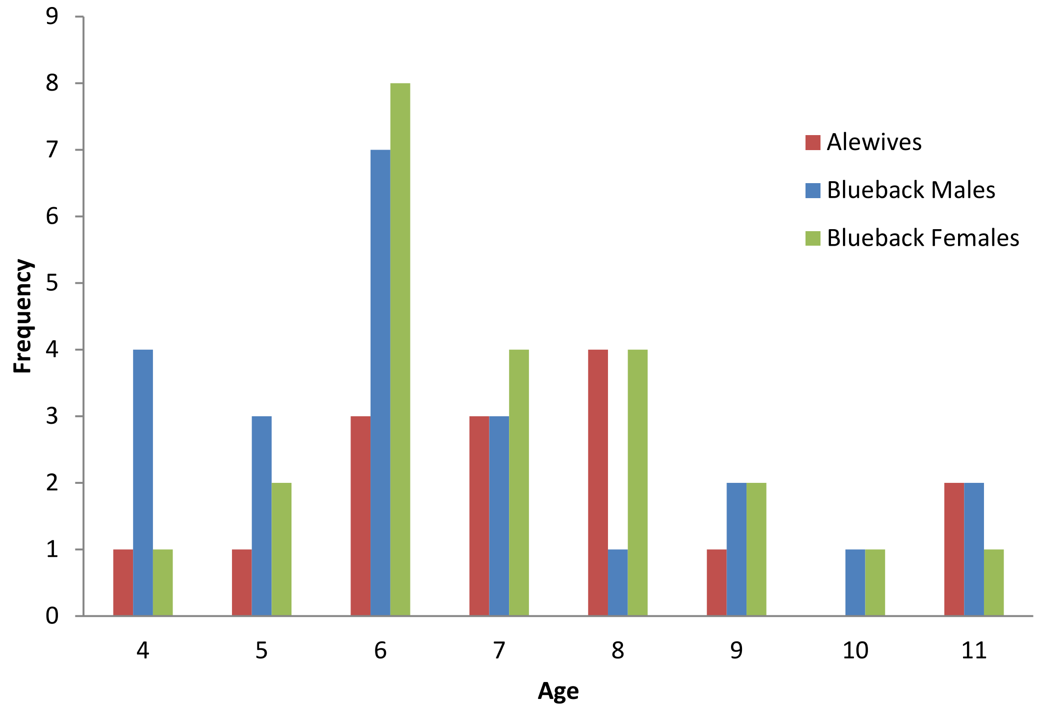

Figure 6. Frequency distribution of ages for alewives (green), blueback herring males (blue) and blueback herring females (green).

15 Status of River Herring in Virginia

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Executive Summary

River herring currently occur in all of Virginia's major rivers (Figure 15.1) and have been exploited by fisheries for a long time in Virginia. Since 1994, the majority of commercial harvest of river herring from Virginia waters has been attributed to the main stem of the Chesapeake Bay, averaging over 35 thousand kilograms (alewives and blueback herring combined) a year from 1994 through 2010. Gill nets were responsible for nearly 82% of the commercial harvest of river herring from the Chesapeake Bay during this time period. The gill net harvests are likely composed of mixed spawning runs of river herring migrating to Virginia and Maryland systems. Fisheries-independent sampling of juvenile abundance depicts considerable annual variability and show little trend over the available time series. However, there

are no data on juvenile abundance during the 1950s to 1970s when landings were higher and spawning runs were presumably stronger. The available data reported here are insufficient to quantitatively assess the current status of alewives and blueback herring in the James, York, and Rappahannock rivers.

The collapse of Virginia's commercial river herring fishery in the late 1970s reflects the same trend that has been observed for river herring landings along the U.S. east coast (Schmidt et al. 2003). This pattern has also been reported for Virginia's stocks of American shad during the same time period (ASMFC 2007). In the case of American shad, the VMRC imposed a ban on fishing in the Chesapeake Bay and its tributaries in 1994 in response to declining harvest. The 2007 ASMFC shad stock assessment confirmed that the 1994 ban on fishing was an appropriate action that has led to some recovery in the York River system (ASMFC 2007). Due in part to lack of available data to address the question of sustainability of river herring stocks in Virginia, and in order to comply with ASMFC Amendment 2 to for Shad and River Herring (ASMFC 2009), the VMRC implemented a ban on the possession of alewife and blueback herring that began on January 1, 2012.

INTRODUCTION

Assessment of alewife and blueback herring stocks is performed on a river-specific basis; each natal river is considered a unit stock. In Virginia, the majority of data available for river herring come from the James, York, and Rappahannock rivers (an assessment of river herring occurring in the Potomac River can be found elsewhere in this report). The stocks occurring in these river systems are the focus of this chapter.

15.1 DESCRIPTION OF MANAGEMENT UNIT(S)

Virginia's Department of Game and Inland Fisheries (VDGIF) is responsible for the management of fishery resources in the state's inland waters. The Virginia Marine Resources Commission (VMRC) oversees the management of resources in the state's marine waters.

15.2 REGULATORY HISTORY

The conservation and management of Virginia's river herring stocks dates back to colonial times. Loesch and Atran (1994) provide a brief historical overview of *Alosa* fisheries management in Virginia.

As of January 1, 2008, possession of alewives and blueback herring is prohibited on rivers draining into North Carolina (VMRC Regulation 4 VAC 15-320-25). Those rivers include the Meherrin River, Nottoway River, Blackwater River (Chowan Drainage), North Landing and Northwest rivers, and their tributaries plus Back Bay. On June 28, 2011, the VMRC voted to implement a ban on the possession of alewives and blueback herring in state waters; this ban became effective January 1, 2012 (VMRC Regulation 4 VAC-20-1260-30). The ban was enacted due to the collapse of the fishery over the last four decades and in order to comply with Amendment 2 to the Interstate Fishery Management Plan for Shad and River Herring (ASMFC 2009).

In evaluating Virginia's fisheries for river herring, it is important to note that the ocean fishery is a mixed-stock fishery, comprising river herring from different river systems. As such, river herring landed in Virginia have not necessarily originated in Virginia waters. The proportion of river herring from Virginia harvested from anywhere along the coast is currently unknown.

15.3 ASSESSMENT HISTORY

During 1966 through 1988, the Virginia Institute of Marine Science (VIMS) collected biological samples from Virginia's inshore alosine fishery as part of their annual assessment of the structure of adult alosine populations in the fishery. See sections 15.10.2–15.10.5, this report, for updated analyses of these data.

Tsimenides (1970) estimated total mortality of alewives using scales sampled from pound nets in the Rappahannock River during 1965 through 1969. The estimate of annual discrete total mortality rate (A) for male alewives was 0.594 and for females the estimate was 0.556. The male estimate of discrete total mortality (A = 0.594) corresponds to an instantaneous total mortality rate (Z) of 0.901. The estimate of discrete total mortality for female alewives (A = 0.556) corresponds to Z equal to 0.812.

A formal assessment of the alewife and blueback herring stocks occurring in the Rappahannock River was performed in 1990 as part of an assessment of multiple river herring stocks along the Atlantic Coast (Crecco and Gibson 1990). Stock status was assessed by comparing the annual discrete fishing mortality rate (u) at the time of the assessment to the river- and stock-specific annual discrete fishing mortality rate that produces maximum sustainable yield (u_{MSY}). The instantaneous natural mortality rate (M) was assumed equal to 1.0 based on a maximum age of 9 years. This value was assumed for all river herring stocks along the coast and was assumed constant for all adult age groups (ages 3–8). That instantaneous value of M (M = 1.0) corresponds to a discrete natural mortality rate (m) of 0.63. Estimated u was 0.37 for alewives and 0.42 for blueback herring based on data collected from 1980 through 1985. The estimated value of u_{MSY} was 0.62 for alewives and 0.67 for blueback herring. Both the alewife and blueback herring stocks were considered partially exploited because the estimate u for each stock was less than 75% of the respective u_{MSY}. The stock condition of the Rappahannock River alewife stock was defined as severely depleted due to a substantial decline in recruitment.

15.4 STOCK SPECIFIC LIFE HISTORY

River herring (alewife, *Alosa pseudoharengus* and blueback herring, *A. aestivalis*) are anadromous, highly migratory, schooling, pelagic fishes that spend most of the annual cycle at sea but enter Virginia's rivers and streams to spawn during late winter and spring. Alewives migrate earlier than other alosine fishes (blueback herring, American shad, hickory shad) and spawn at lower temperatures (Schmidt et al. 2003), thereby being the first anadromous species available for harvest each year in Virginia. The flesh of river herring is consumed usually as a smoked, salted, or fresh product. The ripe ovaries (roes) of females are highly prized. The annual spring spawning run of river herring and American shad is an important cultural and culinary event in Virginia and their traditional fisheries have cultural significance. In addition to human consumption, river herring are the prey of striped bass, blue catfish, longnose gar, and other predators encountered along the migratory route. A comprehensive review of river herring biology and their ecological services is presented by Munroe (2002).

The species are distinct and can be distinguished by cutting the abdomen and examining the pigmentation of the peritoneum—the membrane that lines the abdominal cavity. In alewives, the peritoneum is pale or white; in blueback herring, the peritoneum is sooty dark or black. This dissection is not a routine procedure in most commercial fisheries. When fresh specimens of both species are in hand, the alewife has a much larger eye and is deeper bodied than the blueback herring. Despite these clear differences, the species are often misidentified and mixed in fishery statistics. To further complicate assessments of abundance and stock status, river herrings can be confused with young American shad, hickory shad, Atlantic menhaden, Atlantic herring, and other similar species. Scientists suspect that these species are often misidentified and mixed in reports of harvest and landings.

15.5 HABITAT DESCRIPTION

In Virginia, river herring are found in the Chesapeake Bay and its major tributaries, including the Potomac, Rappahannock, York, and James rivers, as well as smaller tributaries and other coastal habitats (e.g., along the Delmarva peninsula). Additionally, both alewife and/or blueback herring are found in certain rivers in Virginia that drain to North Carolina, including the Meherrin River, Nottoway River, Blackwater River (Chowan Drainage), North Landing and Northwest rivers, and their tributaries plus Back Bay. Both species have been introduced into landlocked reservoirs in Virginia; a reproducing population of blueback herring occurs in Kerr Reservoir, and reproducing populations of alewife are found in at least Smith Mountain Lake, Leesville Reservoir, Claytor Lake, and Bluestone Reservoir (Desfosse et al., 1994). The Potomac Rivers and those of North Carolina are described elsewhere in this assessment; here we focus on the major western tributaries of the Chesapeake Bay.

15.5.1 James River

The James River forms at the junction of Cowpasture and Jackson rivers (rkm 580), and its drainage is the largest watershed in Virginia, totaling 26,164 km^2 (Jenkins and Burkhead, 1994). Average annual spring discharge on the James River is 294.2 m^3/s (Tuckey 2009). Prior to damming, which began in the colonial period, shad and river herring were reported to reach these headwaters and far into the major tributaries of the James River (Loesch and Atran, 1994). The two primary tributaries of the James River below the fall line at Richmond are the Appomattox River, which joins at the city of Hopewell (rkm 112), and the Chickahominy River, which joins at rkm 65. The extent of salt water is variable, but brackish conditions are observed as far up as the mouth of the Chickahominy River on a seasonal basis. Tidal water reaches Boshers Dam in Richmond (rkm 182). Numerous dams on the James River and its tributaries have historically blocked migration of fishes. Between 1989 and 1993 three dams below the fall line were breached or notched, extending available habitat to the base of Boshers Dam. A fish passage was installed in Boshers Dam in 1999, reopening 221 km of the upper James River and 322 km of its tributaries to river herring and other anadromous fishes; the next dam of the mainstem is at Lynchburg, VA (Weaver et al., 2003). The first existing dam on the Appomattox River is at rkm 17; and that on the Chickahominy is Walkers Dam at rkm 35 (with a fish passage rebuilt in 1989). A number of additional dam removal and fishway construction projects have occurred on several smaller creeks and streams in the James River drainage as well (http://www.dgif.virginia.gov/fishing/fish-passage/).

15.5.2 York River System

The York River system includes the Mattaponi and Pamunkey rivers, which merge at West Point, VA, to form the York River (53 rkm). This is the smallest of the three western tributary systems, with a watershed of 6,892 km^2 (Jenkins and Burkhead, 1994); the Pamunkey drainage is larger and has greater average spring discharge than that of the Mattaponi (3,768 km^2 and 47.5 m^3/s vs. 2,274 km^2; 27.2 m^3/s, Bilcovic 2000). Tidal propogation extends to approximately 67 rkm in the Mattaponi and 97 rkm in the Pamunkey (i.e., approximately 120 km and 150 km, respectively, from the mouth of the York River; Lin and Kuo, 2001). The extent of the salt intrusion varies by season, but moderate salinity values (>2 ppt) are often observed in lower portions of these rivers. The Mattaponi, Pamunkey, and York rivers are all undammed.

15.5.3 Rappahannock River

The Rappahannock River, which is approximately 195 km in length (172 km is tidal; 118 is salt water), has its headwaters in the piedmont and is fed by the Rapidan River. The Rappahannock watershed encompasses a total of 7,032 km^2 (Jenkins and Burkhead, 1994), and the average annual discharge at the fall line is 45 m^3/s (O'Connell and Angermeier 1997). The Rappahannock River was dammed until 2004, when the Embrey Dam, built in 1855 at Fredericksburg (rkm 250), was breached. Removal of the dam opened 170 km of potential habitat for migratory fishes, such as river herring. The Embrey Dam was the last remaining dam on the Rappahannock. A fish passage was installed on the Orange Dam on the Rapidan River (http://www.dgif.virginia.gov/fishing/fish-passage/). An estimated 125 tributaries of the Rappahannock River are potentially used by alosines (O'Connell and Angermeier 1997).

15.6 RESTORATION PROGRAMS

Since 2005, Virginia Commonwealth University (VCU) and USFWS's Harrison Lake National Fish Hatchery have conducted a river herring restoration program focused on Kimages Creek, a small tributary of the James River (VCU Rice Center, Charles City County, VA). Historically, Kimages Creek supported a river herring run but was impounded at the mouth in 1928. Remnants of the run persisted below the dam into the 1970s. VCU collected broodstock from several locations, including Herring Creek, Wards Creek, and the James River, and USFWS staff at Harriosn Lake National Fish Hatchery reared and OTC-marked the larvae, which were stocked into Kimages Creek. An informal target of 1M larvae (mostly blueback herring but some alewife) annually up to Spring, 2011. From 2008 through 2011 limited monitoring for returning adults has recovered approximately 10 OTC-marked, reproductive adults in Kimages Creek. However, there are no funds to formally continue any dedicated restoration at this time. In December 2010, VCU, The Nature Conservancy and American Rivers re-established fish passage into a restored tidal Kimages Creek by removing 200 feet of the earthen dam at the Rice Center.

The Virginia Department of Game and Inland Fisheries (VDGIF) has been working to restore access to two major river systems (the James and Rappahannock rivers), and their tributaries as part of a restoration effort for all anadromous species. Most of these projects have taken place over the past two decades.

15.7 AGE

Fisheries dependent sampling for scales was conducted from 1966 through 1978, and for otoliths from 1975 through 1988. In this assessment, data from the following reports were used: Davis et al. 1970, 1971, 1972; Hoagman et al. 1973, 1974; Hoagman and Kriete 1975; Loesch and Kriete 1976, 1980–1984;

Johnson et al. 1978; Loesch et al. 1977, 1981, 1985, 1986; Blumberg and Loesch 1988, 1989. Since 2015, otoliths have been sampled from the VIMS adult spawning stock survey in the Chickahominy River.

15.8 FISHERIES DESCRIPTIONS

Since 2003 (until the moratorium in January 2012), commercial fishing for river herring in Virginia takes place primarily in marine and estuarine waters. The major gears are gill nets and pound nets, with some ancillary use of haul seines, fyke nets, and other gears. The other category includes common dip nets, hand lines, and pots, based on VMRC reporting records. Recreational anglers fish for river herring primarily in upstream areas using hook and line, recreational gill nets, and dip nets. A brief history of Virgnia's *Alosa* fisheries can be found in Loesch and Atran (1994).

15.8.1 Fisheries-Dependent

15.8.1.1 *Commercial Fisheries Reporting*

The VMRC's commercial fisheries records include information on both commercial harvest (fish caught and kept from an area) and landings (fish offloaded at a dock) of marine species in Virginia. The VMRC began collecting voluntary reports (monthly) of commercial landings from seafood buyers in 1973. A mandatory harvester reporting system was initiated in 1993 and collects trip-level data on harvest and landings within Virginia waters. Data collected from the mandatory reporting program are considered reliable starting in 1994, the year after the pilot year of program. The Potomac River Fisheries Commission (PRFC) has provided information on fish caught in their jurisdiction and landed in Virginia since 1973. Records of fish harvested from federal waters and landed in Virginia have been provided by the NMFS and its predecessors since 1929 (NMFS, Fisheries Statistics Division, Silver Spring, MD, pers. comm.).

Estimates of commercial landings for river herring prior to the start of the mandatory harvester reporting program should be interpreted with care. A significant portion of the river herring catch has been used for oil, meal, and crab bait (Joseph and Davis 1965). Prior to 1993, most of that catch was not recorded since data collection programs primarily considered food fish. The mandatory harvester program does, however, allow the reporting of landings as "bait" with no identification to species. As such, some true river landings may be reported as bait and therefore not classified as river herring in the data (VMRC, Fisheries Management Division, pers. comm.). Another issue is that the river herring species were not differentiated in the landings records prior to VMRC's mandatory harvester reporting program—historic landings recorded as alewives include both alewives and river herring (e.g., U.S. Bureau of Fisheries 1941). Data obtained from the VMRC's mandatory reporting program suggest alewives continue to make up the majority (~98%) of Virginia's commercial river herring landings. However, available biological samples from the commercial fisheries suggest the proportion of alewives in the commercial landings is not that excessive or, at least, did not dominate the landings to that degree in the past (see section 1.2.1.3, this report). It is likely that at least a portion of the blueback herring landings continue to be reported as alewives. There is also concern that some commercial landings reported as alewives are, in fact, Atlantic menhaden (VMRC, Fisheries Management Division, pers. comm.). This may be reflected in river herring landings being reported in all months of the year and in gill nets that are harvesting larger fish, like striped bass, which has an eighteen inch minimum size.

Annual commercial landings were available for intermittent years from 1880 through 1925 and were available for all years beginning in 1929 (Table 15.1). Available historical commercial landings data for river herring in Virginia depict an active and productive fishery in the period 1950–1970 with total landings exceeding 14 million kilograms in some years (Figure 15.2). The time series of commercial landings suggest several periods of declining landings (during the 1930s; during the mid-1950s to early 1960s) followed by periods of increased landings. A steep decline in Virginia's landings in the late 1970s was followed by an apparent collapse of the fishery.

Since 1994 (VMRC mandatory harvester reporting), commercial harvest of river herring from Virginia waters ranged from 9.5 thousand kilograms to 118 thousand kilograms from 1994 through 2010 (Figure 15.3). Most of the commercial harvest since 1994 (55%) has been reported from the main stem of the Chesapeake Bay (Figure 15.4). The James (8.43%), York (16.7%), and Rappahannock (10.4%) rivers combined account for about 35% of the commercial harvest. The majority of Virginia's commercial river herring harvest has been taken by gill nets (Figure 15.5).

Annual commercial fishery harvest rates for alewives were calculated for 1994 to 2010 for selected Virginia water bodies. Harvest rates were calculated for gill nets—the major commercial gear for the time period. Annual harvest rates were computed as ratio estimators by dividing commercial harvest (kilograms) by the number of fishing trips for each water body (Pollock et al. 1994). Only fishing trips with positive harvest of alewives were included in the calculations; information on unsuccessful trips were not available. Annual harvest rates have been variable in the James, York, and Rappahannock rivers (Figure 15.6). Harvest rates in the James River have been variable over the time series. Gill-net harvest rates in the York River were relatively low through 2002 and have been variable, but generally increasing, over the rest of the time series. In the Rappahannock River, a three-year period of relatively higher rates occurred from 2002 to 2004. A small peak occurred in 2000, and there is evidence of another peak in 2010, but there is no obvious trend in harvest rates over time in the Rappahannock.

The commercial fishery for river herring was closed in 2012, and therefore there no longer is commercial reporting data available.

15.8.1.2 *Voluntary Logbooks from an Individual*

The VIMS obtained voluntary logbooks of one commercial river herring fisherman. The fisherman and his father fish the upper Rappahannock River above Port Royal, Virginia with drift gill nets and recorded their annual catches of river herring from 1995 through 2008. It was not possible to estimate precise catch rates from these records since the logbooks do not indicate the number of nets fished each day or the catch associated with each net. In addition, mesh sizes, lengths of nets, and the daily number of sets may have changed during the time period. The logbooks show that the total catch of river herring has been generally proportional to the number of days fished each year (Figure 15.7). The highest levels of catch and effort occurred from 1999 through 2002. In this period, the fisherman landed from nearly 4,000 to almost 6,000 fish each year from the Rappahannock River. Since 2002, catches have declined considerably. The fisherman reported to VIMS scientists that he had reduced effort later in this time series because fewer river herring were available. Digitization of these data has recently been completed and any further potential analysis is being investigated.

15.8.1.3 *Biological Sampling*

15.8.1.3.1 VMRC Biological Sampling Program

The VMRC Biological Sampling Program was initiated in 1989 to collect fisheries-dependent biological information to support assessment and management activity within the state and coast-wide. There are currently twenty-one species targeted for sampling in the program; non-target species, such as alewives and blueback herring, are sampled based on availability and staff time. When river herring are available for sampling, samples are identified to species, measured for total length (TL), and individual weights are taken for most samples. The fork length and sex of most samples is also recorded. River herring have been available for sampling from Virginia's commercial fishery in all years since the program's inception, except for 2009 and 2010. The samples were considered insufficient for characterizing the species composition of the commercial landings (J. Cimino, VMRC, pers. comm.).

The lengths of male alewives sampled from Virginia's commercial landings between 1989 and 2008 ranged between 210 and 390 mm TL and demonstrate a mode at 270 mm TL (Figure 15.8). Female alewives sampled from the commercial fishery exhibited a mode at 290 mm TL and ranged between 150 and 390 mm TL. Similar to the alewife samples, the female blueback herrings sampled from the commercial landings tended to be larger than the males (Figure 15.9). Male blueback herring ranged between 210 and 380 mm TL while females ranged between 180 and 350 mm TL. Male and female blueback herring demonstrated modes at 250 mm TL and 270 mm TL, respectively.

The average length of alewives sampled from Virginia's commercial fishery ranged from 258 to 297 mm TL per year between 1989 and 20081 (Figure 15.10). The annual average length of blueback herring samples ranged between 252 and 284 mm TL. The average annual length of both species shows an overall declining trend over the time series. The average individual weight of alewife commercial samples ranged between 161 and 276 g per year and blueback herring samples ranged between 121 and 219 g per year in individual weight (Figure 15.11). Like average length, the average individual weight of both alewives and blueback herring demonstrate a decrease over time.

15.8.1.3.2 VIMS Assessment of Virginia's Inshore Alosine Fishery (Historic Samples)

The VIMS collected biological samples from Virginia's commercial fishery from 1966 to 1988 as part of their annual assessment of the structure of adult alosine populations in Virginia's inshore alosine fishery. Adult alosines were randomly sampled from the commercial fishery—primarily pound nets—over the duration of the spring spawning run. The majority of samples were collected from the James, York, Rappahannock, and Potomac rivers. The Potomac River samples are not included in this report. Individual samples were identified to species, measured for fork length (FL), weighed, and sexed. Structures were also removed and processed for ageing. Scales were collected during 1966 through 1978, and otoliths were collected during 1975 through 1988. In this assessment, data from the following reports were used: Davis et al. 1970, 1971, 1972; Hoagman et al. 1973, 1974; Hoagman and Kriete 1975; Loesch and Kriete 1976, 1980–1984; Johnson et al. 1978; Loesch et al. 1977, 1981, 1985, 1986; Blumberg and Loesch 1988, 1989. Refer to one of the cited reports for a more detailed description of this monitoring program. Also note that most of those data were not available in raw form.

The numbers of each species sampled were summarized by year to evaluate the species composition of Virginia's commercial river herring landings (see also section 15.9.1, this report). During the earliest years of the program (1967–1972), alewives composed the majority of the commercial landings, except in 1971 when nearly equal quantities of alewives and blueback herring were sampled (Table 15.2). The proportion of blueback herring sampled exceeded that of alewives beginning in 1973 and gradually increased through 1981; in 1981, 92% of the commercial samples were identified as blueback herring. The proportion of blueback herring then decreased but remained higher than that of alewives through 1988, the last year of the monitoring program.

The ages of alewives sampled from commercial harvest in the James River ranged from 3 to 9 years (Figure 15.12). Alewives age 4 and 5 dominated the James River commercial samples. In the Rappahannock River, alewives ranged in age from 2 to 9 in the commercial harvest (Figure 15.13). The age-frequency distributions demonstrate that the 1963, 1966, 1981, and 1982 year-classes of alewives were relatively strong in the Rappahannock River. Where both scale and otoliths ages were available, the pattern in the proportion of alewives at age is similar between the two structures, and there is no evidence of consistent over- or under-ageing by either structure. Alewives collected from the York River commercial fishery harvest ranged in age from 3 to 13 years and the majority of samples were 4- and 5-years-old (Figure 15.14). The York River age compositions suggest the 1982 year-class of resident alewives was relatively strong.

Blueback herring sampled from the James River commercial harvest were primarily age 4 and 5 in most years and ranged in age from 3 to 9 years (Figure 15.15). Blueback herring age 3 to 13 were observed in the commercial harvest samples from the Rappahannock River (Figure 15.16). The age-frequency distributions show that the 1966, 1970, 1971, 1975, 1978, and 1979 year-classes of blueback herring in the Rappahannock River were relatively strong. As with the alewife samples from the Rappahannock River, the age compositions of blueback herring based on scales were similar to those based on otoliths, and there is no evidence of consistent over- or under-ageing by either structure. The blueback herring samples from the Rappahannock River commercial harvest were dominated by 4- and 5-year-old fish from 1966 to 1975 and show increasing dominance of 5- and 6-year-olds from 1976 through 1988. In the York River, blueback herring ranged in age from 3 to 13 in the commercial harvest (Figure 15.17). The majority of blueback herring sampled from the York River commercial harvest were 4- to 6-years-old. The 1975, 1978, 1981 year-classes of blueback herring in the York River appeared to be relatively strong.

The spawning frequency data show that male and female alewives sampled from commercial harvest in the James River spawned as many as six times (Figure 15.18). In three of the four years for which data were available, the majority of male alewives sampled from the James River had spawned at least once while the majority of female alewives sampled had not yet spawned. The limited data available characterizing spawning frequencies at age suggest most of the alewives in the James River that have spawned once are 5- or 6-years-old (Table 15.3). In the York River, male alewives spawned as many as five times, and females experienced as many as six spawning events (Figure 15.19). First-time spawners were 4- to 6-years-old (Table 15.3). The blueback herring spawning frequency data collected from the James River commercial harvest show that males spawned as many as six times, and females spawned as many as five times (Figure 15.20). In all years for which data were available, the majority of female blueback herring collected from the James River were virgin spawners. Most of the blueback herring sampled from the James River that spawned once were age 6 (Table 15.4). Both male and female blueback herring spawned as many as six times based on samples collected from commercial harvest in the York River (Figure 15.21). Similar to the James River, the majority of first-time spawners in the York River were 6-years-old (Table 15.4).

15.8.1.4 *Recreational Fisheries Monitoring*

The NMFS Marine Recreational Fishery Statistics Survey (MRFSS) is the primary source of marine recreational fisheries statistics for Virginia. The MRFSS program utilizes telephone surveys, angler-intercept surveys, and at-sea headboat sampling (begun in 2005) to estimate recreational fisheries statistics. The MRFSS raw data files demonstrate that alewives and blueback herring were rarely encountered during surveys of Virginia's recreational anglers. During 1981 through 2010, a total of 206 alewives and 51 blueback herring were encountered in the angler-intercept survey in Virginia. Additionally, one blueback herring was encountered during the MRFSS at-sea headboat survey. These observations occurred in only six years over the available survey time series (1981–2010); recreational statistics of alewives and blueback herring could only be derived for those years where samples were recorded. The limited availability of samples resulted in low precision (high proportional standard error) of the estimates that could be computed. As such, the MRFSS estimates of Virginia's recreational alewife and blueback herring catches are not considered reliable or representative and so are not presented here.

Estimates of recreational catch and effort from non-marine waters are not available, though river herring is a popular recreational species in Virginia's inland waters.

15.9 FISHERIES INDEPENDENT SURVEYS

15.9.1 VDGIF Electrofishing Surveys, 1994–present

The VDGIF has conducted electrofishing surveys for American shad and river herring in the Rappahannock River near Route 1 and in the James River near the Manchester Bridge in downtown Richmond. Sampling is conducted weekly at both locations. The total number of each species collected and the sex of each individual in a sample is recorded. Individual weights and total lengths are collected from a subsample per sampling date at each station.

The Route 1 sampling station starts at the very head of tide (the tidal/non-tidal interface) approximately 1.5 miles downstream of the Embrey Dam and extends downstream several hundred meters (900 seconds of boat electrofishing effort). This area was essentially unchanged by the dam removal in 2004 and represents the most consistently sampled site by the VDGIF on the river. Alewives are observed at the Rappahannock stations in March and April of each year. Blueback herring can be found in April through early June; the two species usually co-occur in April only.

Three of the four stations (Manchester 1, 2, and 4) in the James River start at the very head of tide just downstream of the last riffle/rapids and extend downstream to the 14th Street Bridge (300–500 seconds of electrofishing effort each). The Manchester 5 sampling station starts at Interstate 95 and extends downstream along the bank (500 seconds of electrofishing effort). Alewives appear in March and April at the Manchester Bridge sampling sites on the James River. Blueback herring occur at this site in April, May, and early June.

Annual cumulative catch rates were computed for the Rappahannock River (Route 1 sampling station) for 2000 to 2010 and for the James River (Manchester stations 1, 2, 4, and 5 combined) for 2002 to 2010. The years used represent the most consistent, continuous time series for each location. Catch rates were calculated as the average number of fish collected per minute of electrofishing. In the Rappahannock River, peak catch rates of blueback herring occurred in 2001 (Figure 15.22). In some years, blueback herring were not collected in the survey. Peak catch rates of alewives occurred in 2004 and 2005. In the James River, blueback herring have dominated the catch (Figure 15.23). The 2012 catch rate for blueback herring in the James River was the highest in the time series. The catch rates show a low relative abundance of alewives in the James River relative to the Rappahannock (Figure 15.22 and Figure 15.23).

15.9.2 VIMS Experimental Anchor Gill-Net Survey, 1991–2013

The VIMS performs an annual striped bass spawning stock survey in the James and Rappahannock rivers using multi-mesh anchored gill nets. Adult river herring are encountered in the Rappahannock River, but river herring are rarely observed in the James River samples. The gear is set twice a week from late March through early May, and soak time is twenty-four hours for each set. Although the peak of the blueback herring run takes place during the duration of the survey, a significant portion of the alewife migration occurs before late March and may be missed.

Indices of relative abundance based on observations from the Rappahannock River were calculated as the arithmetic average number of fish per day for alewives and blueback herring. The index for alewives has maintained relatively low levels with no obvious trend over the time series (Figure 15.24). The blueback herring index declined from the beginning of the time series through 1994 and increased to the time series peak in 1995. The index then decreased and has remained at relatively low levels through the present. Between 2010 and 2013, only a single river herring was encountered on the James (in 2012; species not recorded). On the Rappahannock, a total of 39 river herring were encountered in this time period (2010, 10; 2011, 0; 2012, 11; and 2013, 18). Counts of river herring encountered in this program ceased in 2013.

15.9.3 VIMS Juvenile Fish and Blue Crab Trawl Survey, 1979–present

The VIMS Juvenile Fish and Blue Crab Trawl Survey monitors the distribution and abundance of important finfish and invertebrate species occurring in the Chesapeake Bay. The survey sites and sampling frequency have not been consistent throughout the history of the survey (Tuckey and Fabrizio 2010). The survey currently employs a mixed design, incorporating both stratified random sites and fixed (historical mid-channel) sites. The stratification system is based on depth and latitudinal regions in the bay (random stations), or depth and longitudinal regions in the tributaries (random and fixed stations).

Annual juvenile abundance indices (JAIs) for young-of-year alewives and blueback herring were computed as random stratified geometric average number of fish per standard tow. The indices series start in 1996 because that is the year when random stations were added to the survey. The JAIs for both species were calculated based on data collected in December through March and fish less than or equal to 110 mm. Indices were calculated for the James, York, and Rappahannock rivers separately. The relative abundance of juvenile alewives was variable without trend for each river (Figure 15.25). Similar to the alewife JAIs, the JAIs for blueback herring varied without trend for each of the three rivers (Figure

15.26). Variability about the annual JAIs values is fairly high for both species, especially for the Rappahannock River (Figure 15.25 Figure 15.26).

15.9.4 VIMS Juvenile Striped Bass Seine Survey, 1967–present (gap 1974–1979)

The VIMS Juvenile Striped Bass Seine Survey tracks trends in the annual year-class strength of striped bass in the spawning and nursery areas of the lower Chesapeake Bay. JAIs for alewives and blueback herring were calculated as the geometric average number of fish per seine set for the James, York, and Rappahannock rivers separately. The indices series start in 1989 because the number of sites sampled (~109) became consistent in that year. The JAIs for both species were calculated based on data collected in July through September using only data from sites where each species can be expected to be captured. All sampling sites are fixed in location. The JAI for alewife (Figure 15.27) has been consistently lower than the blueback herring JAI (Figure 15.28) in all three rivers. There are no obvious trends in the JAI time series for either of the species, and variability about the annual estimates has been fairly high (Figure 15.27Figure 15.28). Indexes of juvenile abundance based on the seine survey data are variable, but are almost always higher for blueback herring than for alewife, and the Rappahannock River most often shows the highest abundance for both species. No measurable recruitment of alewife was seen in the James River in 1989-1992, 1995, 1999-2003, 2008, and 2011-2012, and in the York River in 1990-1993, 1995, 1998-2000, 2006-2009, and 2012-2014. In the Rappahannock River, indexes of juvenile alewife abundance have been relatively low (e.g., <0.1) in many years (1990-1992, 1995, 2002, 2004-2006, 2008, 2012), but there has always been measureable recruitment throughout the time series. The only instances of no measurable recruitment of blueback herring within the time series occurred in the York River, and in the years 1990, 1992-1993, 1995, 1998-1999, 2002, 2005-2006, 2009, 2012-2013.

15.9.5 VIMS Juvenile Shad-River Herring Push-Net Survey, 1979–2002 (gap 1988–1990)

The VIMS Push-Net Survey, initiated in 1979, was an evening push-net survey of the York River system that targeted American shad. The survey was discontinued in 2002. Sampling in the Mattaponi and Pamunkey rivers was typically conducted from mid-May through August or until the catch of American shad was zero. The survey was temporarily halted following the 1987 sampling year. Sampling resumed again in 1991, though there were changes to the sampling design and methodology. Wilhite et al. (2003) examined the sampling strategies employed in this survey and concluded that data collected before and after the interruption in sampling (1979–1987; 1991–2002) should be considered separate data series and not compared since the collection methods differed substantially in each period. The survey data were used to calculate JAIs for alewives and blueback herring as the geometric average number of fish per standard set. Juvenile indices were calculated for both the Mattaponi and Pamunkey rivers. The majority of alewives and blueback herring caught in the survey were between 27 and 70 millimeters in length. The JAI values for alewives have been lower than that for blueback herring in both tributaries throughout the time series (Table 15.5); however, catchability of alewives and blueback herring by the push net may differ, accounting for these patterns (Loesch et al. 1982).

15.9.6 VIMS American Shad Monitoring Program, 1998–present

Few alewife or river herring are encountered in the VIMS American Shad Monitoring Program in the Rappahannock, York, and James rivers (<70 individuals of both species in all rivers combined over the history of the program) due to specificity of the gear used for the larger species, American shad (this program mimics the historical commercial American shad fishery, which targeted female American shad). Therefore, no trends or inference on alewife and river herring can be drawn from these data, and they are not included in the assessment.

15.9.7 VIMS River Herring Adult Relative Abundance Monitoring Program, 2015-present

In response to the moratorium for river herring enacted in 2012, an annual adult spawning stock monitoring program gill net was established in 2015 on the Chickahominy River, a major tributary of the James River and the location of a historical fishery for river herring; in 2016 this survey was expanded to include sampling on the Rappahannock River. Each week, generally from February to May, nets are fished on two succeeding days (two 24-h sets). All herring are counted and returned to the lab for collection of length, weight, and sex data; otoliths are removed to age the fishes; mortality is calculated. Blueback herring had a marked increase in abundance in the Chickahominy over the three years of sampling, whereas alewife experienced a significant decrease in 2016, with a subsequent increase in 2017. Because the time series only began in 2015, data are not presented herein, but these will be available for future stock assessments.

15.9.8 VIMS River Herring Juvenile Sampling, 2014-present

In 2014, a nighttime surface trawl survey was established to target juvenile alewife and blueback herring in the Chickahominy River. This survey employs a mamou trawl, which is a 6.7 m x 1.8 m floating surface trawl constructed of 35 mm high density polyethylene netting. Sampling occurs between June and September. During each cruise, three stations are randomly chosen within each of four adjacent 9.3 river km long blocks. Stations are designated at every 1.9 river km, beginning approximately 1.2 km (c. 2 miles) below Walker's Dam and ending at the river mouth. Night time sampling is conducted when juvenile *Alosa* spp. are most susceptible to surface trawling (Loesch et al. 1982). Each tow lasts 5 minutes and is conducted along the central axis of the river channel. Alewife and blueback herring caught at each station are identified and counted. Ten randomly selected individuals of each species from each station are measured and weighed. The geometric mean of the catch per tow is calculated for each cruise and the season (i.e., a seasonal catch index). Blueback herring dominate the catches. In 2016, for instance, total catches of alewife = 31 whereas total blueback herring catches = 30,951. Because the time series only began in 2014, data are not presented herein, but will be available for future stock assessments.

15.10 ASSESSMENT APPROACHES AND RESULTS

15.10.1 Trends in Relative Abundance

The indices of relative abundance for adult and juvenile river herring were tested for overall temporal trends and were compared to evaluate whether there was consistency in temporal trends among the indices. Only indices derived from the fishery-independent surveys were considered because the fishery-dependent harvest rate indices have not been corrected for changes in efficiency over time, only include records of positive tows, and would reflect trends in fished areas only. Indices derived from the VIMS Push-Net Survey were not included in the analyses because that survey was discontinued in 2002.

The Mann-Kendall test was applied to quantitatively evaluate the overall trend in relative abundance of alewives and blueback herring, by species, life stage, river, and survey. The Mann-Kendall test is a non-parametric test for monotonic trend in time-ordered data and allows for both missing observations and ties (Gilbert 1987). Trends were considered statistically significant at = 0.05. Spearman's rank-order correlation coefficient, , was calculated to measure the degree of linear association between indices. Spearman's rank-order correlation is a non-parametric test for determining if there is an association between two variables. Indices were considered significantly correlated at = 0.05. Comparisons were made by species and life stage.

The temporal trend of eighteen fishery-independent survey indices was evaluated using the Mann-Kendall test. Statistically significant trends were detected in two indices (Table 15.6). The indices of relative abundance of adult alewives and adult blueback herring in the Rappahannock River derived from the VIMS Experimental Anchor Gill-Net Survey (Figure 15.24) were found to have significantly decreasing trends over the time series until 2010 (alewives: S = -74, P = 0.0176; blueback herring: S = -141, P = 5.50E-06); because the collection of herring data after this time period was pooled (i.e., not separated by species) and ceased in 2013, analyses were not updated in June 2017. Statistically significant trends were not found in any of the other indices evaluated.

There were no statistically significant correlations detected among the adult indices of relative abundance for either species (Table 15.7). The indices of alewife juvenile abundance in the York River derived from the VIMS Juvenile Striped Bass Seine Survey and the VIMS Juvenile Fish and Blue Crab Trawl Survey were found to be significantly and positively correlated (= 0.665, P = 0.00680). Indices of blueback herring juvenile abundance derived from the VIMS Juvenile Striped Bass Seine Survey were significantly and positively correlated between the James and Rappahannock rivers (= 0.712, P = 0.000200), James and York rivers (= 0.478, P = 0.0246), and York and Rappahannock (= 0.560, P = 0.00670; Table 15.8).

15.10.2 Temporal Trends in Size

Size data available from the VIMS inshore alosine fishery sampling were compared to data available from the VMRC's Biological Sampling Program to evaluate trends in average size over time. The historic VIMS sampling program measured lengths in terms of fork lengths; length data from the VMRC were converted to fork lengths for consistency. Size data from the historical VIMS report were only available in summarized form and were typically reported as annual averages for the major tributaries of the Chesapeake Bay. Additionally, the historical VIMS data were primarily collected from commercial pound nets. Pound net samples collected by the VMRC were examined and it was found that only samples collected from the Rappahannock River could provide enough years to include in the evaluation. Note that the comparison may be confounded by the fact that the VIMS sampling only occurred during the spring spawning run and the VMRC sampling can occur anytime during the year when landings are available for sampling.

The Mann-Kendall test was performed to quantitatively evaluate the time-series trend in average length and weight for alewives and blueback herring, by sex. Trends were considered statistically significant at = 0.05.

The average length of male alewives ranged from 125 to 228 mm FL per year and the average lengths of females ranged from 160 to 294 mm FL per year (Figure 15.29). The average weight of male alewives ranged between 224 and 250 g per year while the average weight of females ranged between 236 and 265 g per year (Figure 15.30). The Mann-Kendall test detected statistically significant decreasing trends over time for the average length and weight of both male and female alewives sampled from the Rappahannock River commercial pound net fishery (Table 15.9).

There were only three years (2004, 2007, and 2008) during the recent time period in which blueback herring were available for sampling from commercial pound nets in the Rappahannock River. Despite the limited data from recent years, the annual average lengths of male and female blueback herring show evidence of an overall declining trend over time (Figure 15.31). The Mann-Kendall test found the declining trend in average length of male and female blueback herring to be statistically significant (Table 15.9). The average weight of male blueback herring ranged from 213 to 251 g per year and the average weight of females ranged from 231 to 259 g per year (Figure 15.32). No significant trends were detected in the average weight of blueback herring over time (Table 15.9).

15.10.3 Sex Ratio

Sex ratios for river herring were calculated using the data available from the VIMS sampling of Virginia's inshore alosine fishery. Samples collected by the VMRC's Biological Sampling Program were considered insufficient for calculating sex ratios (J. Cimino, VMRC, pers. comm.) and would not be comparable to the VIMS historical data because the VMRC sampling can occur throughout the year while the VIMS only sampled during the spring spawning run.

Sex ratios were computed for each species by year for the James, York, and Rappahannock rivers. The χ^2 goodness-of-fit test with Yate's correction for continuity was applied to test whether the observed sex ratios departed from a 1:1 (male: female) ratio (Zar 1999).

The sex ratio (male: female) for alewives sampled from the James River ranged from 1.1 (52% male) to 3.9 (79% male) between 1967 and 1980 (Table 15.10). Male alewives were encountered more frequently than females in all the years data were available from the James River (1967–1980). The χ^2 goodness-of-fit indicated that most of the sex ratios for alewives sampled from the James River significantly deviated from a 1:1 ratio ($P < 0.05$), in favor of males. In the York River, the sex ratio of alewives ranged from 0.53 (35% male) to 1.6 (62% male) and demonstrated an overall decrease over the time series (1967–1988). In most years, the sex ratios of alewives collected from the commercial fishery in the York River were not statistically different from a 1:1 ratio ($P \geq 0.05$). Male alewives dominated the Rappahannock River samples in most years of the available time series. Sex ratios of alewives in the Rappahannock River ranged between 0.55 (35% male) and 1.8 (65% male).

The proportion of male blueback herring sampled from the James River fishery was found to be significantly larger ($P < 0.05$) than the proportion of females sampled in all but one of the years samples were available (Table 15.11). The sex ratio of James River blueback herring ranged from 1.2 (54% male) to 5.1 (84% male) between 1967 and 1980. Blueback herring collected from the York River exhibited sex ratios ranging from 0.58 (37% male) to 1.7 (63% male). In the Rappahannock River, blueback herring sex ratios ranged between 0.73 (42% male) and 2.0 (67% male) and were dominated by males in most years.

15.10.4 Spawning Frequency

Data characterizing the spawning frequency of river herring were available for a limited number of years from the James (1967–1970) and York (1967, 1969–1970) rivers. The data were collected by the VIMS inshore alosine fishery sampling program. Repeat spawner rates were calculated by dividing the number of sampled fish with one or more spawning marks by the total number of fish sampled and multiplying the resulting quotient by 100. Rates were calculated by species, sex, and year for each river.

The percentage of male alewives that previously spawned at least one time was nearly 50% or greater for samples collected from the James River commercial fishery (Table 15.12). Repeat spawning rates of female alewives sampled from the James River ranged between 42% and 83%. Alewives in the commercial fishery samples from the York River exhibited repeat spawning rates ranging from 46% to 70%. Female alewives sampled from the York River exceeded 50% in all three of the years for which data were available.

Repeat spawning rates for blueback herring sampled from commercial harvest in the James River ranged from 36% to 82% (Table 15.13). The proportion of females in the James River that previously spawned ranged between 33% and 73% among the years when data were available. In the York River, repeat spawner rates were 60% or greater for male blueback herring sampled from the fishery. Female blueback herring repeat spawner rates in the York River ranged from 50 to 72%.

15.10.5 Mortality

Age data collected from Virginia's inshore alosine fishery by the VIMS were used to derive catch curves in order to estimate instantaneous total mortality rates (*Z*). The age data obtained from the historical VIMS reports were sometimes presented in terms of proportion at age without additional information on sample size. This prevents the calculation of standard error for Z estimates so catch curves were not calculated for years when sample size information was not available. Additionally, the available data were insufficient to calculate longitudinal catch curves. Though longitudinal catch curves are generally preferred, age composition data were not available for a sufficient number of consecutive years to follow cohorts through time. Instead, cross-sectional catch curves, which are based on the estimated abundance of successive age classes within a particular year, were computed for each species by water body, ageing structure, and year based on availability of data. The data used were collected during the mid-1970s through the late 1980s.

Catch curves were computed using the method of Robson and Chapman (1961). Both alewives and blueback herring were considered fully recruited to the gear at age 4 years. Catch curves were only applied to age compositions that had samples for the assumed age at full recruitment and at least three older ages.

Estimates of annual *Z*s for alewives ranged from a low of 0.44 to a high of 1.8 among all computed estimates (Table 15.14). Annual *Z*s were highest in the Rappahannock River for most years. Alewife samples from the James River yielded the lowest estimates of *Z*. Blueback herring total mortality estimates ranged between 0.32 and 2.0 (Table 15.15). Estimates of blueback herring *Z*s were generally similar among the three rivers.

15.11 BENCHMARKS

The available data for alewives and blueback herring in the James, York, and Rappahannock rivers were considered insufficient to perform a reliable assessment of the status of these stocks. The data were also considered inadequate for developing benchmarks.

15.12 CONCLUSIONS AND RECOMMENDATIONS

15.12.1 Management Actions and Outcomes

On June 28, 2011, the VMRC voted to implement a ban on the possession of alewives and blueback herring in state waters; the ban became effective January 1, 2012. The ban was enacted due to the collapse of the fishery over the last four decades and in order to comply with Amendment 2 to the Interstate Fishery Management Plan for Shad and River Herring (ASMFC 2009). The outcome of the moratorium means the loss of harvest information. Additionally, as in the case of American shad in Virginia, a ban on possession of river herrings will not reduce removals by pound nets and some other gears, rendering discards of river herring as unreported.

It would be prudent to initiate an observer program for pound nets in the Chesapeake Bay to obtain information on patterns of species-specific exploitation (catch rates, temporal and spatial trends in catch). This program also would provide materials for biological characterization of the catch and could produce more reliable information of relative abundance of each species. Biological data are collected (2014-present) from a subsample of bycatch of river herring from poundnets by VIMS scientists, but this is not a formal observer program intended to calculate rates of exploitation.

15.12.2 Research Recommendations

- Develop and implement program for sampling commercial landings classified as “bait” in order to evaluate the relative importance of river herring (and other species) in the bait landings
- Estimate magnitude of by-catch and discards in state and ocean waters; estimate associated mortality
- Initiate an observer program for pound nets in the Chesapeake Bay to obtain information on patterns of species-specific exploitation
- Develop studies to estimate stock-specific (river-specific) estimates of natural mortality
- Develop restoration benchmarks for river herring species
- Develop studies to estimate contribution of Virginia stocks to ocean fisheries by-catch
- Develop a fish passage facility monitoring plan to estimate stock size at, and upstream of, dams with fishways and to track population trends
- Use existing creel surveys in rivers to estimate incidental catch of river herring by recreational anglers

15.12.3 Summary

The available data reported here are insufficient to quantitatively assess the current status of alewives and blueback herring in the James, York, and Rappahannock rivers. The most recent comprehensive assessment of river herring stocks examined long-term datasets from large rivers along the U.S. east coast (including the Hudson, Connecticut, Delaware, and Chowan rivers) and concluded that both river herring species in these systems showed signs of overexploitation including reductions in average age, decreases in the percent of repeat spawning, declines in recruitment, and decreases in adult abundance (Schmidt et al. 2003). With the exception of the juvenile abundance surveys, such long-term data are not currently available for Virginia. The analysis of sex ratios and spawning frequency and estimation of mortality rates were based on historical data and not informative about the status of the population in recent years. The recent (2015) initiation of directed adult river herring monitoring program conducted in the Chickahominy and Rappahannock rivers was designed to fill this void.

Based on the results of fishery-independent sampling that depicts the presence of both species of river herring, there is strong evidence that commercial harvest data since 1994 are not an accurate depiction of the species composition of the catch in Virginia. Schmidt et al. (2003) emphasized that alewife and blueback herring should be managed separately. The species are likely misidentified in Virginia reported harvest and landings and this fact significantly diminishes our understanding of their exploitation.

River herring have been exploited by fisheries for a long time in Virginia. Since 1994 (until 2012, when a moratorium became effective), the majority of commercial harvest of river herring from Virginia waters has been attributed to the main stem of the Chesapeake Bay, averaging over 35 thousand kilograms (alewives and blueback herring combined) a year from 1994 through 2010. Gill nets were responsible for nearly 82% of the commercial harvest of river herring from the Chesapeake Bay during this time period. The gill net harvests are likely composed of mixed spawning runs of river herring migrating to Virginia and Maryland systems.

Interviews with one fisherman and examination of his voluntary logbook data suggest that the strength of the spawning run of river herring has declined in the Rappahannock River since 1995. This observation is supported by the VIMS multi-mesh anchored gill-net survey—the longest available fisheries-independent time series of adult river herring occurring in the Rappahannock River (1991–present)—and the commercial harvest rate estimates of gill nets in the river.

Fisheries-independent sampling and commercial harvest reveal that river herring occur in all of Virginia's major rivers. Abundance indices of juveniles depict considerable annual variability and show little trend over the available time series. However, there are no data on juvenile abundance during the 1950s to 1970s when landings were higher and spawning runs were presumably stronger. Additionally, the results of the correlation analyses suggest little consistency among the fishery-independent survey indices of relative abundance.

The collapse of Virginia's commercial river herring fishery in the late 1970s (Figure 15.2) reflects the same trend that has been observed for river herring landings along the U.S. east coast (Schmidt et al. 2003). This pattern has also been reported for Virginia's stocks of American shad during the same time period (ASMFC 2007). In the case of American shad, the VMRC imposed a ban on fishing in the Chesapeake Bay and its tributaries in 1994 in response to declining harvest (4 VAC 20-530 et seq.). At the time, fisheries-independent data were insufficient to assess the stocks and there were no existing monitoring programs to evaluate stock status. Subsequent research and the recent ASMFC stock assessment have confirmed that the 1994 ban on fishing was an appropriate action (ASMFC 2007). Due in part to lack of available data to address the question of sustainability of river herring stocks in Virginia, and in order to comply with ASMFC Amendment 2 to for Shad and River Herring (ASMFC 2009), the VMRC implemented a ban on the possession of alewife and blueback herring that began January 1, 2012 (VMRC Regulation 4 VAC-20-1260-30).

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Table 15.1 Annual commercial landings (kilograms) of river herring in Virginia, 1880–2010. Note that estimates are not available for all years prior to 1929.

Year	Commercial Landings (kilograms)
1880	3,141,127
1887	1,996,713
1888	2,927,031
1890	4,827,129
1891	4,995,412
1896	5,532,919
1897	6,209,679
1901	6,311,283
1904	6,624,262
1908	17,184,345
1909	12,599,887
1915	7,281,971
1920	7,559,116
1921	8,542,958
1925	8,123,838
1929	5,701,681
1930	6,979,433
1931	7,819,510
1932	6,283,384
1933	8,698,743
1934	2,651,791
1935	4,977,767
1936	3,941,128
1937	6,833,051

Year	Commercial Landings (kilograms)
1938	8,024,497
1939	6,727,137
1940	5,186,057
1941	5,420,882
1942	4,199,312
1944	8,092,450
1945	6,631,111
1946	5,455,944
1947	10,057,593
1948	8,783,634
1949	9,980,346
1950	13,018,870
1951	14,788,924
1952	13,082,056
1953	10,875,329
1954	12,668,879
1955	9,907,635
1956	10,027,338
1957	8,508,303
1958	8,328,544
1959	7,913,825
1960	7,014,351
1961	7,042,383
1962	11,092,056

Year	Commercial Landings (kilograms)
1963	11,832,137
1964	12,083,699
1965	16,420,178
1966	12,943,166
1967	12,749,300
1968	14,659,831
1969	13,809,935
1970	8,638,847
1971	4,657,531
1972	4,740,403
1973	4,204,317
1974	6,051,813
1975	5,152,585
1976	1,922,171
1977	630,527
1978	965,278
1979	766,000
1980	537,138
1981	235,650
1982	593,023
1983	833,550
1984	570,220
1985	195,956
1986	343,824

Year	Commercial Landings (kilograms)
1987	355,052
1988	324,152
1989	296,023
1990	227,311
1991	319,583
1992	483,977
1993	160,032
1994	81,063
1995	109,040
1996	64,405
1997	64,929
1998	21,792
1999	23,353
2000	17,671
2001	28,574
2002	120,517
2003	103,416
2004	101,798
2005	44,053
2006	23,695
2007	47,884
2008	72,854
2009	88,835
2010	78,264

Table 15.2 Species composition (%) of river herring sampled from commercial harvest in the James, York, and Rappahannock rivers, 1967–1988.

Year	n	Alewife	Blueback Herring
1967	1,419	56.1	43.9
1968	718	55.7	44.3
1969	1,090	60.2	39.8
1970	978	80.0	20.0
1971	875	49.1	50.9
1972	736	60.0	40.0
1973	865	38.5	61.5
1974	2,498	42.4	57.6
1975	4,846	38.7	61.3
1976	4,110	44.2	55.8
1977	4,860	34.0	66.0
1978	3,066	25.3	74.7
1979	2,113	22.2	77.8
1980	2,050	22.8	77.2
1981	2,168	8.03	92.0
1982	1,703	13.4	86.6
1983	2,327	42.2	57.8
1984	2,098	30.9	69.1
1985	2,452	44.5	55.5
1986	1,911	26.5	73.5
1987	1,283	36.9	63.1
1988	1,159	37.0	63.0

Table 15.3 Percent at age by number of spawning marks for alewives sampled from Virginia's commercial harvest. (Source: Loesch et al. 1977)

Water Body	Year	n	Number Spawn Marks	Percent at Age							
				4	5	6	7	8	9	10	11
James	1977	43	**0**	9.30	83.7	6.98					
	1977	25	**1**		36.0	64.0					
	1977	5	**2**			40.0	60.0				
	1977	2	**3**				100				
York	1977	106	**0**	17.0	74.5	8.49					
	1977	41	**1**	2.44	36.6	58.5	2.44				
	1977	5	**2**			60.0	40.0				
Rappahannock	1977	305	**0**	4.92	54.8	38.4	1.97				
	1977	194	**1**		29.4	66.0	4.64				
	1977	20	**2**			50.0	50.0				
	1977	3	**3**				66.7	33.3			
	1977	2	**4**						100		

Table 15.4 Percent at age by number of spawning marks for blueback herring sampled from Virginia's commercial harvest. (Source: 1965-1966 data—Davis et al. 1970; 1977 data—Loesch et al. 1977)

Water Body	Year	n	Number Spawn Marks	Percent at Age							
				4	5	6	7	8	9	10	11
James	1977	138	**0**	3.62	55.8	39.1	0.725	0.725			
	1977	92	**1**	2.17	15.2	82.6					
	1977	21	**2**		4.76	52.4	42.9				
	1977	7	**3**				85.7	14.3			
	1977	1	**4**					100			
	1977	1	**5**		100						
York	1977	129	**0**	0.775	52.7	44.2	2.33				
	1977	89	**1**		10.1	83.1	6.74				
	1977	29	**2**			72.4	27.6				
	1977	9	**3**				100				
Rappahannock	1965–1966	162	**0**	23.5	48.1	25.3	3.09				
	1965–1966	98	**1**		8.16	66.3	24.5	1.02			
	1965–1966	40	**2**			22.5	65.0	10.0	2.50		
	1965–1966	17	**3**				29.4	47.1	17.6	5.88	
	1965–1966	2	**4**					50.0	50.0		
	1965–1966	1	**5**								100
	1977	240	**0**	3.75	56.7	38.3	1.25				
	1977	202	**1**	1.49	32.7	65.3	0.495				
	1977	34	**2**		2.94	67.6	29.4				
	1977	6	**3**				100				

Table 15.5 Annual JAIs (geometric average number per set) of alewives and blueback herring collected from the Mattaponi and Pamunkey rivers by the VIMS Push-Net Survey, 1979–2002. The push-net survey was not conducted in 1988, 1989, and 1990.

Year	Mattaponi River		Pamunkey River	
	Alewife	**Blueback Herring**	**Alewife**	**Blueback Herring**
1979	0.6	9.7	1.3	31.7
1980	0.6	2.1	0.6	32.7
1981	1.1	0.6	1.2	5
1982	11	40.2	5.2	124.2
1983	1.5	2.3	1.3	28.7
1984	7	8.7	0.4	13.9
1985	7.2	27.6	3.1	25
1986	2.6	2.6	2.7	19.4
1987	0.3	2	0.4	52.2
1988				
1989				
1990				
1991	0.1	2.1	0.1	5
1992	0	0.04	0	0.01
1993	0.1	2.2	0.03	0.8
1994	2.3	10.8	1.5	33.7
1995	0.02	0.1	0.01	2
1996	4	12.8	2.1	28.5
1997	1.9	6.5	0.1	9.8
1998	1.06	21.05	0.12	5.7
1999	0.63	7.93	no data1	no data[1]
2000	1.27	5.37	0.34	9.24
2001	2.23	5.39	0.66	5.39
2002	3.32	5.36	0.41	2.14

1 Data collected from the Pamunkey River by the VIMS push-net survey in 1999 are missing or not available.

Table 15.6 Results of the Mann-Kendall test for temporal trends in relative abundance of alewives and blueback herring sampled from fishery-independent surveys. The number of years for which data were available is represented by n, *S* is the Mann-Kendall test statistic, and *P* is the two-tailed probability. Trend indicates the direction of the trend if a statistically significant temporal trend was detected (□ = 0.05); NS = not significant.

Species	**Life Stage**	**River**	**Survey**	**n**	***S***	***P***	**Trend**
Alewife	Adult	James	Electrofishing	9	3	0.831	NS
		Rappahannock	Electrofishing	11	1	1.00	NS
		Rappahannock	Gill Net	20	-74	0.0176	□
	Juvenile	James	Seine	22	62	0.0580	NS
		James	Trawl	15	15	0.488	NS
		York	Seine	22	8	0.828	NS
		York	Trawl	15	7	0.767	NS
		Rappahannock	Seine	22	-3	0.955	NS
		Rappahannock	Trawl	15	-31	0.138	NS
Blueback Herring	Adult	James	Electrofishing	9	-2	0.919	NS
		Rappahannock	Electrofishing	11	-4	0.813	NS
		Rappahannock	Gill Net	20	-141	5.50E-06	□
	Juvenile	James	Seine	22	-46	0.203	NS
		James	Trawl	15	-1	1.00	NS
		York	Seine	22	8	0.835	NS
		York	Trawl	15	1	1.00	NS
		Rappahannock	Seine	22	-34	0.352	NS
		Rappahannock	Trawl	15	25	0.235	NS

Table 15.7 Spearman's rank-order correlation between indices of adult relative abundance for (A) alewives and (B) blueback herring. *P*-values are shown in parentheses. Values of ⍰ that are statistically significant are formatted in **bold** font.

(A) Alewife

	James—Electrofishing	**Rappahannock—Electrofishing**
Rappahannock—Electrofishing)	0.136 (0.728)	
Rappahannock—Gill Net	-0.272 (0.478)	-0.0228 (0.947)

(B) Blueback Herring

	James—Electrofishing	**Rappahannock—Electrofishing**
Rappahannock—Electrofishing)	0.176 (0.651)	
Rappahannock—Gill Net	0.109 (0.781)	0.290 (0.388)

Table 15.8 Spearman's rank-order correlation between indices of juvenile relative abundance for (A) alewives and (B) blueback herring. *P*-values are shown in parentheses. Values of ⍰ that are statistically significant are formatted in **bold** font.

(A) Alewife

	James—Seine	James—Trawl	Rappahannock—Seine	Rappahannock—Trawl	York—Seine
James—Trawl	0.336 (0.221)				
Rappahannock—Seine	0.135 (0.548)	0.267 (0.336)			
Rappahannock—Trawl	0.143 (0.610)	-0.329 (0.232)	0.210 (0.453)		
York—Seine	0.106 (0.638)	-0.0302 (0.915)	0.533 (0.107)	0.299 (0.280)	
York—Trawl	0.198 (0.479)	0.111 (0.694)	-0.124 (0.660)	0.161 (0.567)	**0.665 (0.00680)**

(B) Blueback Herring

	James—Seine	James—Trawl	Rappahannock—Seine	Rappahannock—Trawl	York—Seine
James—Trawl	0.397 (0.143)				
Rappahannock—Seine	**0.712 (0.000200)**	0.445 (0.0965)			
Rappahannock—Trawl	-0.0232 (0.934)	0.0571 (0.840)	-0.261 (0.348)		
York—Seine	**0.478 (0.0246)**	0.457 (0.0865)	**0.560 (0.00670)**	-0.127 (0.651)	
York—Trawl	-0.107 (0.704)	0.339 (0.216)	0.141 (0.616)	0.368 (0.177)	-0.0572 (0.840)

Table 15.9 Results of the Mann-Kendall test for temporal trends in sex-specific average length and weight of alewives and blueback herring sampled from commercial pound nets in the Rappahannock River. The number of years for which data were available is represented by n, *S* is the Mann-Kendall test statistic, and *P* is the two-tailed probability. Trend indicates the direction of the trend if a statistically significant temporal trend was detected (⍰ = 0.05); NS = not significant.

Species	**Data**	**Sex**	**n**	***S***	***P***	**Trend**
Alewife	Length	Male	26	-90	0.0497	⍰
		Female	26	-127	0.00548	⍰
	Weight	Male	29	-154	0.00409	⍰
		Female	29	-137	0.0107	⍰
Blueback Herring	Length	Male	23	-99	0.00965	⍰
		Female	23	-108	0.00470	⍰
	Weight	Male	23	-65	0.0908	NS
		Female	25	-69	0.112	NS

Table 15.10 Calculated sex ratios (male: female), sample sizes (n), χ^2 values (Yate's corrected), and probabilities (*P*) that the sex ratio for alewives is 1:1 based on historical sampling of the commercial fishery. Statistically significant sex ratios are formatted in bold.

Water Body	**Year**	**n**	**Sex Ratio**	χ^2	***P***
James	1967	372	**3.2**	102	< 0.001
	1968	400	1.1	0.723	0.395
	1969	344	1.2	3.56	0.0592
	1970	367	**3.4**	107	< 0.001
	1974	551	**3.9**	191	< 0.001
	1975	459	**3.1**	119	< 0.001
	1977	189	**2.4**	30.6	< 0.001
	1978	148	**1.9**	13.7	< 0.001
	1979	112	**2.0**	12.2	< 0.001
	1980	151	**1.5**	5.96	0.0146
York	1967	424	**1.6**	23.1	< 0.001
	1969	312	0.82	2.70	0.101
	1970	415	**0.80**	5.10	0.0239
	1974	139	**1.6**	6.47	0.0109
	1975	211	1.2	1.54	0.215
	1976	280	0.84	1.89	0.169
	1977	291	1.2	3.09	0.0786
	1978	203	1.3	3.33	0.0680
	1979	48	0.78	0.521	0.470
	1980	114	0.87	0.430	0.512
	1981	89	**0.59**	5.44	0.0197
	1982	78	0.95	0.0128	0.910
	1983	84	0.68	2.68	0.102
	1984	82	0.64	3.52	0.0605
	1985	352	1.0	0.0256	0.873
	1986	76	0.90	0.118	0.731
	1987	83	0.80	0.771	0.380
	1988	188	**0.53**	17.3	< 0.001
Rappahannock	1974	369	**1.2**	3.91	0.0479
	1975	1,206	1.0	0.000829	0.977
	1976	1,537	**1.2**	7.87	0.00502
	1977	1,171	**1.4**	34.8	< 0.001
	1978	425	**1.3**	7.92	0.00490
	1979	309	0.94	0.207	0.649
	1980	202	1.1	0.401	0.527
	1981	85	**0.55**	6.78	0.00924
	1982	151	**1.8**	12.8	< 0.001
	1983	897	**0.86**	4.86	0.0275
	1984	567	1.0	0.0635	0.801
	1985	738	**1.2**	8.03	0.00459
	1986	431	0.99	0.00928	0.923
	1987	390	0.96	0.126	0.723
	1988	241	0.79	3.25	0.0713

Table 15.11 Calculated sex ratios (male: female), sample sizes (n), χ^2 values (Yate's corrected), and probabilities (*P*) that the sex ratio for blueback herring is 1:1 based on historical sampling of the commercial fishery. Statistically significant sex ratios are formatted in bold.

Water Body	**Year**	**n**	**Sex Ratio**	χ^2	***P***
James	1967	291	**2.4**	49.5	< 0.001
	1968	318	**2.2**	46.0	< 0.001
	1969	241	**2.3**	35.1	< 0.001
	1970	177	**5.1**	78.7	< 0.001
	1974	224	1.2	1.61	0.204
	1975	682	**1.9**	61.6	< 0.001
	1977	586	**1.7**	36.9	< 0.001
	1978	223	**1.5**	9.49	0.00207
	1979	245	**1.3**	4.18	0.0409
	1980	247	**1.8**	21.0	< 0.001
York	1967	332	**1.3**	5.06	0.0244
	1969	193	**1.4**	4.66	0.0308
	1970	19	0.90	0	1.00
	1974	171	0.99	0	1.00
	1975	546	**1.6**	28.6	< 0.001
	1976	206	0.82	1.75	0.186
	1977	777	**1.3**	15.6	< 0.001
	1978	726	1.1	2.10	0.148
	1979	436	1.1	0.828	0.363
	1980	577	1.1	1.56	0.212
	1981	1,205	0.93	1.46	0.226
	1982	708	**1.7**	47.3	< 0.001
	1983	826	0.93	1.02	0.313
	1984	827	**0.58**	58.5	< 0.001
	1985	680	1.1	0.649	0.421
	1986	881	**0.78**	13.2	< 0.001
	1987	515	1.1	0.280	0.597
	1988	402	0.86	2.09	0.148
Rappahannock	1974	489	**1.9**	47.2	< 0.001
	1975	1,300	**1.2**	13.6	< 0.001
	1976	2,087	**1.5**	90.3	< 0.001
	1977	1,846	**1.3**	25.0	< 0.001
	1978	1,341	**0.84**	10.4	0.00127
	1979	963	**1.5**	35.2	< 0.001
	1981	789	**0.83**	6.57	0.0104
	1980	759	0.94	0.638	0.425
	1982	766	**2.0**	84.9	< 0.001
	1983	520	1.1	2.09	0.148
	1984	622	1.1	1.75	0.186
	1985	682	**1.3**	13.8	< 0.001
	1986	523	**1.3**	7.35	0.00671
	1987	295	1.1	0.488	0.485
	1988	328	**0.73**	7.93	0.00486

Table 15.12 Estimated rates of repeat spawning for male and female alewives sampled from the commercial fishery in the James and York rivers.

Water Body	Year	Males			Females		
		Total	Repeats	% Repeats	Total	Repeats	% Repeats
James	1967	284	185	65.1	88	46	52.3
	1968	209	145	69.4	191	127	66.5
	1969	190	134	70.5	154	128	83.1
	1970	283	141	49.8	84	35	41.7
York	1967	262	134	51.1	162	92	56.8
	1969	141	98	69.5	171	135	78.9
	1970	184	84	45.7	231	123	53.2

Table 15.13 Estimated rates of repeat spawning for male and female blueback herring sampled from the commercial fishery in the James and York rivers.

Water Body	Year	Males			Females		
		Total	Repeats	% Repeats	Total	Repeats	% Repeats
James	1967	206	115	55.8	85	28	32.9
	1968	220	130	59.1	98	36	36.7
	1969	167	137	82.0	74	54	73.0
	1970	148	53	35.8	29	12	41.4
York	1967	187	117	62.6	145	84	57.9
	1969	112	79	70.5	81	58	71.6
	1970	9	6	66.7	10	5	50.0

Table 15.14 Catch curve estimates of instantaneous total mortality (*Z*) for alewives sampled from commercial harvest in the James, York, and Rappahannock rivers.

Water Body	**Structure**	**Year**	***Z***	**SE[*Z*]**
James	Scale	1974	0.846	0.0373
		1975	1.38	0.0748
		1978	0.502	0.0492
	Otolith	1979	1.04	0.162
		1980	0.894	0.0896
York	Scale	1974	1.18	0.107
		1975	1.26	0.102
		1978	0.539	0.0593
	Otolith	1979	1.23	0.246
		1980	0.934	0.105
		1981	0.804	0.109
		1982	1.16	0.147
		1983	0.834	0.101
		1984	0.728	0.0956
		1985	0.791	0.0624
		1986	0.437	0.0531
		1987	0.488	0.0661
		1988	0.527	0.0561
Rappahannock	Scale	1974	1.02	0.0558
		1975	1.83	0.0718
		1978	0.487	0.0291
	Otolith	1979	1.04	0.0917
		1980	1.05	0.0892
		1981	1.09	0.152
		1982	1.42	0.132
		1983	1.02	0.0506
		1984	0.970	0.0612
		1985	0.799	0.0460
		1987	0.511	0.0364
		1988	0.507	0.0461

Table 15.15 Catch curve estimates of instantaneous total mortality (*Z*) for blueback herring sampled from commercial harvest in the James, York, and Rappahannock rivers.

Water Body	Structure	Year	*Z*	SE[*Z*]
James	Scale	1974	0.758	0.0546
		1975	1.60	0.0845
		1978	0.355	0.0326
	Otolith	1979	0.768	0.0745
		1980	0.677	0.0631
York	Scale	1974	2.04	0.187
		1975	1.31	0.0774
		1978	0.441	0.0224
	Otolith	1979	0.958	0.0698
		1980	0.849	0.0650
		1981	0.674	0.0374
		1982	0.777	0.0465
		1983	0.481	0.0236
		1984	0.448	0.0286
		1985	0.419	0.0210
		1987	0.324	0.0280
		1988	0.428	0.0376
Rappahannock	Scale	1974	0.767	0.0360
		1975	1.95	0.0816
		1978	0.410	0.0137
	Otolith	1979	1.00	0.0536
		1980	0.667	0.0383
		1981	0.775	0.0410
		1982	0.888	0.0538
		1983	0.886	0.0607
		1984	0.681	0.0452
		1985	0.445	0.0256
		1986	0.420	0.0289
		1987	0.459	0.0381
		1988	0.461	0.0438

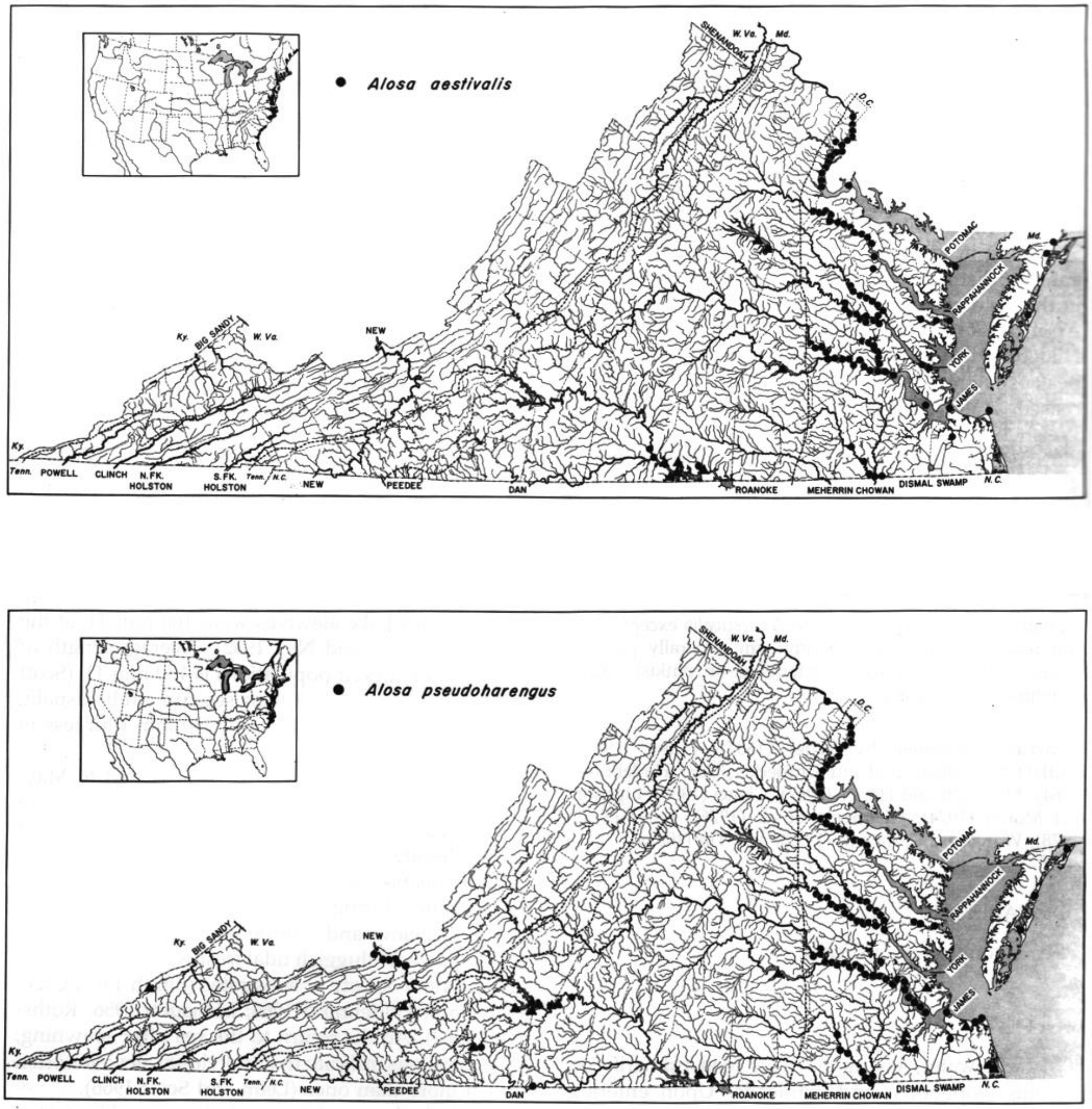

Figure 15.1 Distribution of blueback herring (top) and alewife (bottom) in Virginia. From Lee et al. 1980.

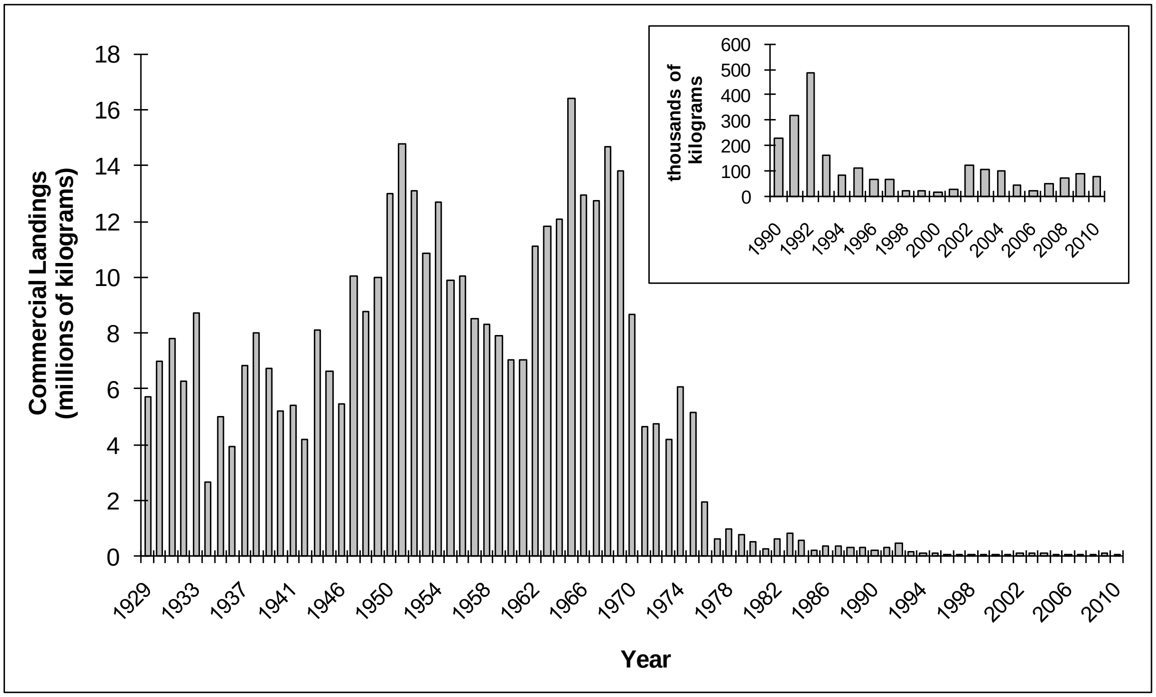

Figure 15.2 Annual commercial landings (millions of kilograms) of river herring in Virginia, 1929–2010. Inset depicts annual commercial landings (thousands of kilograms) during 1990 through 2010.

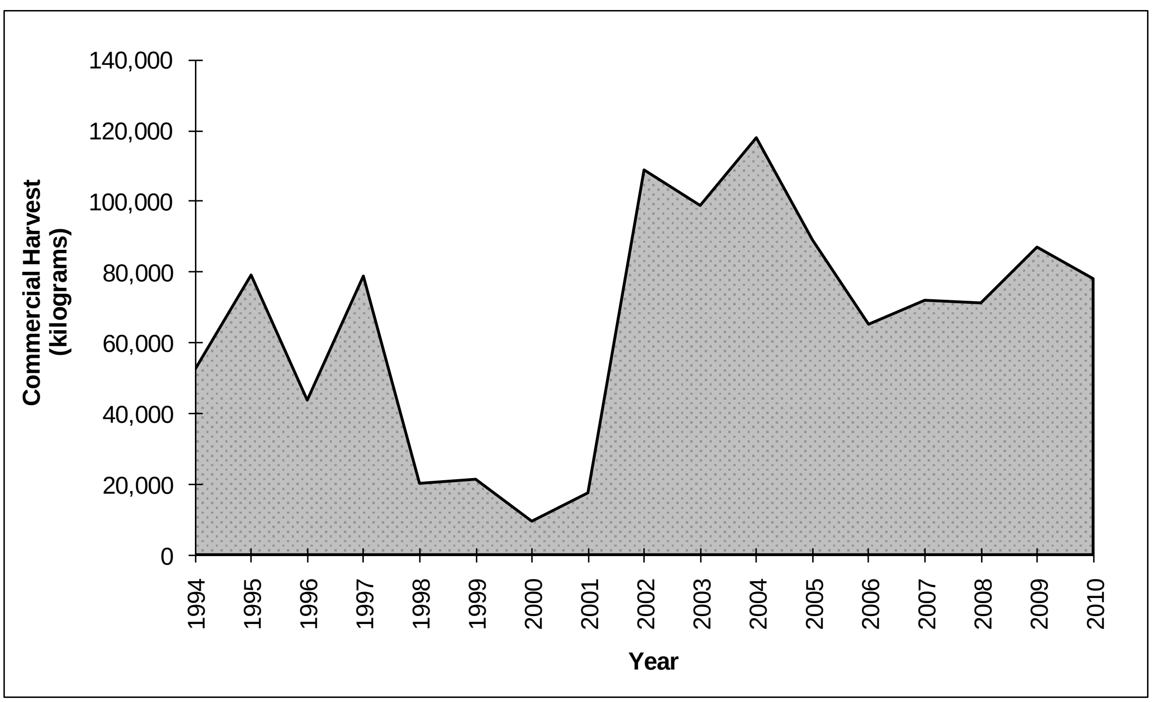

Figure 15.3 Annual commercial harvest (kilograms) of river herring from Virginia waters, 1994–2010.

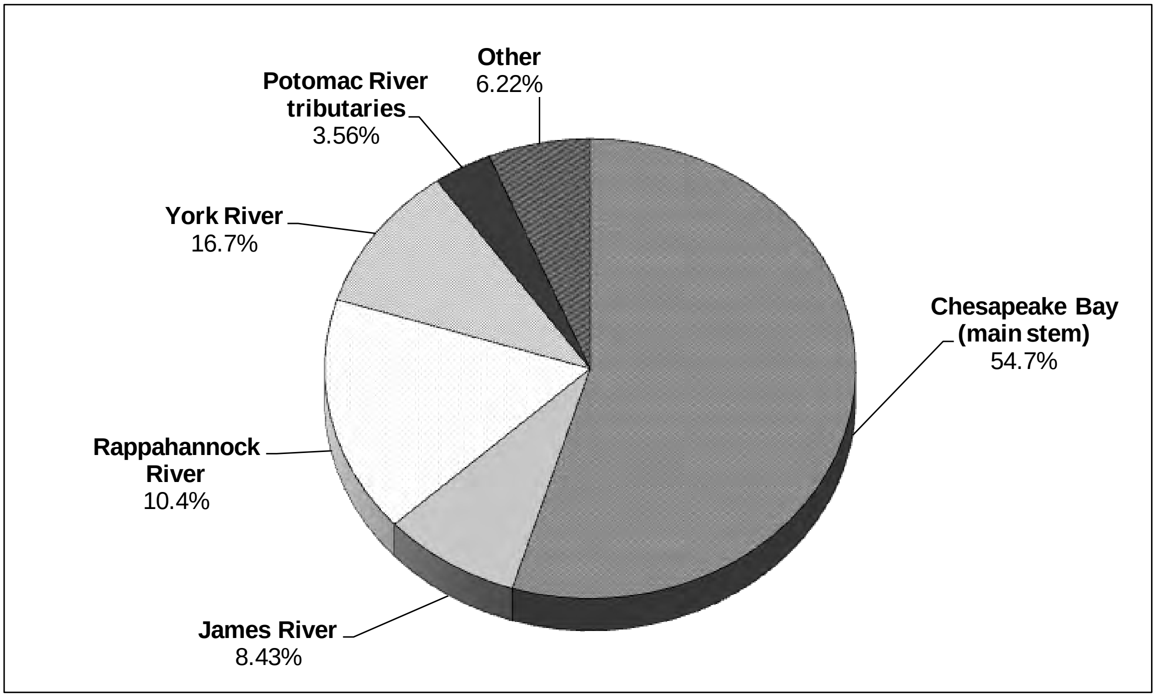

Figure 15.4 Commercial harvest (% of total kilograms) of river herring from Virginia waters, by harvest area, based on 1994–2010 average.

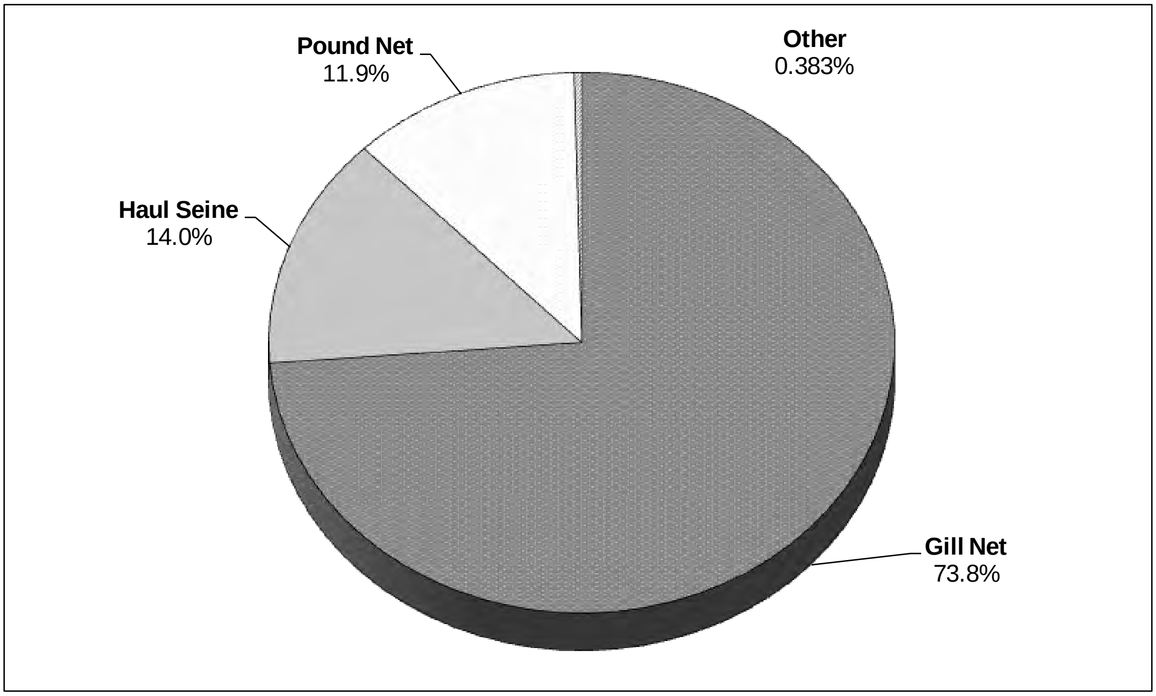

Figure 15.5 Commercial harvest (% of total kilograms) of river herring from Virginia waters, by major gear, based on 1994–2010 average.

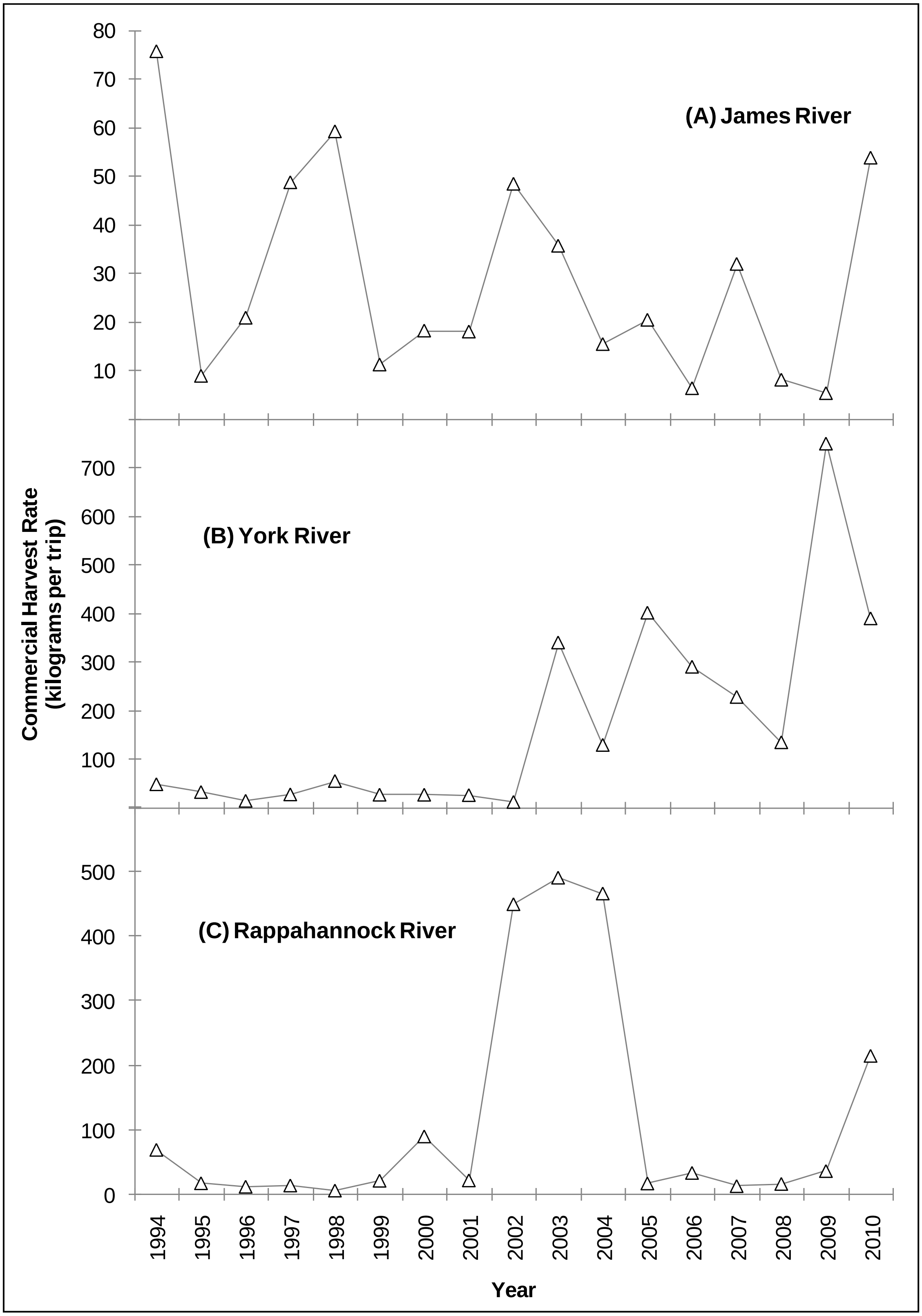

Figure 15.6 Annual commercial harvest rates (kilograms per trip) for alewives harvested by gill nets from the (A) James, (B) York, and (C) Rappahannock rivers, 1994–2010.

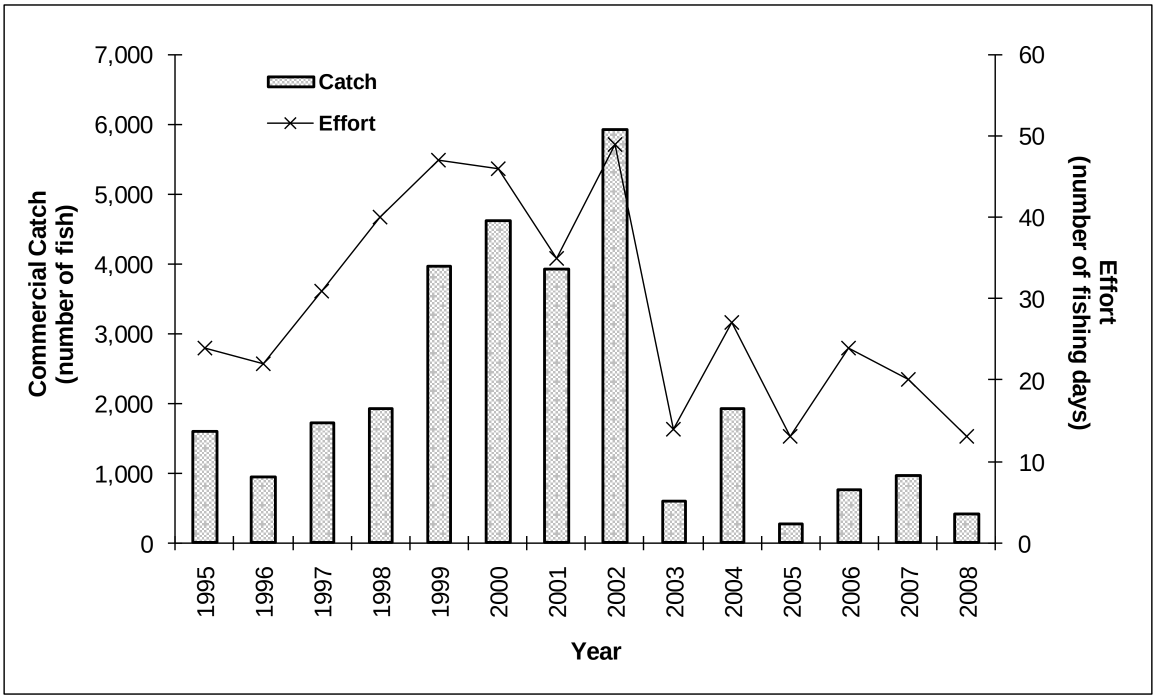

Figure 15.7 Annual commercial catch (number of fish) of river herring and effort (number of fishing days) in the upper Rappahannock River recorded in commercial logbooks, 1995–2008.

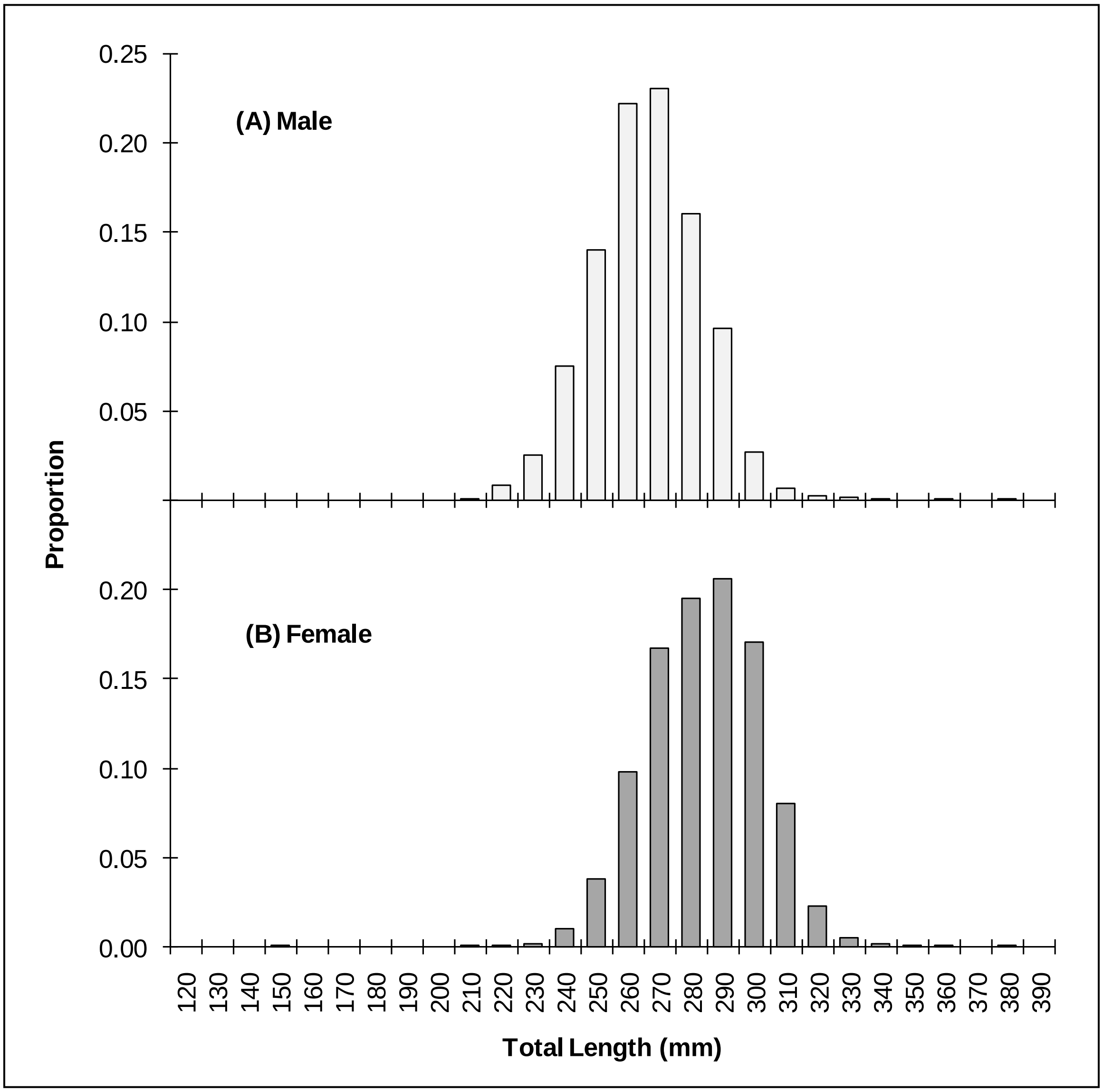

Figure 15.8 Proportion of commercial fishery samples at total length for (A) male and (B) female alewives pooled over gears, water bodies, and years, 1989–2008. Note that no river herring were sampled from the commercial fishery in 2009 and 2010.

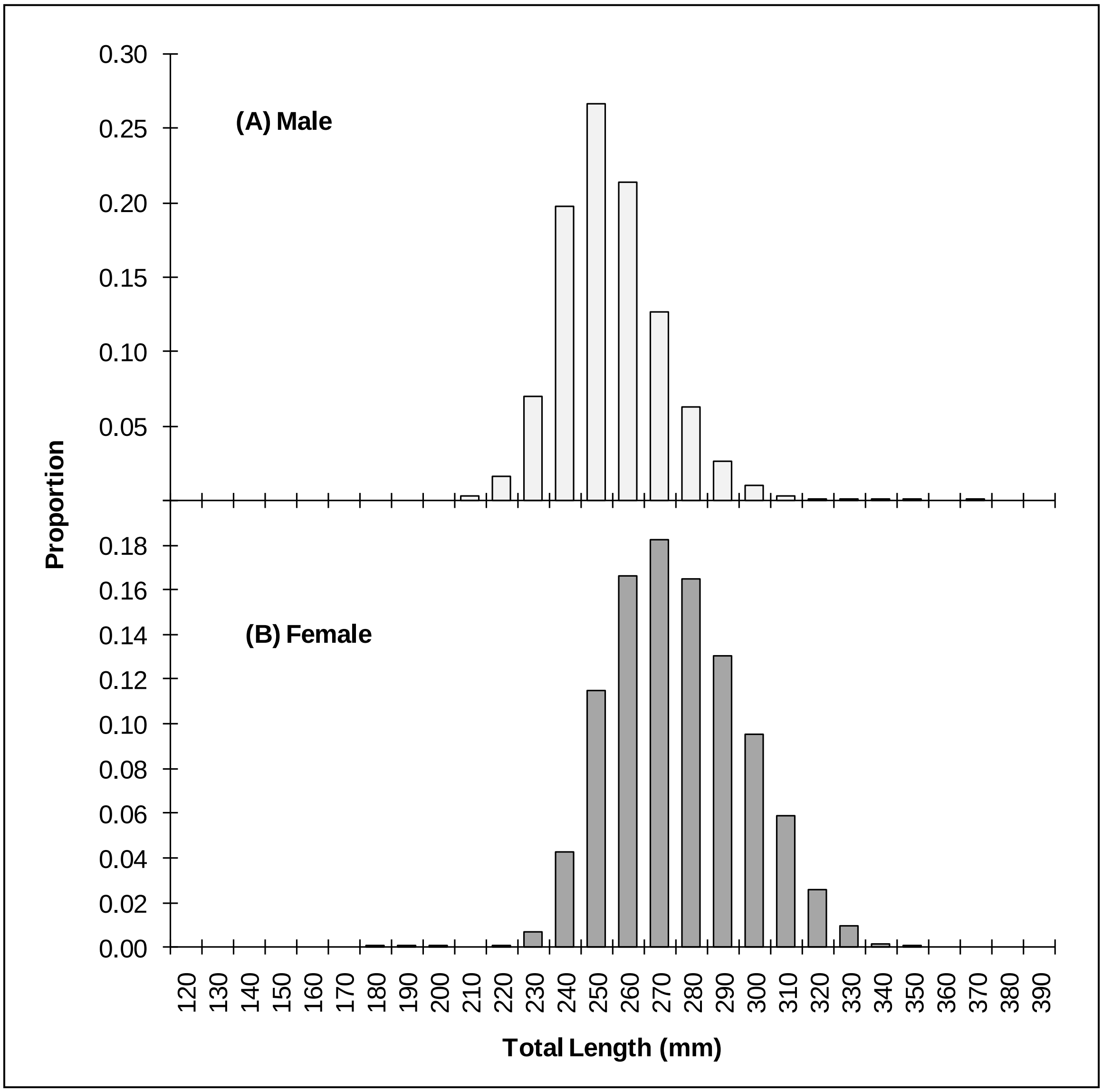

Figure 15.9 Proportion of commercial fishery samples at total length for (A) male and (B) female blueback herring pooled over gears, water bodies, and years, 1989–2008. Note that no river herring were sampled from the commercial fishery in 2009 and 2010.

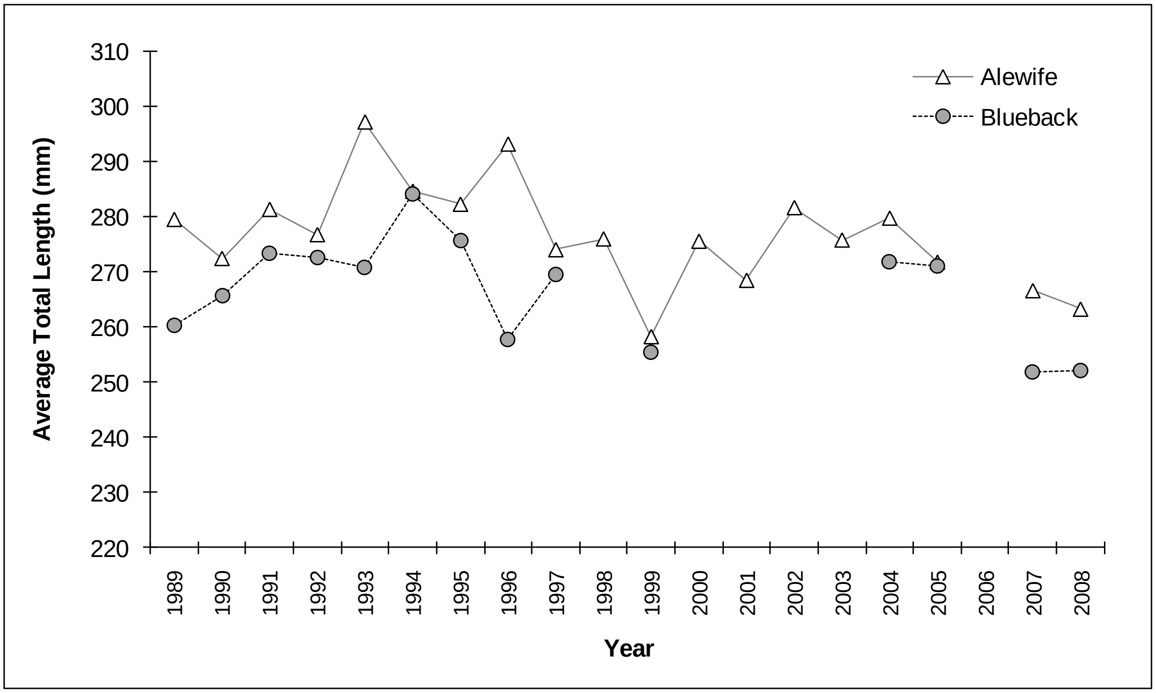

Figure 15.10 Average total length (mm) of alewives and blueback herring sampled from Virginia's commercial landings, 1989–2008. Note that no river herring were sampled from the commercial fishery in 2009 and 2010.

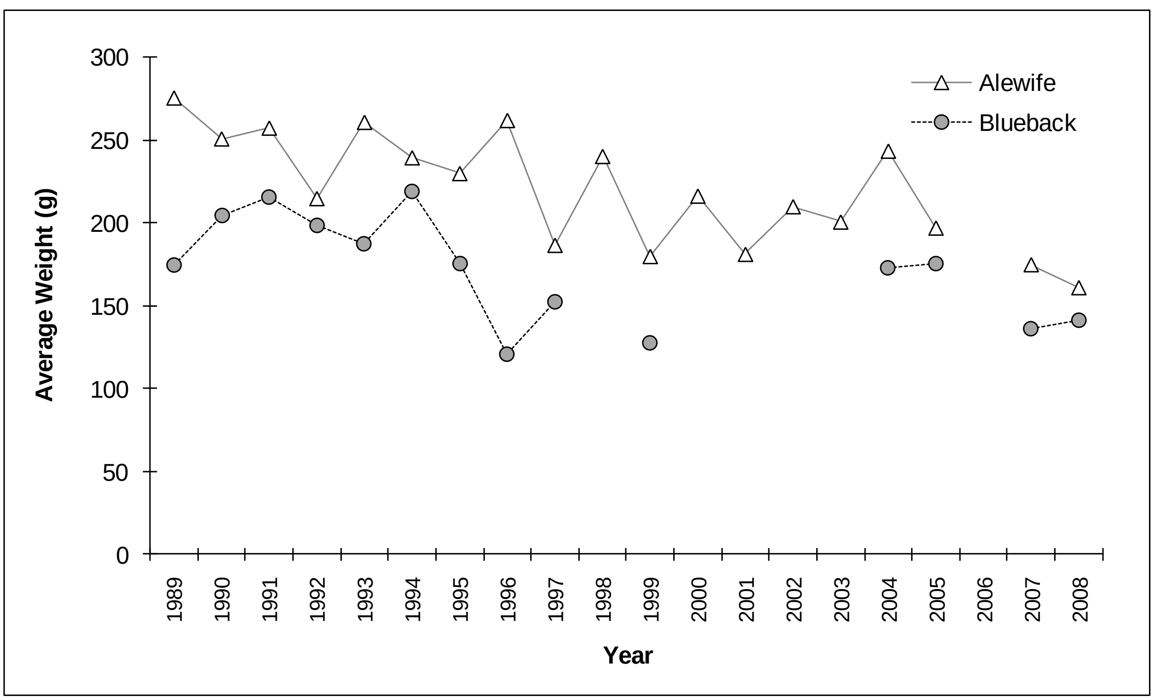

Figure 15.11 Average weight (g) of alewives and blueback herring sampled from Virginia's commercial landings, 1989–2008. Note that no river herring were sampled from the commercial fishery in 2009 and 2010.

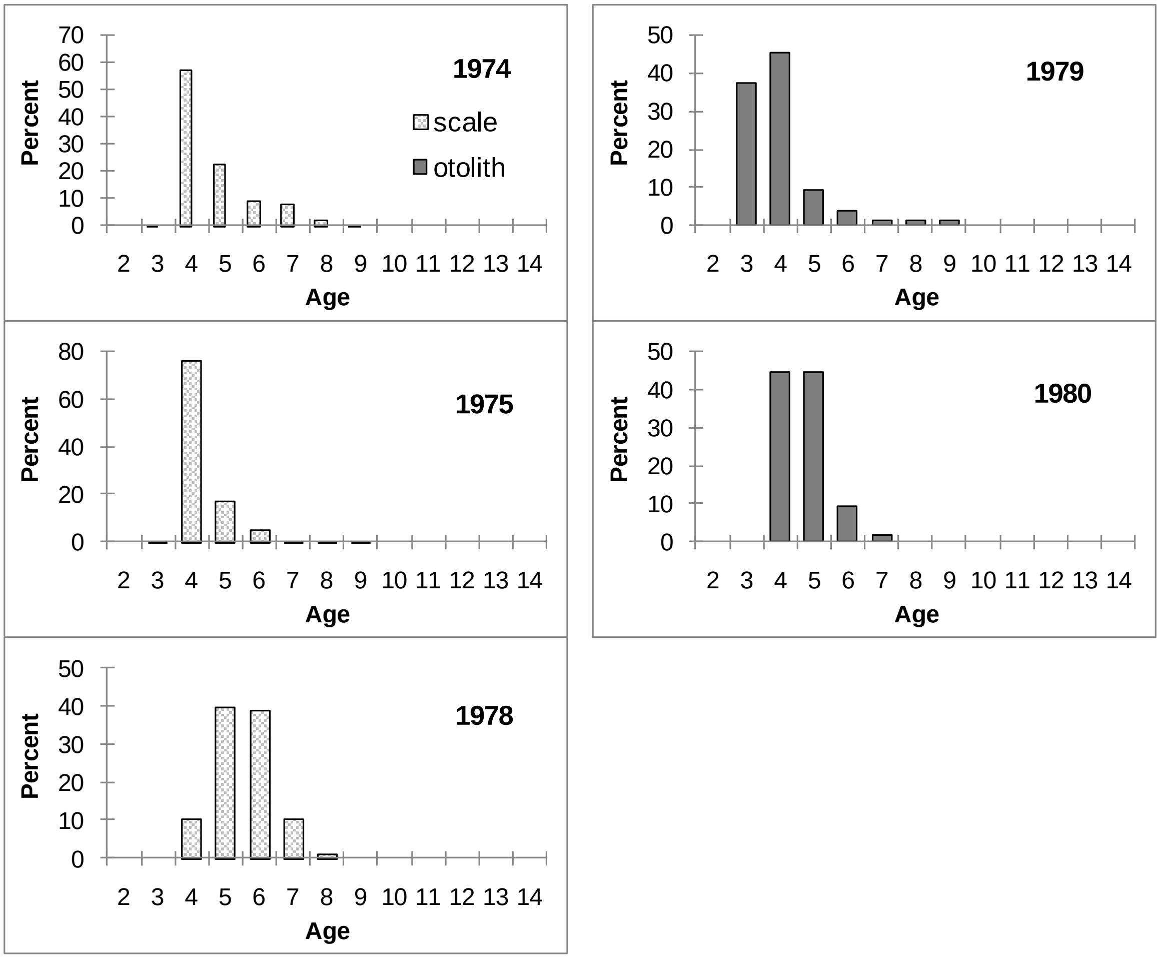

Figure 15.12 Percent at age for alewives sampled from commercial harvest in the James River, 1974–1980.

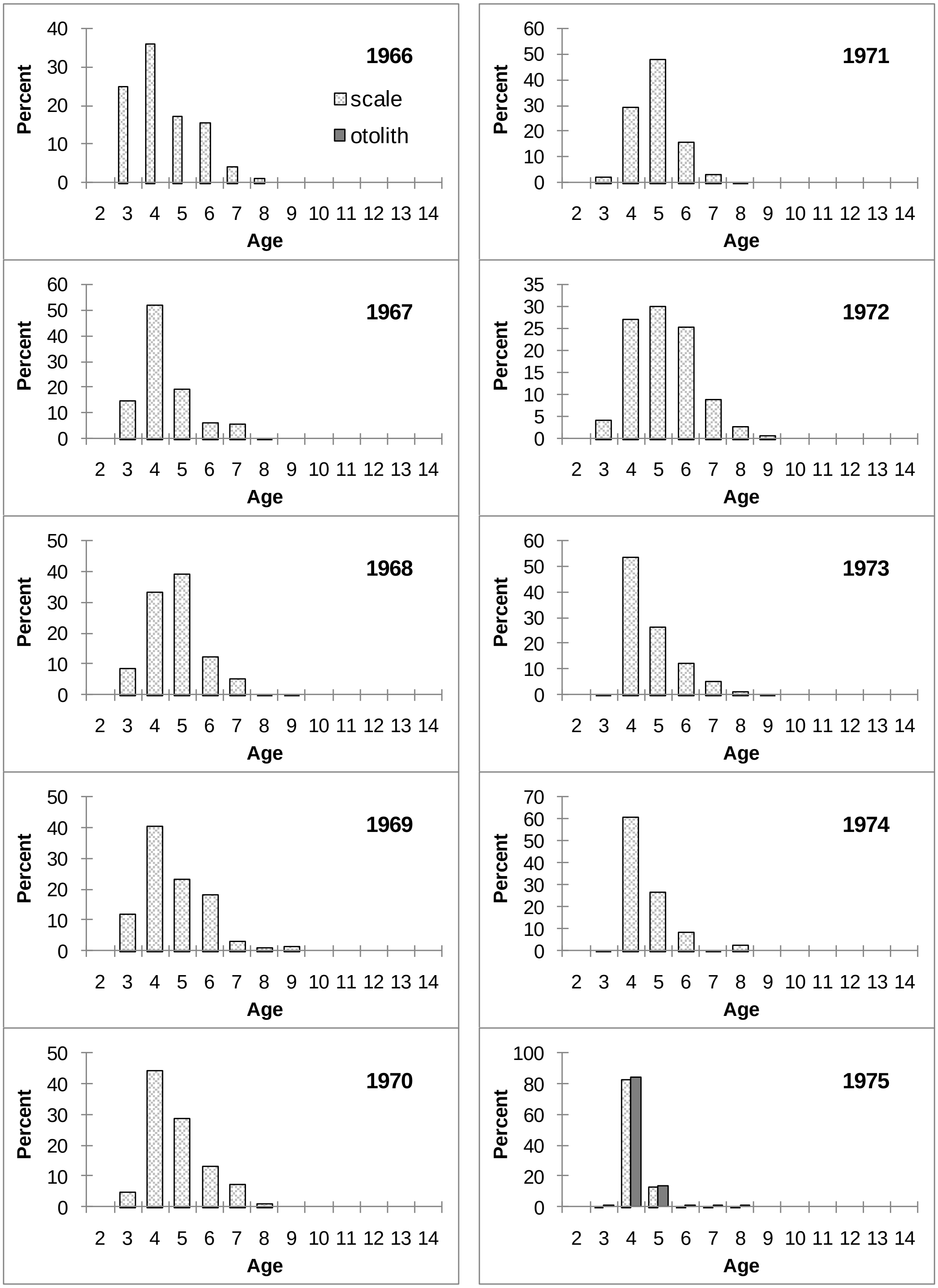

Figure 15.13 Percent at age for alewives sampled from commercial harvest in the Rappahannock River, 1966–1988.

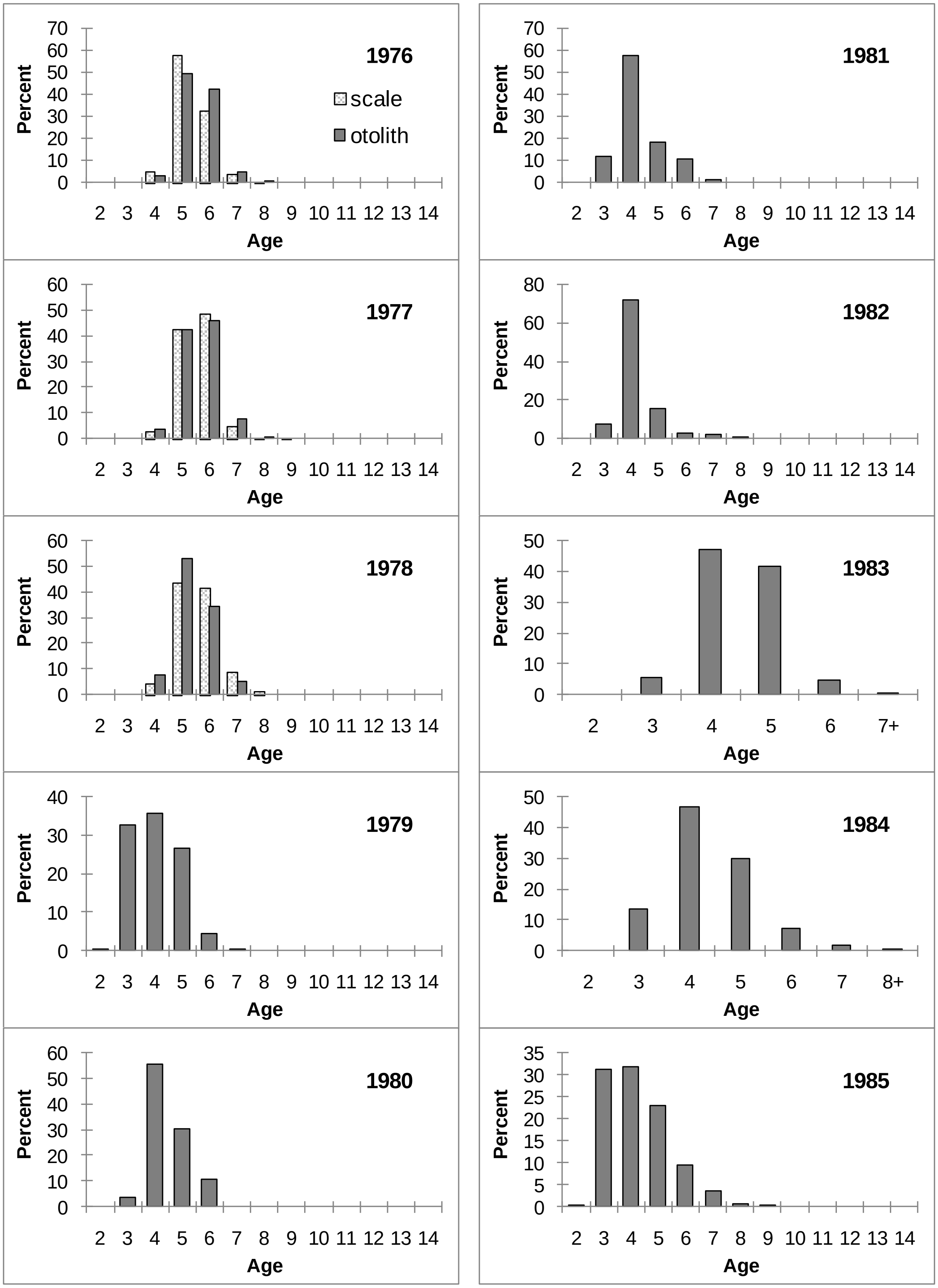

Figure 15.13. Continued.

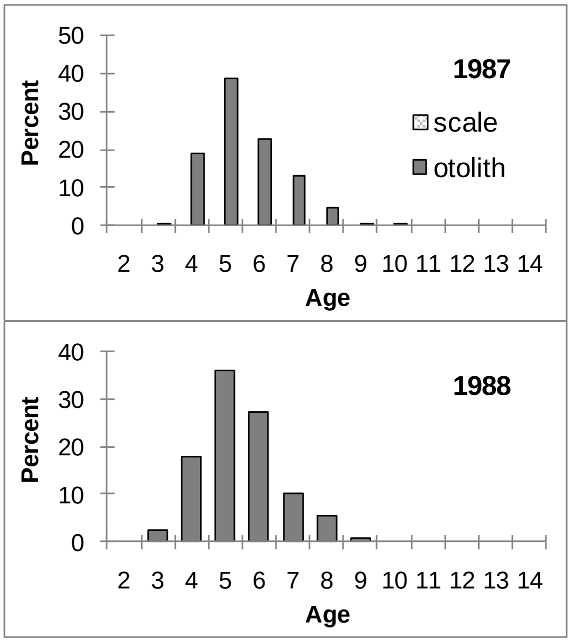

Figure 15.13. Continued.

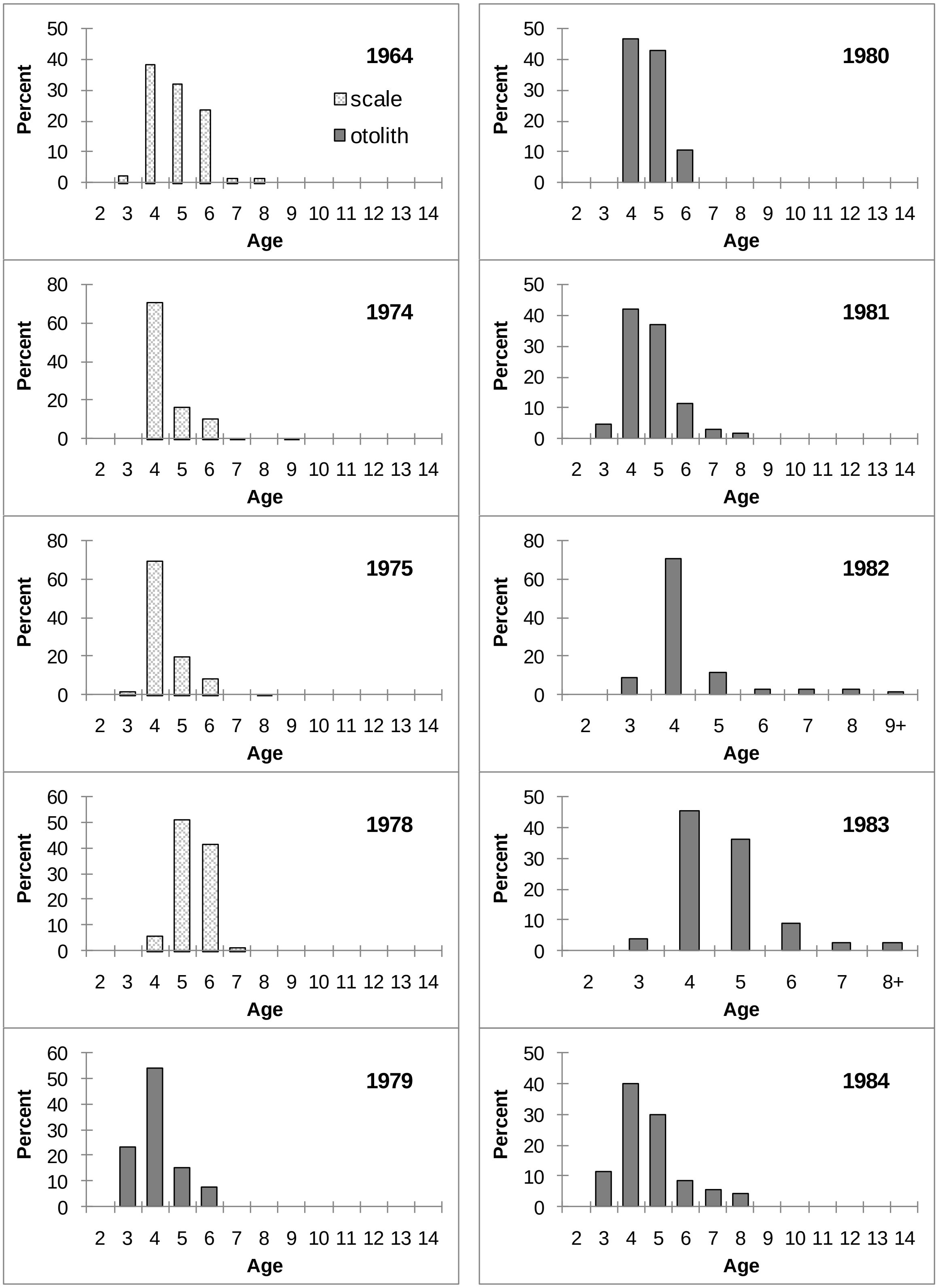

Figure 15.14 Percent at age for alewives sampled from commercial harvest in the York River, 1964–1988.

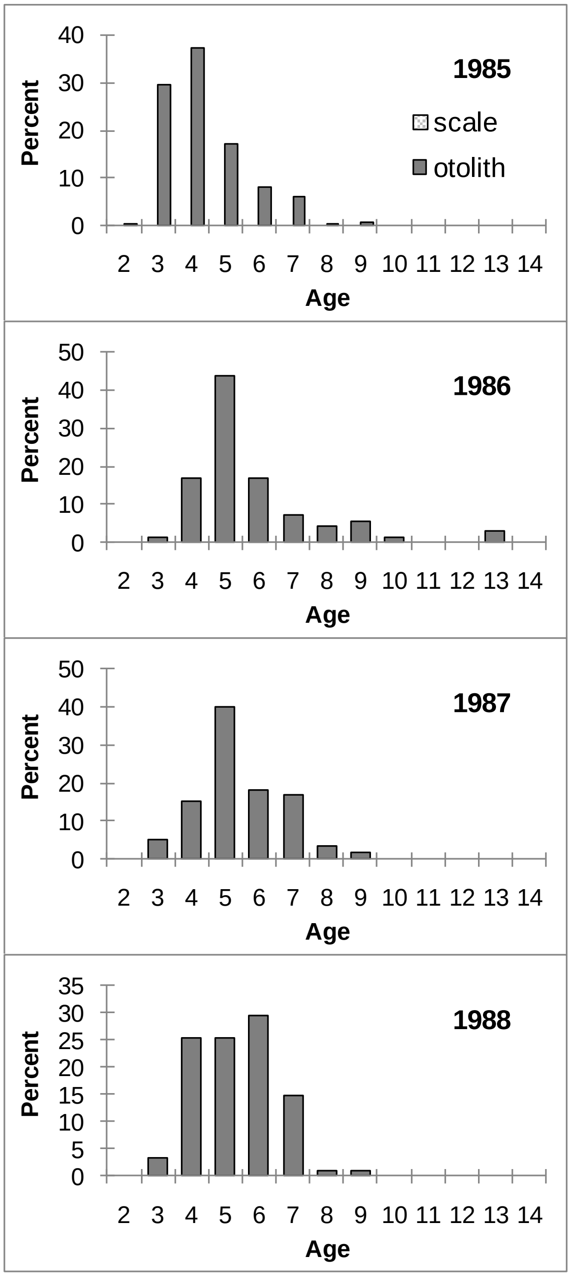

Figure 15.14. Continued.

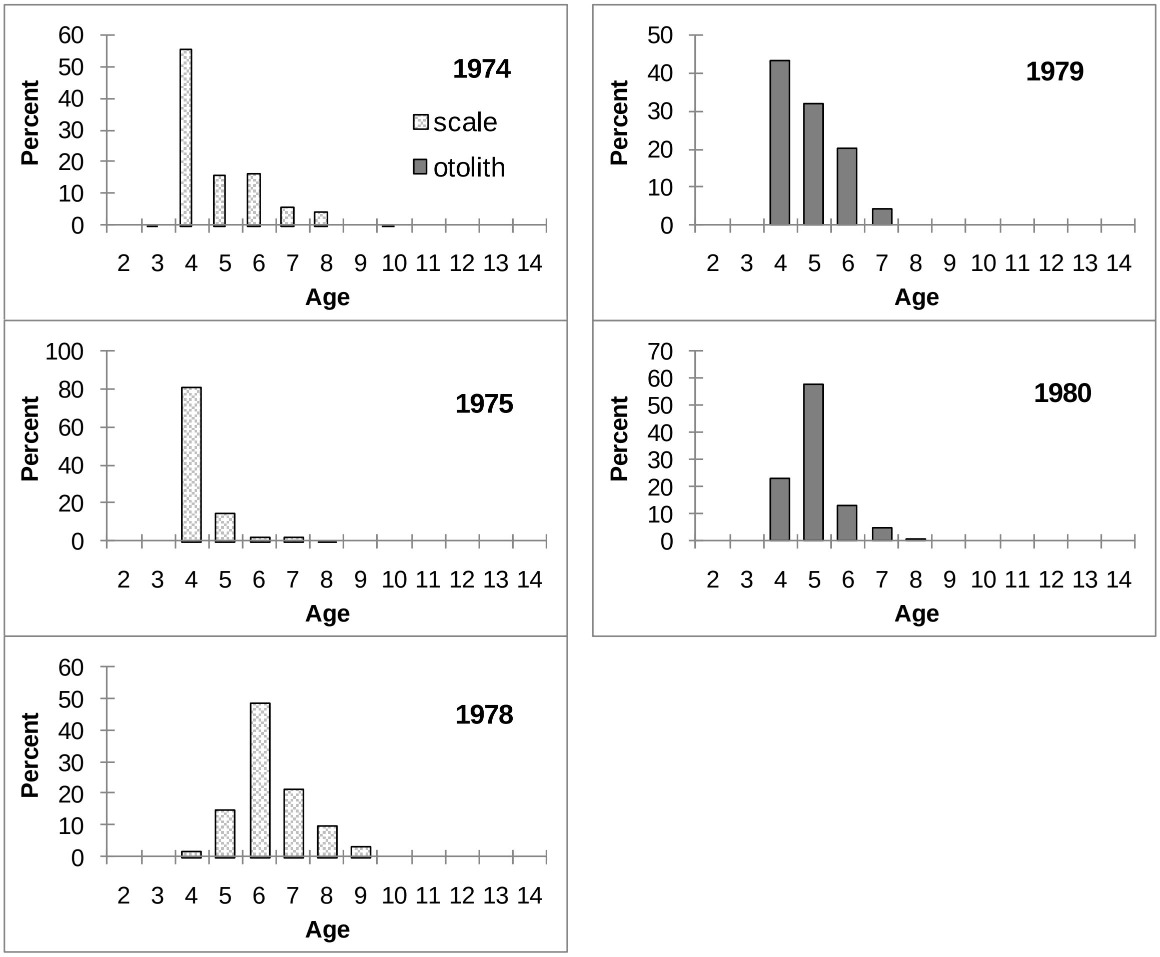

Figure 15.15 Percent at age for blueback herring sampled from commercial harvest in the James River, 1974–1980.

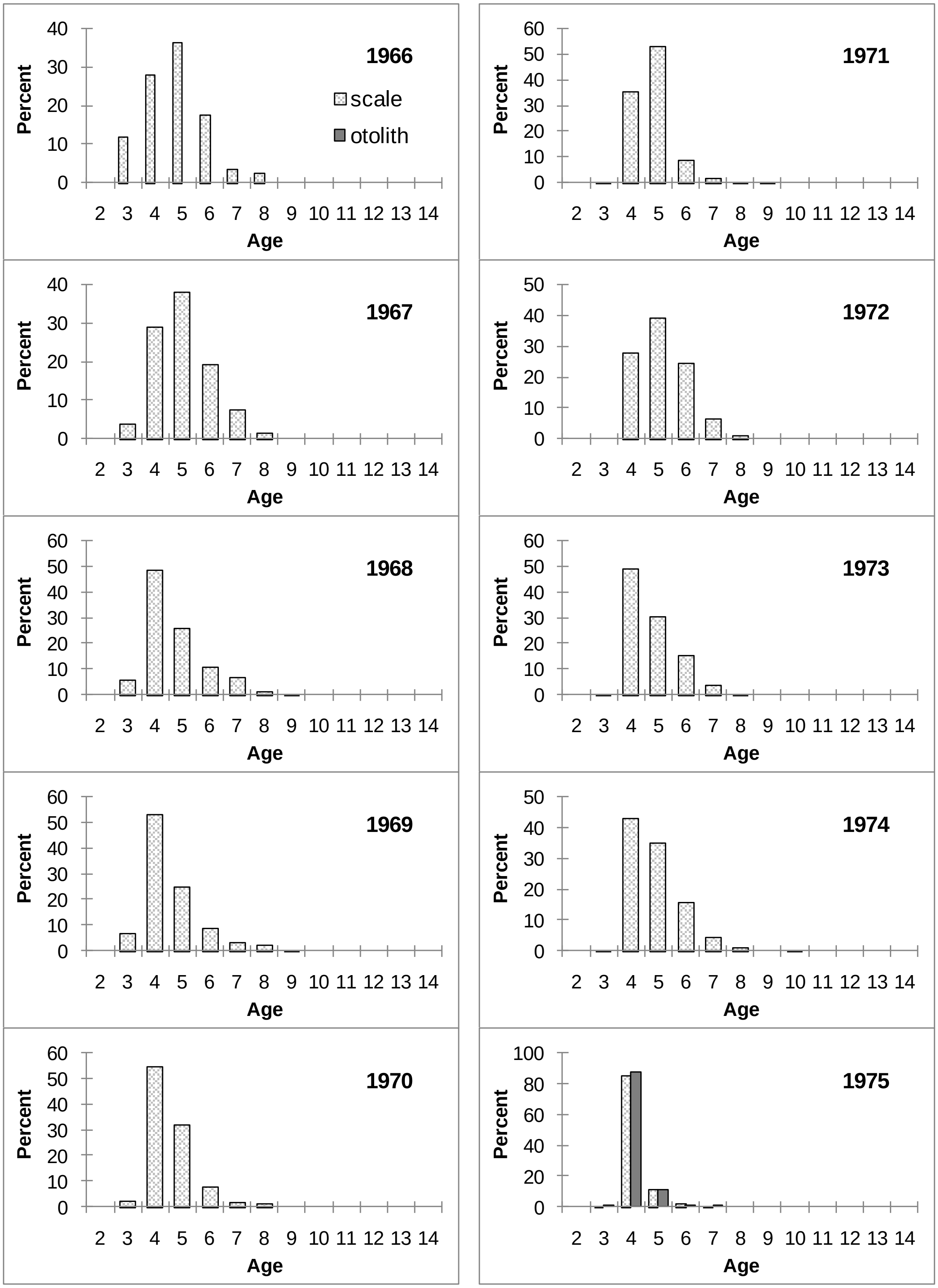

Figure 15.16 Percent at age for blueback herring sampled from commercial harvest in the Rappahannock River, 1966–1988.

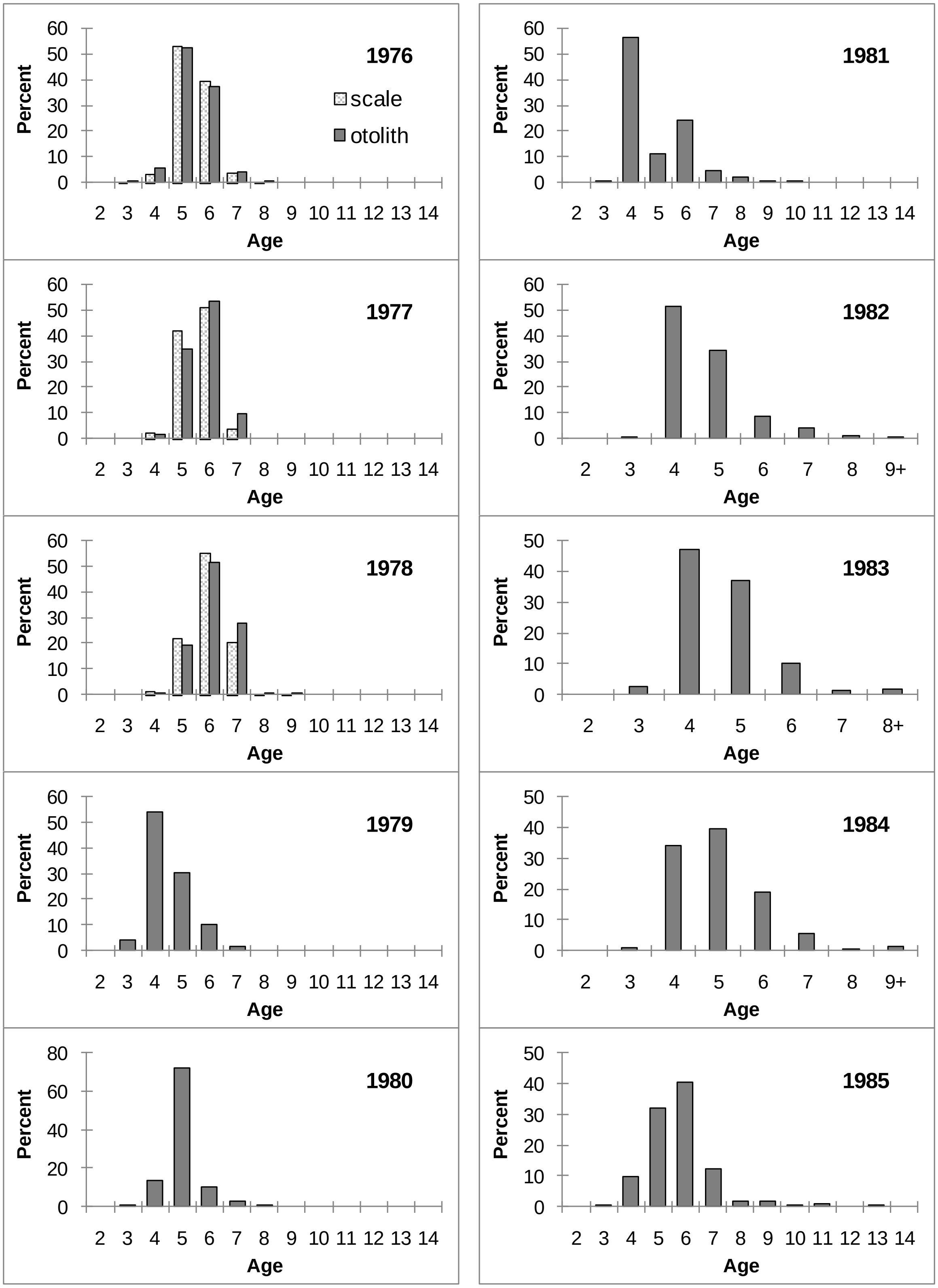

Figure 15.16. Continued.

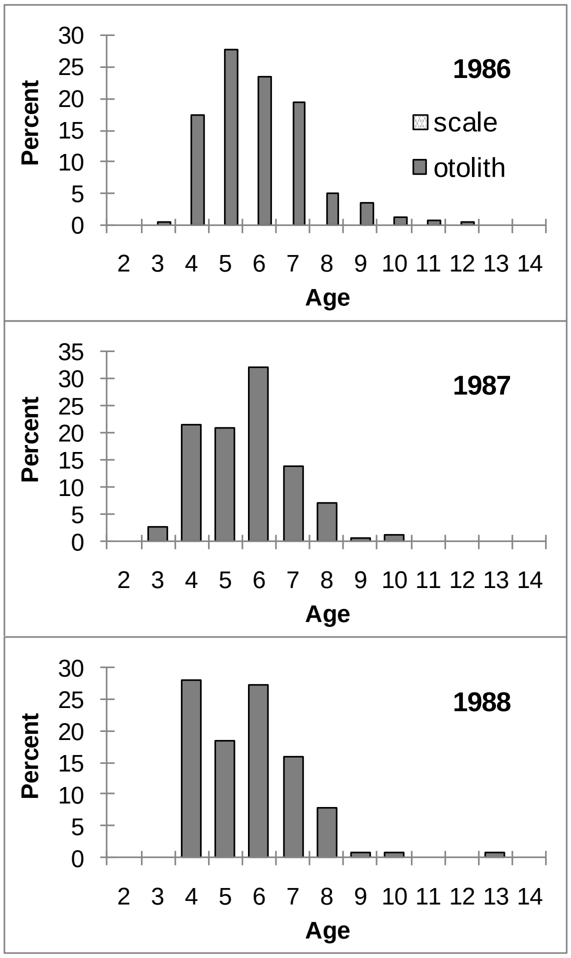

Figure 15.17 Percent at age for blueback herring sampled from commercial harvest in the York River, 1974–1988.

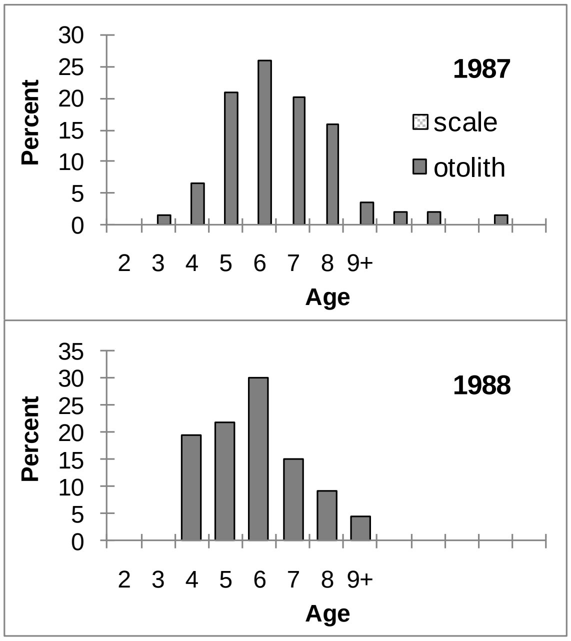

Figure 15.17. Continued.

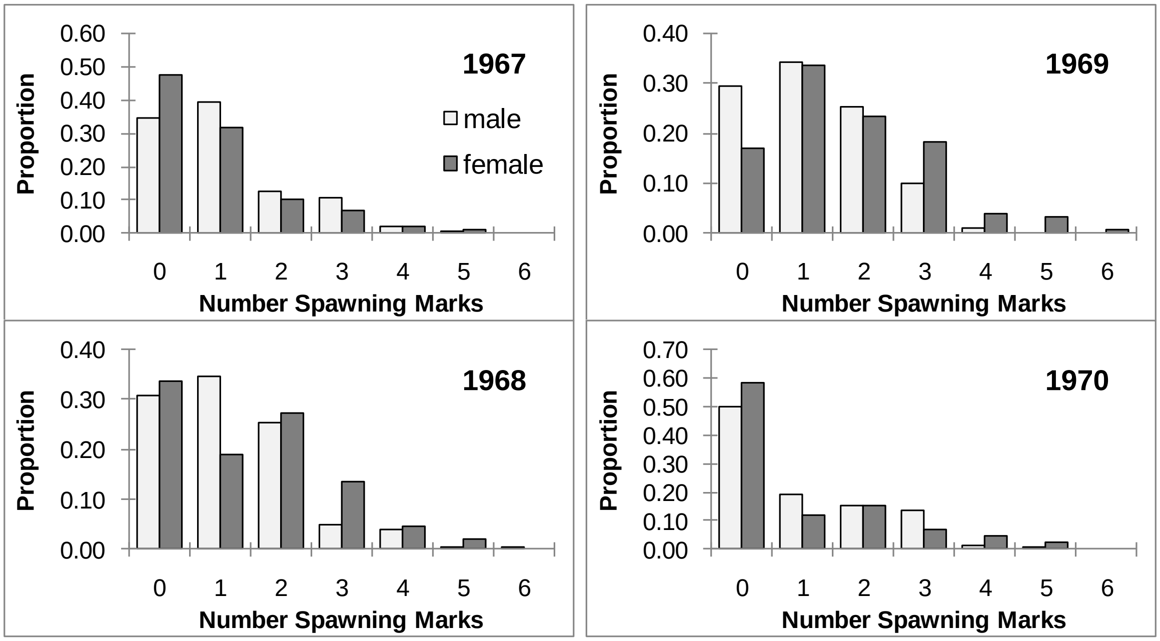

Figure 15.18 Spawning frequency of alewives sampled from commercial harvest in the James River, 1967–1970.

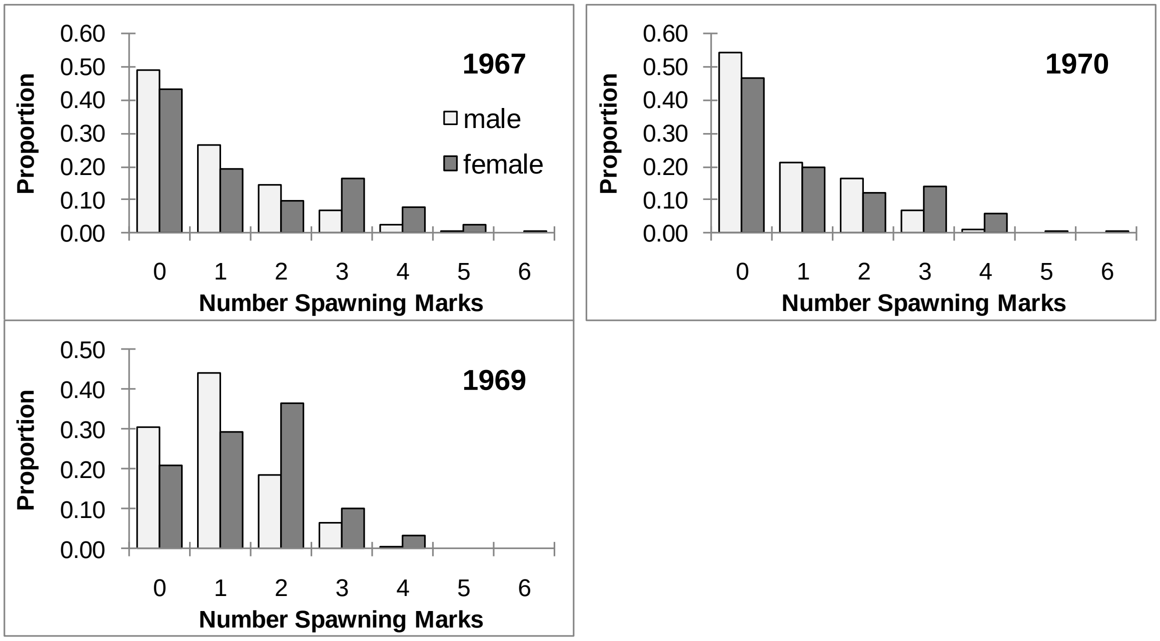

Figure 15.19 Spawning frequency of alewives sampled from commercial harvest in the York River, 1967–1970.

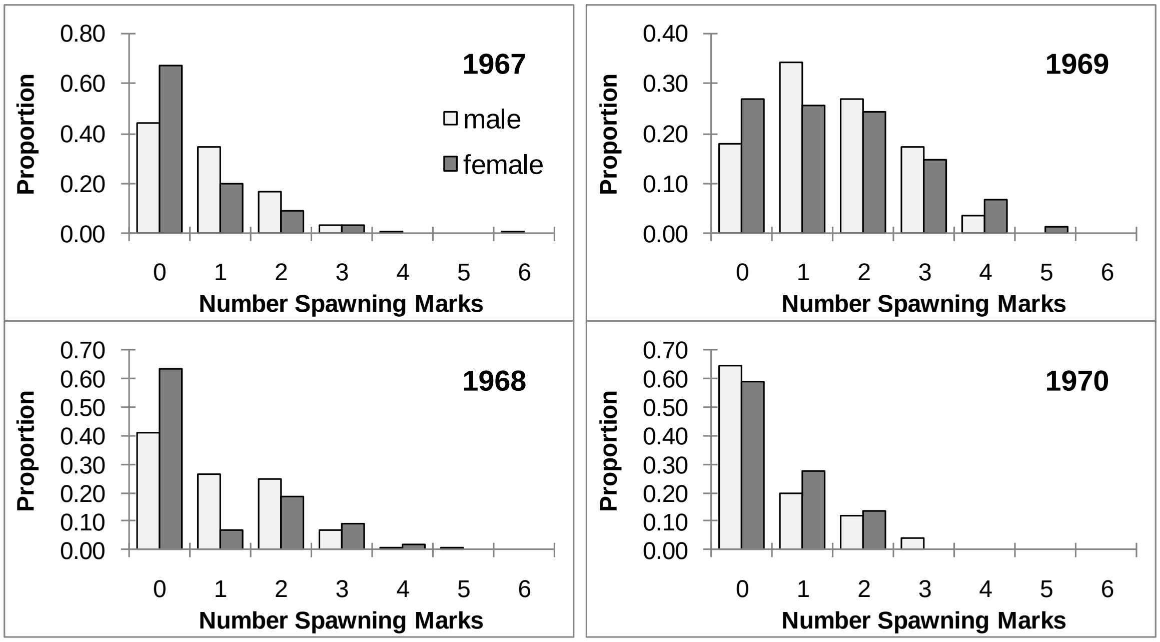

Figure 15.20 Spawning frequency of blueback herring sampled from commercial harvest in the James River, 1967–1970.

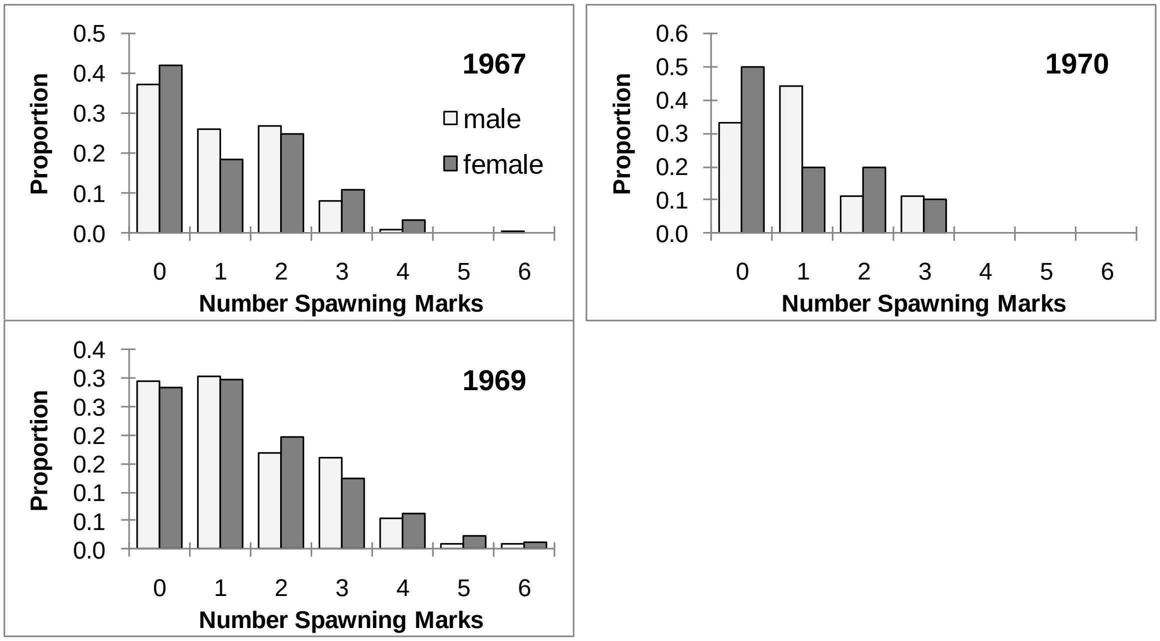

Figure 15.21 Spawning frequency of blueback herring sampled from commercial harvest in the York River, 1967–1970.

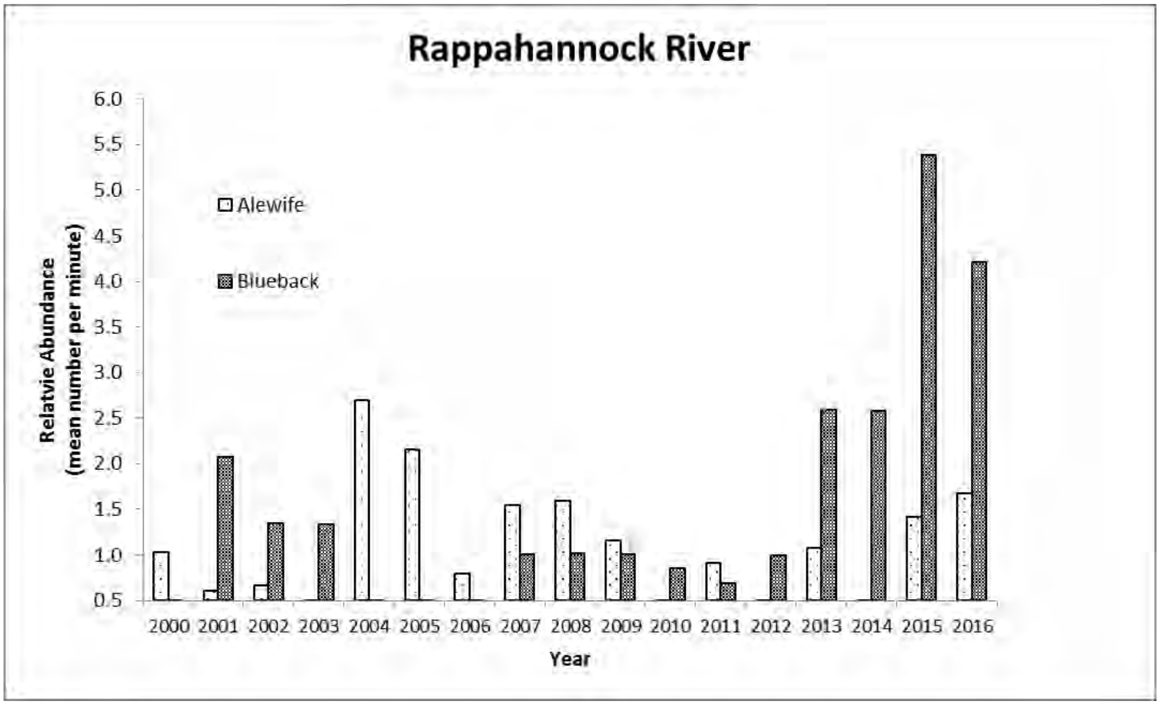

Figure 15.22 Catch rates (arithmetic average number of fish per minute) of alewives and blueback herring collected by the VDGIF's electrofishing survey of the Rappahannock River (Route 1 station), 2000–2016.

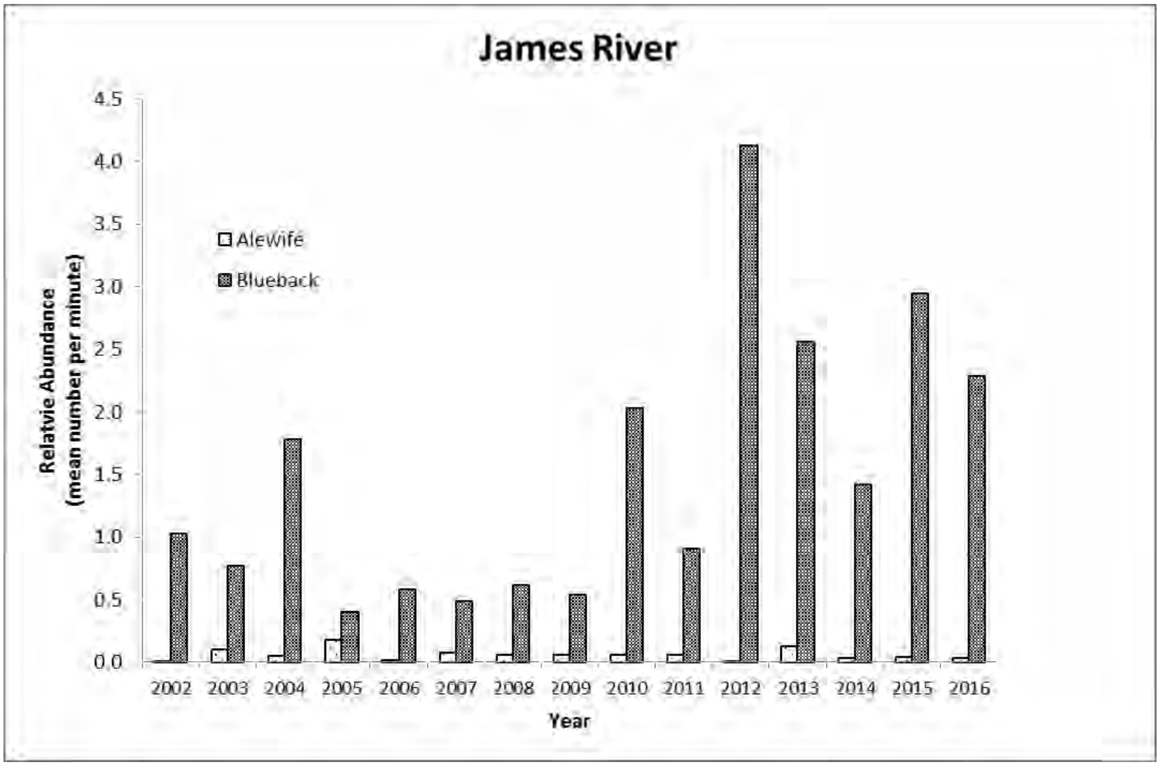

Figure 15.23 Catch rates (arithmetic average number of fish per minute) of alewives and blueback herring collected by the VDGIF's electrofishing survey of the James River (Manchester stations 1, 2, 4, and 5 combined), 2002–2016.

Figure 15.24 Annual relative abundance (average number per day) of adult river herring collected from the Rappahannock River by the VIMS Experimental Anchor Gill-Net Survey, 1991–2010.

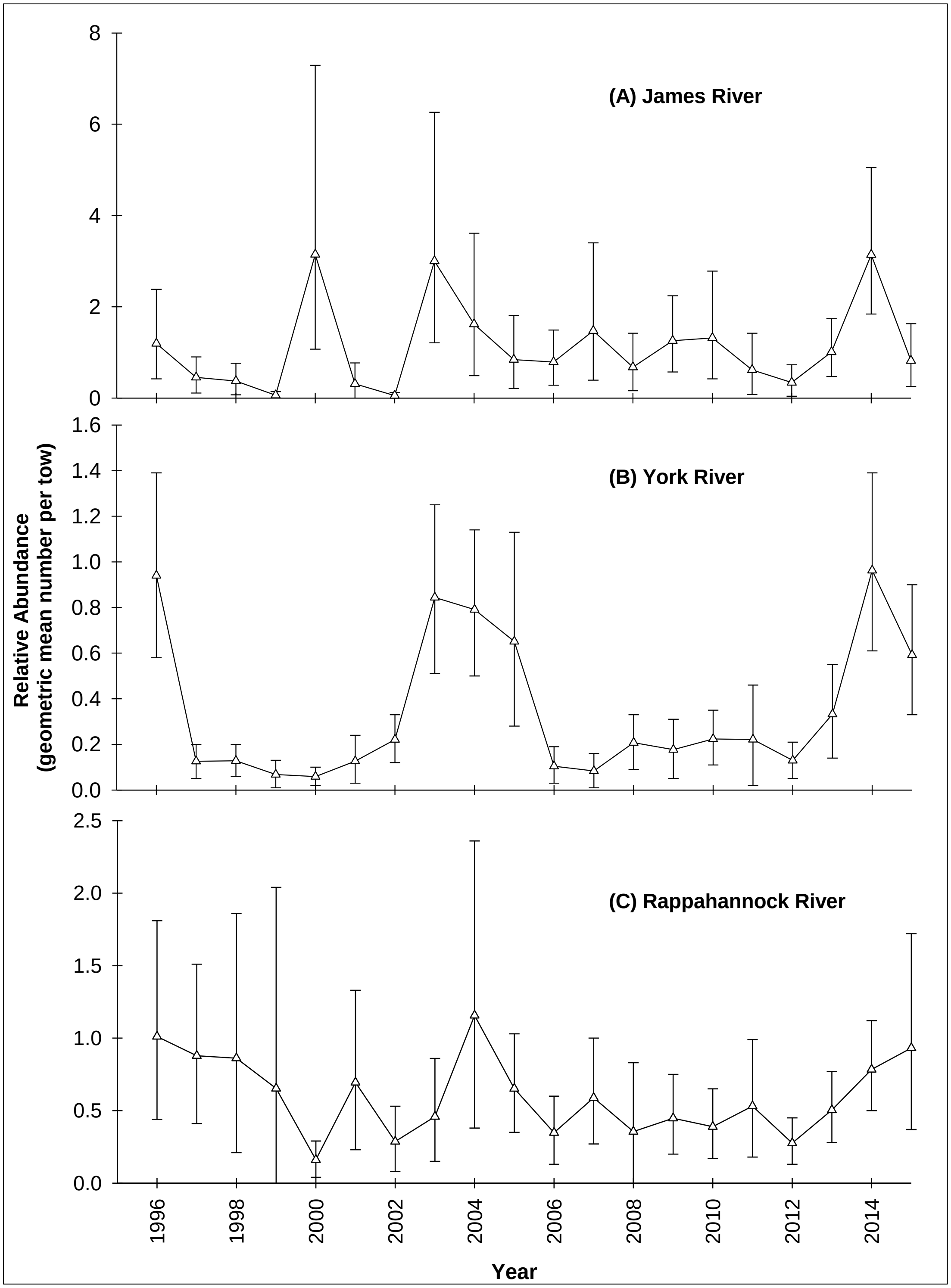

Figure 15.25 Annual JAIs (geometric average number per standard tow) for alewives collected from the (A) James, (B) York, and (C) Rappahannock rivers by the VIMS Juvenile Fish and Blue Crab Trawl Survey, 1996–2015. Error bars represent the 95% confidence intervals.

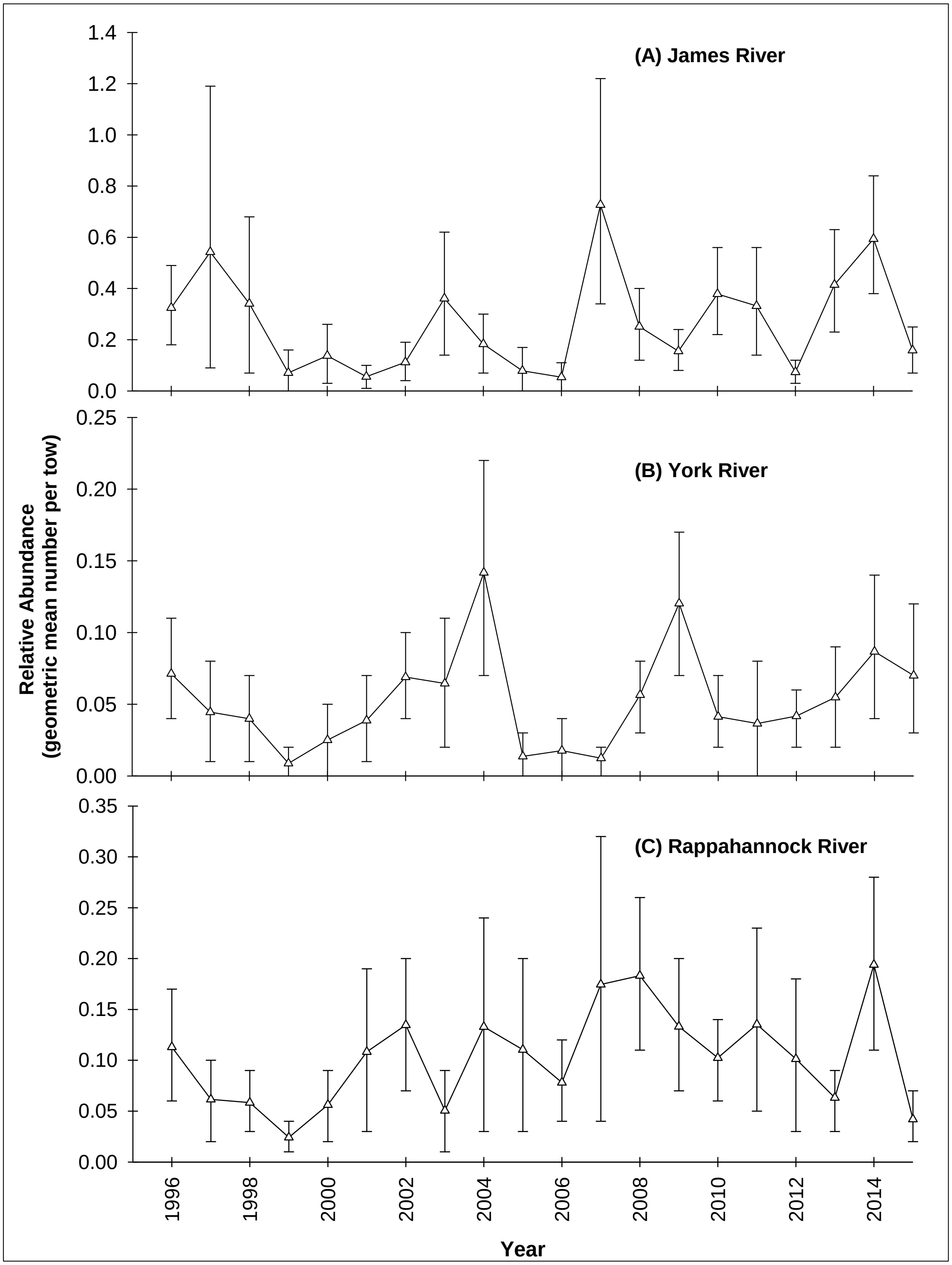

Figure 15.26 Annual JAIs (geometric average number per standard tow) for blueback herring collected from the (A) James, (B) York, and (C) Rappahannock rivers by the VIMS Juvenile Fish and Blue Crab Trawl Survey, 1996–2015. Error bars represent the 95% confidence intervals.

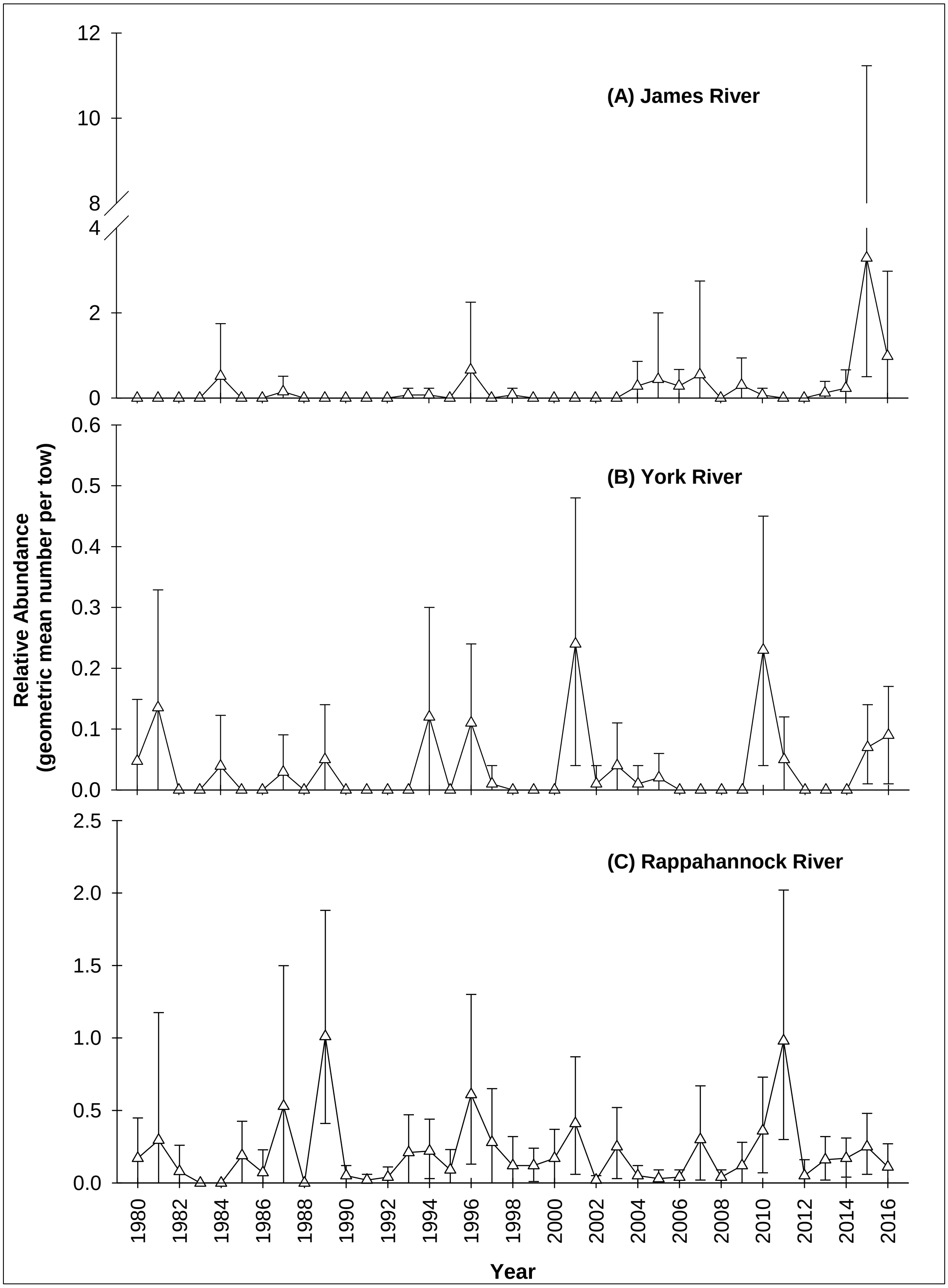

Figure 15.27 Annual JAIs (geometric average number per seine set) for alewives collected from the (A) James, (B) York, and (C) Rappahannock rivers by the VIMS Juvenile Striped Bass Seine Survey, 1989–2016. Error bars represent the 95% confidence intervals.

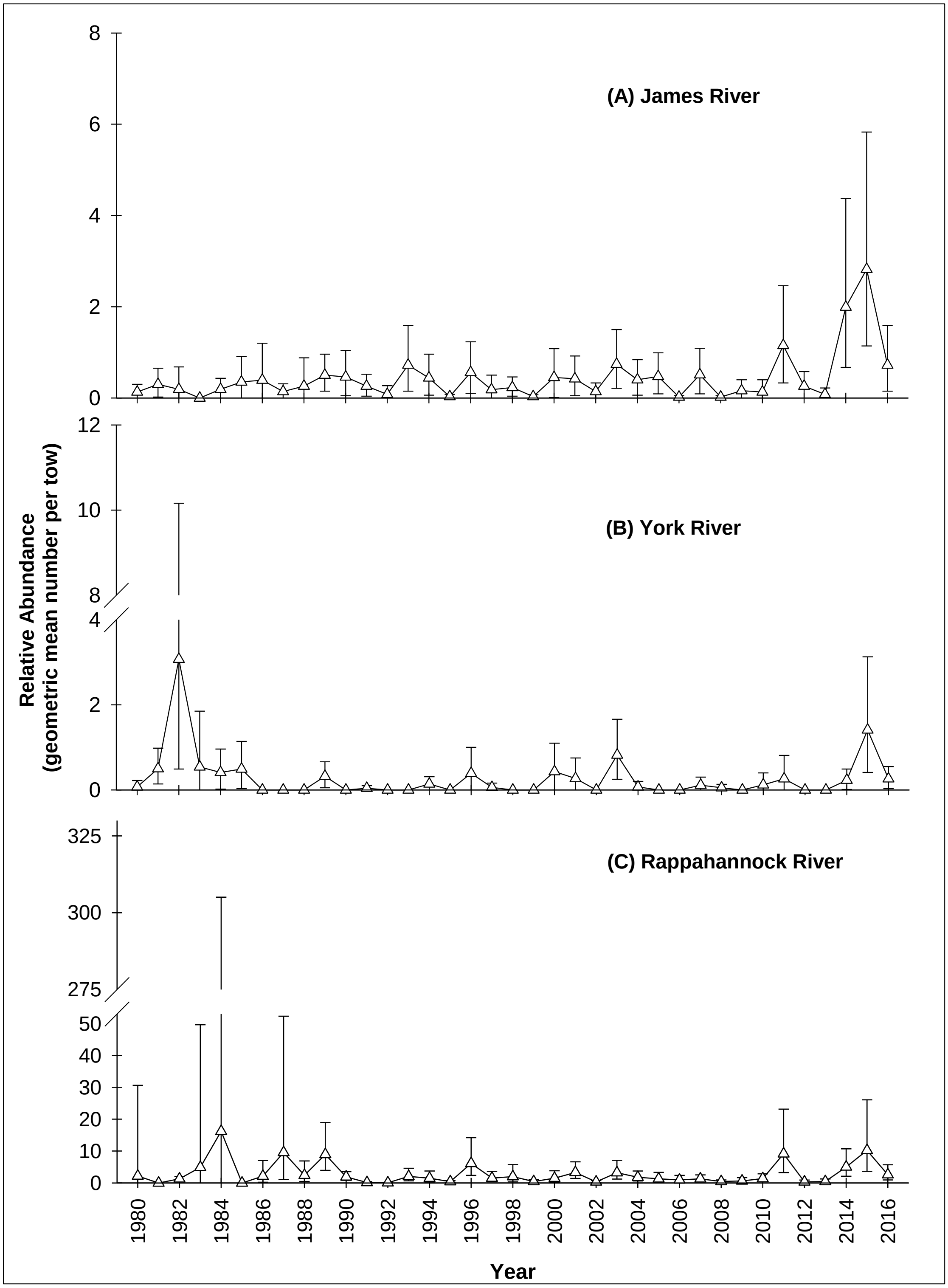

Figure 15.28 Annual JAIs (geometric average number per seine set) for blueback herring collected from the (A) James, (B) York, and (C) Rappahannock rivers by the VIMS Juvenile Striped Bass Seine Survey, 1989–2016. Error bars represent the 95% confidence intervals.

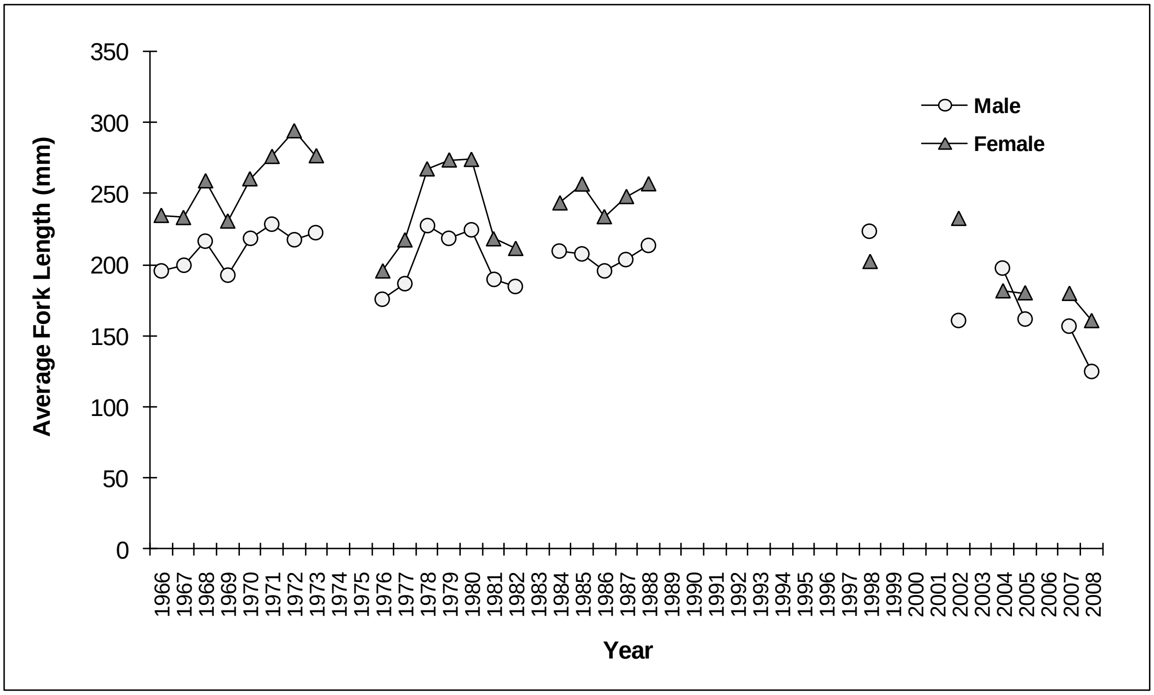

Figure 15.29 Average fork length (mm) of alewives sampled from commercial pound net harvest in the Rappahannock River, by sex, 1966–2008. Note that no river herring were sampled from the commercial fishery in 2009 and 2010.

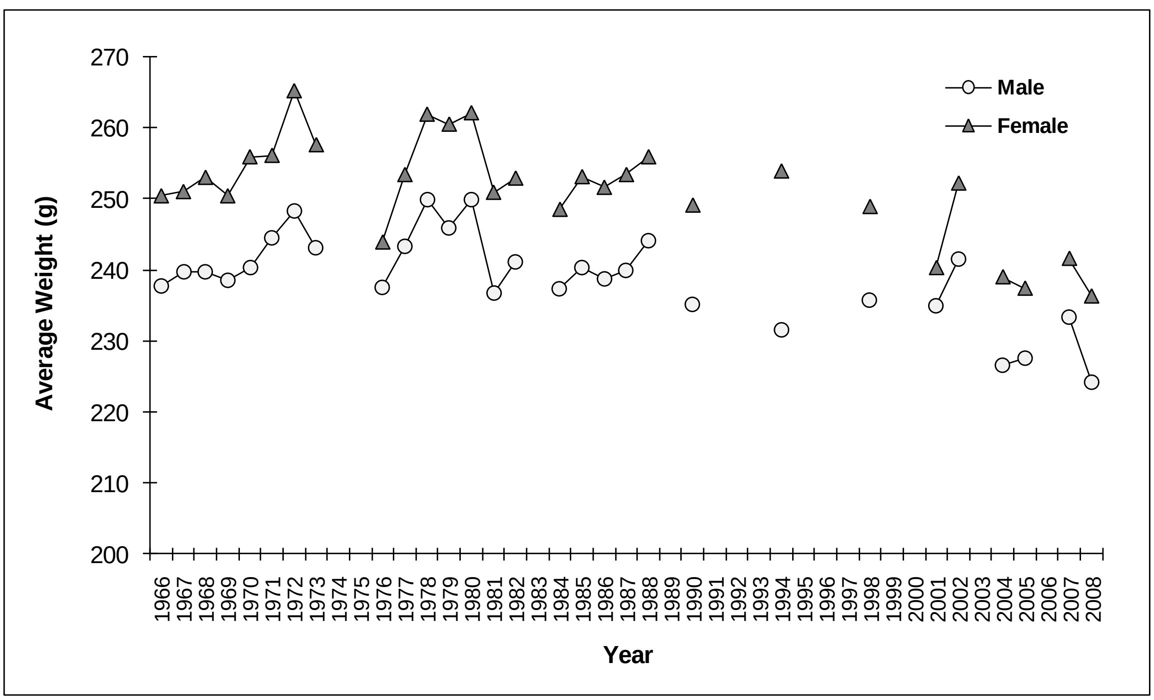

Figure 15.30 Average weight (g) of alewives sampled from commercial pound net harvest in the Rappahannock River, by sex, 1966–2008. Note that no river herring were sampled from the commercial fishery in 2009 and 2010.

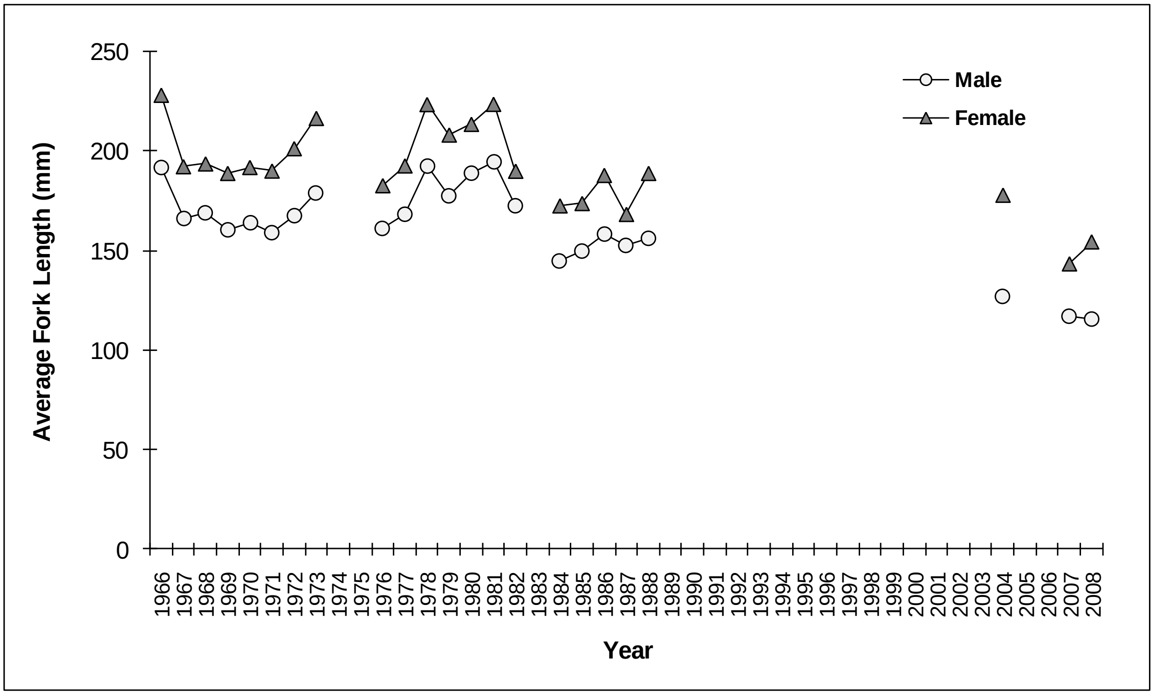

Figure 15.31 Average fork length (mm) of blueback herring sampled from commercial pound net harvest in the Rappahannock River, by sex, 1966–2008. Note that no river herring were sampled from the commercial fishery in 2009 and 2010.

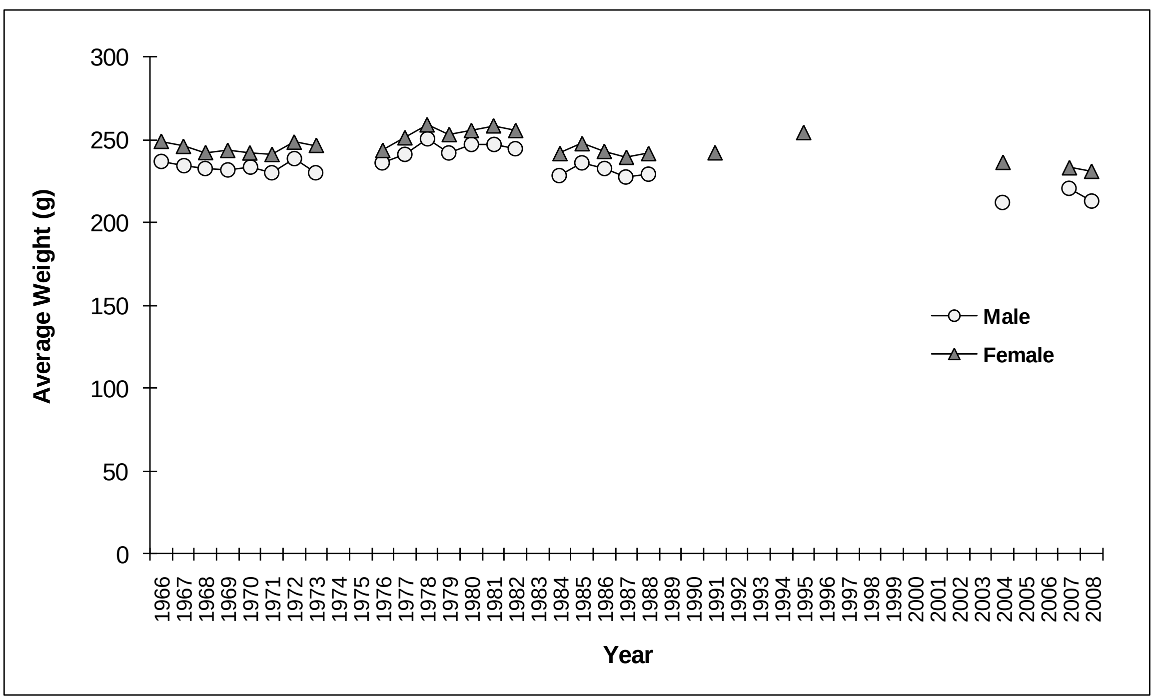

Figure 15.32 Average weight (g) of blueback herring sampled from commercial pound net harvest in the Rappahannock River, by sex, 1966–2008. Note that no river herring were sampled from the commercial fishery in 2009 and 2010.

16 Status of River Herring in North Carolina

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Executive Summary

River herring fisheries in North Carolina’s coastal sounds and rivers were once among the largest freshwater fisheries in the world. Significant declines in commercial landings and overall stock abundance began in the mid to late 1980s and continues an overall declining trend. The NC Marine Fisheries Commission (NCMFC) adopted the NC River Herring Fishery Management Plan (NCRHFMP) in 2000. The plan focused on issues pertaining to stock conditions of overfished and recruitment overfishing, habitat degradations, and research and monitoring expansion to provide assessment data and socioeconomic data. In 2007, Amendment 1 to the NCRHFMP was adopted by the NCMFC, a no harvest provision for commercial and recreational river herring fisheries in the coastal and joint waters of the state was implemented. Currently, river herring are managed under Amendment 2 to the NCRHFMP. The NCMFC adopted Amendment 2 in 2015, which eliminated the discretionary harvest season, prohibited the possession of river herring greater than six inches aboard a vessel or while

engaged in fishing from the shore or a pier in all internal joint and coastal waters of North Carolina, and removed river herring from exceptions in the NCMFC mutilated finfish rule.

A forward- projecting age structured statistical catch -at -age (SCA) model for Chowan River blueback herring (*Alosa aestivalis)* was applied to the total in-river catches, age compositions, length compositions, and a fisheries independent young-of-year (YOY) index to estimate age-3 abundance, total abundance, and mortality rates. The benchmark assessment time period was 1972-2009 and this update covers 2010-2015. Exploitation rates for blueback herring in the Chowan River before the 2007 moratorium ranged as low as 0.12 in 1979 to as high as 0.85 in 1986. Exploitation averaged about 0.24 prior to 1985, increased to an average of 0.68 during 1985–1988, and averaged about 0.43 between 1989 and 2006. Since the moratorium, exploitation rates have been close to zero. Fishing mortality averaged about 0.29 prior to 1985, increased to an average of 1.1 during 1985–1988, and averaged about 0.61 between 1989 and 2006. Since the moratorium, fishing mortality has been close to zero. Blueback herring total abundance (age 3+) declined steadily from 127 million fish in 1976 to 62 million fish in 1980. Total abundance increased through 1983 to 104 million fish and then declined precipitously to 0.95 million fish in 2003 and bottomed out at approximately 0.6 million fish in 2006 and 2007. Total abundance increased slightly from 0.6 million fish in 2007 to 9.63 million fish in 2014. Age- 3 abundance increased through 2014 to 7.5 million fish. Female SSB (spawning stock biomass) fluctuated but declined steadily from the peak of 6.5 million kilograms in 1972 to a low of 0.17 million kilograms in 1986. Female SSB increased slightly to 0.5 million kilograms through 1990, but then it declined slowly to its lowest level of 11,000 kilograms in 2005. Female SSB has been increasing since 2006 and has averaged 61,067 kilograms, peaking in 2015 at 227,333 kilograms. From the spawner-recruit data and production model, F_{MED} (level of fishing mortality where recruitment has been sufficient to balance losses to fishing mortality in half the observed years) was estimated to be 0.59. The fishing mortality rate that produces maximum sustainable yield, F_{MSY}, was 0.39 and corresponding spawning stock bass, SSB_{MSY} (the spawning stock biomass at MSY), was 1,894,382 kilograms. SSB_{MSY} was higher than the 20% of the equilibrium spawner biomass, $SSB_{20\%}$ (1,126,623 kilograms). Current female spawning stock biomass is only 12% of SSB_{MSY}. The fishing mortality rate that drives the population to extinction, F_{COL} (the fishing mortality that drives the population to extinction), was 0.9. The estimates of F_{MSY} (the fishing rates that produces maximum sustainable yield) and F_{COL} (the fishing mortality that drives the population to extinction) are considerably lower than those estimated for alewife (F_{MSY} > 1.0; F_{COL} >1.82) in three Canadian rivers by Gibson and Myers (2003b). When comparing fishing mortality rate estimates to the derived reference points the fishing mortality exceeded all reference points several times over the time series, particularly after 1985.

Excessive exploitation and poor recruitment have led to depletion of the Chowan River blueback herring stock. Despite fishing pressure that is negligible since implementation of the 2007 no- harvest provision, the stock remains overfished as the spawning stock biomass remains less than 12% of the amount necessary to replace itself in the complete absence of fishing.

16.1. INTRODUCTION

Historically, river herring (blueback herring *Alosa aestivalis* and alewife *Alosa pseudoharengus)* supported commercial and recreational fisheries in most of North Carolina's coastal rivers. The major concentrations of river herring historically and currently are found in the Albemarle Sound and its tributaries (Figure 16.1). Due to overfishing, habitat loss and water quality degradation, river herring landings in North Carolina began to decline in the mid to late 1980's. The 2005 North Carolina River Herring Stock Assessment conducted by NCDMF indicated that river herring were overfished and that overfishing was occurring (Grist 2005). In 2006 the NC Wildlife Resources Commission (NCWRC) adopted a rule that prohibits possession of river herring six inches and greater in all inland waters of the state. In 2007 the NCMFC adopted Amendment 1 to the NCRHFMP, which prohibited commercial and recreational harvest in all coastal and joint waters of the state and set aside a 7,500 pound annual research harvest with area, season and gear restrictions. A maximum 4,000 pounds (of the 7,500 pounds) are allocated for commercial harvest and data collection in a limited fishery with quota, time and area restrictions. This fishery was approved by the ASMFC Shad & River Herring Management Board in 2011. Amendment 1 also identified four stock recovery indicators to be monitored by the NC Division of Marine Fisheries (NCDMF). The NCMFC adopted Amendment 2 to the NCRHFMP in 2015, which eliminated the discretionary harvest season, prohibited the possession of river herring greater than six inches aboard a vessel or while engaged in fishing from the shore or a pier in all, and removed river herring from exceptions in the NCMFC mutilated finfish rule. Additionally, during the development of Amendment 2 the stock recovery indicators identified in Amendment 1 were reduced from four to three, and the name was change to stock status indicators.

Although the 2000 NCRHFMP was a statewide plan, river herring data from systems outside of the Albemarle Sound area are limited. The NCDMF has conducted spawning and nursery area surveys and some age composition work for most of the coastal streams outside the Albemarle Sound area, but continuous monitoring ended over 20 years ago, as federal aid funds were decreased. Current data, other than historic landings data, do not exist for river herring outside the Albemarle Sound area. Data from the Albemarle Sound and particularly Chowan River were used to determine the 2005 and 2012 stock status of alewife and blueback herring in NC. Blueback herring was selected as the indicator species for the 2005 NC River Herring Stock Assessment and the overall development of the NCRHFMP. Key research recommendations from Amendment 1 to the NCRHFMP were to reestablish a spawning area survey in the Albemarle Sound and to expand data collection programs to other river systems in the state. Since 2008, NCDMF has conducted anadromous spawning areas surveys from January through May in the Chowan River system in conjunction with one other system in the Albemarle Sound area on a rotating basis. These surveys have provided information as to which areas currently function as productive spawning habitat. In 2016, NCDMF contracted with North Carolina State University for a 2-year study to analyze the spawning area survey collection and environmental data in order to provide estimates of habitat availability including land use change in North Carolina coastal rivers. Results of the study are due to be presented in the winter of 2018. Starting in 2006, the NCWRC began weekly boat-electrofishing surveys for adult river herring from February through April at various sample sites in various systems throughout North Carolina at locations that have a prior history of spawning adults. At the present time, NCWRC sampling occurs in the Chowan River, Tar River, Neuse River and Cape Fear River Basins. No other expansion of those data collection programs has occurred, except for the NCWRC electrofishing survey, due to lack of funds and personnel.

16.2. DESCRIPTION OF MANAGEMENT UNIT

The management of river herring in North Carolina is conducted in joint and coastal waters by the NCDMF and in inland waters by the NCWRC. The management units established in the 2000 NCRHFMP include the two species of river herring (blueback and alewife) and their fisheries throughout coastal North Carolina.

The management areas are defined as follows:

The Albemarle Sound River Herring Management Area (ASRHMA)- Albemarle Sound and all its coastal, joint and inland water tributaries; Currituck Sound; Roanoke and Croatan sounds and all their coastal, joint and inland water tributaries, including Oregon Inlet, north of a line from Roanoke Marshes Point 35° 48.5015’ N -74° 44.1228’ W across to the north point of Eagles Nest Bay 35° 44.1710’ N - 75° 31.0520’ W.

The Chowan River Herring Management Area (CRHMA)- Northwest of a line from Black Walnut Point 35° 59.9267’ N - 76° 41.0313’ W to Reedy Point 36°02.2140’ N - 76° 39.3240’ W, to the North Carolina/Virginia state line; including the Meherrin River.

16.3. REGULATORY HISTORY

From 1915-1965 various regulations including season and area closures as well as gear restrictions were implemented in the N.C. river herring fisheries. Beginning in 1995 various restrictions including season closures and total allowable catch limits were implemented.

The two management areas (ASRHMA and CRHMA) were established in the 2000 NCRHFMP and defined in North Carolina Fisheries Rules for coastal waters 2003 rule 15A NCAC 3J. 0209. An annual quota, or total allowable catch (TAC) of 300,000 pounds was established in 2000 for the ASRHMA and was allocated as follows: 200,000 pounds to the pound net fishery for the CRHMA; 67,000 pounds to the ASRHMA gill net fishery; 33,000 pounds to be allocated at the discretion of the NCDMF Director (15A NCAC 3M.0513). The same rule also granted the Director proclamation authority as it applies to blueback herring, alewife, American and hickory shad fisheries, and also established a 25 fish per person per day (blueback herring and alewife combined) recreational creel limit.

The commercial TAC was further reduced in 2006 for the ASRHMA with 65,000 pounds allocated to CRHMA pound net fishery; 35,000 pounds to the ASRHMA gill net fishery; 5,000 pounds to be allocated at the NCDMF Director discretion.

Rule 15A NCAC 3O.0503 outlines the requirements for the Albemarle Sound Management Area River Herring Dealer Permit. To purchase river herring a dealer must obtain an Albemarle Sound Management Area River Herring Dealer Permit. The permit conditions require the dealer to report landings daily to the NCDMF, and allow biological sampling of catches by NCDMF personnel.

The NCMFC through the development and approval of Amendment 1 to the NCRH FMP approved a no harvest provision for river herring, commercial and recreational, in waters under their jurisdiction in 2007. The NCMFC approved a 7,500 pound limited research set aside to be allocated at the NCDMF Director’s discretion to collect data necessary for stock analysis, and to provide availability of local product for local festivals. To implement the harvest of this discretionary amount, a Discretionary Herring Fishing Permit (DHFP) was created. Individuals interested in participating had to meet the following requirements: (1) obtain a DHFP, (2) harvest only from the Joint Fishing Waters of Chowan River during the harvest period, (3) must hold a valid North Carolina Standard Commercial Fishing License (SCFL) or a Retired SCFL, and (4) participate in statistical information and data collection programs. If harvested river herring were sold they had to be sold to a licensed and permitted River Herring Dealer. The Director allocated a maximum of 4,000 pounds of the 7,500 pounds set aside for harvest in the limited fishery. Each permit holder was allocated 125-250 pounds for the four day season during Easter weekend from 2007-2010. This limited fishery has also met the requirements of Amendment 2 to the ASMFC Shad & River Herring Fisheries Management Plan and was approved by the ASMFC Shad & River Herring Management Board in 2011. In 2015, through the development and approval of Amendment 2 to the NCRHFMP the NCMFC eliminated the discretionary harvest season for river herring; prohibited the possession of river herring greater than six inches aboard a vessel or while engaged in fishing from the shore or a pier in all coastal waters (NC rule 15A NCAC 03M.0513); and removed river herring from exceptions in the NC rule 15A NCAC 03M.0101 for mutilated finfish.

Anadromous Fish Spawning Areas (AFSA) have been adopted by NCWRC and NCMFC into NC rule 15A NCAC 03R.0115 through the implementation of Amendment 1 of the NCRHFMP. These areas are designated using spawning area surveys conducted in North Carolina as well as current and future surveys that will continue to re-evaluate spawning habitat.

The NCWRC has authority over the Inland Waters of the state. Since July 1, 2006 harvest of river herring, greater than 6 inches has been prohibited in the inland waters of North Carolina's coastal systems.

16.4. ASSESSMENTS HISTORY

In 2005, an updated stock assessment was conducted by NCDMF examining both blueback herring and alewife in North Carolina, using blueback herring as the indicator species. Although blueback herring and alewife are landed in other areas of the Albemarle Sound by a variety of gears, the largest fishery was Chowan River pound nets. Catch-at-age data from the Chowan River pound net fishery were used to estimate exploitation rates and abundance from 1972 to 2003. Cohort and annual catch curves provided initial estimates of mortality, while a spreadsheet- based catch at age model incorporating a multinomial error distribution provided estimates of annual recruitment, abundance at age, and fishing mortality. Bootstrapping and log-likelihood profiling were used to evaluate the precision of model estimates.

Estimated fishing mortality for 1972 to 1994 was 0.90 for blueback herring and, except for 1995 and 1997, fishing mortality ranged from a low of 0.98 in 1998 to a high of 1.91 in 2003, with a corresponding exploitation ranging from 63% to 85%. Estimated fishing mortality for 1972 to 1994 was 0.98 for alewife and, except for 1995 and 1997, fishing mortality ranged from a low of 1.01 in 1998 to a high of 1.86 in 2002, with corresponding exploitations ranging from 64% to 85%. Chowan River blueback herring recruitment averaged 28.9 million age-3 fish per year between 1972 and 1985. However, it only averaged 552,000 fish from 1998 to 2003. Chowan River alewife recruitment averaged 7.5 million age-3 fish a year between 1972 and 1986. However, it only averaged 317,000 fish from 1998-2003.

Declines in blueback herring recruitment through the1990s dramatically reduced SSB to 89,678 pounds in 2003. Similarly, alewife spawning stock biomass declined rapidly during the early 1990s. From 1994 to 1999, alewife SSB averaged 22,953 pounds, with a record low of 10,862 pounds in 1995. Excessive exploitation combined with poor recruitment significantly reduced abundance of both river herring species and led to much lower catches than were supported historically. Utilizing blueback herring as an indicator species, a Beverton-Holt stock-recruitment model and a stochastic recruitment model were fit and estimated model parameters were used to project population conditions under various management strategies (Grist 2005).

In 2012, a coast-wide benchmark stock assessment was conducted by the ASMFC examining both blueback herring and alewife, using blueback herring as the indicator species (ASMFC 2012). A forward-projecting age structured statistical catch-at-age model for Chowan River blueback herring was applied to the total in-river catches, age compositions, length compositions, and a fisheries independent young-of-year index to estimate age-3 abundance and mortality rates. The assessment time period was 1972-2009. Exploitation rates for blueback herring in the Chowan River before the 2007 moratorium ranged as low as 0.14 in 1979 to as high as 0.87 in 1986. Exploitation averaged about 0.28 prior to 1985, increased to an average of 0.70 during 1985–1988, and averaged about 0.40 between 1989 and 2006. Exploitation rates were close to zero in all years after the moratorium was enacted. Fishing mortality averaged about 0.34 prior to 1985, increased to an average of 1.3 during 1985–1988, and averaged about 0.56 between 1989 and 2006. Similar to exploitation rates, fishing mortality was close to zero in all years following the moratorium. Blueback herring total abundance (age 3+) declined steadily from 133 million fish in 1979 to 55 million fish in 1980. Total abundance increased through 1983 to 103 million fish and then declined precipitously to 1.1 million fish in 2002. From 2002 to 2009, total abundance averaged 1.9 million fish. Age-3 abundance peaked at 81 million fish in 1975, and declined precipitously from 1983 to 0.62 million fish in 2001. From 2002 to 2009, total abundance of age-3 fish averaged 1.0 million fish. Female SSB fluctuated but declined steadily from the peak of 5.2 million kilograms in 1972 to a low of 0.14 million kilograms in 1986. Female SSB increased slightly to 0.46 million kilograms through 1990, but then it declined slowly to its lowest level of 15,000 kilograms in 2003. Female SSB averaged about 81,000 kilograms 2004-2009.

From the spawner-recruit data and production model, F_{MED} was estimated to be 0.59. The fishing mortality rate that produces maximum sustainable yield, F_{MSY}, was 0.39 and corresponding spawning stock bass, SSB_{MSY}, was 1,955,333 kilograms. SSB_{MSY} was higher than the 20% of the equilibrium spawner biomass, $SSB_{20\%}$ (1,195,873 kilograms). Terminal year female spawning stock biomass was only 5% of SSB_{MSY}. The fishing mortality rate that drives the population to extinction, F_{COL}, was 0.91. The estimates of F_{MSY} and F_{COL} are considerably lower than those estimated for alewife (F_{MSY} > 1.0; F_{COL} >1.82) in three Canadian rivers by Gibson and Myers (2003b). When comparing fishing mortality rate estimates to the derived reference points, fishing mortality exceeded all reference points several times over the time series, particularly after 1985.

The 2012 stock assessment indicated excessive exploitation and poor recruitment led to the depletion of the Chowan River blueback herring stock. Despite a fishing pressure that was negligible since implementation of the 2007 no-harvest provision, the stock remained overfished because the spawning stock biomass was less than 5% of the amount necessary to replace itself in the complete absence of fishing.

The 2017 Chowan River blueback herring stock assessment update report results can be found in section 16.11 of this document.

16.5. STOCK SPECIFIC LIFE HISTORY

The alewife and the blueback herring, collectively known as river herring, are anadromous members of the family Clupeidae (herrings and shads). "Anadromous" means they migrate from the ocean, enter coastal bays and sounds through inlets, and ascend into freshwater rivers and streams to spawn, traveling further upstream in wet years and remaining downstream in dry years. Surviving adults then return to the ocean after spawning. The young-of-the-year fish use rivers and estuaries as nursery grounds as they migrate downstream after hatching. After the juveniles leave the rivers and estuaries in the fall or early winter, they complete their development in the Atlantic Ocean, over the continental shelf off New England (Loesch 1987; Jenkins and Burkhead 1993). The two species occur geographically together from New Brunswick and Nova Scotia in Canada south to the northern coastal area of South Carolina. Blueback herring occur further south, to northern Florida. There are important life history differences between the two species (Loesch 1987). Alewives select slower-flowing areas for spawning, with blueback herring reported to select faster-flowing sites in areas where both species occur. In areas where both species occur, alewives generally spawn earlier. While fish are believed to return to the streams of their birth for spawning, both species readily colonize new streams or ponds and will reoccupy systems from which they have been extirpated (Loesch 1987). Both juveniles and adults respond negatively to light, in both riverine and offshore habitats, with alewives remaining deeper in the water column in both habitats (Klauda et al. 1991). Both species are important prey during all life stages for many other species of commercial and recreational importance. Both species have also been widely stocked in inland freshwater lakes and reservoirs where they live and reproduce entirely in freshwater and serve as prey for freshwater game fish.

In the collective population of river herring, the percentage of alewife and blueback herring present in major Albemarle Sound tributaries has varied based on sampling of the commercial catch (Johnson et al. 1981). For example, percent composition of alewife ranged from 4 % in 1977 to 49 % in 1979, with alewife dominating the early catches in each year. From 1989 through 1992, the percentage of alewife ranged from 14.2 to 31.2% (Winslow and Rawls 1992). The same pattern of early dominance by alewife, with subsequent later dominance by blueback herring, is evident in weekly species composition samples taken during the 1980-92 spawning runs on the Chowan and Scuppernong rivers (Winslow et al. 1983;

Winslow and Rawls 1992). The fraction of alewife in the commercial catch for those years ranged from 27 to 37%.

16.6. HABITAT DESCRIPTION

River herring have historically been found in all N.C. coastal rivers and streams. The main populations of river herring are found in the Albemarle Sound and its tributaries, with smaller runs historically in the Tar, Pamlico, Neuse and Cape Fear River systems.

The Albemarle Sound system includes Albemarle, Croatan, Roanoke and Currituck Sounds and all of their tributaries. The Albemarle Sound, located in the northeastern portion of North Carolina, is a shallow estuary extending 55 miles in an east-west direction averaging 7 miles wide and 13-20 feet deep. Ten rivers drain into the Albemarle Sound which joins Pamlico Sound through Croatan and Roanoke Sounds and empties into the Atlantic Ocean via Oregon Inlet. The majority of tributaries that empty into the sound originate in extensive coastal swamps.

The Chowan River flows approximately 50 miles and is formed with the merging of Virginia's Blackwater and Nottoway rivers. It is a major tributary to the Albemarle Sound and it is the primary spawning area for river herring in North Carolina. The Chowan River empties into western Albemarle Sound. This area as well as most of the Albemarle Sound and all of its tributaries serves as a major anadromous fishery nursery area for river herring.

Anadromous spawning area surveys conducted by the NCDMF demonstrated that river herring use a wide range of habitat types for spawning, such as small, densely vegetated streams; fresh and brackish marshes; hardwood swamps; and flooded low-lying areas adjacent to both mainstem rivers and tributaries. In North Carolina, anadromous fish spawning areas are designated in NCMFC rule 15A NCAC 03R.0115 and NCWRC rule 15A NCAC 10C .0603 and include areas in most river systems.

River herring spawn in the upper reaches of North Carolinas coastal rivers and streams in the early spring. The juveniles spend most of their first year in the nearshore waters of the coastal rivers and sounds and emigrate to the ocean when water temperatures begin to cool in the fall.

16.7. RESTORATION PROGRAMS

In 2007, Amendment 1 to the NCRHFMP identified various restoration targets for the river herring stocks. Amendment 1 used the Chowan River blueback herring stock as the indicator species to establish stock recovery indicators. The plan identified stock recovery indicators that would be used to evaluate and determine recovery status of the river herring stock. The stock recovery indicators for the NCRHFMP are as follows:

> Juvenile abundance – The restoration target for juvenile abundance of blueback herring is to achieve a three year moving average catch per unit of effort of at least 60.
>
> Percent Repeat Spawners – The Chowan River blueback herring spawning stock should contain at least 10% repeat spawners (percent of the spawning stock that have spawned more than once).
>
> Spawning Stock Biomass (SSB) – The restoration target to restore Chowan River blueback herring SSB to a minimum stock size threshold (MMST) of 4 million pounds.
>
> Recruitment – Recruitment of age three blueback herring should be restored to a three-year moving average of at least 8 million fish.

In 2015, under Amendment 2 to the NCRHFMP, it was determined that only three of the stock recovery indicators were necessary and the recruitment indicator was dropped from the NCRHFMP. Additionally, the term stock recovery indicator was changed to stock status indicator, this term was deemed more appropriate for the restoration targets.

In addition to the above stock recovery indicators, Amendment 2 to the NCRHFMP recommended a variety of research needs and management options that address various issues such as habitat availability and degradation, predation, bycatch, critical habitat and water quality and that would contribute to the recovery of river herring stocks in North Carolina. A full description of these recommendations can be found in Amendment 2 to the NCRHFMP.

16.8. AGE

Age samples of the blueback herring and alewife catch from the Chowan River commercial pound net fishery are available from fish house sampling conducted from 1972-2006. The target sampling frequency is to collect unculled samples of at least 30 fish weekly, from at least 3 area commercial fishhouses during the fishing season.

Following the closure of the commercial river herring fisheries in North Carolina a commercial pound net survey was implemented to collect aging samples of river herring from the Chowan River. Depending on the year 3-4 commercial fishermen were contracted to fish commercial pound net sets in the Chowan River, NC during the traditional river herring commercial harvest season. All fishermen were required to obtain a weekly unculled adult sub-sample of approximately 20 pounds of river herring from their contracted pound nets. In 2009 sampling was expanded to include a visual estimate of the total daily catch of river herring in pounds from all of the pound nets set regardless of whether it was a designated contracted net or not. Adult samples were sorted to species and all individuals of each alosine species present were measured in millimeters (mm) fork length (FL) and total length (TL), weighed (kg), sexed, spawning maturity was determined, and an ageing sample was taken.

Scale samples collected for ageing were mounted between two microscope slides and read under an Eyecom 3000 microfiche reader and aged by methods similar to that in Street et al. (1975). Stratified sub-sampling, based on techniques developed by Ketchen (1950), was used to compile individuals for ageing. Samples were sorted by species, and sex, then placed in 10 mm size groups. If 15 or less samples were present in a size group, all of the samples were aged. If more than 15 samples were present in a size group, half of the fish in the group were aged. Proportions within each sex and size group were calculated and expanded to the remaining sample.

16.9. FISHERY DESCRIPTIONS

Since 2007 the commercial and recreational harvest of river herring is prohibited in all coastal and joint waters of the state. From 2007-2014 there was a 7,500 pound research set-aside harvest, with 4,000 pounds allocated for discretionary harvest to be taken over a four day period with area and gear restrictions (see section 13.3 for a complete description). The discretionary harvest season was eliminated in 2015 due to the depleted state of the river herring stocks and the lack of biological data for stock analysis and local product for area festivals obtained during the short season. The possession of river herring greater than 6 inches in the inland waters of North Carolina has been prohibited since 2006. The NCMFC complemented this rule in all internal coastal waters in 2015 under Amendment 2 to the NCRHFMP (see section 16.3).

16.9.1. Commercial Fishery

Commercial Landings

River herring have been subjected to intensive exploitation since colonial times along the Atlantic coast. The Albemarle Sound area has always been the center of the North Carolina fishery. In North Carolina, river herring were among the first fish to be exploited commercially because their oily flesh allowed them to be salt-preserved, without ice or refrigeration.

NCDMF has monitored commercial landings of river herring since 1972. Prior to 1994, commercial landings in North Carolina were acquired via a NCDMF and National Marine Fisheries Service (NMFS) Cooperative statistics program on a monthly basis from licensed seafood dealers; however, reporting at the time was not mandatory. In 1994 NCDMF implemented a mandatory commercial harvest data collection system known as the Trip Ticket Program (TTP). The Trip Ticket Program is a dealer-based reporting program that obtains a trip-level census of commercial landings in North Carolina.

The annual commercial harvest of river herring for the Albemarle Sound as well as other areas of the state is presented in Table **Error! Reference source not found.** As mentioned previously, the howan River is the historical mainstay of the North Carolina river herring fishery and continued to serve in that capacity until the close of the commercial fishery statewide in 2007.

The use of pound nets revolutionized fishing in North Carolina, especially in the Albemarle Sound (Taylor 1992). Chestnut and Davis (1975) reported that 2,767 pound nets were set in North Carolina in 1927. Since the 1960s, the majority of the river herring pound nets have been set in the rivers, and the leads seldom exceeded 200 yards in length (Walburg and Nichols 1967). The Chowan River has been the center of the river herring pound net fishery, and from the late 1970s to the late 1980s the number of river herring pound nets ranged from 421 to 615 nets annually, with the amount of pound nets declining from 348 in 1989 to a low of 18 in 2009.

Gill nets, anchor and drift, have historically been utilized in the river herring fishery. The amount of gill net effort in the fishery prior to 1994 is unknown. During the 1970s, the gill net harvest of river herring accounted for approximately 15% of the total Albemarle Sound area harvest. However, from 1987 to 1994, the proportion of gill net landings increased to 24-40% of the total river herring harvest from the Albemarle Sound area. This increase may have been due to a directed fishery for roe fish. In 1986, approximately 6 million pounds were harvested in pound nets and 900,000 pounds from gill nets. During 1988, pound nets landed 2.3 million pounds and gill nets 1.5 million pounds. In contrast, 1994 totals of 425,000 pounds from pound nets and 175,000 pounds from gill nets was harvested.

Several other types of commercial gears have been used in the river herring fishery: fyke nets, fish wheels and dip nets. These gears have contributed very little to the total harvest in the Albemarle area. From 1915 through 1965, various regulations were enacted for the Albemarle Sound river herring fishery (seasons, area closures, gear restrictions).

The Albemarle Sound area accounted for 66-100% of the state's river herring harvest from 1889 to 1994. Between 1962 and 1994, the Chowan River pound net fishery contributed 43-97% of the state's total river herring landings. From 1950 to 1994, North Carolina accounted for 13.6-84.5% of the river herring landings of the Atlantic coast states.

Since the late 1800s, the areas fished and gears used to harvest river herring have remained essentially unchanged. The extent of the river herring fisheries in both the amount of gear and harvest, however, has declined significantly. The fisheries in the Albemarle Sound area are now pursued as multi-species fisheries, which are not totally dependent on river herring.

During 1995-1998, North Carolina accounted for 29-52% of the total river herring landings

from the Atlantic coast. From 1999-2004, the State contributed 9-33% of the Atlantic coast river herring harvest. Landings from the Albemarle Sound area accounted for 91.6-99.8% of the state's total river herring landings during 1995-2004. The Chowan River pound net fishery contributed 60.3-76.5% of North Carolina's annual river herring harvest during 1995-1999.

Since 2000, the Chowan River pound net fishery contributed 41-66% of the state's total river herring harvest. Since 1988, regulations enacted for striped bass conservation (gill net mesh size restrictions, yardage restrictions, area closures) have impacted river herring harvest in the Albemarle Sound area. Even with these regulations, the river herring gill net fishery has accounted for a greater proportion of the overall harvest from 1995 - 1999 (21.2-38.1%). Since the 67,000 pound TAC was implemented in 2000, gill nets have accounted for 24.4-39.5% of the annual river herring landings in the Albemarle area.

From 2007 to 2014 the commercial harvest was restricted to a 7,500 pound research set aside, with a 4,000 pound maximum discretionary harvest allocation to be harvested over a four day period during the Easter holiday weekend in the Chowan River. The discretionary harvest fishery was eliminated in 2015 under Amendment 2 to the NCRHFMP (see section 16.3). Participation in the discretionary harvest fishery was limited to permitted fishermen. Landings for the research set aside season ranged from 643 pounds in 2009 to 1,765 pounds in 2010 (Table 16.2). The number of permits issued to participate in the fishery ranged from 30 in 2010 to 12 in 2013.

Commercial Catch Rates

Catch per unit effort (CPUE) for the Chowan river pound net fishery has been calculated since 1977 (Table 16.3; Figure 16.2). Catch effort was calculated by dividing the total weight (kg) by the total effort in pound net weeks (calculated as the number of pound nets fished each week summed over the entire season). Weeks were considered Sunday to Saturday and begin the first full week in January. Pound net effort was determined by an aerial survey, conducted with the assistance of the NCDMF marine patrol as well as pound net permit application data.

While the maximum number of pound nets set in any given week decreased drastically from a high of 624 in 1977 to only 36 in 2004, the total weeks fished has differed little over the years with the exception of 1997 when nets were only set for 5 weeks. Therefore, the overall decrease in total effort is due more to fewer nets set than to a reduction in the length of the fishing season. Since 2001, the number of weeks fished increased slightly as a result of the TAC not being met, and the season remaining open longer, or nets being set earlier in the fishing season. Effort decreased considerably since the implementation of a harvest quota in 1995 and varied without trend since that time until 2006, when the moratorium was introduced.

Catch per unit effort for blueback herring and alewife from the Chowan River commercial pound net fishery declined considerably since the mid-1980s. Blueback herring CPUE increased slightly during the 1995-1999 seasons, but declined significantly after 2000. Alewife CPUE decreased considerably in 1993-1999, with slight increases in 200 and 2001. Both CPUEs remained well below the historical levels until the close of the fishery in 2006. Following the close of the fishery, CPUE estimates from contracted pound net fishermen continued to decline for both blueback herring and alewife until 2012. From 2013-2015 CPUE estimates for both species have increased each year, with no real change in total pound nets or weeks fished. Despite this short-term increase, CPUE for both species remains much lower than historic values.

Repeat Spawners

The NCDMF has monitored repeat spawning for the Chowan River blueback herring and alewife since 1972 (Table 16.4). Percent repeat spawners for blueback herring from the Chowan River spawning stock is one of the stock recovery indicators identified in Amendment 1 to the NCRHFMP. The Chowan River blueback herring spawning stock should contain at least 10% repeat spawners (percent of the spawning stock that have spawned more than once). The percent of blueback herring repeat spawners in the pound net harvest averaged 14.8% during 1972-1982. From 1983 through 1989, the percentage of repeat spawners declined significantly, ranging from 0.6% to 6.1%. During the 1990s, blueback herring spawning repetition remained low, ranging from 1.2% (1994) to 4.7% (1993). During 2000 through 2003, a slight increase in the percentage was observed but declined again in 2004 (2.9%). Percentages increased again in 2007 and 2008 but declined again in 2009. Since, 2011 percentages have increased to levels above the restoration target. In 2015 the percent repeat spawners averaged 16.8%, the highest in a 34-year time series, showing signs that that the harvest moratorium is likely allowing increased survival of blueback herring.

The percentage of alewife repeat spawners also decreased since the 1970s, with a mean of 9.4% from 1972 through 1981. From 1988-1999, no or very small samples of alewife were obtained from the Chowan River pound net fishery, due to scarcity in the harvest. During 2001-2004, alewife samples were obtained from the pound net fishery and an increase in the percentage of repeat spawners was observed. Percent repeat spawners averaged 9.1 from 2004-2009. Alewife ages are incomplete due to significant staff turnover between 2010 and 2016. Since blueback herring were selected as the indicator species for North Carolina, staff focused on completion of blueback herring data for submittal into the stock assessment update.

Age Composition/Mean Size at Age

The age structure of blueback herring taken in the Chowan River pound net fishery has been characterized since 1972. From the 1970s to the early 1990s, sampling was conducted at up to six fish houses on a weekly basis. From 2000 through 2006, samples were obtained weekly from up to three fish houses until the season closed in 2006. Throughout the years, unculled pound net samples of at least 30 individuals each of blueback herring and alewife were obtained at least weekly during the spring. Size, age and sex composition of the harvest was determined from these samples. Samples of up to 30 fish from each fishhouse were obtained, up to three times per week during the season, and after the season, into the second week of May. Samples in 2007 were obtained from Chowan River pound nets during the research set aside season. Samples since 2008 have been collected from the Chowan River Pound Net Survey.

The aged pound net samples were dominated by fish ages 4-6 throughout the entire time period (Appendix Table 16.3.) From 1972-1981, age 7 fish comprised 4.1 % of the aged sample annually. In recent years, age 7 fish comprised less than 1% of the aged sample, except for 2014 where age 7 fish comprised 3% of the aged sample.

Data from pound net samples for blueback herring show a decline in mean length at age since 1972 (Figure 16.3).

16.9.2. Recreational Fishery

Historically, river herring have been taken for personal consumption in every major North Carolina coastal river system. An analysis of river herring harvest by Baker (1968) indicated the majority of herring harvested by special device licensees in 1967-1968 occurred in the Chowan and Roanoke River basins. River herring were also harvested in other river basins, but American shad and hickory shad (*Alosa mediocris*) were of more importance to fishermen in those areas. Coastwide, Baker (1968) estimated that special device licensees harvested 2.9 million pounds of river herring some of which were sold. The recreational component of this total, however, is unknown. Although these fish were taken by fishermen licensed by NCWRC at that time, changes in designations of coastal/joint/inland waters, changes in jurisdictional responsibilities between NCDMF and NCWRC, and the unknown proportion of these fish which were harvested with the intent of sale precludes an estimate of the historical level of river herring harvest for personal consumption. The recreational fishery for river herring closed in 2007. It is now illegal to possess recreationally caught river herring in the coastal and joint waters of the state. It is also illegal to possess river herring greater than 6 inches from the inland waters of the state.

For the years leading up to the 2007 harvest closure, the extent of river herring harvest for personal consumption in coastal North Carolina is unknown. According to NCWRC Enforcement Officers who patrolled the inland waters of the Cape Fear, Neuse, and Tar-Pamlico river basins at that time, very few (usually none) special device licensees specifically targeting river herring were encountered in these areas, principally due to the low numbers or absence of these species. Special device licensees targeting river herring are still encountered in small tributaries of the Roanoke and Chowan rivers during the spring months of years prior to the closure, and an active recreational herring fishery persisted in tributaries to the Meherrin River. Recreational river herring fishermen are still found at small bridge crossings over tributaries to other Albemarle Sound river systems such as the Pasquotank, Perquimans, Yeopim and Scuppernong rivers. Low effort directed at river herring harvest in these areas is likely indicative of low river herring abundance.

A recreational drift net river herring fishery existed on the Roanoke River for many years. This fishery has never been fully assessed by NCDMF or NCWRC. The NCDMF initiated a pilot drift net creel survey in 1999 to characterize this fishery for development of future monitoring strategies and to provide managers with weekly reports of recreational drift net activity (participation, catch rates, species composition, net sizes, etc). Sampling was conducted in the lower river area including Williamston, Jamesville, and Plymouth. Interviews were conducted three days per week, for a total of 21 sampling days in 1999. Catches of river herring ranged from 20 to 300 fish per vessel with a mean of 106. Drift duration ranged from 1 to 5 hours with a mean of 2.2 hours. A total of 2,764 river herring were observed in the survey. Because there was no estimate of total effort, total catch cannot be estimated.

The recreational fishery for river herring closed in 2007. It is illegal to possess recreationally caught river herring in the coastal and joint waters of the state. It is also illegal to possess river herring greater than 6 inches from the inland, coastal, and joint waters of the state.

16.10. FISHERIES INDEPENDENT SURVEYS

16.10.1. Juvenile abundance

The NCDMF began nursery area sampling for juvenile blueback herring and alewife in the Albemarle Sound area in 1972, with eleven core stations being established and sampled throughout the time period (Figure 16.4). This survey was designed to index annual relative abundance of juvenile blueback herring and alewife. Thirty-four stations were established in the western Albemarle Sound area and sampled with trawls and seines. The Carolina wing trawl was adopted as the standard trawl in place of the Cobb trawls in June 1974 (Johnson et al. 1977), and the seines continued. The 34 stations (23 trawls and 11 seines) were sampled monthly during June-October. During September, an additional 43 stations (28 trawls and 15 seines) were sampled throughout the Albemarle Sound area to determine distribution and nursery areas of anadromous species.

Seine stations were sampled with a 60 foot bag seine with ¼ inch mesh bag, with a single haul considered one catch-per-unit-of-effort (CPUE). The Carolina wing trawl had a headrope length of 26 feet, containing webbing which ranged from 4 inch stretched mesh in the wings to 1/8 inch mesh tail bag. The trawl was pulled for 10 minutes, and was considered one CPUE. Samples were sorted to species, and up to 30 individuals of each alosine species present were measured to the nearest millimeter fork length (mm, FL), and all others were counted.

Based on catch consistency the seine proved to be the best sampling gear for blueback herring, and the wing trawl was the best for alewife. Due to a further reduction in federal aid funds, trawl sampling was dropped at the end of June 1984. Sampling with seines at the 11 cores stations has continued during June-October each year from 1972-present. During September, an additional 13 seine stations are sampled throughout the Albemarle Sound area to determine distribution and migration.

Juvenile abundance indices (JAI) are established for alewife and blueback herring using data from the 11 core stations sampled once per month, June-October, 1972-2015 (Figures 16.5 and 16.6). The JAI for blueback herring and alewife fluctuated over the years. The highest CPUE recorded for blueback herring was in 1973 (426.6 fish/seine); the lowest was in 1994 (0 fish/seine), part of a very low CPUE trend during 1986-2015. The average CPUE for blueback herring during 1972-2015 is 55.8 fish/seine, compared to the 63.0 fish/seine from the benchmark assessment time period, 1972-2009. The stock recovery indicator for juvenile abundance of blueback herring is to achieve a 3-year moving average catch per unit of effort of at least 60. The 3-year average based on the 2013-2015 data is 6.9.

The average CPUE for alewife during the 1972-2015 period is 2.6 fish/seine compared to the 2.4 fish/seine from the benchmark assessment time period, 1972-2009. Throughout the time series alewife numbers have not been observed in the same magnitude as blueback herring. Alewife JAI increased slightly in 2005 and 2010. In 2013, alewife numbers increased to the highest level since 1980, declined to 0 fish/seine the following year before peaking again in 2015 at 7.1 fish/seine. The current 3-year average based on the 2013-2015 data is 5.6 fish/seine.

16.10.1.1. Independent Gill Net Survey

Since 1990, NCDMF has been conducting an independent gill net survey (IGNS) throughout the Albemarle Sound area (Figure 16.7). The survey was designed for striped bass data collection. However, river herring are captured during the survey and size, age, and sex data are collected. Gill nets are set in sizes from 2.5 through 7.0 inch stretched mesh (ISM), in half-inch increments and 8.0, and 10.0 ISM are utilized.

River herring CPUE has been calculated from the IGNS throughout the Albemarle Sound area since 1991. Blueback herring and alewife CPUE from the 2.5 ISM and 3.0 ISM (combined) January-May, 1991-2015 are shown in 8. The CPUE of blueback herring has continued a general decline through 2012, the lowest value in the time series (0.86 fish/net). In 2013 the CPUE of blueback herring slightly increased before declining again in 2014, then increasing in 2015 to the highest level in the 10-year time series (5.6

fish/net). Alewife CPUE has been low for most of the time series with a general increase since 2005. CPUE has been steady from 2008-2015, except for 2012 when the CPUE dropped to 0.98 fish/net.

16.11. ASSESSMENT APROACHES AND RESULTS

16.11.1. Statistical catch-at-age model for the Chowan River

A forward-projecting age-structured statistical catch-at-age (SCA) model for the Chowan River blueback herring stock was applied to total in-river catches, age compositions, length compositions, and a fisheries-independent young-of-year (YOY) index to estimate age-3 abundance and mortality rates. The benchmark assessment time period was 1972 to 2009. The assessment update adds the most recent 5 years of data covering the time period from 1972 to 2015.

16.11.1.1. Model Structure

The population model is aged-based and projects the population numbers-at-age by sex *s* forward through time given model estimates of age-3 numbers and mortality rates, assumed known values of natural mortality for immature and mature fish by age, and proportion mature-at-age. The population numbers-at-age ($N_{s,d,y,a}$) matrix has dimensions *s* x *d* x *y* x *A-2*, where *s* is number of sexes, *d* is the number of maturity phases, *y* is the number of years, and *A* is the oldest age group (age 8+). There were six year-classes in the model, representing ages 3 through 8+.

The cohort dynamics of the model is a hybrid of the Margaree River model in Gibson and Myers (2003a). The model incorporates the immature and mature phases by sex and assumes the year begins at the start of spawning. Mature individuals of each age move into the Chowan River where they are intercepted and removed for harvest. The model assumes harvest occurs before the fish reach the spawning grounds. Biological samples for sex, and age and repeat-spawning data are collected from fishery landings. The model allows different natural mortality values for each year, age, sex, and maturity phase.

Given the above dynamics, population numbers-at-age by sex and maturity phases are calculated through time by using the cohort survival models shown in Figure 16.9. The number of age-3 bluebacks at the beginning of spawning season (R_y) are directly estimated in the model, and these estimates are partitioned into sex- (1=female; 2=male) and maturity phase- (1=immature*;* 2=mature) specific estimates of age-3 abundance using sex ratio and mature proportions-at-age (derived outside of the model):

<u>Female</u>

Immature: $$\hat{N}_{1,1,y,3} = \hat{R}_y \cdot f \cdot (1 - p_{1,y,3})$$

$$\hat{N}_{1,2,y,3} = \hat{R}_y \cdot f \cdot p_{1,y,3}$$

Mature:

Male

Immature: $$\hat{N}_{2,1,y,3} = \hat{R}_y \cdot (1-f) \cdot (1-p_{2,y,3})$$

Mature: $$\hat{N}_{2,2,y,3} = \hat{R}_y \cdot (1-f) \cdot p_{2,y,3}$$

where *f* is the female sex ratio (proportion) and *p* is the proportion mature by sex s, year *y*, and age *a*. Recruitment of age-3 bluebacks (R_y) is modeled as a log-normal deviation from average recruitment:

$$\hat{R}_y = \hat{\overline{R}} \cdot \exp^{\hat{e}_y}$$

where $\overline{R}$ is the average recruitment parameter and e_y are independent and identically distributed normal random errors with mean zero and constant variance and are constrained to sum to zero over all years. This formulation differs from the original Gibson and Meyers model, which linked recruitment via a Beverton-Holt equation to log-normal deviations.

The initial population abundance-at-age for ages 4 to 8+ in 1972 for each sex and maturity phase is calculated by assuming a static stock:

Immature: $$\hat{N}_{s,1,1972,a} = \hat{N}_{s,1,1972,a-1} \cdot \exp^{-M_{s,1,1972,a-1}} \cdot (1-p_{s,1972,a})$$

Mature: $$\hat{N}_{s,2,1972,a} = \hat{N}_{s,2,1972,a-1} \cdot (1-\hat{u}_{1972}) \cdot \exp^{-M_{s,2,1972,a-1}} + \hat{N}_{s,1,1972,a-1} \cdot \exp^{-M_{s,1,1972,a-1}} \cdot p_{s,1972,a}$$

where *M* is the sex-, maturity phase-, year-, and age-specific instantaneous natural mortality rate, and *u* is the year-specific exploitation rate. Population abundance-at-age for ages 4 through 7 in the remaining years is calculated by:

Immature: $$\hat{N}_{s,1,y,a} = \hat{N}_{s,1,y-1,a-1} \cdot \exp^{-M_{s,1,y-1,a-1}} \cdot (1-p_{s,y,a})$$

Mature: $$\hat{N}_{s,2,y,a} = \hat{N}_{s,2,y-1,a-1} \cdot (1-\hat{u}_{y-1}) \cdot \exp^{-M_{s,2,y-1,a-1}} + \hat{N}_{s,1,y-1,a-1} \cdot \exp^{-M_{s,1,y-1,a-1}} \cdot p_{s,y,a}$$

The population abundance of the plus group (8+) is calculated as:

Mature: $$\hat{N}_{s,2,y,8+} = \hat{N}_{s,2,y-1,a-1} \cdot (1-\hat{u}_{y-1}) \cdot \exp^{-M_{s,2,y-1,a-1}} + \hat{N}_{s,1,y-1,a-1} \cdot \exp^{-M_{s,1,y-1,a-1}} \cdot p_{s,y,a} +$$

$$\hat{N}_{s,2,y-1,8+} \cdot (1-\hat{u}_{y-1}) \cdot \exp^{-M_{s,2,y-1,8+}}$$

Exploitation rates for each year (u_y) are estimated as individual parameters in the model.

Input values for age- and sex-specific *M* were calculated using the Lorenzen (1996) equation that relates body weight (in grams) to natural mortality. The grand mean of average weight-at-age of blueback herring from the pound net fishery during 1972 through 1980 was used to derive *M*. Natural mortality rate was assumed constant with time and among maturity phases for the base model runs. The *M* estimates for each sex and age were:

	Age					
	3	4	5	6	7	8
Female	0.71	0.66	0.64	0.62	0.60	0.59
Male	0.72	0.70	0.67	0.64	0.62	0.61

The annual proportions of fish mature at each age and sex were calculated from repeat-spawner frequency data provided by the NCDMF. When data were missing in some years and ages, averaged values from surrounding cells were used to fill in missing data (Appendix Table 16.1).

Total removals of blueback herring are one set of data from which age-3 abundances and exploitation rates are estimated. Total catch in numbers was provided by NCDMF (Appendix Table 16.2). Total catch for 2007 to 2015 was estimated by using pound net catch proportions provided in 2008, average blueback landings to alewife landings ratio from years prior to 2007, and annual mean weight by species. Given estimates of annual numbers of mature for fish at each sex and age, predicted removals-at-age is computed by:

$$\hat{C}_{y,s,a} = \hat{N}_{y,s,m,a}\hat{u}_y$$

where $C_{y,s,a}$ is the predicted in-river removals of sex (*s)* of age (*a)* during year (*y)*. All predictions are stored in an array of dimensions *s* x *y* x *A-2*. Predicted catch-at-age data are then compared to the observed total catch and observed proportions of catch numbers-at-age data (sample numbers at age are provided in Appendix Table 16.3) through the equations:

Predicted Total Catch: $$\hat{C}_y = \sum_s \sum_a \hat{C}_{y,s,a}$$

Predicted Proportions of Catch Numbers-At-Age: $$\hat{P}_{y,s,a} = \frac{\hat{C}_{y,s,a}}{\sum_a \hat{C}_{y,s,a}}$$

The North Carolina YOY seine survey index for blueback herring was incorporated into the model by linking it to the recruitment estimates:

$$\hat{I}_y = \hat{q} \cdot \hat{R}_{y+3}$$

where $\hat{I}_y$ is the predicted index of survey in year *y*, and *q* is the catchability coefficient. Based on the lagged year comparison, YOY indices from 1972 to 2015 (Appendix Table 16.4) were used to tune recruitment estimates for 1975 to 2015

Female spawning stock biomass (SSB) in year *y* was calculated as:

$$SSB_y = \sum_a \hat{N}_{1,2,y,a} \cdot (1-\hat{u}_y) \cdot w_{1,2,y,a}$$

where $w_{1,2,y,a}$ is the mean weight-at-age for mature females in year *y* and age *a*. Calculated mean weights-at-age are provided in Appendix Table 16.5.

Fishing mortality rates were calculated from the estimated exploitation rates assuming a Type I fishery:

$$\hat{F}_y = -\log_e(1-\hat{u}_y)$$

Standard errors of fishing mortality rates were derived using the delta method provided in AD Model Builder.

Lognormal errors were assumed for the total catch data and YOY index. The concentrated likelihood was weighted for variation in each observation. The generalized concentrated negative log-likelihood ($-L_l$; Parma 2002; Deriso et al. 2007) is:

$$-L_l = 0.5 * \sum_i n_i * \ln\left(\frac{\sum_i RSS_i}{\sum_i n_i}\right)$$

where n_i is the total number of observations and RSS_i is the weighted residual sum-of-squares from dataset *i*. Equations for the weighted residual sum-of-squares of total removals (*C*) and escapement numbers (*E*) are:

$$RSS_C = \lambda_C \sum_y \left(\frac{\log_e(C_y + 1e^{-5}) - \log_e(\hat{C}_y + 1e^{-5})}{CV_y}\right)^2$$

$$RSS_I = \lambda_E \sum_y \left(\frac{\log_e(I_y + 1e^{-5}) - \log_e(\hat{I}_y + 1e5)}{CV_y}\right)^2$$

where CV_y is the coefficient of variation for the observed catch or index estimate in year *y*, and λ_C and λ_E are the relative weights (Parma 2002; Deriso et al. 2007). The CVs for the YOY index were high; therefore, the lambda value for total catch was set to 10 to force the model to fit the pattern in total catch since the catch values are likely more accurate.

For catch age composition data, a multinomial error distribution is assumed and the negative log-likelihood is calculated using the general equation:

$$-L_p = \lambda_p \sum_y \sum_s - n_{y,s} \sum_a (P_{y,s,a} + 1e^{-5}) \cdot \ln(\hat{P}_{y,s,a} + 1e^{-5})$$

where $n_{y.s}$ is the effective number of fish of sex *s* aged in year *y*, and $P_{y,s,a}$ is the observed proportions of catch-at-age.

Effective sample size is estimated using the iterative procedures of McAllister and Ianelli (1997). In essence, the average effective sample size for catch age (or length) composition data of each sex is calculated using the following formula:

$$\hat{\bar{n}}_s = \frac{\sum_y \hat{n}_{y,s}}{d_{y,s}}$$

and $\hat{n}_y$ is defined as:

$$\hat{n}_{y,s} = \frac{\sum_a \hat{P}_{y,s,a}(1-\hat{P}_{y,s,a})}{\sum_a (P_{y,s,a}-\hat{P}_{y,s,a})^2}$$

where $\hat{P}_{y,s,a}$ is the predicted proportion-at-age *a* (or *l* for length data) in year *y* from the escapement numbers, $P_{y,s,a}$ is the observed proportion-at-age, and d_y is the number of years of data for escapement series. The average effective sample size is applied, re-calculated, and re-substituted until the average effective sample size stabilizes under equal weighting of all likelihood components.

The total log-likelihood of the model is:

$$f = -L_l - L_p$$

The total log-likelihood was estimated by the auto-differentiation routine in AD Model Builder to search for the "best" age-3 abundance estimates that minimize the total log-likelihood. AD Model Builder allows the minimization process to occur in phases. During each phase, a subset of parameters is held fixed and minimization is done over another subset of parameters until eventually all parameters have been included. In this model, the following parameters were solved over two phases:

Phase

1 average recruitment (log scale) and exploitation rates

2 catchability coefficient(s) (log scale)

3 recruitment deviations

Model fit for all components was checked by using standardized residual plots and root mean square errors. Standardized residuals (*r*) for lognormal (total catch and YOY index) were calculated as:

Total Catch:

$$r_{C,y} = \frac{\log_e(C_y + 1e^{-5}) - \log_e(\hat{C}_y + 1e^{-5})}{\sqrt{\log_e(CV_y^2 + 1)}}$$

YOY Index:

$$r_{I,y} = \frac{\log_e(I_y + 1e^{-5}) - \log_e(\hat{I}_y + 1e^{-5})}{\sqrt{\log_e(CV_y^2 + 1)}}$$

The root mean square error for total catch and the YOY index was calculated as:

YOY Index

$$RMSE_C = \sqrt{\frac{\sum_y r_{C,y}^2}{n}}$$

Total Catch

$$RMSE_I = \sqrt{\frac{\sum_y r_{I,y}^2}{n}}$$

where n is the total for Total Catch or YOY index values.
For catch age composition data, standardized residuals were derived as:

$$r_{y,s,a} = \frac{P_{y,s,a} - \hat{P}_{y,s,a}}{\sqrt{\frac{\hat{P}_{y,s,a}(1 - \hat{P}_{y,s,a})}{\hat{\hat{n}}_s}}}$$

where n_s is the average effective sample size for sex *s* and type of data.

16.11.1.2. Reference Point Derivation

Reference points for management were derived using three analytical approaches. First, yield-per-recruit (YPR) analyses were conducted to derive $F_{0.10}$ (*F* where slope between two adjacent YPR values is 10% of the slope at the origin) and F_{MAX} (*F* at maximum yield) reference values. Second, spawning biomass-per-recruit (SPR) analysis was conducted to derive the $F_{40\%}$ and $F_{20\%}$ reference points (fishing mortality rates that reduce the spawning biomass to 40% and 20% of the maximum unfished biomass, respectively). Third, recruitment and spawning stock biomass estimates in conjunction with SPR and YPR (production model method in Gibson and Myers 2003b) were used to derive values for F_{MED} (level of fishing mortality where recruitment has been sufficient to balance losses to fishing mortality in half the observed years), F_{COL} (the fishing mortality that drives the population to extinction), F_{MSY} (the fishing rates that produces maximum sustainable yield), SSB_{MSY} (the spawning stock biomass at MSY), and $SSB_{20\%}$ (minimum threshold population size).

The YPR and SPR analyses follow the model adapted by Gibson and Myers (2003c) for alewife. For a given *F*, YPR is calculated as:

$$YPR_F = \sum_{a=3}^{\max a} SS_a w_a (1 - e^{-F})$$

where SS_a is given by:

$$\begin{aligned}
SS_3 &= p_3 \\
SS_4 &= SS_3 e^{-M_{m,3}-F} + (1-p_3)e^{-M_{i,3}} p_4 \\
SS_5 &= SS_4 e^{-M_{m,4}-F} + (1-p_3)(1-p_4)e^{-M_{i,3}-M_{i,4}} p_5 \\
SS_6 &= SS_5 e^{-M_{m,5}-F} + (1-p_3)(1-p_4)(1-p_5)e^{-M_{i,3}-M_{i,4}-M_{i,5}} p_6 \\
SS_7 &= SS_6 e^{-M_{m,6}-F} + (1-p_3)(1-p_4)(1-p_5)(1-p_6)e^{-M_{i,3}-M_{i,4}-M_{i,5}-M_{i,6}} p_7 \\
SS_8 &= SS_7 e^{-M_{m,7}-F} + (1-p_3)(1-p_4)(1-p_5)(1-p_6)(1-p_7)e^{-M_{i,3}-M_{i,4}-M_{i,5}-M_{i,6}-M_{i,7}} p_8
\end{aligned}$$

Where *a* is the age of the fish, p_a is the proportion mature at that age, $M_{m,a}$ and $M_{i,a}$ are the instantaneous natural mortality rates for mature and immature fish of age *a*, and w_a is the female weight at age.

Since a plus group was used in the model, one additional SS_a was calculated to match the maximum observed age (9) for female blueback:

$$SS_9 = SS_8 e^{-M_{m,8}-F} + (1-p_3)(1-p_4)(1-p_5)(1-p_6)(1-p_7)(1-p_8)e^{-M_{i,3}-M_{i,4}-M_{i,5}-M_{i,6}-M_{i,7}-M_{i,8}} p_8$$

Similarly, SPR is calculated as:

$$SPR_F = \sum_{a=3}^{\max a} SS_a w_a e^{-F}$$

YPR and SPR were calculated for a set of *F*s that ranged from 0 to 5 with an increment of 0.01. F_{MAX} was found by selecting the fishing mortality where YPR_F takes its largest value, and $F_{0.10}$ was found by selecting the fishing mortality where the marginal gain in yield was 10% that at F = 0. The $SPR_{x\%}$ reference points were found by selecting the fishing mortality rate where SPR_F was x% that of $SPR_{F=0}$. Data from 1976 were used to calculate SPR and YPR values to develop historical estimates of population quantities before the decline in abundance and changes in age structure.

F_{MED} was calculated by finding the fishing mortality rate that produced a SPR replacement line with a slope that equals the median survival ratio (median of $R_y/SSB_{y\text{-}3}$) from the spawner-recruitment (S-R) biomass estimates. The remaining quantities were produced using a production model based on the Beverton-Holt spawner-recruit model. A Beverton-Holt spawner-recruit model was fit externally to the age-3 recruitment numbers (R_y) and corresponding spawning stocking biomass ($SSB_{y\text{-}3}$). The model is:

$$R_y = \frac{aSSB_{y-3}}{1+(aSSB_{y-3}/R_0)} e^{\epsilon}$$

Here, a is the slope at the origin of the spawner-recruit relationship (the maximum rate at which spawners can produce recruits at low population sizes) and R_0 is the asymptotic recruitment level which is the carrying capacity expressed as the number of fish that survive to age-3 (Gibson and Myers 2003b, 2003c). The linearized form of the model:

$$\log_e(R_y) = \log_e(a) + \log_e(SSB_{y-3}) - \log_e(1 + aSSB_{y-3}/R_0) + \varepsilon$$

was fitted to the spawner-recruitment data using non-linear least-squares regression. Only estimates of recruitment from 1978–2005 and SSB from 1975–2002 were used to estimate the S-R relationship to eliminate the influence and possible bias of the static stock abundance estimates during the first year (1972) and the retrospective bias near the terminal (see below). For a given level of F, the equilibrium spawning biomass (SSB*) is calculated using the relationship:

$$SSB^* = \frac{(\hat{a}SPR_F - 1)\hat{R}_0}{\hat{a}}$$

The corresponding equilibrium number of recruits (R*) is found by substituting SSB* in the spawner-recruit model:

$$R^* = \frac{\hat{a}SSB^*}{1 + (\hat{a}SSB^* / \hat{R}_0)}$$

The equilibrium catch (C*) is R* multiplied by the yield-per-recruit for the given value of *F*:

$$C^* = R^* \cdot YPR_F$$

F_{MSY} is found by finding the fishing mortality rate that produces the maximum C*, and SSB_{MSY} is the value of SSB* corresponding to this fishing mortality rate. F_{COL} is the value of *F* where $1/SPR_{F=0} = a$. The minimum threshold population size ($SSB_{20\%}$) was calculated as 20% of the equilibrium spawner abundance in the absence of fishing:

$$SSB_{20\%} = 0.2 \frac{(\hat{a}SPR_{F=0} - 1)\hat{R}_0}{\hat{a}}$$

16.11.1.3. Model Results

Being an update, the current assessment uses female sex ratio (0.5), the effective sample sizes for females and males (35), and age-specific natural mortality rates specified in the 2012 assessment. Initial CVs used for the total catch were 0.30, and for the YOY index, the CVs estimated for the arithmetic mean were used as a proxy since the standard error for the geometric mean was not provided. As noted in the 2012 assessment, a lambda for the total catch was set of 10 to force the model match the total catch patterns. The root mean square error (RMSE) for the YOY index was 2.41.

Resulting contributions to total likelihood are listed in Table 16.5. The converged total likelihood was 4,354.45. A total of 90 parameters was estimated in the model. The resulting estimates of recruitment, exploitation rates, and catchability coefficients are given in Table 16.6. The model fit the observed total catch YOY index (Figure 16.10) and catch age composition of each sex fairly well (Figure 16.11). Exceptions for the age compositions were that the proportions of age-3 fish from 2010 to 2015 were greatly under-estimated by the model and produced very large standardized residuals (Figure 16.12). This was due to age-3 fish comprising higher proportions of sample than were observed prior to 2010. Parameter estimates for years prior to 2006 were fairly precise (CV<0.20; Table 16.6), but the error in estimates increased thereafter due in part to low numbers of harvested fish.

16.11.1.4. *Exploitation and Fishing Mortality Rates*

Exploitation rates for blueback herring in the Chowan River before the 2007 moratorium ranged as low as 0.12 in 1979 to as high as 0.85 in 1986 (Table 16.6; Figure 16.13). Exploitation averaged about 0.24 prior to 1985, increased to an average of 0.68 during 1985–1988, and averaged about 0.43 between 1989 and 2006. Since the moratorium, exploitation rates have been close to zero. Corresponding fishing mortality rates are listed in Table 16.7 and are plotted in Figure 16.13. Fishing mortality averaged about 0.29 prior to 1985, increased to an average of 1.1 during 1985–1988, and averaged about 0.61 between 1989 and 2006. Since the moratorium, fishing mortality has been close to zero.

16.11.1.5. *Population Abundance*

The abundance estimates of the Chowan River blueback herring stock by sex, maturity phase, year, and age are given in Table 16.8, and total abundance by maturity state and year is given in Table 16.9. Blueback herring total abundance (age 3+) declined steadily from 157 million fish in 1976 to 62 million fish in 1980 (Table 16.9; Figure 16.13). Total abundance increased through 1983 to 104 million fish but then declined precipitously to 0.95 million fish in 2003 (Figure 16.14). After a slight increase in 2004 and 2005, total abundance declined to the lowest value of the time series (0.57 million fish) in 2006. Total abundance increased to 9.6 million fish in 2014, but declined to 5.1 million fish in 2015. Age-3 abundance peaked at 96 million fish in 1975, declined to 28.0 million fish in 1980, increased to 65 million through 1983, and then declined precipitously to its lowest value of 0.2 million fish in 2006 (Table 16.6; Figure 16.13). The model estimated that age-3 fish increased through 2014 to 7.5 million fish before decreasing to 0.4 million fish in the terminal year.

16.11.1.6. *Spawning Stock Biomass*

Estimates of female spawning stock biomass for blueback herring are provided in Table 16.10. Female SSB fluctuated but declined steadily from the peak of 6.5 million kilograms in 1972 to a low of 0.17 million kilograms in 1986 (Figure 16.13). Female SSB increased slightly to 0.5 million through 1990, but then it declined slowly to its lowest level of 11 thousand kilograms in 2005. The model estimated that female SSB, while still low, has been increasing since 2010 (Table 16.10; Figure 16.13).

16.11.1.7. *Retrospective Analysis*

In the 2012 assessment, small to moderate retrospective bias was evident in estimates of age-3 abundance, exploitation rate, female SSB, and total population abundance (Figure 16.15A). For age-3 abundance and total population abundance, the values before the terminal year were over-estimated but the terminal year estimate was consistently under-estimated. For exploitation rates and female SSB, the retrospective patterns were over- and under-estimation of the values near the terminal year, respectively.

For this update, the retrospective patterns were similar except the magnitudes of the differences were 3-4 times greater (Figure 16.15B) and indicated worsening model fit likely due to the mis-match in age composition and small catches for 2010-2015.

Small to moderate retrospective bias was evident in estimates of age-3 abundance, exploitation rate, female SSB, and total population abundance. For age-3 abundance and total population abundance, the terminal year estimate was consistently under-estimated. For exploitation rates and female SSB, the retrospective patterns were over- and under-estimation of the value, respectively.

16.12. BENCHMARKS

The fit of the Beverton-Holt stock-recruitment equation to the age-3 abundance and female SSB is shown in Figure 16.16. A plot of the residuals indicated reasonable model fit (Figure 16.16). The estimates of a and R_0 are 22.46 (SE = 3.706) and 39,346,610 fish (SE = 14,797,017), respectively. The estimate of a was precise (CV=0.16), but the estimate of R_0 was only moderately precise (CV=0.38) (Figure 16.4; Figure 16.17). Reference points generated from YPR, SPR, and the production model are shown in Table 16.11. For YPR analysis, the fishing mortality rate that maximized the yield-per-recruit, F_{max}, was greater than 5, and $F_{0.1}$ was 1.03. The fishing mortality that reduced the female spawning biomass to 40% and 20% of the level without fishing was 0.53 and 1.04, respectively.

From the spawner-recruit data and production model, F_{MED} was estimated to be 0.59 (Table 16.5; Figure 16.18). The fishing mortality rate that produces maximum sustainable yield, F_{MSY}, was 0.39 and corresponding spawning stock bass, SSB_{MSY}, was 1,894,382 kilograms. SSB_{MSY} was higher than the 20% of the equilibrium spawner biomass, $SSB_{20\%}$ (1,126,623 kilograms). Current female spawning stock biomass is only 12% of SSB_{MSY}. The fishing mortality rate that drives the population to extinction, F_{COL}, was 0.9. The relationships between the reference points from the production model are shown with the S-R data in Figure 9. The estimates of F_{MSY} and F_{COL} are considerably lower than those estimated for alewife (F_{MSY} > 1.0; F_{COL} >1.82) in three Canadian rivers by Gibson and Myers (2003b). Historical fishing mortality rate estimates exceeded most reference points several times over the time series, particularly after 1985.

16.12.1. Sensitivity Analyses

Sensitivity analyses were not conducted because this is an update. Refer to section 16.12.1 of the 2012 stock assessment for more information.

16.12.1.1. Alternate Natural Mortality Rates

The impact of alternate estimates of age- and sex-specific natural mortality on model results were evaluated in the 2012 assessment. Refer to section 16.12.1.1 of the 2012 stock assessment for more information.

16.13. CONCLUSIONS AND RECOMMENDATIONS

The previous assessment concluded that the Chowan River blueback herring stock was not experiencing overfishing but was overfished. Amendment 1 to the NCRHFMP identified four stock recovery indicators for the Chowan River blueback herring stock: a three-year running average juvenile abundance index of greater than 60 fish per haul, a spawning population comprised of greater than 10% repeat spawners, a spawning stock biomass of greater than 4 million pounds (1.8 million kg) and a three-year running average of greater than 8 million age-3fish. Amendment 2 to the NCRHFMP removed recruitment (three-year running average of greater than 8 million age-3 fish) as a stock recovery indicator and changed the name of stock recovery indicators to stock status indicators.

Based on the 2015 fishing mortality rate and female spawning stock biomass estimates, the Chowan River blueback herring population is overfished (2015 SSB=227,333 versus SSB_{MSY}=1.8 million kilograms), but over-fishing is not occurring (F=0.000 versus F_{MSY}=0.39). Estimates of fishing mortality have been close to zero since the moratorium (Table 16.7, Figure 16.13). The forward-projecting statistical catch-at-age model estimates juvenile abundance as well below the target of 60 fish per haul (Figure 16.10), with no increasing pattern evident. Percentage of repeat spawners varied from 2007 through 2010, remaining below the target of 10%. Starting in 2011, there was an abrupt increase of the percentage of repeat spawners that has continued to increase annually, exceeding the target, to the highest level in 34-years of 16.8% in 2015 (Table 16.4). Female SSB has been increasing since 2010, but still remains at approximately 12% of the target of 1.8 million kilograms (Table 16.10; Figure 16.13). The factors leading to this recommendation of stock status remain largely unchanged since the 2012 stock assessment, despite a fishing pressure that is negligible. Therefore, although the stock is not currently experiencing overfishing, it remains overfished since the spawning stock biomass remains less than 12% of the amount necessary to replace itself in the complete absence of fishing.

While current research programs are recommended to continue, assessing progress towards recovery goals would be improved with additional research and surveys. Many recommendations made in the previous assessment (ASMFC 2012) and in Amendments 2 to the NCRHFMP are echoed here. Amendment 2 to the NCRHFMP identified three stock status indicators as restoration targets. Continued data collection through the Chowan River Pound Net Survey and a juvenile abundance survey to monitor these indicators are essential in determining stock status of Chowan River blueback herring. Monitoring efforts in other river basins should continue and be expanded as well.

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Table 16.1 Commercial landings in pounds of river herring in North Carolina, 1972-2006.

Year	Atlantic Ocean	Albemarle Sound Area (excluding Chowan River)	Chowan River	Other Areas	Lb
1972	--	643,026	10,594,117	0	11,237,143
1973	--	573,931	7,350,578	1,389	7,925,898
1974	--	467,992	5,736,905	4,645	6,209,542
1975	2,338	917,723	5,031,756	250	5,952,067
1976	--	666,584	5,734,776	0	6,401,360
1977	--	1,102,125	7,418,218	3,470	8,523,813
1978	--	954,939	5,615,113	37,101	6,607,153
1979	19,388	796,099	4,303,663	0	5,119,150
1980	*	796,237	5,382,954	39,332	6,218,523
1981	143,232	1,245,401	3,314,447	50,643	4,753,723
1982	7,679	1,872,156	7,459,968	97,900	9,437,703
1983	--	1,453,033	4,405,915	9,384	5,868,332
1984	9,497	1,931,492	4,561,503	13,617	6,516,109
1985	*	2,665,334	8,871,391	11,553	11,548,278
1986	40,270	999,093	5,767,874	7,086	6,814,323
1987	19,279	838,689	2,334,719	2,288	3,194,975
1988	19,517	1,570,788	2,259,888	341,018	4,191,211
1989	--	581,486	908,145	1,446	1,491,077
1990	11,073	433,891	710,849	1,812	1,157,625
1991	--	372,843	1,202,535	0	1,575,378
1992	110,794	476,649	1,135,340	395	1,723,178
1993	--	115,072	801,115	*	916,235
1994	38,834	211,372	390,852	3,251	644,309
1995**	19,174	150,082	280,681	4,049	453,984
1996**	*	123,725	404,884	894	529,503
1997**	5,568	126,453	201,929	861	334,809
1998**	--	143,424	377,312	1,197	521,930
1999**	--	110,657	332,464	373	443,494
2000**	599	140,696	182,658	8,378	332,336
2001**	*	89,767	201,717	15,277	306,761
2002**	*	75,736	92,979	6,145	174,860
2003**	*	98,440	84,591	16,685	199,716
2004**	*	107,430	77,177	3,934	188,542
2005**	--	92,688	157,088	245	250,021
2006**	--	40,590	67,404	1,249	109,243

**Denotes confidential data*

***Season or TAC in ASMA*

Table 16.2 Commercial landings in pounds and value of research set-aside river herring harvest in North Carolina, 2007-2014. Research set-aside harvest eliminated in 2015.

Year	# of Permits Issued	Quota (lb/permit/period)	Harvest (lb)
2007	15	200	1,103
2008	13	250	1,292
2009	27	125	643
2010	30	125	1,765
2011	23	150	1,611
2012	18	150	678
2013	12	150	743
2014	27	150	989
Average	21	163	8,824
Total	165		1,103

Table 16.3 Catch-per-unit effort of blueback herring and alewife in the commercial pound net fishery, Chowan River, NC.

Year	Total PN fished	Weeks fished	Effort in PN weeks	PN BB Catch	BB CPUE	PN ALE.Catch	ALE. CPUE
1977	624	9	4,854	7,001,059	1,442	291,711	60
1978	383	10	3,645	4,050,767	1,111	1,209,970	332
1979	502	12	4,996	2,118,907	424	2,035,813	407
1980	500	9	3,090	3,388,983	1,096	1,824,837	590
1981	525	10	4,120	2,041,319	495	1,198,870	291
1982	480	11	4,461	5,388,115	1,207	1,992,865	446
1983	486	12	4,895	2,380,261	486	1,947,488	398
1984	480	12	5,040	3,196,416	634	1,305,578	259
1985	421	12	3,708	6,845,568	1,846	1,930,802	520
1986	451	12	4,241	4,244,280	1,000	1,340,299	316
1987	501	11	4,969	1,353,601	272	980,194	197
1988	506	12	4,689	1,430,114	305	804,440	171
1989	348	9	3,063	626,222	204	281,347	92
1990	360	11	3,077	610,931	198	99,455	32
1991	226	11	2,037	720,218	353	294,174	144
1992	180	12	1,669	806,091	483	329,249	197
1993	197	11	1,729	640,092	370	160,023	92
1994	175	8	1,173	377,728	322	7,709	6
1995	73	8	484	263,163	543	5,371	11
1996	95	10	555	394,491	711	3,985	7
1997	102	5	461	190,071	412	1,920	4
1998	75	11	463	361,285	780	7,373	16
1999	68	8	471	318,495	676	6,500	14
2000	51	9	445	146,126	328	36,532	82
2001	63	7	385	136,998	356	64,470	167
2002	62	12	648	47,235	73	38,648	60
2003	50	10	419	45,326	108	35,614	85
2004	36	12	376	29,595	79	42,589	113
2005	41	15	447	148,552	332	7,424	16
2006	39	13	355	45,578	128	20,224	57
2007*							
2008*							
2009**	18	14	217	65,763	303	23,482	108
2010**	24	13	260	36,004	139	35,528	137
2011**	26	14	286	28,304	99	46,181	162
2012**	22	18	315	7,181	23	11,233	36
2013**	23	17	238	10,136	43	17,259	73
2014**	21	16	271	18,247	67	27,371	101
2015**	23	18	253	18,041	71	30,719	121

* Fishery closed in 2007.

** Results based on visual estimates in contracted pound net sets from commercial fishermen in Chowan River, NC.

Table 16.4 Percentage of blueback herring and alewife repeat spawners (spawned more than once) from the Chowan River pound net fishery, 1972-2015. Alewife ages are incomplete past 2009.

Year	Percent BB	Percent Alewife
1972	21.1	15.9
1973	18.3	13.2
1974	16.4	4.6
1975	3.9	9.3
1976	5.3	14.4
1977	7.3	4.1
1978	7.1	4.9
1979	20.1	3.3
1980	24.6	13.7
1981	16.2	9.7
1982	13.9	0.5
1983	1.6	2.5
1984	1.3	10.2
1985	3.3	0.0
1986	6.1	0.0
1987	3.3	0.7
1988	2.0	2.5
1989	0.6	0.0
1990	2.5	No Samples
1991	4.2	5.7
1992	3.7	12.5
1993	4.7	No Samples
1994	1.2	No Samples
1995	1.6	No Samples
1996	2.8	No Samples
1997	2.7	No Samples
1998	2.7	No Samples
1999	2.6	No Samples
2000	6.0	1.1
2001	3.1	5.0
2002	4.7	14.8
2003	5.9	5.4
2004	2.9	10.4
2005	2.1	12.6
2006	0.0	3.1
2007^	7.7	10.0
2008^	5.8	8.0
2009*	1.7	10.5
2010*	6.4	
2011*	11.2	
2012*	13.8	
2013*	14.8	
2014*	12.2	
2015*	16.8	

^ Based on research set aside data
*Based on samples obtained from contracted pound net sets

Table 16.5 Likelihood components with respective contributions in base model run.

Likelihood Components

	Weight	RSS
YOY Index	1	171.235
Total Catch	10	7.64875
Catch Age Comps	1	4322.71
Total Likelihood		4354.45
Number of Estimates		90
AIC		8888.91

Catch RMSE	0.134739
Index RMSE	2.41498

Table 16.6 Parameter estimates and associated standard deviations of base model configuration.

Year	Age-3 Numbers	SD	CV
1972	72,952,900	8.60E+06	0.12
1973	47,728,200	8.74E+06	0.18
1974	81,983,600	1.37E+07	0.17
1975	96,210,600	1.41E+07	0.15
1976	85,804,300	1.28E+07	0.15
1977	65,580,500	1.04E+07	0.16
1978	37,360,500	6.34E+06	0.17
1979	29,763,600	5.48E+06	0.18
1980	28,231,900	5.28E+06	0.19
1981	47,423,000	6.88E+06	0.15
1982	57,042,500	7.71E+06	0.14
1983	65,293,300	7.65E+06	0.12
1984	26,773,200	3.95E+06	0.15
1985	12,430,000	1.98E+06	0.16
1986	9,846,420	1.43E+06	0.15
1987	10,286,900	1.36E+06	0.13
1988	6,383,570	1.02E+06	0.16
1989	7,386,410	1.10E+06	0.15
1990	8,793,980	1.09E+06	0.12
1991	8,841,130	9.99E+05	0.11
1992	2,562,740	4.68E+05	0.18
1993	5,208,300	6.83E+05	0.13
1994	3,643,120	5.18E+05	0.14
1995	2,651,640	4.29E+05	0.16
1996	3,985,310	5.11E+05	0.13
1997	3,398,870	4.05E+05	0.12
1998	1,733,320	2.36E+05	0.14
1999	1,199,020	1.57E+05	0.13
2000	958,427	1.28E+05	0.13
2001	562,900	9.37E+04	0.17
2002	521,042	9.46E+04	0.18
2003	531,648	9.25E+04	0.17
2004	862,169	1.16E+05	0.13
2005	576,283	1.20E+05	0.21
2006	249,054	8.62E+04	0.35
2007	381,575	1.35E+05	0.35
2008	514,725	1.83E+05	0.35
2009	631,761	227663	0.36
2010	851,792	303,507	0.36
2011	1,217,180	440,560	0.36
2012	1,942,740	752,513	0.39
2013	2,826,010	1,213,060	0.43
2014	7,499,110	3,486,680	0.46
2015	427,514	465,579	1.09

Year	u	SD	CV
1972	0.218	0.033	0.15
1973	0.277	0.051	0.18
1974	0.314	0.061	0.19
1975	0.131	0.026	0.20
1976	0.187	0.034	0.18
1977	0.407	0.073	0.18
1978	0.207	0.038	0.19
1979	0.116	0.023	0.19
1980	0.270	0.050	0.19
1981	0.246	0.050	0.20
1982	0.425	0.067	0.16
1983	0.155	0.026	0.17
1984	0.203	0.030	0.15
1985	0.663	0.055	0.08
1986	0.851	0.047	0.05
1987	0.599	0.079	0.13
1988	0.613	0.073	0.12
1989	0.368	0.063	0.17
1990	0.211	0.034	0.16
1991	0.318	0.045	0.14
1992	0.387	0.050	0.13
1993	0.614	0.076	0.12
1994	0.401	0.058	0.14
1995	0.330	0.053	0.16
1996	0.478	0.067	0.14
1997	0.161	0.026	0.16
1998	0.459	0.055	0.12
1999	0.661	0.060	0.09
2000	0.504	0.059	0.12
2001	0.615	0.066	0.11
2002	0.365	0.061	0.17
2003	0.443	0.077	0.17
2004	0.216	0.040	0.19
2005	0.767	0.076	0.10
2006	0.462	0.105	0.23
2007	0.005	0.002	0.37
2008	0.007	0.002	0.37
2009	0.003	0.001	0.37
2010	0.004	0.002	0.36
2011	0.004	0.001	0.37
2012	0.002	0.001	0.37
2013	0.002	0.001	0.37
2014	0.001	0.001	0.40
2015	0.000	0.000	0.45

q	Estimate	SD	CV
1	2.43E-07	3.41E-08	0.14

Table 16.7 Derived fishing mortality values for Chowan River blueback herring.

Year	F	SD	CV
1972	0.245	0.042	0.17
1973	0.325	0.070	0.22
1974	0.377	0.089	0.24
1975	0.140	0.030	0.21
1976	0.207	0.042	0.20
1977	0.522	0.123	0.24
1978	0.232	0.048	0.21
1979	0.124	0.026	0.21
1980	0.315	0.069	0.22
1981	0.282	0.066	0.23
1982	0.553	0.116	0.21
1983	0.169	0.031	0.18
1984	0.227	0.038	0.17
1985	1.088	0.163	0.15
1986	1.905	0.313	0.16
1987	0.914	0.198	0.22
1988	0.950	0.188	0.20
1989	0.460	0.099	0.22
1990	0.237	0.043	0.18
1991	0.383	0.066	0.17
1992	0.489	0.081	0.17
1993	0.953	0.197	0.21
1994	0.512	0.096	0.19
1995	0.401	0.079	0.20
1996	0.650	0.129	0.20
1997	0.175	0.031	0.17
1998	0.615	0.101	0.16
1999	1.081	0.178	0.16
2000	0.702	0.120	0.17
2001	0.955	0.172	0.18
2002	0.454	0.096	0.21
2003	0.586	0.137	0.23
2004	0.243	0.051	0.21
2005	1.456	0.326	0.22
2006	0.621	0.195	0.31
2007	0.005	0.002	0.37
2008	0.007	0.003	0.37
2009	0.003	0.001	0.37
2010	0.004	0.002	0.36
2011	0.004	0.001	0.37
2012	0.002	0.001	0.37
2013	0.002	0.001	0.37
2014	0.001	0.001	0.40
2015	0.000	0.000	0.45

Table 16.8 Estimates of population abundance by sex, maturity state, year, and age.

Female Immature

Year	Total	Age 3	4	5	6	7	8+
1972	22,365,780	20,426,800	1,918,160	20,820	0	0	0
1973	27,089,162	23,577,700	3,474,780	36,682	0	0	0
1974	43,774,342	40,991,800	2,712,500	70,042	0	0	0
1975	48,558,500	47,047,000	1,511,500	0	0	0	0
1976	48,044,550	42,215,700	5,828,850	0	0	0	0
1977	46,903,989	32,790,200	14,092,700	21,089	0	0	0
1978	26,223,878	18,493,500	7,657,540	72,838	0	0	0
1979	16,392,903	14,197,300	2,163,940	31,663	0	0	0
1980	18,016,525	13,988,900	3,971,620	55,922	83	0	0
1981	29,311,859	23,711,500	5,323,240	277,119	0	0	0
1982	32,269,540	28,236,000	4,033,540	0	0	0	0
1983	35,255,990	31,993,700	3,262,290	0	0	0	0
1984	17,794,930	12,824,400	4,970,530	0	0	0	0
1985	11,227,500	6,215,010	5,012,490	0	0	0	0
1986	7,051,886	4,923,210	2,071,680	56,996	0	0	0
1987	5,741,761	4,891,430	837,482	12,849	0	0	0
1988	3,749,714	3,191,790	557,924	0	0	0	0
1989	3,900,135	3,608,260	291,875	0	0	0	0
1990	3,716,828	3,557,170	159,658	0	0	0	0
1991	3,958,120	3,713,280	244,840	0	0	0	0
1992	1,739,037	1,209,610	529,427	0	0	0	0
1993	2,874,112	2,541,650	325,895	6,567	0	0	0
1994	2,246,860	1,763,270	483,590	0	0	0	0
1995	1,600,125	1,299,310	300,815	0	0	0	0
1996	2,442,927	1,992,660	447,157	3,110	0	0	0
1997	1,993,304	1,655,250	335,050	3,004	0	0	0
1998	1,243,380	866,662	375,159	1,559	0	0	0
1999	810,775	599,511	210,488	776	0	0	0
2000	594,871	479,214	111,414	4,243	0	0	0
2001	420,266	280,324	139,712	230	0	0	0
2002	356,306	260,521	95,785	0	0	0	0
2003	371,732	265,824	105,413	495	0	0	0
2004	461,073	412,979	48,094	0	0	0	0
2005	283,201	259,039	24,162	0	0	0	0
2006	142,994	124,527	18,467	0	0	0	0
2007	192,149	166,558	25,591	0	0	0	0
2008	284,473	257363	26859	251	0	0	0
2009	350,804	315881	34923	0	0	0	0
2010	394,159	362012	32147	0	0	0	0
2011	758,669	608588	149682	399	0	0	0
2012	1,208,581	971371	234580	2630	0	0	0
2013	1,788,076	1413000	362952	12124	0	0	0
2014	4,196,846	3749550	432101	15195	0	0	0
2015	1,263,677	213757	1045230	4690	0	0	0

Female Mature

Year	Total	Age 3	4	5	6	7	8+
1972	41,577,129	16,049,600	14,297,600	6,751,760	2,796,170	1,176,760	505,239
1973	24,241,438	286,369	12,741,000	6,735,900	2,796,170	1,176,760	505,239
1974	19,605,329	0	8,981,110	6,484,580	2,585,980	1,086,970	466,689
1975	28,028,648	1,058,320	18,641,900	4,584,470	2,381,210	953,755	408,993
1976	31,262,141	686,435	17,753,600	9,153,620	2,100,560	1,113,090	454,836
1977	22,732,265	0	6,936,860	10,454,200	3,925,400	918,993	496,812
1978	22,824,157	186,803	8,463,590	9,338,750	3,282,520	1,253,180	299,314
1979	20,970,798	684,564	7,001,100	7,395,450	3,943,780	1,400,450	545,454
1980	13,708,936	127,044	3,305,770	4,259,950	3,462,380	1,874,650	679,142
1981	8,400,207	0	1,599,900	3,022,240	1,668,390	1,359,020	750,657
1982	13,872,806	285,212	7,624,090	3,375,200	1,348,450	677,138	562,716
1983	17,358,376	652,933	10,700,400	4,350,760	1,023,440	417,140	213,703
1984	20,546,443	562,237	11,030,200	6,357,740	1,937,840	465,049	193,377
1985	12,329,269	0	1,512,770	7,111,430	2,671,110	830,601	203,358
1986	5,681,506	0	983,895	2,797,070	1,263,020	483,983	153,538
1987	3,358,946	252,030	1,582,990	1,133,610	249,623	101,150	39,543
1988	2,979,882	0	1,896,590	760,825	246,386	53,829	22,253
1989	2,247,693	84,944	1,277,350	667,529	155,176	51,268	11,427
1990	3,341,169	839,825	1,640,700	567,837	222,312	52,724	17,771
1991	3,642,408	707,291	1,829,870	751,740	236,293	94,379	22,835
1992	2,769,014	71,757	1,533,340	771,564	270,337	86,691	35,325
1993	1,473,720	62,500	290,435	752,993	249,453	89,168	29,172
1994	1,289,660	58,290	777,847	226,327	156,576	51,749	18,871
1995	1,239,568	26,516	583,257	490,814	71,501	50,465	17,015
1996	772,368	0	200,372	354,309	173,368	25,766	18,553
1997	1,126,157	44,185	644,628	282,155	99,138	48,671	7,380
1998	1,101,714	0	456,866	451,229	126,445	44,757	22,417
1999	715,835	0	215,601	320,761	129,429	36,767	13,277
2000	413,931	0	183,332	142,350	57,785	23,619	6,845
2001	262,634	1,126	95,890	104,331	39,450	15,411	6,426
2002	166,234	0	42,248	91,279	21,288	8,165	3,254
2003	126,239	0	22,671	62,880	30,569	7,273	2,846
2004	191,798	18,106	82,597	61,005	18,716	9,153	2,222
2005	310,356	29,102	185,858	58,335	25,226	7,896	3,939
2006	158,456	0	112,225	34,885	7,172	3,164	1,010
2007	113,488	24,230	35,632	40,729	9,890	2,074	934
2008	125,962	0	66878	31296	21364	5292	1132
2009	170,646	0	91608	48215	16523	11415	2885
2010	292,760	63884	123154	65262	25350	8863	6247
2011	191,858	0	59573	79597	34265	13579	4843
2012	237,868	0	64629	105414	42032	18367	7426
2013	346,578	0	114617	142461	56869	22569	10062
2014	618,450	0	262595	231546	81396	30545	12367
2015	1,342,826	0	798212	354192	129949	43731	16742

Table 16.8. Continued.

				Male Immature Age			
Year	Total	3	4	5	6	7	8+
1972	22,546,834	21,192,800	1,351,350	2,684	0	0	0
1973	22,696,770	21,262,900	1,433,870	0	0	0	0
1974	41,278,930	40,212,900	1,066,030	0	0	0	0
1975	46,888,730	44,305,000	2,583,730	0	0	0	0
1976	42,747,040	39,641,600	3,105,440	0	0	0	0
1977	45,255,200	32,790,200	12,465,000	0	0	0	0
1978	23,555,789	17,503,400	5,953,350	99,039	0	0	0
1979	14,855,921	13,944,300	911,621	0	0	0	0
1980	16,313,052	13,791,300	2,511,340	10,412	0	0	0
1981	27,498,163	23,498,100	3,953,920	46,143	0	0	0
1982	29,195,510	26,496,200	2,699,310	0	0	0	0
1983	30,414,970	28,957,600	1,457,370	0	0	0	0
1984	14,009,540	11,204,600	2,804,940	0	0	0	0
1985	8,934,060	5,972,620	2,961,440	0	0	0	0
1986	5,544,339	4,696,740	834,363	13,236	0	0	0
1987	5,066,903	4,783,420	283,483	0	0	0	0
1988	2,537,859	2,409,800	128,059	0	0	0	0
1989	2,943,689	2,873,310	70,379	0	0	0	0
1990	2,381,965	2,356,790	25,175	0	0	0	0
1991	2,911,844	2,829,160	82,596	88	0	0	0
1992	1,201,352	1,157,080	44,067	205	0	0	0
1993	2,619,173	2,481,750	137,423	0	0	0	0
1994	1,318,926	1,225,910	93,016	0	0	0	0
1995	1,400,017	1,274,110	125,907	0	0	0	0
1996	1,667,385	1,614,050	53,335	0	0	0	0
1997	1,103,558	1,038,350	65,208	0	0	0	0
1998	879,454	776,529	102,601	324	0	0	0
1999	653,943	564,740	89,203	0	0	0	0
2000	480,012	468,192	11,820	0	0	0	0
2001	297,418	275,540	21,878	0	0	0	0
2002	263,642	254,790	8,852	0	0	0	0
2003	253,824	245,887	7,937	0	0	0	0
2004	306,379	302,190	4,189	0	0	0	0
2005	227,103	224,750	2,353	0	0	0	0
2006	110,359	103,358	7,001	0	0	0	0
2007	147,954	146,143	1,811	0	0	0	0
2008	256,514	236,516	19,989	9	0	0	0
2009	344,192	307,352	36,840	0	0	0	0
2010	346,674	324,533	22,141	0	0	0	0
2011	533,555	530,080	3,475	0	0	0	0
2012	1,130,568	971,371	159,197	0	0	0	0
2013	1,776,295	1,413,000	358,868	4,427	0	0	0
2014	4,111,324	3,749,550	361,774	0	0	0	0
2015	586,078	213,757	372,321	0	0	0	0

				Male Mature Age			
Year	Total	3	4	5	6	7	8+
1972	40,553,293	15,283,600	14,784,300	6,411,920	2,568,200	1,059,420	445,853
1973	27,790,973	2,601,190	14,701,700	6,414,610	2,568,200	1,059,420	445,853
1974	20,727,660	778,844	10,198,700	5,987,730	2,371,970	978,583	411,833
1975	28,370,962	3,800,320	17,249,900	4,001,640	2,100,680	857,503	360,919
1976	35,197,259	3,260,560	20,067,500	8,726,520	1,779,330	962,512	400,837
1977	22,583,797	0	8,121,400	9,646,620	3,631,640	763,039	421,098
1978	23,978,059	1,176,860	10,007,400	8,484,290	2,929,470	1,136,440	243,599
1979	21,101,493	937,555	8,062,520	6,897,620	3,493,870	1,225,080	484,848
1980	14,313,129	324,667	4,679,310	3,980,090	3,118,830	1,627,900	582,332
1981	9,314,229	213,404	2,874,320	2,896,360	1,491,310	1,199,890	638,945
1982	16,104,252	2,025,010	8,816,820	3,040,350	1,141,800	593,282	486,990
1983	20,978,187	3,689,070	12,006,500	3,858,210	894,656	346,220	183,531
1984	22,972,493	2,182,010	12,807,000	5,760,020	1,667,660	398,481	157,322
1985	13,261,198	242,385	3,338,670	6,460,230	2,348,470	700,645	170,798
1986	6,012,326	226,468	2,112,560	2,015,800	1,113,450	417,097	126,951
1987	3,230,779	360,042	2,019,080	570,511	160,336	87,406	33,404
1988	3,764,974	781,987	2,270,530	542,693	117,025	33,890	18,848
1989	2,707,773	819,891	1,249,830	499,717	107,415	23,868	7,052
1990	4,298,017	2,040,200	1,625,480	426,948	161,506	35,773	8,110
1991	4,343,927	1,591,400	1,848,290	649,429	172,414	67,207	15,187
1992	2,965,746	124,293	1,861,330	666,776	226,687	62,003	24,657
1993	1,476,947	122,395	462,882	588,621	209,308	73,290	20,451
1994	2,064,412	595,651	1,137,960	156,883	116,153	42,561	15,204
1995	1,179,490	51,707	644,517	384,756	48,098	36,695	13,717
1996	1,401,336	378,605	583,703	276,926	131,889	16,989	13,223
1997	1,770,457	661,080	816,609	177,754	73,952	36,293	4,770
1998	1,260,838	90,133	672,874	372,384	76,336	32,726	16,385
1999	713,258	34,772	312,489	231,561	103,164	21,757	9,516
2000	439,389	11,022	268,810	96,938	40,196	18,453	3,970
2001	326,655	5,910	208,675	72,048	24,592	10,508	4,921
2002	204,190	5,731	126,375	50,734	14,185	4,989	2,175
2003	204,988	19,937	117,854	44,254	16,489	4,751	1,705
2004	305,176	128,894	120,899	36,517	12,605	4,839	1,422
2005	328,397	63,391	193,938	49,161	14,654	5,212	2,042
2006	162,703	21,170	109,590	23,623	5,865	1,802	654
2007	140,101	44,644	54,038	32,736	6,499	1,663	521
2008	142,157	20,846	72,764	27,585	16,663	3,409	890
2009	167,281	8,529	88,363	45,816	14,025	8,727	1,821
2010	330,445	101,363	131,602	62,048	23,377	7,374	4,681
2011	406,035	78,508	203,620	76,068	31,615	12,274	3,950
2012	301,356	0	136,899	102,481	38,786	16,611	6,579
2013	338,111	0	113,949	142,485	52,344	20,414	8,919
2014	674,303	0	326,009	234,707	75,064	27,558	10,965
2015	1,968,402	0	1,452,780	341,337	119,949	39,530	14,806

Table 16.9 Total population abundance (number of fish 3+) estimate for the Chowan River blueback herring stock by maturity state.

Year	Immature	Mature	Total
1972	44,912,614	82,130,422	127,043,036
1973	49,785,932	52,032,411	101,818,343
1974	85,053,272	40,332,989	125,386,261
1975	95,447,230	56,399,610	151,846,840
1976	90,791,590	66,459,400	157,250,990
1977	92,159,189	45,316,062	137,475,251
1978	49,779,667	46,802,216	96,581,883
1979	31,248,824	42,072,291	73,321,115
1980	34,329,577	28,022,065	62,351,642
1981	56,810,022	17,714,436	74,524,458
1982	61,465,050	29,977,058	91,442,108
1983	65,670,960	38,336,563	104,007,523
1984	31,804,470	43,518,936	75,323,406
1985	20,161,560	25,590,467	45,752,027
1986	12,596,224	11,693,832	24,290,056
1987	10,808,664	6,589,725	17,398,389
1988	6,287,573	6,744,856	13,032,429
1989	6,843,824	4,955,466	11,799,290
1990	6,098,793	7,639,186	13,737,978
1991	6,869,964	7,986,335	14,856,299
1992	2,940,389	5,734,760	8,675,149
1993	5,493,285	2,950,667	8,443,953
1994	3,565,786	3,354,071	6,919,857
1995	3,000,142	2,419,058	5,419,200
1996	4,110,312	2,173,704	6,284,015
1997	3,096,863	2,896,614	5,993,477
1998	2,122,833	2,362,552	4,485,385
1999	1,464,717	1,429,093	2,893,811
2000	1,074,883	853,319	1,928,202
2001	717,684	589,289	1,306,973
2002	619,948	370,424	990,372
2003	625,556	331,228	956,784
2004	767,452	496,975	1,264,427
2005	510,304	638,753	1,149,057
2006	253,353	321,159	574,512
2007	340,103	253,589	593,693
2008	540,987	268,119	809,107
2009	694,995	337,927	1,032,922
2010	740,834	623,205	1,364,039
2011	1,292,224	597,893	1,890,117
2012	2,339,149	539,224	2,878,374
2013	3,564,371	684,689	4,249,060
2014	8,308,170	1,292,753	9,600,923
2015	1,849,755	3,311,229	5,160,983

Table 16.10 Estimates of female spawning stock biomass (kilograms) for the Chowan River blueback herring stock

		Female SSB (kg)					
		Age					
Year	Total	3	4	5	6	7	8+
1972	6527531	2335420	2293000	1103950	485627	193327	116207
1973	3589943	30213	1721720	1022190	478882	229598	107340
1974	2800559	0	1151450	933634	420192	201213	94070
1975	4818669	134265	3029190	836572	490389	223767	104486
1976	5102914	81506	2700030	1563330	404877	244418	108753
1977	2858744	0	769831	1302870	552107	147254	86682
1978	3787339	21630	1255220	1555360	616990	268348	69791
1979	3919213	88315	1156850	1372320	825907	334119	141702
1980	2230983	13533	451038	652712	598716	369302	145682
1981	1519711	0	241415	517603	323499	270688	166506
1982	1675895	21322	841781	432827	188430	105136	86399
1983	2930033	74457	1663100	815865	224768	94079	57764
1984	2976737	59581	1485270	942222	344318	100046	45299
1985	783582	0	85602	426361	187135	64346	20138
1986	170389	0	23729	82033	40615	17293	6720
1987	238481	12831	103433	85885	21414	10258	4660
1988	192367	0	111508	53266	20585	4477	2531
1989	265099	7511	134731	88960	23032	8743	2122
1990	496277	108032	247307	82903	43510	10402	4123
1991	436159	65121	195932	111254	38354	20919	4579
1992	301522	6160	151367	88467	34809	14352	6368
1993	95894	2410	16800	49074	16738	7565	3307
1994	114382	4191	59652	19120	22514	5581	3324
1995	138469	2132	60170	53264	9579	9973	3351
1996	81622	0	19659	35871	20086	3160	2847
1997	187271	4079	88724	58489	20883	13275	1821
1998	99001	0	36301	40000	13259	5879	3562
1999	42132	0	11483	19260	7596	2470	1324
2000	34955	0	13724	12421	5271	2541	998
2001	19305	52	5755	7667	3491	1613	727
2002	19750	0	4186	10841	2975	1141	608
2003	11873	0	1565	5915	3199	729	466
2004	22943	1704	9068	7176	2789	1694	512
2005	11015	814	6067	2312	1117	434	270
2006	13395	0	9050	3001	783	401	160
2007	20195	3302	6238	7779	2115	487	273
2008	19934	0	9167	4973	4223	1241	331
2009	26909	0	12423	7692	3262	2686	846
2010	44126	8142	16677	10397	4998	2083	1829
2011	36756	0	10507	14911	6726	3193	1419
2012	40788	0	9096	17467	7720	4327	2179
2013	66000	0	20142	26742	10845	5318	2954
2014	115238	0	49567	39313	15527	7200	3631
2015	227333	0	122924	63046	26120	10321	4922

Table 16.11 Reference points derived from YPR, SPR and production model methods

Reference Points

	Basis	Estimate
Yield Per Recruit	F0.1	1.03
	Fmax	5
Spawner Per Recruit	F40%	0.53
	F20%	1.04
Production Model	Fmed	0.59
	Fcol	0.9
	Fmsy	0.39
	SSBmsy	1894382
	SSB20%	1126623

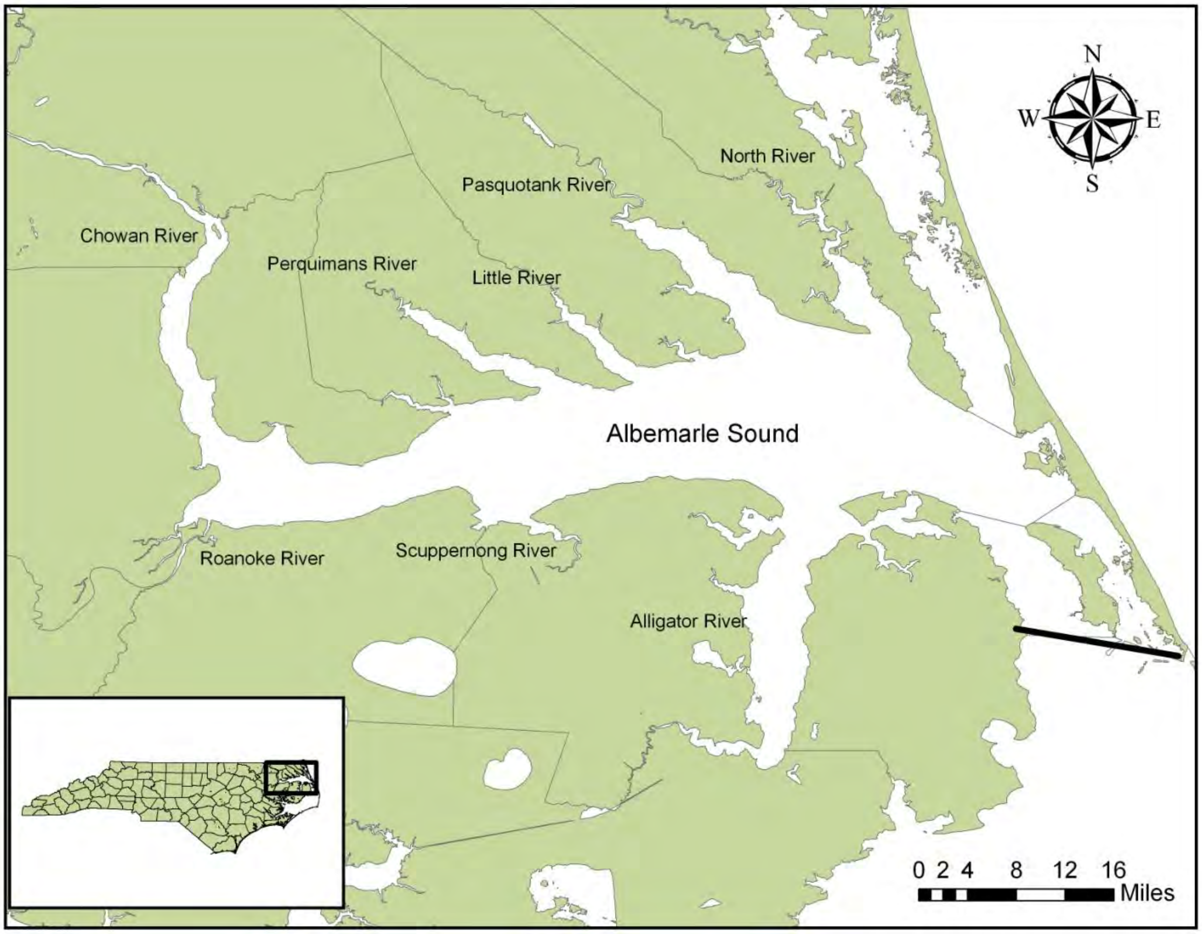


Figure 16.1 Albemarle Sound and tributaries, NC.

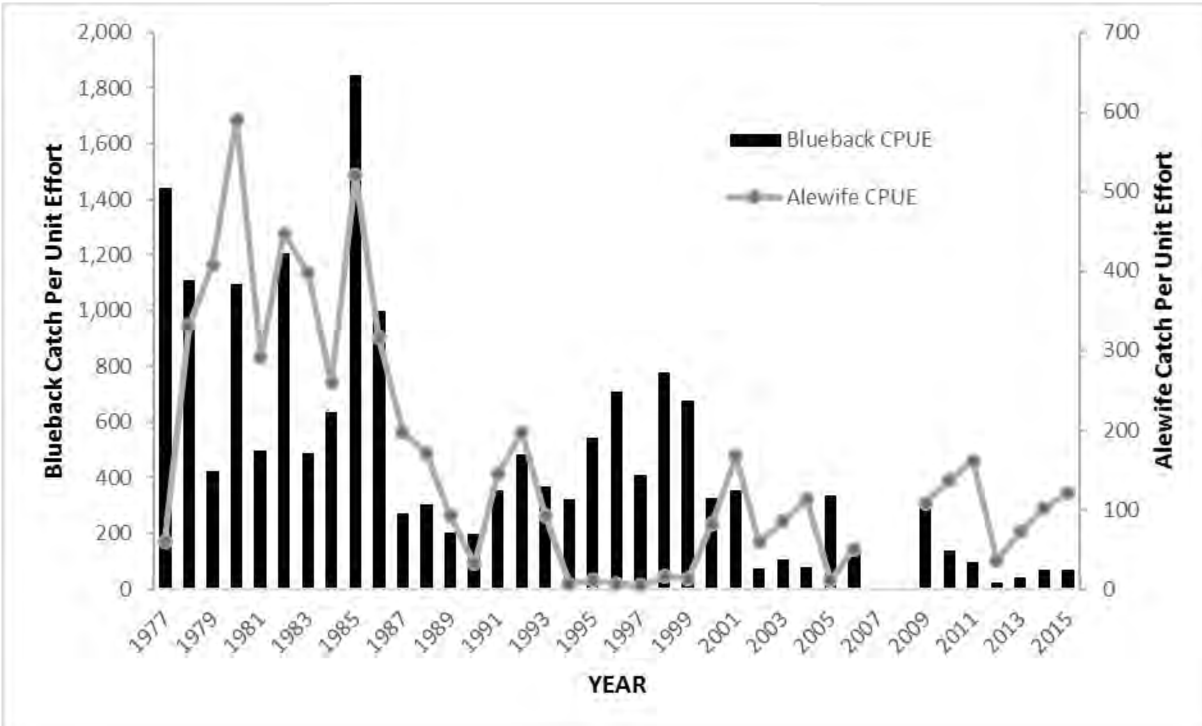
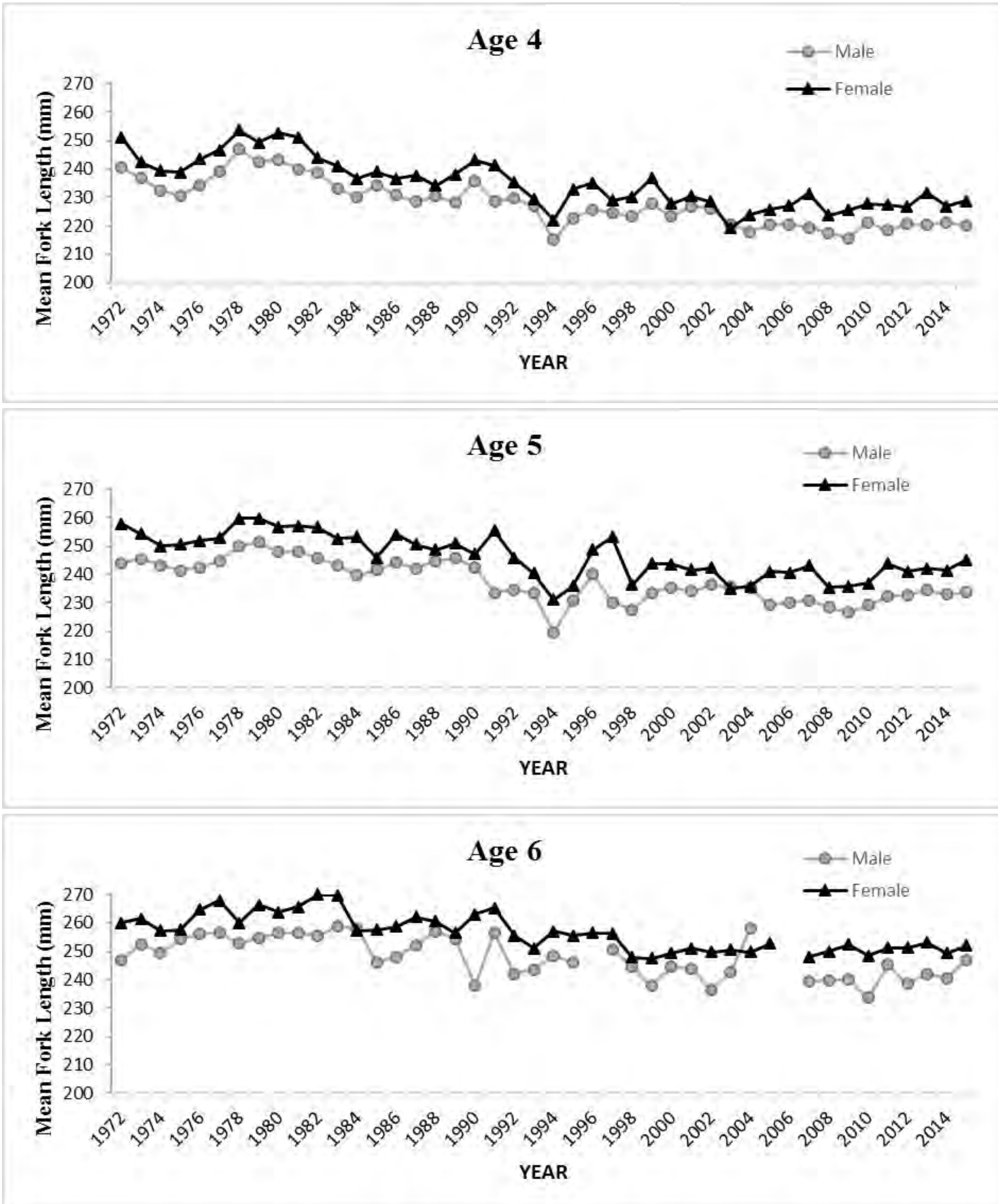


Figure 16.2 Catch per unit effort for blueback herring and alewife from the Chowan River commercial pound net fishery 1977-2015.



**2007 results based on samples collected from the research set aside harvest, April 4-7*

***2008-2015 results based on samples obtained from contracted pound net sets*

Figure 16.3 Mean length at age of blueback herring from the Chowan River pound net fishery, NC, 1972-2015.

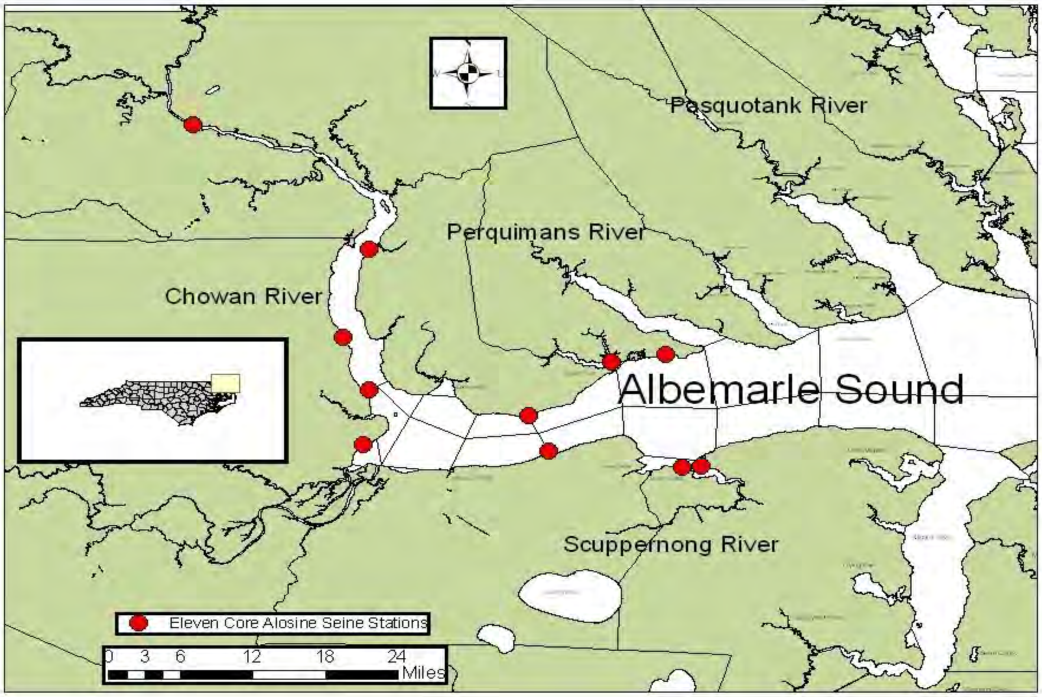


Figure 16.4 Alosine nursery area sampling sites in the Albemarle Sound area, NC 1972-2015.

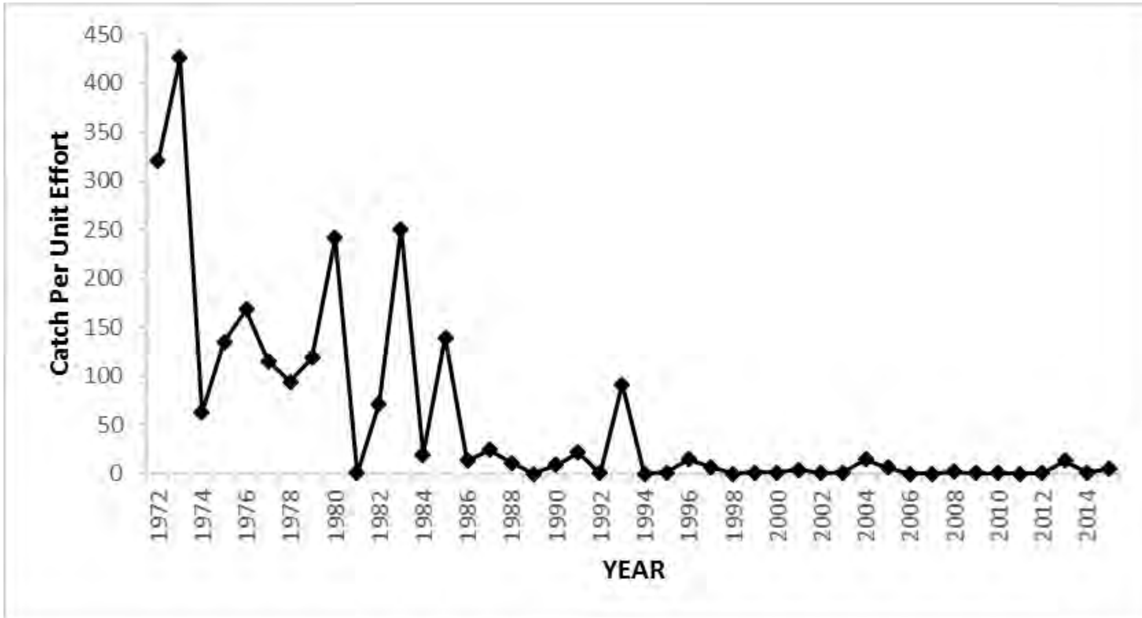


Figure 16.5 Juvenile blueback herring catch per unit effort from core seine stations, Albemarle Sound area, NC, 1972-2015.

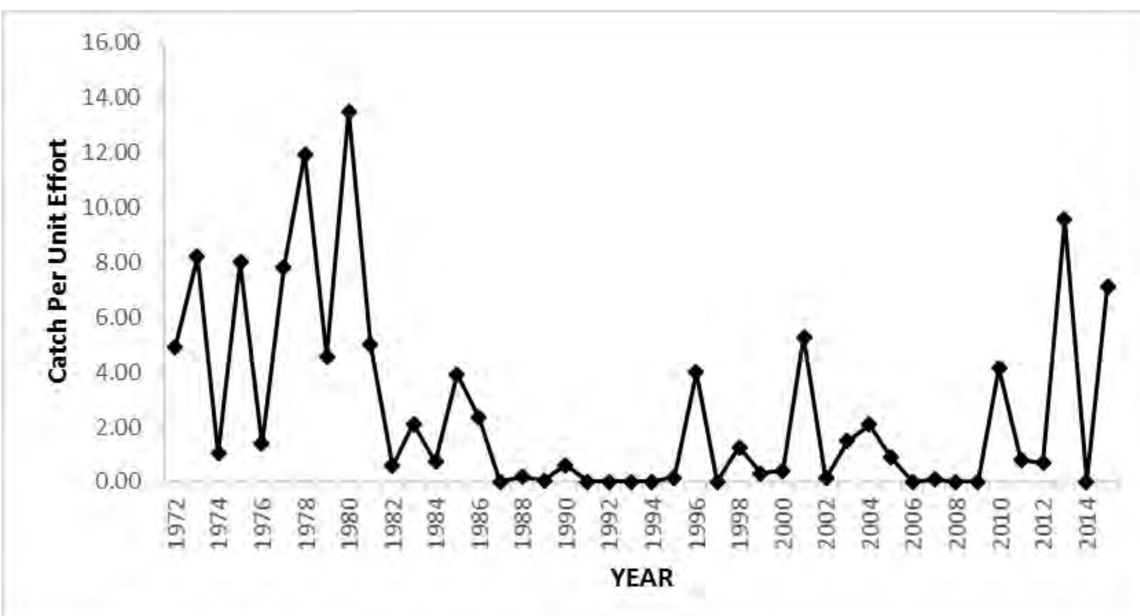


Figure 16.6 Juvenile alewife catch per unit effort from core seine stations, Albemarle Sound area, NC, 1972-2015.

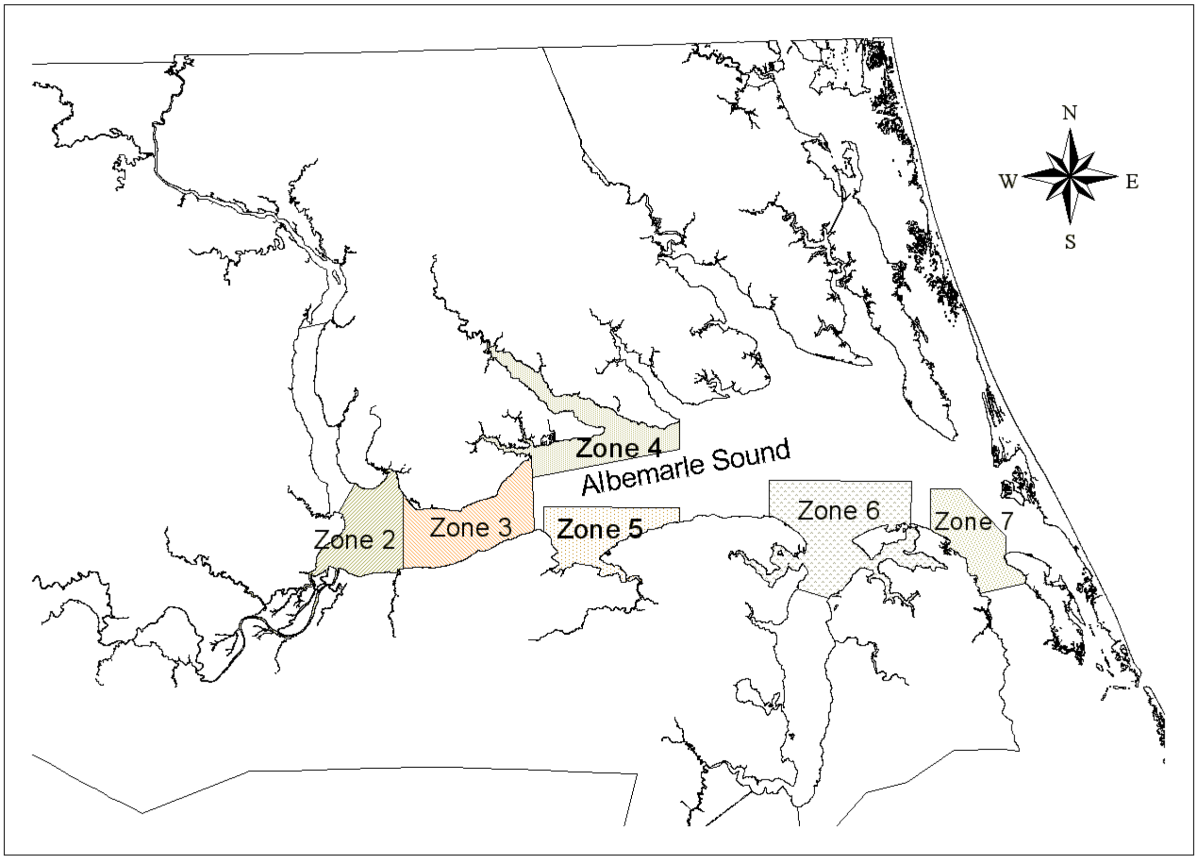


Figure 16.7 Location of sample zones for NCDMF independent gill net survey, Albemarle Sound area, 1990 – 2015.

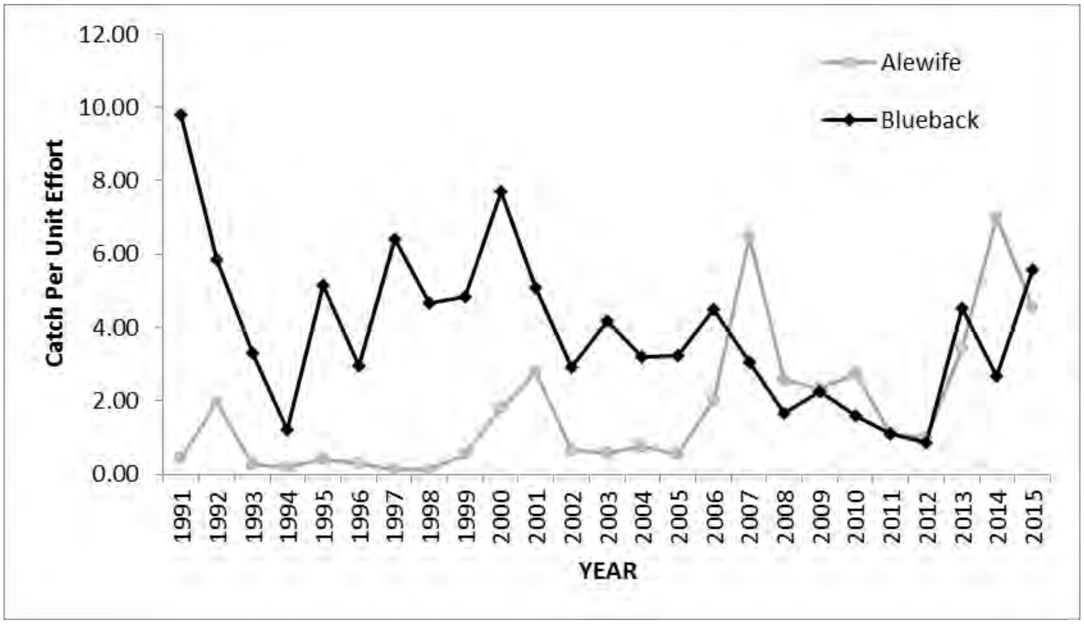


Figure 16.8 Catch per unit effort for alewife and blueback herring from the Albemarle Sound Independent Gill Net Survey, 2.5 and 3.0 ISM gill net, January-May, 1991-2015.

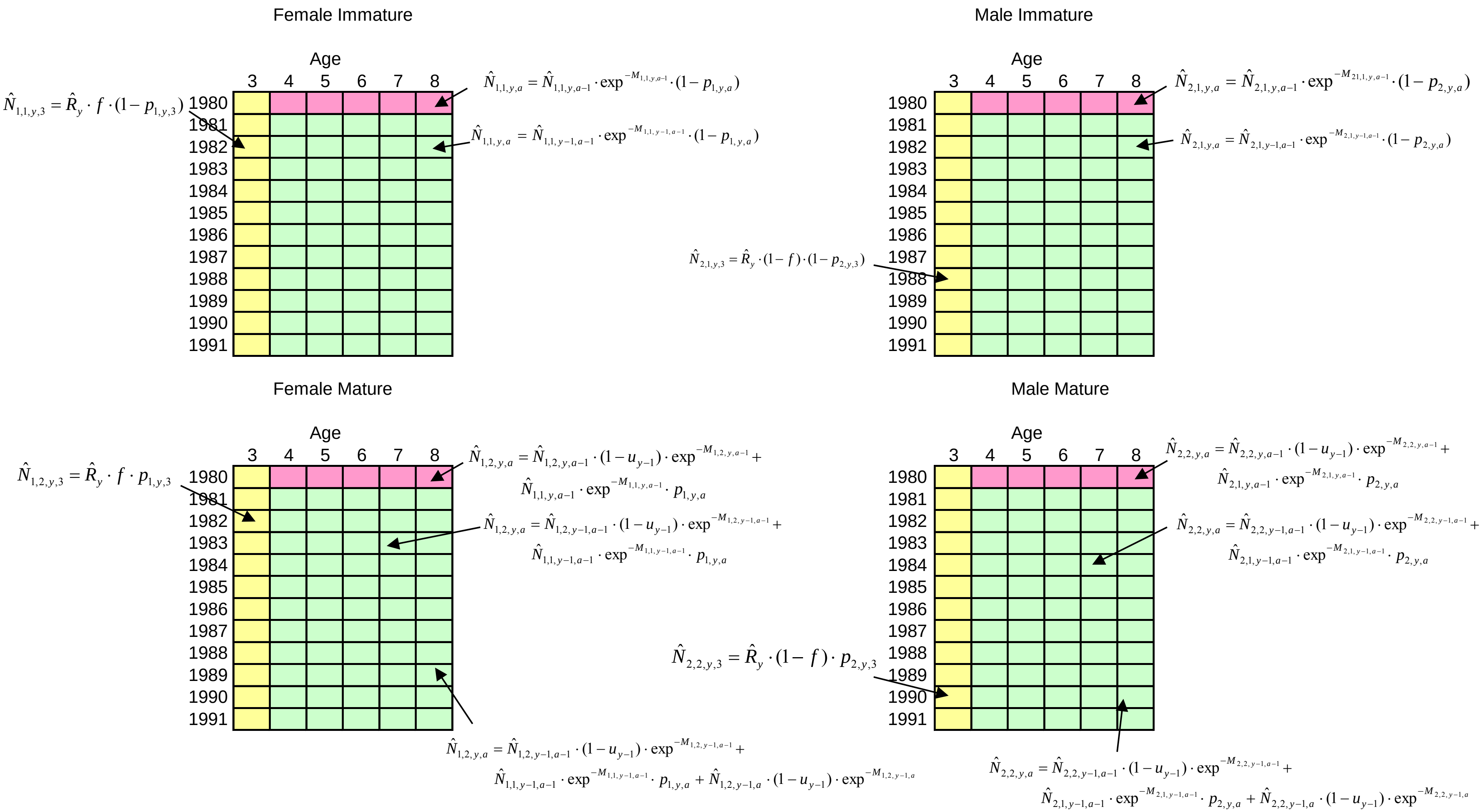


Figure 16.9 Diagram of blueback herring cohort population dynamics .

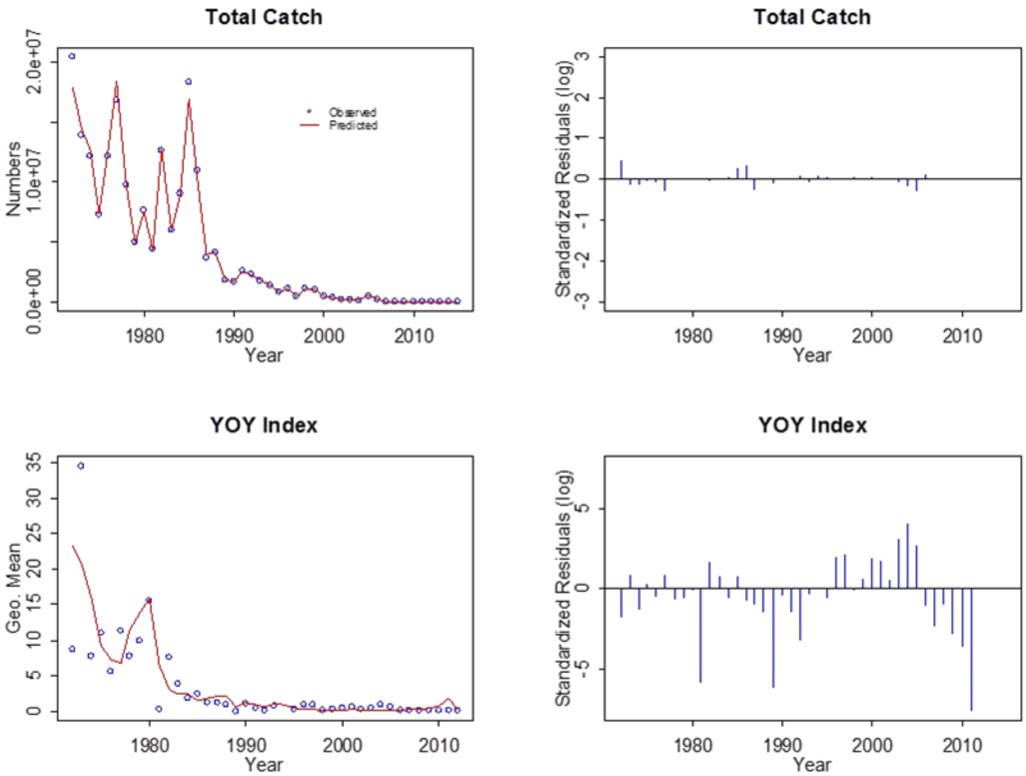


Figure 16.10 Comparison of total catch and YOY index observed and predicted values and standardized residuals for Chowan River blueback herring.

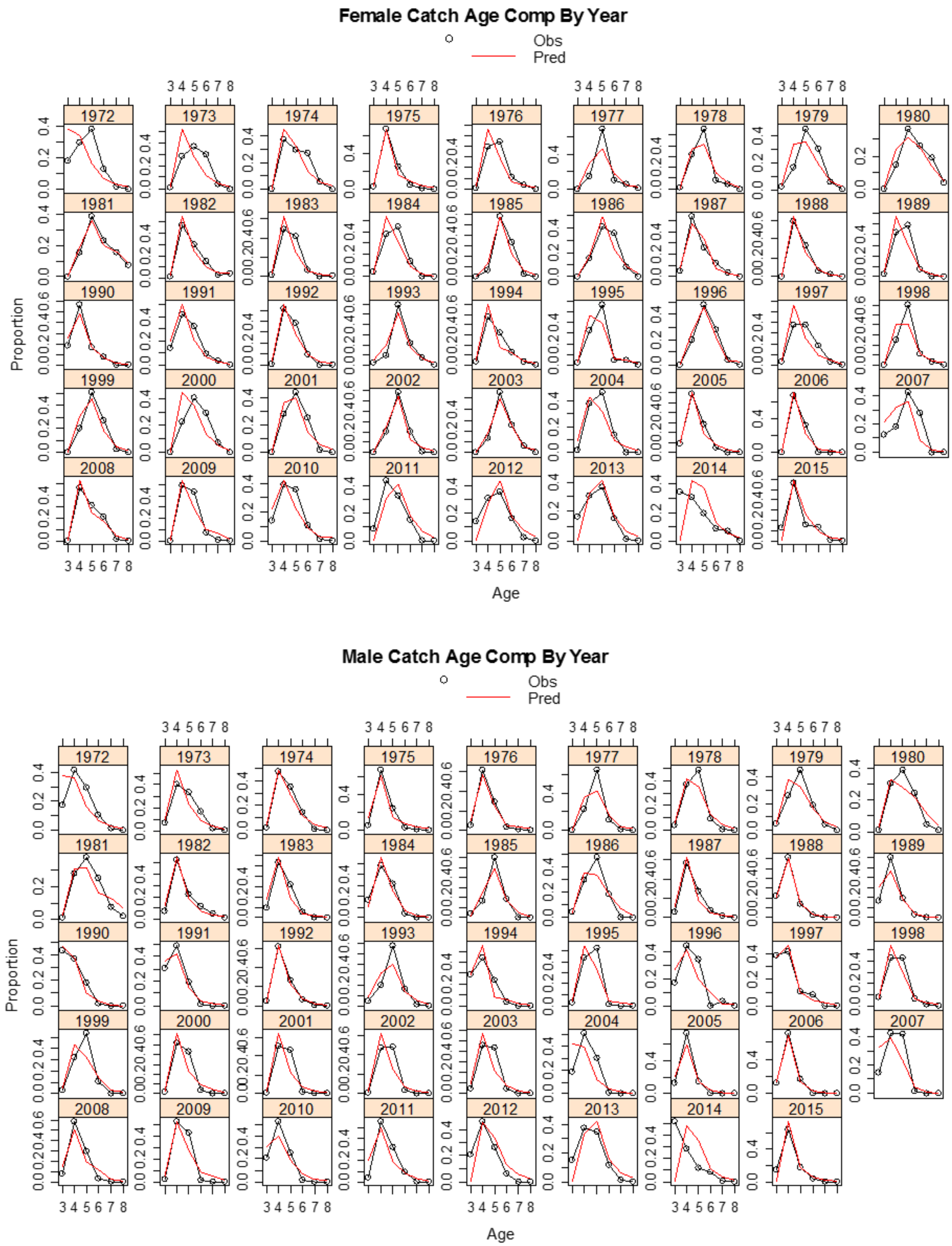


Figure 16.11 Observed and predicted catch age composition (proportions) for Chowan River blueback herring by sex, age, and year.

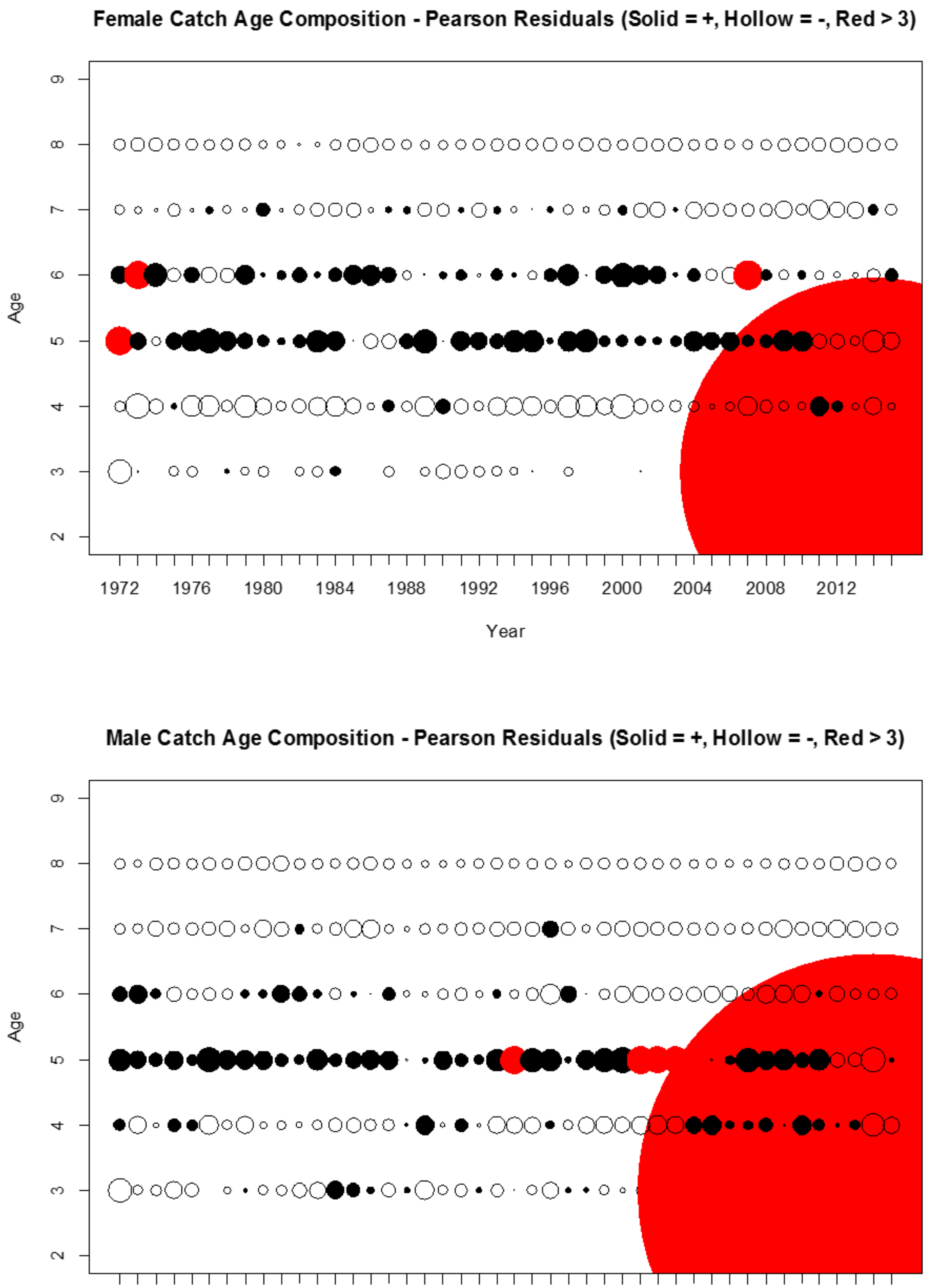


Figure 16.12 Bubble plots of standardized residuals of catch age composition by sex, year, age.

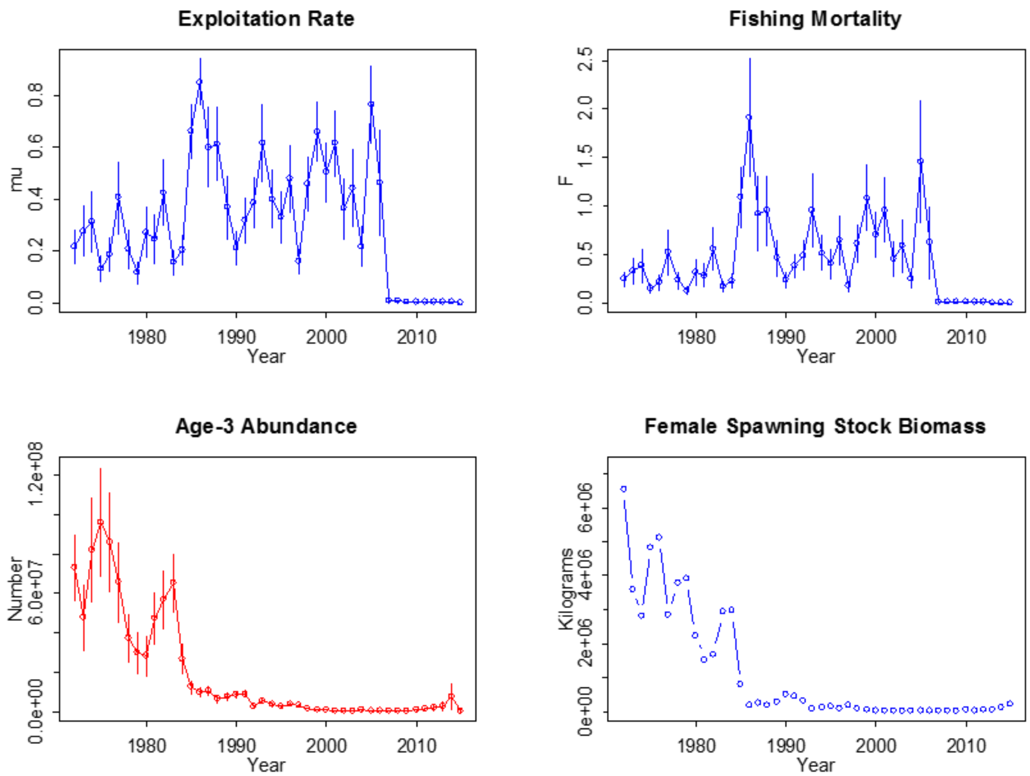


Figure 16.13 Estimates of exploitation rates, derived fishing mortality rates, recruitment (age-3 numbers), and estimates of female spawning stock biomass (in kilograms) for Chowan River blueback herring. Vertical lines, where present, represent 95% confidence intervals.

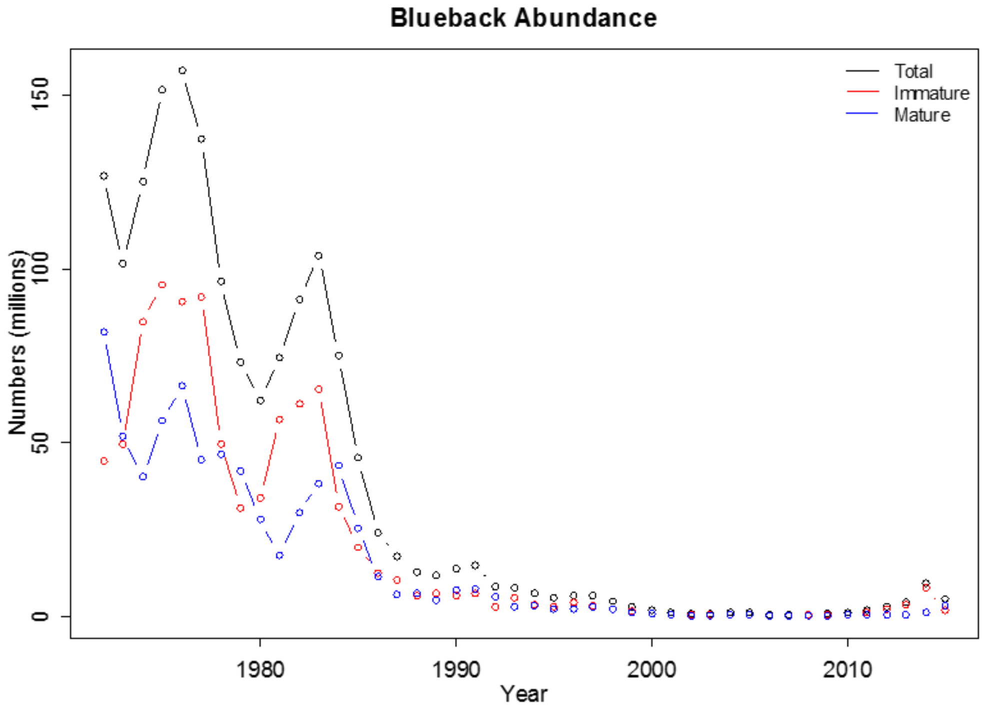
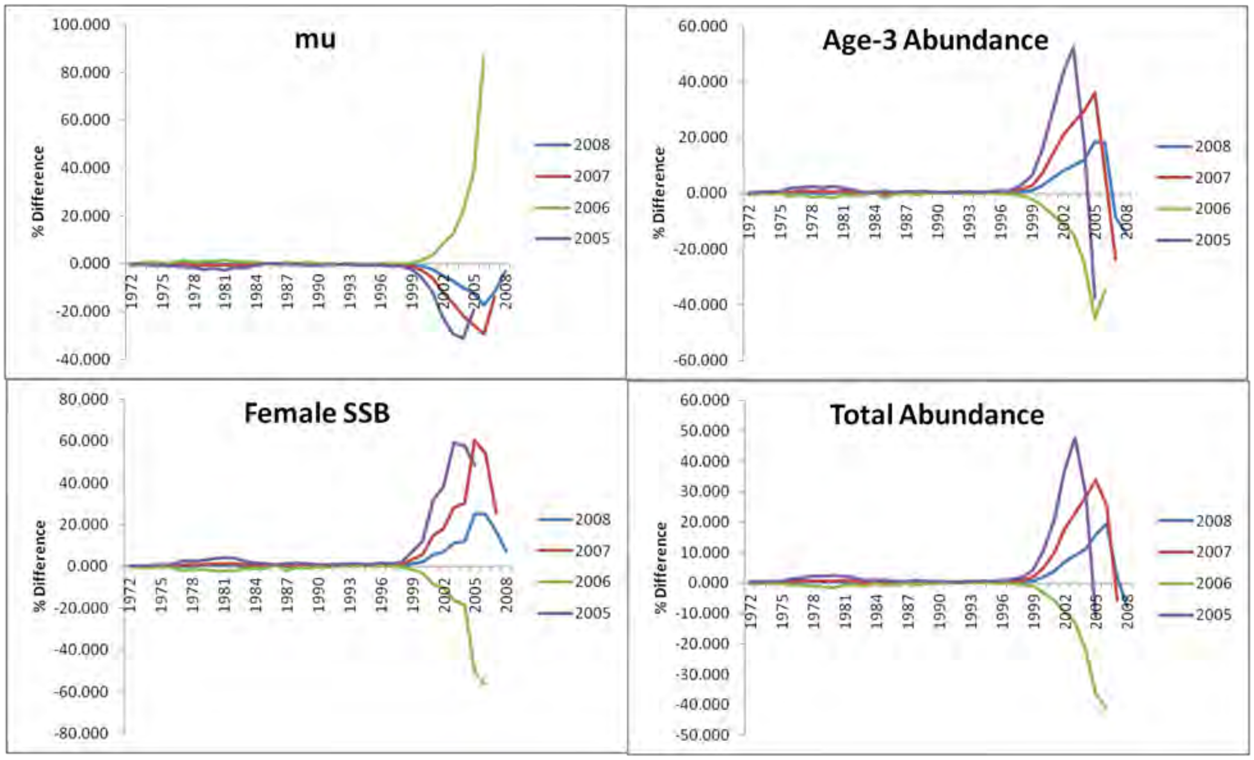
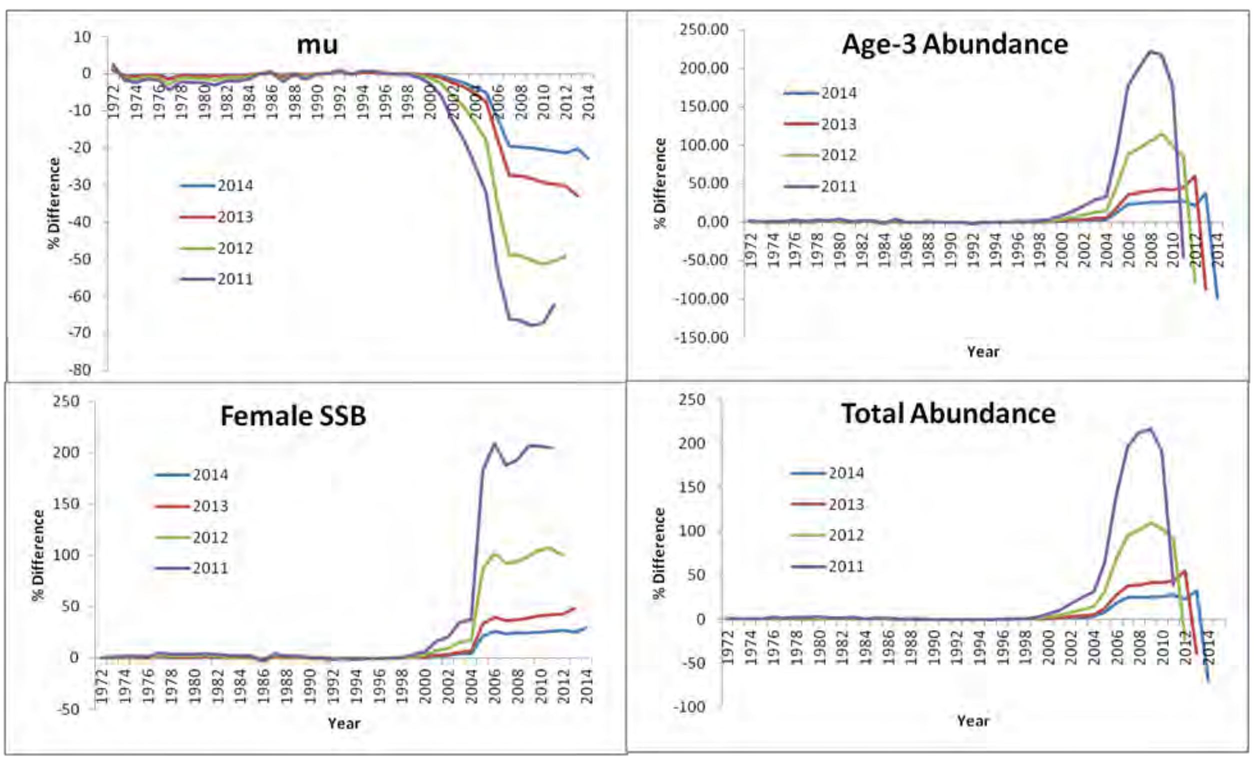


Figure 16.14 Population abundance (3+) estimates of the Chowan River blueback stock. Abundances are shown for immature and mature fish (sexes combined) and the total population.



A.



B.

Figure 16.15 Retrospective analyses for age-3 abundance, exploitation rate, female spawning stock biomass, and total population abundance.

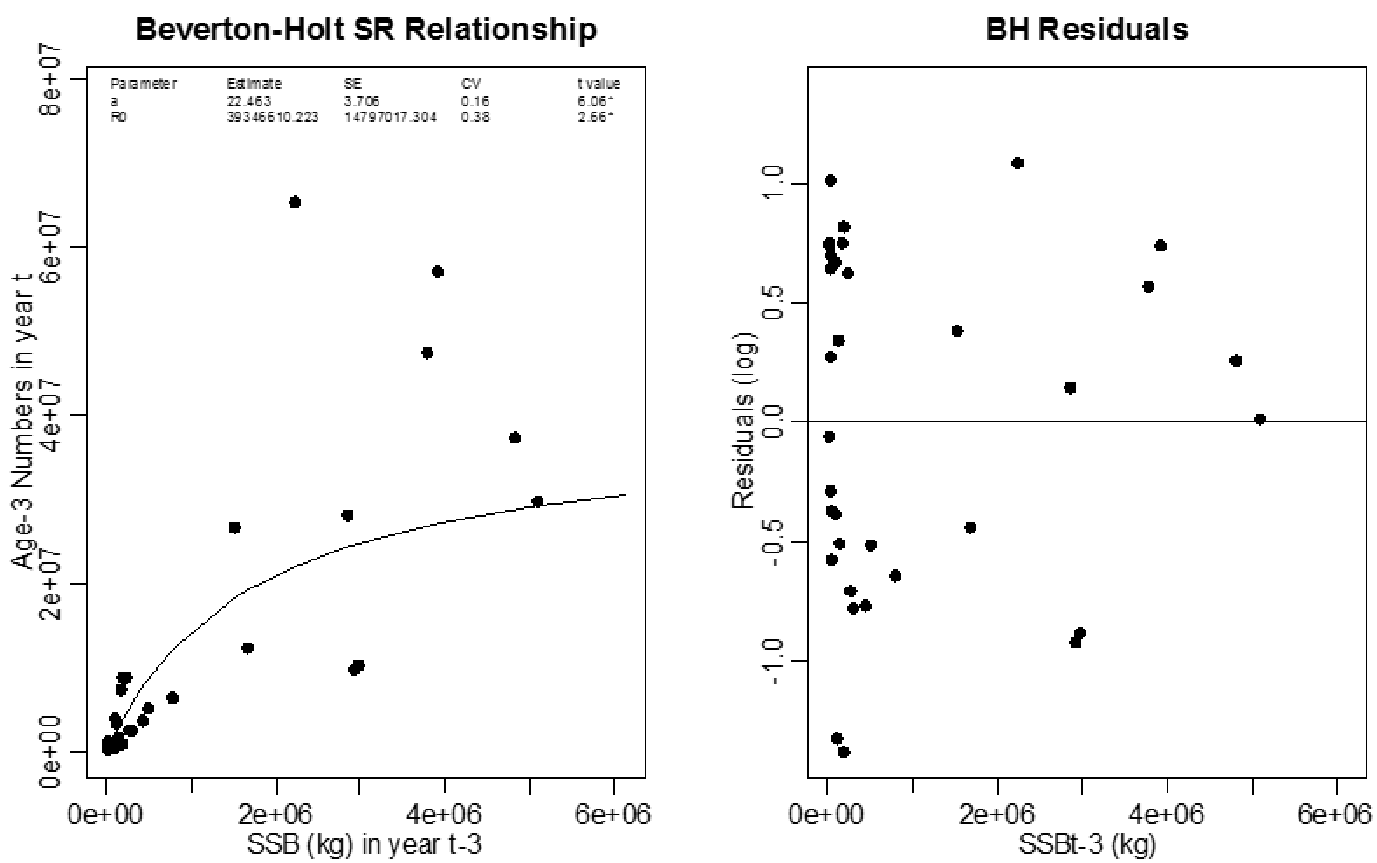


Figure 16.16 Fit of the Beverton-Holt stock-recruitment relationship to the age-3 abundance and female spawning stock biomass. Estimates of parameters *a* and R_0 from the Beverton-Holt equation are provided in the first graph, and residuals for the model fit are shown in the second graph.

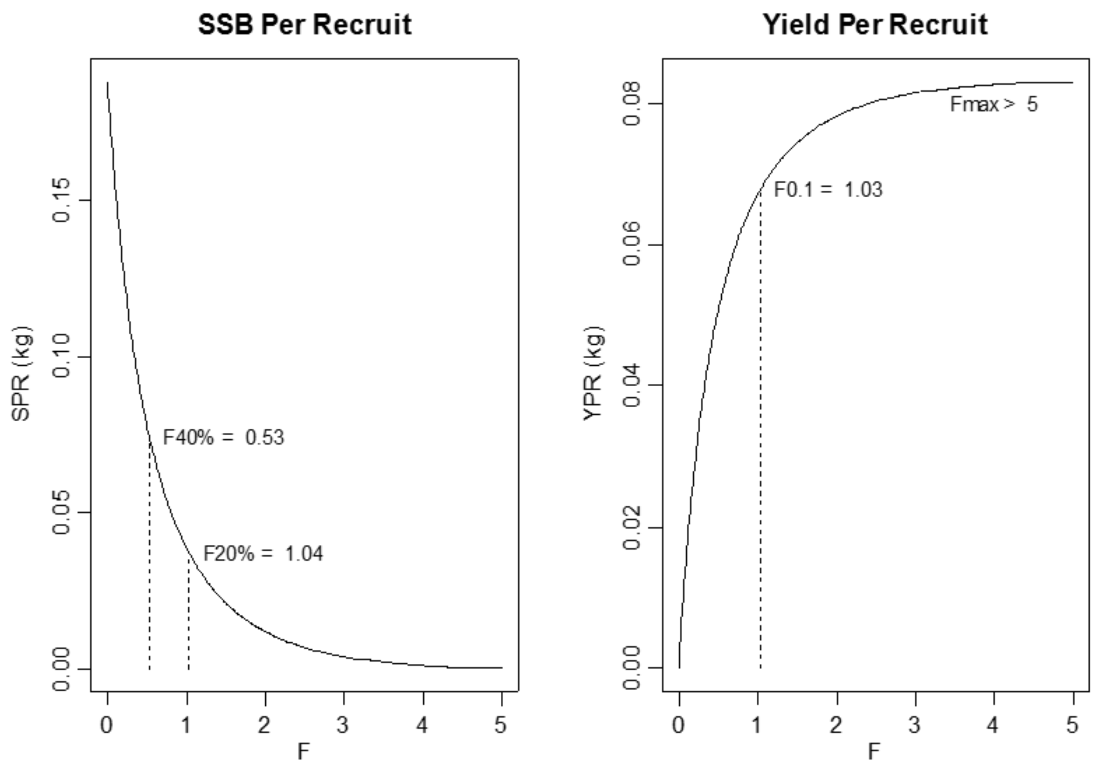


Figure 16.17 Results of spawning biomass per recruit and yield-per-recruit and analyses for the Chowan River blueback herring stock.

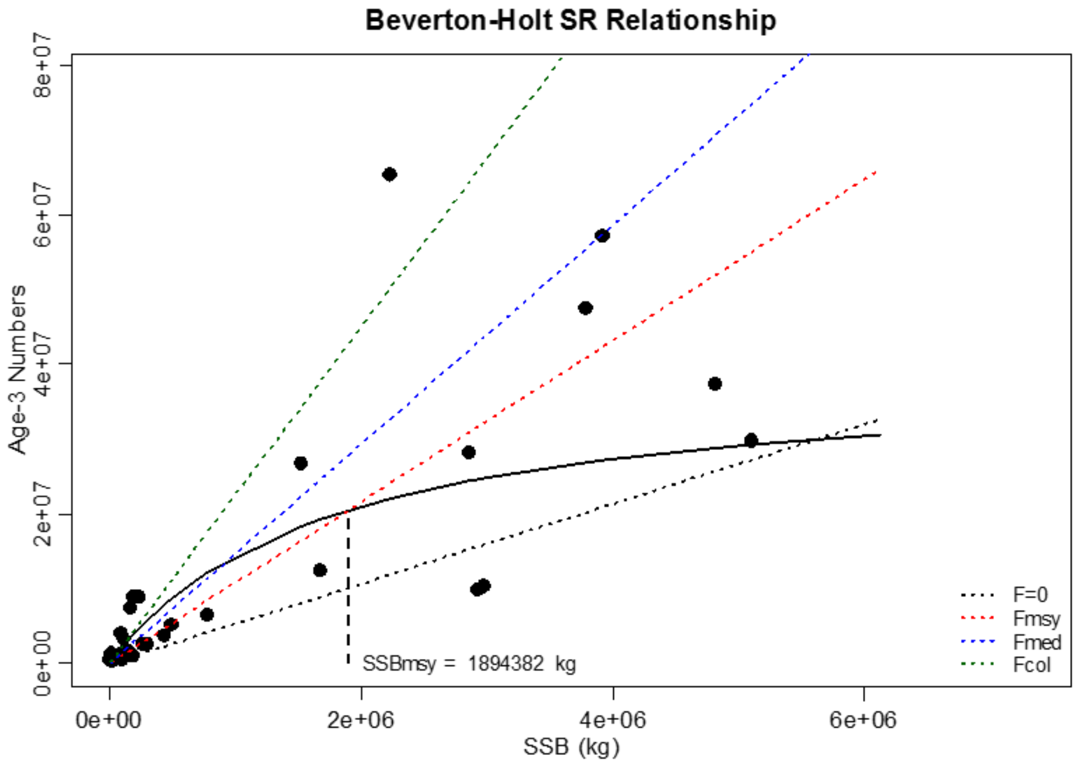


Figure 16.18 Beverton-Holt spawner-recruit model and production model reference points (see text) for the Chowan River blueback herring stock. Also shown is the replacement line in absence of fishing mortality (F=0).

Appendix Table 16.1. Estimates of proportion mature-at-age for female and male blueback herring in the Chowan river by year.

Female

Year	3	4	5	6	7	8
1972	0.440	0.809	0.979	1.000	1.000	1.000
1973	0.012	0.654	0.963	1.000	1.000	1.000
1974	0.000	0.766	0.961	1.000	1.000	1.000
1975	0.022	0.925	1.000	1.000	1.000	1.000
1976	0.016	0.748	1.000	1.000	1.000	1.000
1977	0.000	0.321	0.993	1.000	1.000	1.000
1978	0.010	0.525	0.990	1.000	1.000	1.000
1979	0.046	0.762	0.992	1.000	1.000	1.000
1980	0.009	0.431	0.950	0.995	1.000	1.000
1981	0.000	0.226	0.865	1.000	1.000	1.000
1982	0.010	0.654	1.000	1.000	1.000	1.000
1983	0.020	0.765	1.000	1.000	1.000	1.000
1984	0.042	0.684	1.000	1.000	1.000	1.000
1985	0.000	0.205	1.000	1.000	1.000	1.000
1986	0.000	0.322	0.978	1.000	1.000	1.000
1987	0.049	0.654	0.988	1.000	1.000	1.000
1988	0.000	0.768	1.000	1.000	1.000	1.000
1989	0.023	0.814	1.000	1.000	1.000	1.000
1990	0.191	0.910	1.000	1.000	1.000	1.000
1991	0.160	0.860	1.000	1.000	1.000	1.000
1992	0.056	0.710	1.000	1.000	1.000	1.000
1993	0.024	0.452	0.976	1.000	1.000	1.000
1994	0.032	0.613	1.000	1.000	1.000	1.000
1995	0.020	0.653	1.000	1.000	1.000	1.000
1996	0.000	0.300	0.980	1.000	1.000	1.000
1997	0.026	0.658	0.987	1.000	1.000	1.000
1998	0.000	0.539	0.991	1.000	1.000	1.000
1999	0.000	0.506	0.996	1.000	1.000	1.000
2000	0.000	0.622	0.961	1.000	1.000	1.000
2001	0.004	0.407	0.996	1.000	1.000	1.000
2002	0.000	0.305	1.000	1.000	1.000	1.000
2003	0.000	0.177	0.990	1.000	1.000	1.000
2004	0.042	0.632	1.000	1.000	1.000	1.000
2005	0.101	0.881	1.000	1.000	1.000	1.000
2006	0.000	0.855	1.000	1.000	1.000	1.000
2007	0.127	0.582	1.000	1.000	1.000	1.000
2008	0.000	0.672	0.981	1.000	1.000	1.000
2009	0.000	0.724	1.000	1.000	1.000	1.000
2010	0.150	0.793	1.000	1.000	1.000	1.000
2011	0.000	0.159	0.976	1.000	1.000	1.000
2012	0.000	0.216	0.966	1.000	1.000	1.000
2013	0.000	0.240	0.900	1.000	1.000	1.000
2014	0.000	0.378	0.919	1.000	1.000	1.000
2015	0.000	0.433	0.979	1.000	1.000	1.000

Male

Year	3	4	5	6	7	8
1972	0.419	0.869	0.996	1.000	1.000	1.000
1973	0.109	0.861	1.000	1.000	1.000	1.000
1974	0.019	0.897	1.000	1.000	1.000	1.000
1975	0.079	0.868	1.000	1.000	1.000	1.000
1976	0.076	0.856	1.000	1.000	1.000	1.000
1977	0.000	0.354	1.000	1.000	1.000	1.000
1978	0.063	0.627	0.984	1.000	1.000	1.000
1979	0.063	0.893	1.000	1.000	1.000	1.000
1980	0.023	0.630	0.977	1.000	1.000	1.000
1981	0.009	0.411	0.963	1.000	1.000	1.000
1982	0.071	0.764	1.000	1.000	1.000	1.000
1983	0.113	0.887	1.000	1.000	1.000	1.000
1984	0.163	0.801	1.000	1.000	1.000	1.000
1985	0.039	0.457	1.000	1.000	1.000	1.000
1986	0.046	0.713	0.991	1.000	1.000	1.000
1987	0.070	0.876	1.000	1.000	1.000	1.000
1988	0.245	0.945	1.000	1.000	1.000	1.000
1989	0.222	0.940	1.000	1.000	1.000	1.000
1990	0.464	0.982	1.000	1.000	1.000	1.000
1991	0.360	0.928	0.993	1.000	1.000	1.000
1992	0.097	0.968	0.995	1.000	1.000	1.000
1993	0.047	0.756	1.000	1.000	1.000	1.000
1994	0.327	0.923	1.000	1.000	1.000	1.000
1995	0.039	0.789	1.000	1.000	1.000	1.000
1996	0.190	0.914	1.000	1.000	1.000	1.000
1997	0.389	0.917	1.000	1.000	1.000	1.000
1998	0.104	0.797	0.990	1.000	1.000	1.000
1999	0.058	0.764	1.000	1.000	1.000	1.000
2000	0.023	0.957	1.000	1.000	1.000	1.000
2001	0.021	0.904	1.000	1.000	1.000	1.000
2002	0.022	0.934	1.000	1.000	1.000	1.000
2003	0.075	0.936	1.000	1.000	1.000	1.000
2004	0.299	0.965	1.000	1.000	1.000	1.000
2005	0.220	0.984	1.000	1.000	1.000	1.000
2006	0.170	0.936	1.000	1.000	1.000	1.000
2007	0.234	0.964	1.000	1.000	1.000	1.000
2008	0.081	0.719	0.990	1.000	1.000	1.000
2009	0.027	0.680	1.000	1.000	1.000	1.000
2010	0.238	0.852	1.000	1.000	1.000	1.000
2011	0.129	0.978	1.000	1.000	1.000	1.000
2012	0.000	0.383	1.000	1.000	1.000	1.000
2013	0.000	0.241	0.944	1.000	1.000	1.000
2014	0.000	0.474	1.000	1.000	1.000	1.000
2015	0.000	0.796	1.000	1.000	1.000	1.000

Appendix Table 16.2. Estimates of total catch (in numbers) of pound nets for blueback herring in the Chowan River used in the base model run.

Year	Numbers
1972	20,443,867
1973	13,918,880
1974	12,141,597
1975	7,286,423
1976	12,121,822
1977	16,831,692
1978	9,762,107
1979	4,921,229
1980	7,617,940
1981	4,360,204
1982	12,658,422
1983	5,955,402
1984	9,023,870
1985	18,364,344
1986	10,997,451
1987	3,664,782
1988	4,162,095
1989	1,772,115
1990	1,612,157
1991	2,545,614
1992	2,281,605
1993	1,763,114
1994	1,380,804
1995	814,048
1996	1,043,026
1997	468,830
1998	1,105,760
1999	948,791
2000	436,067
2001	363,260
2002	133,659
2003	143,201
2004	102,534
2005	447,376
2006	153,862
2007	1,325
2008	1,808
2009	970
2010	2,658
2011	2,125
2012	991
2013	1,051
2014	1,644
2015	10

Appendix Table 16.3. Number of Chowan River blueback samples from pound nets aged by sex, year, and age.

Female

Year	3	4	5	6	7	8
1972	25	42	54	18	2	0
1973	1	23	30	24	3	0
1974	0	29	23	21	4	0
1975	2	63	23	4	1	0
1976	1	49	55	14	4	0
1977	0	20	98	14	7	1
1978	1	31	55	8	4	0
1979	3	21	58	39	8	1
1980	0	32	80	57	41	8
1981	0	50	122	73	50	23
1982	1	49	31	15	3	4
1983	2	50	42	7	0	1
1984	4	36	42	13	0	0
1985	0	5	48	28	2	0
1986	0	14	37	32	7	0
1987	4	43	21	10	3	0
1988	0	48	27	5	2	0
1989	1	18	21	3	0	0
1990	16	51	15	7	0	0
1991	14	42	32	9	3	0
1992	1	55	41	10	0	0
1993	1	4	25	9	3	0
1994	1	15	10	4	1	0
1995	1	16	28	2	2	0
1996	0	10	24	14	2	0
1997	2	29	29	14	2	0
1998	0	131	321	60	17	0
1999	0	50	125	67	7	0
2000	0	58	102	74	19	1
2001	1	72	111	64	5	0
2002	0	29	82	29	1	0
2003	0	13	53	24	6	0
2004	2	36	44	13	0	0
2005	15	98	47	8	0	0
2006	0	37	18	0	0	0
2007	7	10	23	15	0	0
2008	0	148	98	66	5	0
2009	0	105	93	15	1	0
2010	30	83	76	22	2	0
2011	7	35	26	12	0	0
2012	12	27	31	14	2	0
2013	16	30	36	15	1	0
2014	25	22	14	6	5	0
2015	12	54	15	13	1	0

Male

Year	3	4	5	6	7	8
1972	46	112	78	28	3	0
1973	16	93	76	38	5	2
1974	3	74	55	22	1	0
1975	6	77	27	3	1	0
1976	12	147	69	7	1	0
1977	0	39	115	20	1	0
1978	5	47	62	11	1	0
1979	12	66	116	48	11	0
1980	2	66	85	53	9	2
1981	3	97	131	87	25	7
1982	10	74	31	16	7	2
1983	19	108	65	11	1	0
1984	23	68	44	6	0	0
1985	5	22	76	24	0	0
1986	5	32	51	20	0	0
1987	8	73	36	10	2	0
1988	36	99	23	4	1	0
1989	20	70	23	4	0	0
1990	48	41	20	2	0	0
1991	42	68	27	2	0	0
1992	9	116	49	12	1	0
1993	4	17	50	14	1	0
1994	15	23	12	2	0	0
1995	2	33	40	1	0	0
1996	10	26	20	0	2	0
1997	14	15	4	3	0	0
1998	30	163	163	23	6	0
1999	9	101	167	35	1	0
2000	15	383	316	24	1	0
2001	3	170	155	7	0	0
2002	2	86	87	6	0	0
2003	9	80	76	8	0	0
2004	27	73	43	1	0	0
2005	16	89	18	0	0	0
2006	12	66	16	0	0	0
2007	25	70	69	3	0	0
2008	49	358	181	20	0	0
2009	7	174	142	5	0	0
2010	123	310	149	6	0	0
2011	3	51	29	8	0	0
2012	20	44	25	6	0	0
2013	17	42	39	13	1	0
2014	65	35	15	10	1	0
2015	13	57	16	3	0	0

Appendix Table 16.4. Young-of-the-year blueback herring seine index by year. -1 = not used. The 1994 value was not used because the model could not reconcile zero YOY fish.

Year	Geo Mean
1972	8.63
1973	34.52
1974	7.70
1975	11.08
1976	5.52
1977	11.32
1978	7.76
1979	9.90
1980	15.57
1981	0.25
1982	7.58
1983	3.80
1984	1.75
1985	2.47
1986	1.16
1987	1.25
1988	0.95
1989	0.02
1990	0.99
1991	0.40
1992	0.10
1993	0.79
1994	-1.00
1995	0.29
1996	0.90
1997	0.81
1998	0.13
1999	0.18
2000	0.38
2001	0.58
2002	0.19
2003	0.36
2004	0.90
2005	0.56
2006	0.09
2007	0.06
2008	0.17
2009	0.10
2010	0.09
2011	0.03
2012	0.10
2013	0.72
2014	0.15
2015	0.56

Appendix Table 16.5. Female weights-at-age (kg). Color indicates that values were estimated from observed values from other years.

Year	3	4	5	6	7	8
1972	0.19	0.20	0.21	0.22	0.21	0.29
1973	0.15	0.19	0.21	0.24	0.27	0.29
1974	0.15	0.19	0.21	0.24	0.27	0.29
1975	0.15	0.19	0.21	0.24	0.27	0.29
1976	0.15	0.19	0.21	0.24	0.27	0.29
1977	0.15	0.19	0.21	0.24	0.27	0.29
1978	0.15	0.19	0.21	0.24	0.27	0.29
1979	0.15	0.19	0.21	0.24	0.27	0.29
1980	0.15	0.19	0.21	0.24	0.27	0.29
1981	0.15	0.20	0.23	0.26	0.26	0.29
1982	0.13	0.19	0.22	0.24	0.27	0.27
1983	0.14	0.18	0.22	0.26	0.27	0.32
1984	0.13	0.17	0.19	0.22	0.27	0.29
1985	0.13	0.17	0.18	0.21	0.23	0.29
1986	0.13	0.16	0.20	0.22	0.24	0.29
1987	0.13	0.16	0.19	0.21	0.25	0.29
1988	0.13	0.15	0.18	0.22	0.22	0.29
1989	0.14	0.17	0.21	0.24	0.27	0.29
1990	0.16	0.19	0.18	0.25	0.25	0.29
1991	0.13	0.16	0.22	0.24	0.33	0.29
1992	0.14	0.16	0.19	0.21	0.27	0.29
1993	0.10	0.15	0.17	0.17	0.22	0.29
1994	0.12	0.13	0.14	0.24	0.18	0.29
1995	0.12	0.15	0.16	0.20	0.30	0.29
1996	0.13	0.19	0.19	0.22	0.24	0.29
1997	0.11	0.16	0.25	0.25	0.33	0.29
1998	0.12	0.15	0.16	0.19	0.24	0.29
1999	0.13	0.16	0.18	0.17	0.20	0.29
2000	0.13	0.15	0.18	0.18	0.22	0.29
2001	0.12	0.16	0.19	0.23	0.27	0.29
2002	0.13	0.16	0.19	0.22	0.22	0.29
2003	0.13	0.12	0.17	0.19	0.18	0.29
2004	0.12	0.14	0.15	0.19	0.24	0.29
2005	0.12	0.14	0.17	0.19	0.24	0.29
2006	0.13	0.15	0.16	0.20	0.24	0.29
2007	0.14	0.18	0.19	0.22	0.24	0.29
2008	0.13	0.14	0.16	0.20	0.24	0.29
2009	0.13	0.14	0.16	0.20	0.24	0.29
2010	0.13	0.14	0.16	0.20	0.24	0.29
2011	0.14	0.18	0.19	0.20	0.24	0.29
2012	0.13	0.14	0.17	0.18	0.24	0.29
2013	0.17	0.18	0.19	0.19	0.24	0.29
2014	0.16	0.19	0.17	0.19	0.24	0.29
2015	0.14	0.15	0.18	0.20	0.24	0.29

17 Status of River Herring in South Carolina

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Executive Summary

Historically, river herring (blueback herring, *Alosa aestivalis,* and alewife, *Alosa pseudoharengus*) occurred in most of South Carolina's major rivers. In recent years, there has been no evidence of alewife in South Carolina and we believe that North Carolina has become the southernmost extent of their range. All available data show that river herring landings have declined from historic levels in South Carolina. Abundance of blueback herring in the Santee and Cooper Rivers has varied widely between rivers and among years. Changes in abundance appear to have resulted from a combination of habitat alteration from flow regulation and drought, and from fishing. Abundance of blueback herring in the Cooper River was reduced in the early 1970s from apparent over fishing and following the rediversion of water from the Cooper back to the Santee River and has remained low since the mid-1980s. Blueback herring abundance in the Santee River increased following rediversion and peaked at relatively high levels through the 1990s. Droughts throughout the 2000s were thought to have negatively impacted abundance, but since then abundance has returned to a relatively moderate level throughout the 2010s. It is unlikely that

fishing has affected stock abundance or age structure and we do not know if current abundance indices (CPUE, minimum population size) reflect moderate stock levels following a peak and precipitous decline or are just rebuilding stock levels following the droughts of the 2000s. Commercial harvest regulations should not be relaxed for the Santee-Cooper system. Harvest in the Cooper River and Rediversion Canal recreational fisheries appear to be minor since herring are not target species. However, we advise continuing the creel survey to monitor this fishery. As of January 1, 2012 the Santee-Cooper and Pee Dee Rivers are the only systems in South Carolina with an approved commercial and recreational sustainable fishing plan, as required under Amendment 2 to the ASMFC Shad & River Herring FMP.

17.1. INTRODUCTION

Historically, river herring (blueback herring, *Alosa aestivalis,* and alewife, *Alosa pseudoharengus*) occurred in most of South Carolina's major rivers (Figure 17.1). In recent years, there has been no evidence of alewife in South Carolina and we believe that North Carolina has become the southernmost extent of their range. Commercial fisheries for blueback herring in South Carolina occur to a limited extent in open rivers such as Winyah Bay tributaries, but most fishing activity occurs in hydro-electric tailraces of the Santee-Cooper River system. Recreational fisheries for blueback herring exist, but only as a bycatch to the American shad fishery. Data are available to assess trends in fishery and stock status of blueback herring for the following river systems and life stages in South Carolina: Cooper River, Santee River, and the Rediversion Canal for adult herring and Winyah Bay, Waccamaw River, Santee River, Cooper River, Edisto River, and Combahee River for juveniles.

17.2. MANAGEMENT UNIT

Management of blueback herring in South Carolina is shared between the Marine Resources and Freshwater Divisions of the Department of Natural Resources (SCDNR). Management units are defined by stock and the complex of river(s) utilized. Management units include all rivers and tributaries within each area complex: Winyah Bay (Sampit, Lynches, Pee Dee, Bull Creek, Black, and Waccamaw Rivers), the Santee-Cooper Rivers complex, the Savannah River and the ACE Basin (Ashepoo-Combahee-Edisto Rivers). Detailed descriptions of these units are in Section 17.6.

17.3. REGULATORY HISTORY

The SCDNR manages commercial herring fisheries using a combination of seasons, gear restrictions, and catch limits. In 1964, commercial blueback herring fishing in Cooper River was restricted to daylight hours with a dip net not more than three feet in diameter and a limit of 100 lb (45.4 kg) per man per day. By 1969, regulations had been liberalized to allow nets with six foot diameters, fishing until ten o'clock p.m., and no limit on the harvest. Between 1966 and 1969, herring were abundant and the fishery expanded. Fishing success declined in the early 1970s and a limit of 45.4 kg of herring per man day was reimposed in 1975. Today, the commercial fishery for blueback herring has a 10 bushel daily limit (227 kg) per boat in the Cooper and Santee Rivers and the Santee-Cooper Rediversion Canal and a 250 lb (113.4 kg) per boat limit in the Santee-Cooper lakes. Seasons generally span the spawning season. All licensed fishermen have been required to report their daily catch and effort to the SCDNR since 1998. Current regulations are summarized in the Appendix.

The recreational fishery has a 1 bushel (22.7 kg) fish aggregate daily creel for blueback herring in all rivers; however very few recreational anglers target blueback herring.

17.4. ASSESSMENT HISTORY

The first ASMFC assessment of the coast-wide river herring stocks occurred in 1990 (ASMFC 1990). South Carolina stocks were not included in this analysis.

17.5. STOCK SPECIFIC LIFE HISTORY

Blueback herring of South Carolina spawn in the spring in freshwater portions of coastal rivers and streams. The best life history information comes from of studies of blueback herring in the Santee-Cooper system in the central part of the state (Figure 17.4) prior to rediversion of Cooper River flows to the Santee River. Spawning in these systems occurred in Lakes Moultrie and Marian and below the Pinopolis Dam on the Cooper River and the Wilson Dam on the Santee River (Bulak and Curtis 1977). Spawning was concentrated between the Pinopolis Dam (km 143) and km 77 in the Cooper River and around km 60 on the Santee River. Limited spawning also occurred in the tributaries of the Santee and Cooper Rivers and in rice fields adjacent to the Cooper River. Use of these rice fields may have declined since rediversion and the resulting decline of Cooper River flows. Prior to rediversion, blueback herring spawned from March through early May in the Cooper River and February to April in the Santee River. Bulak and Curtis (1977) observed spawning in the Santee River at water temperatures of 12 to 20°C. River spawning below the Pinopolis and Wilson Dams was often disrupted by changes in dam discharge (Meador et al. 1984). Since rediversion, blueback herring have expanded spawning in the Santee River to the rediversion canal and spawning times in the two rivers have become more closely synchronized (Cooke and Leach 2000). Mature fish leave the spawning reaches shortly after spawning. Once in the ocean, blueback herring from the Santee River migrate widely along the Atlantic Coast. Tag returns from fish tagged in spring in the Santee River have been recaptured from as far north as the Bay of Fundy (Christie and Cooke 1987)

Meristic and enzyme studies by Christie and Cooke (1985) indicated that separate stocks of blueback herring were present in the Cooper and Santee Rivers prior to rediversion. However, the authors found evidence of straying between these two rivers and of fish from other South Carolina coastal rivers. It is likely that stocks in the Santee and Cooper rivers have mixed to a greater degree since completion of the rediversion project in 1985 and subsequent flow changes.

Young blueback herring are important forage in Lakes Moultrie and Marian (Bulak and Curtis 1978). Downriver movement of each year's juveniles starts in June and may continue through the following June (Cooke and Coale 1996). Downriver movement of adults that spawn above the dams and of young produced above the dams occurs through power turbines at all three dams, spillage over the Wilson Dam, or through the navigation locks at the Pinopolis Dam. In drought years, downriver passage declines as dam discharge declines.

Blueback herring in the Santee River are iteroparous and have been observed to spawn up to four times over their lifetime (Christie and Barwick 1984). Percent of repeat spawn has been observed as high as 31% for males and 33% for females. Male and female blueback herring can begin spawning as early as age two

(Table 17.1). However, full maturity of both sexes does not occur until age six. Males generally mature at a faster rate than females.

17.6. HABITAT DESCRIPTION

Blueback herring are present in tributaries of Winyah Bay, the Santee-Cooper system, and the Savannah River. Abundance is highest in the Winyah Bay tributaries and the Santee-Cooper system. Blueback herring are at low abundance or absent from the Edisto, Ashepoo, and Combahee Rivers.

South Carolina's Major Rivers

17.6.1. Winyah Bay System

Winyah Bay extends nearly 24 km inland and has six major tributaries that have spawning runs of anadromous fish (Sampit, Lynches, Pee Dee, Bull Creek, Black, and Waccamaw). The Sampit is a small, tidal river that is navigable to about km 64. The mouth of the Black River is near the junction of the Great Pee Dee River and upper Winyah Bay and it has approximately 40 km of navigable waters. The Pee Dee River estends well into North Carolina and it is dammed at Blewett Falls, North Carolina (320 km inland) (Post *et al*. 2004).The Little Pee Dee is the largest tributary of the Pee Dee River and it extends about 96 km to the North Carolina state line. Bull Creek and Lynches River are both tributaries of the Pee Dee River. The Lynches River is navigable for over 113 km from its confluence with the Pee Dee. Bull Creek extends 24 km and borders the Waccamaw River to the south and the Great Pee Dee to the north.

17.6.2. Santee-Cooper System

The Santee River, formed by the Wateree and Congaree Rivers, was historically one of the longest river systems on the Atlantic coast. At one time, it supported spawning runs of anadromous fish to Great Falls (km 438) on the Wateree River and up to river km 602 on the Congaree River (Walburg and Nichols 1967). In 1938, the South Carolina Public Service Authority (SCPSA) initiated a large diversion project to move water from the Santee River to the Cooper River. The project included the construction of the Wilson Dam for flood control on Santee River at km 143, which created Lake Marion and the construction of Pinopolis Dam at km 77 on the Cooper River, which is a hydroelectric facility with a navigation lock (Figure 17.4). Pinopolis Dam formed Lake Moultrie (Cooke and Leach 2003). Flows were diverted from Lake Marion on the Santee River to Lake Moultrie on the Cooper River and mean annual flows in the Santee River declined from 525 m^3 /s to 63 m^3 /s. When not in flood, the Santee River is a shallow, slow moving, meandering river that flows through hardwood swamps (Bulak and Curtis 1977). Discharge from the Pinnopolis Dam flows 29 km through a discharge canal to its confluence with the East Branch of the Cooper River. The Cooper River downriver of the confluence receives drainage from several swamps and tributaries and is adjacent to many abandoned rice fields.

Increased flows from the Santee-Cooper Diversion Project to the Cooper River led to shoaling in Charleston Harbor, due to increased sediment loads. Consequently, starting in 1985, water was rediverted through a 15 km Rediversion Canal from Lake Moultrie to the Santee River below Lake Marion. The St. Stephen Dam was constructed 7 km up the Rediversion Canal to control flow and to provide hydro power.

The Rediversion Canal diverted 75 percent of the Cooper River flow to the Santee River and increased the mean annual flow in the Santee River from 63 m^3 /s to 295 m^3 /s (Cooke and Leach 2003a). However, SCPSA has set a mean weekly discharge of 127 m^3 /s from the Pinopolis Dam on the Cooper River and when inflow to Lake Moultrie declines below that threshold flow to the Rediversion Canal declines. Discharge from the Wilson Dam on the Santee above the confluence with the Rediversion Canal was set at a continuous release of 14.6 m^3 /s. The result of this water management regime is that flow to the Santee River is greater from the Rediversion Canal than from Wilson Dam except on low flow years when flow through the Rediversion Canal is reduced. Data suggested that large numbers of blueback herring which utilized the Cooper River before rediversion, switched to Santee River after rediversion (Cooke and Coale 1996).

17.6.3. ACE Basin (Edisto River, Combahee River, and Ashepoo River)

The lower portions of these systems comprise the ACE (Ashepoo-Combahee-Edisto) Basin National Estuarine Research Reserve. The Edisto River drains approximately 4,800 km^2 within the South Carolina Coastal Plain. This river is approximately 320 km long and has no dams. At approximately km 180, the North and South Forks merge forming the Edisto River proper. Anadromous fish can reach at least 161 km in the North Edisto and at least 193 km in the South Edisto on their spawning migration (Walburg and Nichols 1967). The lower 75 km of this system is tidally influenced and the lower 50 km drains substantial areas of fresh, brackish and salt marsh. The Edisto, Combahee and Ashepoo Rivers are connected for 20 km before entering the Atlantic Ocean through St. Helena Sound. The Combahee River is a black-water river about 72 km long. The Salkehatchie and Little Salkehatchie are major tributaries. There are no impoundments on the Combahee River and anadromous fish reach could reach river km 137 near Walker, South Carolina (Walburg and Nichols 1967). The Ashepoo River is the smallest of the ACE Basin Rivers and it has no obstructions to anadromous fish migration.

Increased timber harvest in the 1980s may have affected the river herring population in the ACE Basin by increasing siltation of river spawning habitat (Chris Thomason, SCDNR, personal communication).

17.6.4. Savannah River

The Savannah River is approximately 560 km long. The first barrier to upstream migration is the New Savannah Bluff Lock and Dam (NSBLD) located at Augusta, Georgia (approximately km 301). The lock at NSBLD is designed for navigation and does not provide effective fish passage. However, fish can use the navigation lock and during high flow periods, the river rises above the NSBLD allowing some fish passage. There are 43 km between NSBLD and the next dam which is the J. Strom Thurmond Dam (Billy McCord, SCDNR, personal communication). Water quality may be a problem in the Savannah since the dissolved oxygen in the lower Savannah can fall below 1.0 ppm (Billy McCord, SCDNR, personal communication).

17.7. RESTORATION PROGRAMS

17.7.1. Restoration Objectives

The U.S. Fish and Wildlife Service, the National Marine Fisheries Service (NMFS) and SCDNR developed a fish restoration plan for the Santee-Cooper River basin with proposed restoration targets (USFWS 2001). River-specific goals were not established for other systems in South Carolina.

17.7.2. Hatchery Evaluations

Larval or adult river herring are not stocked in South Carolina Rivers.

17.7.3. Fish Passage Efficiency

17.7.3.1. Santee-Cooper System

Pinopolis Dam (Cooper River)

Upriver passage at the Pinopolis Dam occurs through a tailrace canal and navigation lock. Fish passage through the lock is measured by hydro-acoustic methods that estimate annual passage of fish biomass. However, fish species is generally not known and double counting may occur as fish congregate over the hydro-acoustic array. Therefore, we did not consider annual estimates of passage biomass to be good indicators of blueback herring abundance in this system. Downriver passage may occur through the navigation lock.

St. Stephen Dam (Rediversion Canal)

The St. Stephen fish lock is located approximately mid-way on the Santee-Cooper Rediversion Canal at river kilometer 92 (Figure 17.4). Migratory fish are attracted into the entrance of the fish lock by an attraction flow. Fish are forced into the lock chamber and the chamber is then flooded to head level. A brail basket prompts the fish to swim 15 -20 m up in the water column and releases the fish into the exit channel. There they pass viewing windows before continuing on to the upper Rediversion Canal and Santee-Cooper system. Generally, fish lock operations occur on the hour during daylight periods. Operations occur every 30 minutes when warranted by increased fish densities.

Passage efficiency at the St. Stephen Dam is unknown and likely varies among years. Poor passage efficiency was demonstrated by Cooke and Coale (1997), Cooke and Leach (2000), and Cooke and Leach (2002). Initially, high or intermittent discharges from the St. Stephen Dam on the Rediversion Canal prevented fish from entering the lock. In the 1990s, the SCPSA implemented a flow agreement to improve the fish-lock function, and a series of modifications were completed from 1995 through 2000 that may have increased the efficiency of the fish-lock. Annual variation in attraction flow, turbine discharge and water temperature in addition to fish abundance in the Rediversion Canal alter annual passage numbers of blueback herring at this facility.

The number of blueback herring that enter the Rediversion Canal from the Santee River varies among years depending on the relative flows in the Rediversion Canal and the Santee River above the canal. In moderate to high flow years, discharge of water from the St. Stephen Dam attracts fish into the Rediversion Canal. However, in low flow years when limited water is released from the St Stephen Dam, fish may bypass the Rediversion Canal and use the Santee River proper.

Fish moving downriver through the Rediversion Canal go through the turbines at the St. Stephen Dam. There have been no directed studies to determine turbine mortality on blueback herring at this facility, but it is believed that turbine strike mortality is minimal, with anecdotal information indicating that passage is more problematic for larger fish. Blueback herring appear to be more affected by pressure differential than by turbine strikes during their downstream migration at this facility (William McCord, SCDNR, pers. comm.).Above Lake Marion, several impediments to migration exist on Santee River tributaries.

17.7.3.2. Wilson Dam

There are no fish passage facilities on the Wilson Dam on the Santee River although downriver passage may occur over the spillway.

17.7.3.3. Savannah River

New Savannah Bluff Lock and Dam are located at rkm 301 of the Savannah River. The dam was constructed in the 1930s as a commercial navigation lock. Currently, fish passage is possible only at flows greater than 453 m^3/s when water levels above and below the dam are roughly equal. A navigation lock was used prior to 2015 for passage, however the lock is currently inoperable. When river flows do not reach 453 m^3/s there is no passage above the dam.

17.8. AGE

Scale samples were used to age blueback herring using methods of Cating (1953) and Marcy (1969). Scales were taken from the left side of each herring in the area below the dorsal fin and above the lateral line. Samples were cleaned in 2% potassium hydroxide and read under a microfiche reader at a magnification of 26 x. Scale ageing was done by two independent researchers and results were not accepted until concurrence was achieved on 75 % of the age estimates for a given days sample. From 1979 to 1985, a single group of readers read scale samples, and from 2013-2015 scales have been read by two readers. Maximum age that South Carolina herring stocks can attain is unknown.

17.9. FISHERY DESCRIPTION

17.9.1. Overview

Several commercial herring fisheries occur within South Carolina. Most of the herring landed in the State over the past several decades have been taken in cast and drop net fisheries immediately below Pinopolis Dam on the Cooper River and below St. Stephen Dam on the Santee Rediversion Canal. Landings were typically greater in the Cooper River prior to the completion of the canal in 1986 because flow was greater in the Cooper River. The fishery gradually shifted to the Rediversion Canal once the canal was completed. Exceptions occur during low flow or drought years when the hydroelectric facility at St. Stephen dam does not pass water, thus reducing the attraction flow needed for herring. In such years, herring tend to stay in the main channel of the Santee River, bypassing the Rediversion Canal and continuing to the Santee Dam. During those years, the fishery shifts to the Santee River below the Wilson Dam. A small fishery continues below the Pinopolis Dam on the Cooper River.

A haul seine fishery operated below Wilson Dam on the Santee River prior to completion of the Santee-Cooper Rediversion Project in 1985. However, increased water levels and flows have largely prevented the operation of this fishery since rediversion. A recreational bow net fishery also occurred below the Wilson Dam on the Santee River prior to 1985, but only a small percent of the landings occurred in this gear. Fisheries in the Santee-Cooper system target pre-spawning adult blueback herring. Catch from these fisheries is sold for both bait and for human consumption, particularly the roe.

A limited, more traditional gill-net fishery occurs in rivers of the Winyah Bay watershed. Take in these fisheries is presumed to be largely adult blueback herring and most landings are consumed locally by fishers or sold as bait.

Blueback herring are also caught in commercial fisheries of several South Carolina reservoirs. Cast and drop nets are the legal gears for these bait fisheries. Catches within the Santee-Cooper Lakes where passage is provided for adult blueback herring, hickory, and American shad may include a mixture of adults and juveniles of these and other clupeids such as threadfin shad and gizzard shad. The Savannah River impoundments are not equipped with fish passage devices, but blueback herring populations are dam-locked within these reservoirs as a result of forage-fish stockings taken from the Santee-Cooper Lakes. Catches in the Savannah River reservoirs are also likely a mixed bag, but would not include American or hickory shad. “Shad” and “herring” landed in above-dam areas are generally sold (or used personally) as live, or fresh dead, bait for striped bass, hybrid striped bass, or catfishes.

Hook & line and cast nets are the only legal recreational gears for herring in South Carolina. Currently, most of the recreational take occurs as bycatch to the American shad fishery in the Cooper, Santee (including the Rediversion Canal)., There is also some undetermined amount of directed effort for herring by fishermen using sabiki rigs to catch herring to consume or use as bait.

17.9.2. Fishery Data

Reported commercial landings data of river herring in South Carolina are available from the National Marine Fisheries Service and the state. Landings reported to the NMFS prior to 1979 were collected from major wholesale outlets located near the coast and probably did not account for inland landings which were generally not sold at these outlets. NMFS data collected since 1979 usually include inland landings. In 1998, the state of South Carolina instituted mandatory reporting of commercial catch and effort. However, questions regarding the integrity of the reports, accuracy of effort data, irregular or infrequent fishing by license holders, and year-to-year variability in river-wide records have hindered successful development of total catch and effort statistics by river from these data. The SCDNR is working to improve the scope and reliability of licensee data. The wholesale dealer reporting system utilized by the NMFS may not include herring landings because herring sold as bait to licensed bait dealers may not be reported.

In 1969, the South Carolina Department of Natural Resources instituted a commercial creel survey to estimate catch and effort in the fisheries in the Santee Cooper system. Surveys occured at landings used to off-load and transport catch. The majority of herring harvested from the Cooper River (1969-1989) were landed at two locations between the hours of six p.m. and ten p.m. daily. Creel clerks stationed at these locations interviewed individual fishermen as the catch was unloaded. The time, date, type of gear used, catch, and number of fishermen aboard were recorded as each boat landed. The survey was expanded to the major landing below the St. Stephen Dam on the Rediversion Canal starting in 1990 as fish abundance declined in the Cooper River and increased in the Santee River and the Rediversion Canal. During low flow years, herring and the fishery move to the Santee River below the Wilson Dam. Surveys have been infrequent at that location. Weight of harvest was estimated from the number of bushels of herring landed and a mean bushel weight of 25.4 kg (Cooke 1998). Numbers of adult blueback herring landed were estimated by dividing kg landed by the mean weight of an adult herring (0.14 kg). Although some landings are occasionally missed during the creel survey, the survey produces the most reliable estimates of catch and effort available for South Carolina waters. Landings were not estimated for reservoir fisheries with landings of mixed species and size composition.

SCDNR has conducted an annual recreational creel survey since 2001 to estimate exploitation and catch-per-effort in the recreational American Shad fishery of the Santee Cooper system. These data consist of access point creel surveys (at end of a party's fishing day) for at least 2 h/d, 4 d/week along with effort estimates made by counting boats below the Pinopolis Dam, the Wilson Dam, or the Rediversion Canal at approximately 1400h each day of survey. Previous data demonstrated that a 1400h boat count measures maximum daily fishing pressure. This does not account for angler turnover, particularly of anglers that fish in the morning only. Also, while the majority of the season is surveyed, some fishing activity occurs prior to and after the study period, so results presented here are underestimated.

SCDNR also conducted sportfishing creel surveys on the Cooper and Santee Rivers in 1981 - 1982 and 1991 - 1993 to evaluate the impact of the Rediversion Canal on these recreational fisheries (Cook and Chappelear 1994). These surveys examined the total recreational fisheries on each river, but did not provide data on catch of blueback herring. Thus, the surveys could only be used to indicate change in the size of the fishery.

Recreational creel surveys were conducted on the Savannah River in the late 1990s by the Georgia Department of Natural Resources in 1997 and SCDNR in1998 and 1999. Estimates of catch from these surveys varied from year to year largely due to dramatically different flow conditions. Catch estimates from each of these creel surveys were provided in Boltin (1999).

17.9.3. Fishery Dependent Data - Commercial

Reported Landings

Over 1,000,000 kg of river herring were reported from South Carolina commercial fisheries in 1969 (Table 17.2 and Figure 17.5). Landings declined precipitously soon after. They rebounded to a high of approximately 180,000 kg in the early 1980s and have maintained an average of 89,000 kg (1980-2015). The bulk of the reported landings since 1989 have come from the Santee-Cooper system (Table 17.3). Reported landings for the Pee Dee River of the Winyah Bay system are a small fraction of the total South Carolina reported landings, annually averaging 524 kg (range 1 - 3,192 kg) from 1998-2015 (

Table 17.4).

Annual variation in reported landings since the early 1970s may have been influenced by changes in allowable catch over the years. Landings in the Santee Cooper system were also affected by changes in discharge from the three dams and concurrent changes in fish migration and gear effectiveness.

Estimated Effort, Harvest, and Catch Rates

Annual estimates of catch in kg, effort in man days, and kg catch/man day (CPUE) are available since 1969 from surveys of the Santee-Cooper fishery (Table 17.5, Figure 17.6). Estimates of all three parameters have fluctuated widely over the time series. Highest estimates of landings and CPUE occurred early in the time series in the Cooper River. Estimates of effort, landings, and CPUE in the Cooper River declined dramatically soon after to a low that lasted through the late 1970s. Estimates climbed again through the early 1980s and then declined as the Rediversion Canal was completed and flows shifted to the Rediversion Canal and the Santee River. Estimates of effort, landings, and CPUE then increased in the Rediversion Canal and the Santee River. Effort and fishing success fluctuated throughout the 2000s due to water availability.

Many factors likely affected effort and landings. To evaluate potential causes of change, we separated data from the Cooper River into two times series (1969 - 1974 and 1975 – 2015) and subset data for the Santee River to those from 1990 – 202015. We then normalized the estimates by dividing annual values by the series mean (Figure 17.5). Sub setting the Cooper River data reduced the influence of the relatively large estimates obtained early in the time series on the rest of the data. Normalizing the time series placed all of the parameters on a comparable scale. Effort and landings were highly correlated in both the Cooper River fisheries (1969-1974, r^2=0.85; 1975-2015, r^2=0.81) and the Santee River fisheries (1990-2015, r^2=0.91) (Figure 17.8). Apparently, effort played an important role in dictating landings. However, CPUE was also related to effort (Figure 17.5). If we assume that CPUE was a measure of relative stock abundance, then we can speculate that changes in stock abundance and related fishing success led to changes in effort and then in landings.

The variation in CPUE among years suggests that several cycles in blueback herring abundance occurred in the Santee Cooper System (Figure 17.6 and Figure 17.5). The dramatic CPUE decline in the first six years of the Cooper River time series may have been caused by overfishing. Following the imposition of harvest restrictions in 1975, CPUE bottomed out and remained at low levels for four years before rebounding through the early 1980s. Cooper River CPUE declined again following completion of the Rediversion Canal in 1985 and it has remained at relatively low levels since 1987. It is likely that reduced flows in the Cooper River led to degradation of spawning and nursery habitat in the river below the Pinopolis Dam and reduced access to flooded rice fields that had been previously used for spawning.

CPUE in the Santee River fishery increased rapidly following increased flows from rediversion. CPUE leveled off in the mid to late 1990s, fluctuated significantly from 2001-2008 in relation to below normal stream flow levels, and stabilized at an above average level from 2009-2015. The initial CPUE increase in the Santee River fishery likely resulted from a combination of herring from the Cooper River stock that began to migrate into the Santee River as flow increased and improved production from improved spawning and nursery habitat. Stock increase was enhanced by regulations that prevented harvest from the Rediversion Canal from 1985 through 1989. Reduced CPUEs in 2001, 2002, 2004, 2006, and 2008 were related to low fishing success caused by low water levels. It is unknown if stock levels were reduced during the same time frame; however, CPUEs stabilized after the drought and have been trending slightly above average for 2009-2015.

It is interesting to note that the CPUE of the Cooper River fishery during the peak years of 1979 through 1986 (135.2) exceeded estimates obtained for the Santee River fishery during its peak years of 1992 through 2001 (102.9). Highest CPUE on the Cooper River since 1975 was 163.3 in 1983 just before rediversion. Highest CPUE on the Santee-Cooper Rediversion Canal was 137.2 in 1998 some 13 years after rediversion. It is not yet known if habitat in the Santee system will support greater numbers of blueback herring than did the Cooper River prior to rediversion. The highest CPUE of the time series (607.5) occurred in the Cooper River in 1969.

CPUE in the Santee-Cooper commercial fisheries may have been affected by changes in harvest regulations. However, affects must have been minor because in many cases the low estimates of catch per man day were well below the minimum daily catch at the time. For example, the fishery went from one with no take limits in the early 1970s to one with a daily maximum take limit of 45.4 kg (100 lbs) per person in 1975. CPUE dropped from a high of 608 kg per fisherman day in 1969 to 55 kg in 1974 and then dropped to and remained at less than 35 kg through 1978. If the daily cap had been the cause of decline, then one would expect the CPUE to drop too and remain at the cap as soon as it was imposed. Since this did not occur, it is more likely that much of the change in CPUE was caused by concomitant changes in herring abundance.

Information on the number of fish harvested in the Santee River Diversion Canal is collected in two ways. Fisherman report their monthly catch via a mandatory reporting system and nightly creel surveys are conducted (March 1-April 30) at the single access point to the fishery where all harvested blueback herring are landed. Information from these two sources was nearly identical from 1998-2015, with the exception of 2005, 2009, and 2010 (Figure 17.7). This discrepancy has not been rectified, however the creel surveys provide more accurate information, and the harvest from 2009 and 2010 is better represented by creel data.

Bycatch

River herring occur as bycatch in fisheries along the Atlantic coast from North Carolina up to the Gulf of Maine. Since blueback herring from South Carolina migrate through this reach of ocean, it is likely that South Carolina fish are included. River herring bycatch in the Atlantic herring and mackerel fishery in the New York Bight and Gulf of Maine is of concern. Results of analysis suggest that bycatch of river herring in the Atlantic herring fishery can be equal to, or exceed the total of all in-river landings (ASMFC 2008, Cieri et al 2008).

Size and Age Distribution

Mean fork length of blueback herring taken in the commercial fishery in the Santee Rediversion Canal fluctuates annually but has remained relatively stable (Table 17.6 and Figure 17.8). From 1995-2001, mean lengths of harvested herring of both sexes were nearly identical; since that time, 2002-2015, harvested females have averaged 15 mm larger than harvested males. Beginning in 2013, blueback herring scales were used to estimate ages of harvested herring in the commercial fishery (Table 17.7). Fish from ages 4-7 were collected and ~30% were repeat spawners (Table 17.8).

17.9.4. Fishery Dependent Data - Recreational

Catch per unit effort of blueback herring in the recreational fishery varied without trend from 2003 through 2007 (Table 17.9). Blueback herring are not targeted in the recreational fishery and are most often not harvested. Therefore CPUE is based on the number of blueback herring the angler remembered catching and releasing and this number was often guessed by the angler. The data was not a reliable source of information and is no longer reported.

17.10. FISHERY INDEPENDENT SURVEYS

A variety of sampling efforts have been conducted to assess the condition of blueback herring stocks in South Carolina. Annual passage counts at St. Stephen Dam on the Santee-Cooper Rediversion Canal and the Pinopolis Dam on the Cooper River provide the longest times series of data. Periodic electrofishing and gill net sampling occurred in the Santee River below the Wilson Dam and population estimates were obtained for several years at that location. In addition, annual electrofishing for juvenile herring has been conducted in Winyah Bay and the Santee, Cooper, Edisto, and Combahee Rivers. Ichthyoplankton surveys were made for several years on the Santee and Cooper Rivers. The following summarizes results of the more useful surveys.

17.11. ASSESSMENT APPROACHES AND RESULTS

17.11.1. Adult Surveys

Santee River Population Estimates

Mark recapture population estimates of blueback herring were conducted in the Santee River from 1977 through 1990. During the first two years, researchers attempted to tag immigrating fish in the lower river and recapture the tagged fish upriver of the tagging sites. Researchers used seines, fyke nets, pound nets, and electrofishing to capture fish, but failed to obtain adequate numbers of fish for valid population estimates (Christie and Cooke 1987). Moreover, fish tagged in the lower reaches of the river often moved downriver and out of the system (Christie and Cooke 1986). Starting in 1979, fish for tagging were collected by electrofishing below Wilson Dam. Additional fish for tagging were obtained from the Cooper River and once the rediversion system was in place, from the Rediversion Canal. Number of marked fish was decremented by 10% to account for handling mortality and tag loss for fish caught by electrofishing and by 20% for fish caught in the St. Stephen fish lift. Results were further discounted by estimates of the number of tagged fish that went upstream through the St. Stephen fish lift rather than spawning below the dam and then emigrating downriver. Recaptures were obtained by gill netting downriver of the tagging site in the Santee River. To insure that only the tagged population was included in the recapture effort, only fish moving downriver (from the upriver side of the net) were counted in recapture collections. Valid recaptures were those captured between three days after tagging began through 10 days after tagging ended.

Estimates were calculated by Chapman's non-stratified modification of the Peterson formula (Ricker 1975):

$$N = ((M+1)*(C+1)/(R+1))-1$$

Where:

M = number of marked herring tagged and released decremented by the appropriate factor for handling mortality, tag loss, and upriver passage

C = number of herring captured at the recapture site

R = number of tagged herring that were recaptured.

Standard error was calculated as:

$$SE = \sqrt{} (N-M)*(N-C)/M*C*(N-1)$$

The coefficient of variation (CV) was calculated as SE/N.

Resulting population estimates varied substantially among years and had wide confidence limits (Table 17.10 and Figure 17.9). Estimates declined from 1980 to 1982, then increased through 1990 with the exception of a one-year decline in 1987 one year after completion of the Rediversion Canal. The increase in Santee River population estimates after completion of the canal occurred concurrently with the decline in CPUE in the commercial fishery on the Cooper River (Figure 17.6 and Figure 17.9). It is interesting to note that estimates began to increase in the Santee River in 1984 which was the second year of a harvest ban in the Santee Fishery, but one year before the rediversion was completed. The population estimates did not correlate with passage numbers at St. Stephen Fish Lift in 1986-1990 ($r^2 = 0.0$).

St. Stephen Fish Lift Counts- Santee-Cooper Rediversion Canal

Fish released upriver of St. Stephen Dam are counted as they pass through the exit channel of the fish lift. Numbers were interpreted from hydro-acoustic sampling in 1986 and 1987, real-time observer counts in

1988-1994, and from time-lapse video recording from 1994 through 2015. Passage counts varied widely among years and did not appear to be affected by changes in counting methodology (Table 17.11 and Figure 17.10). With the exception of 1996 and 2001 annual counts were below 700,000 blueback herring. Passage was less than 100,000 in 1990, 2003, 2004, 2007, 2008, and 2012.

Peaks in passage occurred in 1992, 1996, and 2001 and are of interest. Cooke and Leach (2000) suggested that these peaks reflected the cycling of strong year classes through the population. They developed a predictive model for passage numbers that indicated high passage numbers were expected in 2000 and 2004. Cooke and Leach (2001) explained the lower than expected passage in 2000 and the higher than expected passage in 2001 as a result of differences in spring flows and turbine operation at St Stephen Dam. They hypothesized that four year old fish were not able to enter the fish lift entrance in 2000 and they returned again in 2001 as five year olds. Unfortunately, no significant increase in mean length of lifted fish occurred in 2001 that would have supported this hypothesis. The hypothesis continues to be unproven as passage numbers continue to vary widely without pattern.

Since efficiency of the lift operation is poorly known and probably varied among years with changes in operational characteristics and river flow, we did not consider passage numbers to be good indices of numbers of blueback herring in the Santee-Cooper system. We normalized annual number lifted at the St. Stephen Dam and CPUE from the Rediversion Canal fishery by dividing each value by the series mean. A comparison of the two time series indicated little, if any relationship among years (Figure 17.11). However, number lifted did constitute a minimum number of fish that survived the canal commercial fishery below the dam. Therefore, we added annual number lifted to annual harvest in numbers for estimates of annual minimum population size in the Rediversion Canal. Annual results were a small fraction of estimated annual population size for the overlapping years of 1986 – 1990 suggesting that a very small fraction of blueback herring in the Santee River are caught or are lifted over the St. Stephen Dam.

Santee River System Abundance Trends

A comparison of population estimates, minimum population size, and CPUE in the Rediversion Canal indicated a very general trend of abundance increase through the 1980s, a peak during the 1990s, a decline in the 2000s, and a return to a more moderate abundance throughout the 2010s (Figure 17.12). Since it is not clear if reduced recruitment or reduced fishing and dam passage efficiency are involved, monitoring of lift numbers and fishery catch rates should continue. It would also be wise to conduct several years of Santee River/Rediversion Canal population estimates to verify trends apparent in other abundance data. Cooke and Leach (2003b) argue convincingly that changes in the flow regimes of the Cooper and Santee Rivers were responsible for the demise of the Cooper River fish and the resurgence of the Santee River stock.

Navigation Lock at the Pinopolis Dam on the Cooper River

We did not consider estimates of fish biomass passed through the lock to be reliable indices of annual run size. Not only was the fish species composition of the estimates poorly known, but double counting of passed fish was a factor in some years of operation. However, estimated biomass of fish has declined since rediversion was completed (Cooke and Leach 2000).

17.11.2. Size and Age Distribution

Mean size (fork length-mm) of blueback herring collected in the St. Stephen Fish Lock on the Rediversion Canal declined between 2003 and 2007, but rebounded to long term averages from 2013-2015 (Table 17.12 and Figure 17.813). Mean lengths of females generally exceeded those of males. The decrease in mean length in the 2000s was concerning, but the increase in recent years may be indicative of a population rebound after many years of drought.

Data on annual age composition of blueback herring were obtained prior to rediversion from fishery independent sampling in the Cooper River in 1975-1982 (Table 17.13) and by fishery independent gill net sampling in the Santee River in 1975-1982 (Table 17.14 and Table 17.15). Mean age of blueback herring in both rivers increased prior to rediversion as the age structure broadened to include older fish (Figure 17.14). This increase was most dramatic in the Cooper River where the increase encompassed a time period prior to and during rapid population increase. Such a change in age structure often accompanies declining rates of fishing mortality which could also explain the population growth. Mean age of females generally exceeded that of males in the Santee River data (Table 17.14 and Figure 17.14). Current age data from the blueback herring harvested in the commercial fishery in the Santee Rediversion Canal were similar to what was historically occurring in the Cooper River. The age structure of the population continues to be varied containing multiple year classes.

Data on frequency of repeat spawning were obtained for blueback herring in the Santee River prior to rediversion. Percent of males and females that spawned more than once varied without trend (Table 17.16 and Table 17.17). Since high variation in frequency of repeat spawning often occurred between years, it likely reflected recruitment variation rather than changes in mortality. Percent of repeat spawn ranged from 0.0% to 31.6 % in males and from 18.4 to 40.0 % in females.

17.11.3. Growth

Mean fork length at age was available for blueback herring of the Cooper River (sexes combined) and the Santee River (by sex). Mean length at age varied without trend among years for herring of both stocks. However interannual variation was greater for Cooper River herring (Table 17.88, Figure 17.95) than for herring of the Santee River (Table 17.99, Figure 17.106 and Figure 17.117). We calculated Von Bertalanffy curves for mean fork length at age for Santee River herring by sex (Figure 17.128). Since growth curves are often influenced by lengths of age one and younger fish, we converted length at date data from young emigrating blueback herring to length at age using an assumed hatch date of March (Table 17.20). Data on length of young blueback herring from the Cooper River came from the forebay of the Pinopolis Dam (Cooke and Coale 1996). Data for blueback herring of the Santee River came from the Wilson Dam tailrace. Von Bertalanffy parameters suggested very similar growth curves for males and females in the Santee system and a slightly larger maximum length for Cooper River herring (Table 17.21).

17.11.4. Mortality Estimates

We calculated total instantaneous mortality (Z) using catch curves of number at age within collection year (Ricker 1975). We confined estimates to ages from the Cooper River because collections were made by a variety of gears. We did not use age date from the Santee River because Santee fish were collected with a single mesh gill net and size/age selectivity was expected. We estimated Z as the negative slope of the linear regression of log e number at age on log e age. Results ranged from Z = 0.23 in 1977 to Z = 2.15 in 1975 (Table 17.22). The extreme interannual fluctuation in Z estimates suggested a strong influence of recruitment variation on analyses. No trend in Z among years was apparent.

We evaluated relative exploitation in the Santee River stock as it appears in Table 17.23. Relative exploitation is calculated as estimated harvest in numbers divided by a minimum population estimate in numbers. The minimum population estimate is calculated as the harvest in numbers plus passage in numbers at the St. Stephen fish lock on the Rediversion Canal. Since only a portion of fish in the Rediversion Canal and the Santee River actually move above the St. Stephen Dam, the minimum population estimate is an underestimate of the actual population. During years when both passage counts and population estimates were made (1986-1990), the minimum population estimates averaged 2.3 percent of the population estimate. Consequently, estimates of relative exploitation are gross over estimates of the true exploitation rate for the Santee stock. To account for this, adjusted exploitation rates were developed using “scalar” values. These were created by dividing minimum population estimates by population estimates for years when population estimates occurred and calculating a mean for those years (0.023). In an attempt to address variation and the possibility that the relationship between population size and fish passage has changed over time, an additional scaler was created in the same manner using the lower confidence limits for the population estimates (0.440). When compared to other years in this range, the estimate for 1998 appeared to be an outlier. As a result, a final scaler was created using the lower confidence limits, but excluding the estimates for 1998 (0.052). All scalers (0.023, 0.440, and 0.052) were then multiplied by the annual relative exploitation to produce adjusted and more realistic estimates of exploitation rates. The 0.052 scaler was chosen as the most appropriate and realistic to depict exploitation from this fishery.

Adjusted exploitation rates using the 0.052 scaler were very low and no trend was apparent among years. By comparison, u_{msy} (target exploitation rates) for blueback herring of the Chowan River, North Carolina was u_{msy} = 0.67, while that for herring of the Connecticut River, Connecticut and St. John River, New Brunswick were U_{msy} = 0.75 (Crecco and Gibson 1990). Adjusted estimates of u imposed by the commercial fishery in the Rediversion Canal are well under all of these benchmarks.

Although fishing rates may not be an issue in Santee River blueback herring stock, the picture for fish passage is not as clear. We do not know if fish lifted over the St. Stephen Dam emigrate after spawning or if they do, whether they survive emigration through the turbines. It is also not clear if a significant number of juveniles produced above the dams in the Santee Cooper Lake system successfully emigrate to the ocean. If adults lifted over the dam do not survive, and if few lake-produced progeny survive emigration to the ocean, then high lift numbers may be harmful to the main river population. Santee River blueback herring were iteroparous prior to construction of dams and it is likely that iteroparourity is necessary for the maintenance of resilient populations. If a high percentage of adults are lifted over the St. Stephens Dam and they do not survive to spawn again, then the population suffers high mortality that erodes age structure and reduces incidence of repeat spawning. Such changes are similar to those caused by excessive fishing mortality. Continued monitoring of population age structure and passage efficiency will be required.

17.11.5. Young-of-the-Year Surveys

Limited juvenile abundance data for blueback herring in South Carolina have been obtained by electrofishing (Table 17.24). Collections were made in Winyah Bay in 2001-2015, the Santee River in 2001-2003, the Cooper River in2001-2015, the Edisto River in 2001-2015, and the Combahee River 2001-2015. Catches of blueback herring in this sampling program is too low to detect annual trends.

17.12. BENCHMARKS

A benchmark of u = 0.050 is in place for the Santee-Cooper herring fishery. Status of the fishery relative to this benchmark will continue to be measured by three year running averages of the scaled annual relative exploitation rates. Since the development of the benchmark, three year running average scaled exploitation rates have not exceeded the sustainability benchmark (Table 17.23).

17.13. CONCLUSIONS AND RECOMMENDATIONS

All available data show that river herring landings have declined from historic levels in South Carolina.

Abundance of blueback herring in the Santee and Cooper Rivers has varied widely between rivers and among years. Changes in abundance appear to have resulted from a combination of habitat alteration from flow regulation and drought, and from fishing.

Abundance of blueback herring in the Cooper River was reduced in the early 1970s from apparent over fishing. It rebounded a bit in the early 1980s after imposition of harvest regulations, but declined again following the rediversion of water from the Cooper back to the Santee River in 1985. Abundance has remained low in the Cooper River since that time.

Blueback herring abundance in the Santee River increased following rediversion and remained at relatively high levels through the 1990s. Abundance declined abruptly in the early 2000s after several years of drought, but has rebounded at in the 2010s. Rates of mortality from commercial harvest of this stock from 1990 through the present have been low and it is unlikely that fishing has affected stock abundance or age structure.

We recommend that age data be obtained from blueback herring of the Santee River, the Santee-Cooper Rediversion Canal, and the Cooper River and that the commercial creel survey of tailrace fisheries in the system be continued. Age and harvest data are important to understanding current stock dynamics and factors affecting recent river herring abundance.

We recommend updating population estimates of blueback herring in the Santee system. Estimates should be made for three or more contiguous years.

We also recommend that a sample program be developed or existing programs be improved to track annual production of young. Numbers of blueback herring collected in current sample programs for juvenile fish are too low for meaningful evaluations.

Commercial harvest regulations should not be relaxed for the Santee-Cooper system.

Harvest in the Cooper River and Rediversion Canal recreational fisheries appear to be minor since herring are not target species. However, we advise continuing the creel survey to monitor this fishery.

We recommend that bycatch of river herring in near-shore-ocean fisheries should be evaluated, in concert with other states.

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Table 17.1 Maturity at age of blueback herring collected from the Santee River in SC, 1978-1983

	Percent Mature	
Age	Males	Females
1	0.0	0.0
2	2.5	0.7
3	21.4	12.6
4	72.2	53.4
5	95.6	89.8
6	99.6	99.6
7	100.0	100.0

Table 17.2 Reported weight (kg) of blueback herring taken in the commercial fishery of SC, 1969-2015.

Year	Weight (kg)	Year	Weight (kg)	Year	Weight (kg)
1969	1,111,774	1985	111,430	2001	25,471
1970	145,379	1986	111,430	2002	730
1971	629,234	1987	61,350	2003	48,559
1972	448,973	1988	48,830	2004	14,821
1973	164,657	1989	37,560	2005	40,547
1974	40,053	1990	31,300	2006	7,619
1975	8,318	1991	33,800	2007	51,304
1976	11,689	1992	88,890	2008	7,273
1977	13,572	1993	127,710	2009	140,776
1978	15,255	1994	100,160	2010	212,994
1979	65,341	1996	130,210	2011	54,417
1980	169,020	1996	160,260	2012	22,729
1981	117,690	1997	112,680	2013	47,402
1982	175,280	1998	187,505	2014	75,372
1983	146,490	1999	118,425	2015	85,124
1984	180,290	2000	122,193		

Table 17.3 Number and weight of blueback herring reported by the commercial cast net fishery in the Cooper and Santee Rivers, SC, 1998-2015.

	Cooper River	Santee River		
Year	Kg	Number	Kg	Mean Weight (Kg)
1998	6,207	906,500	181,296	0.20
1999		592,050	118,410	0.20
2000	152	669,450	121,718	0.18
2001	856	152,014	24,184	0.16
2002	94	2,738	497	0.18
2003	1,552	342,926	46,763	0.14
2004	6,763	59,083	8,057	0.14
2005	5,240	257,500	35,114	0.14
2006	84	50,106	7,516	0.15
2007	232	338,709	50,806	0.15
2008	3,065	26,457	3,608	0.14
2009	13,050	913,250	124,534	0.14
2010	2,973	1,532,490	208,976	0.14
2011	2,973	374,740	51,101	0.14
2012	2,874	126,297	18,945	0.15
2013	13,273	246,227	33,576	0.14
2014	22,656	383,017	52,230	0.14
2015	61,910	165,377	22,551	0.14

Table 17.4 Number and weight (kg) of blueback herring reported by the commercial gill net fishery of the Pee Dee River, SC, 1998-2015.

Year	Number	Kg	Mean Weight (Kg)
1998	10	2	0.23
1999	73	15	0.20
2000	1,777	323	0.18
2001	2,375	431	0.18
2002	768	139	0.18
2003	1,790	244	0.14
2004	10	1	0.14
2005	1,416	193	0.14
2006	140	19	0.14
2007	1,779	266	0.15
2008	4,403	600	0.14
2009	23,407	3,192	0.14
2010	6,897	1,045	0.14
2011	2,513	343	0.14
2012	6,066	910	0.15
2013	4,063	553	0.14
2014	3,567	486	0.14
2015	4,877	663	0.14

Table 17.5 Estimated commercial effort, landings (kg), and CPUE of blueback herring in the Santee-Cooper System, SC. Data obtained via a point access creel survey of the commercial fishery.

	Cooper River			Santee River below Wilson Dam		Santee River Rediversion Canal			Totals		
Year	Fisherman Days	Landings	CPUE	Fisherman Days	Landings	Fisherman Days	Landings	CPUE	Fisherman Days	Landings	CPUE
1969	1830	1111774	607.5						1830	1111774	607.5
1970	737	145379	197.3						737	145379	197.3
1971	1059	629234	594.2						1059	629234	594.2
1972	1215	448973	369.5						1215	448973	369.5
1973	1065	164657	154.6						1065	164657	154.6
1974	724	40053	55.3						724	40053	55.3
1975	399	8318	20.8						399	8318	20.8
1976	391	11689	29.9						391	11689	29.9
1977	468	13572	29.0						468	13572	29.0
1978	449	15255	34.0						449	15255	34.0
1979	566	65341	115.4						566	65341	115.4
1980	1399	177444	126.8		31900				1399	209344	149.6
1981	755	71392	94.6	500	101802				1255	173194	138.0
1982	639	93428	146.2						639	93428	146.2
1983	1608	262618	163.3		a				1608	262618	163.3
1984	1727	251450	145.6		a				1727	251450	145.6
1985	1520	135926	89.4	60	9600		a		1580	145526	92.1
1986	737	66029	89.6	32	35200		a		769	101229	131.6
1987	1369	67988	49.7				a		1369	67988	49.7
1988	515	20133	39.1				a		515	20133	39.1
1989	592	17791	30.1				a		592	17791	30.1
1990	662	17846	27.0			87	1154	13.3	749	19000	25.4
1991	324	7829	24.2			296	8859	29.9	620	16688	26.9
1992	145	7723	53.3			1118	82673	73.9	1263	90395	71.6
1993	145	4170	28.8			1479	162977	110.2	1624	167147	102.9
1994	66	3047	46.2			1407	116125	82.5	1473	119172	80.9
1995	35	472	13.5			1743	186378	106.9	1778	186850	105.1
1996						1854	238781	128.8	1854	238781	128.8
1997						1414	128133	90.6	1414	128133	90.6
1998						1319	180919	137.2	1319	180919	137.2
1999						1052	118164	112.3	1052	118164	112.3
2000	NS	NS	NS	NS	NS	1026	120114	117.1	1026	120114	117.1
2001	55	550	10.0	NS	NS	244	24134	98.9	299	24684	82.6
2002	NS	NS	NS	NS	NS	0	0		0	0	
2003	35	807	23.1	NS	NS	595	46665	78.4	630	47472	75.4
2004	56	3200	57.1	NS	NS	259	8040	31.0	315	11240	35.7
2005	NS	NS	NS	NS	NS	309	10412	33.7	309	10412	33.7
2006	NS	NS	NS	NS	NS	229	6743	29.4	229	6743	29.4
2007	NS	NS	NS	NS	NS	439	50701	115.5	439	50701	115.5
2008	120	3000	25	NS	NS	89	3600	40.5	209	6600	31.6
2009	NS	NS	NS	NS	NS	402	71600	178.7	402	71600	178.7
2010	NS	NS	NS	NS	NS	470	69600	148.1	470	69600	148.1
2011	NS	NS	NS	NS	NS	475	37600	79.2	475	37600	79.2
2012	NS	NS	NS	NS	NS	255	18900	74.1	255	18900	74.1
2013	NS	NS	NS	NS	NS	333	33500	100.6	333	33500	100.6
2014	NS	NS	NS	NS	NS	386	52116	135.0	386	52116	135.0
2015	NS	NS	NS	NS	NS	516	22521	43.6	516	22521	43.6

a- Fishing prohibited
NS- No Surveyed

Table 17.6 Mean fork length (mm) of blueback herring taken in the commercial cast net fishery below the St. Stephen Dam on the Santee - Cooper Rediversion Canal.

	Males			Females			Total		
Year	Number	Mean Fork Length	SD	Number	Mean Fork Length	SD	Number	Mean Fork Length	SD
1995	346	232		248	231				
1996	128	232		122	235				
1997	154	229		73	230				
1998	207	223		263	221				
1999	207	221		193	221				
2000	166	220		215	222				
2001	238	237	10.4	97	248	17.7	335	240	13.9
2002	-	-	-	-	-	-	-	-	-
2003	183	235	10.7	127	246	11.5	310	239	12.3
2004	361	223	13.8	280	239	15.7	641	230	16.7
2005	539	228	8.0	498	238	9.1	1037	233	10.0
2006	310	219	26.6	224	243	30.3	554	230	30.5
2007	333	216	8.7	248	234	11.2	581	224	13.3
*2008									
2009	490	219	10.4	518	233	10.3	1008	226	0.0
2010	295	231	9.0	581	240	10.6	876	329	11.0
2011	130	214	7.1	245	237	28.4	375	228	26.2
2012	12	230	7.1	8	236	10.5	20	232	8.8
2013	230	227	9.4	183	234	13.8	413	227	12.9
2014	68	233	6.9	63	242	8.5	131	238	8.9
2015	90	234	8.3	75	248	12.0	165	240	12.1

**Due to low flows, fishery did not occur in this area*

Table 17.7 Number at age of blueback herring harvested in the commercial cast net fishery in the Rediversion Canal, 2013-2015.

	Males			Females			Totals		
Age	2013	2014	2015	2013	2014	2015	2013	2014	2015
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	11	22	0	4	13	0	15	35	0
5	34	60	56	22	57	40	56	117	96
6	8	11	26	12	31	22	20	42	48
7	0	0	0	2	1	2	2	1	2

Table 17.8 Percent of repeat spawning blueback herring harvested in the commercial cast net fishery in the Rediversion Canal, 2013-2015.

	2013	2014	2015
% with one spawning mark	28	26	22
% with two spawning marks	7	3	9
% repeat spawners	36	29	30

Table 17.9 Catch per unit effort of blueback herring caught in the American shad recreational fishery on the Santee and Cooper Rivers, SC, 2003-2007.

Year	CPUE
2003	0.13
2004	1.15
2005	0.93
2006	1.10
2007	0.85

Table 17.10 Mark recapture population estimates of blueback herring in the Santee River, SC.

			Confidence Interval	
Year	N	CV	Lower	Upper
1980	5,895,796	0.25	3,012,000	8,780,000
1981	4,054,521	0.23	2,236,000	5,873,000
1982	664,151	0.17	400,000	888,000
1983	2,352,005	0.45	297,000	4,407,000
1984	2,625,000	0.24	1,417,000	3,833,000
1985	6,205,353	0.71	0	14,822,650
1986	9,061,064	0.41	1,817,496	16,304,632
1987	3,805,457	0.29	1,657,618	5,953,296
1988	5,507,918	0.50	116,348	10,899,488
1989	5,501,964	0.22	3,153,678	7,850,250
1990	9,353,003	0.22	5,358,472	13,347,534

Table 17.11 Annual number of blueback herring passed at St. Steveph Fish Lift, caught in the commercial fishery, and minimum population size in the Santee-Cooper Rediversion Canal, SC.

Year	Number Passed	Number Caught	Minimum Population
1986	187,000		187,000
1987	74,000		74,000
1988	232,000		232,000
1989	147,000		147,000
1990	71,000	9,408	80,408
1991	400,000	72,251	472,251
1992	589,000	674,510	1,263,510
1993	345,000	1,329,762	1,674,762
1994	298,000	947,489	1,245,489
1995	561,000	1,520,642	2,081,642
1996	1,452,285	1,948,191	3,400,476
1997	176,814	1,045,464	1,222,278
1998	112,466	1,320,134	1,432,600
1999	182,798	884,793	1,067,591
2000	695,586	991,001	1,686,587
2001	1,862,015	178,532	2,040,547
2002	421,459	0	421,459
2003	86,909	384,038	470,947
2004	35,545	66,150	101,695
2005	175,184	257,544	432,728
2006	105,129	55,125	160,254
2007*	49,343	372,645	421,988
2008*	8,503	0	8,503
2009	438,746	526,260	965,006
2010	217,750	511,560	729,310
2011	336,210	276,360	612,570
2012	37,117	138,915	176,032
2013	113,860	246,225	360,085
2014	171,200	383,082	554,282
2015	244,631	165,375	410,006

Minimum population size = number lifted + number caught in fishery

**Fish lift was not operated normally due to restricted flows (i.e. extreme drought).*

Table 17.12 Mean fork length (mm) of blueback herring from St. Stephen Dam Fish Lift on the Santee River Rediversion Canal, SC.

	Males			Females			Combined		
Year	Number	Mean Fork Length	SD	Number	Mean Fork Length	SD	Number	Mean Fork Length	SD
1991	166	241		258	255				
1992	345	238		303	252				
1993	181	235		290	247				
1994	75	235		126	251				
1995	180	233		175	252				
1996	257	237		233	248				
1997	140	238		102	253				
1998	251	240		359	256				
1999	200	238		208	245				
2000	250	232		230	245				
2001	227	237	10.1	86	252	15.2	313	241	13.3
2002	119	235	8.7	67	250	17.3	186	240	14.4
2003	122	239	8.7	111	254	10.5	233	246	12.2
2004	8	256	35.2	29	250	12.2	37	251	19.1
2005	52	231	6.8	60	245	8.6	112	238	10.5
2006	34	216	31.2	39	233	16.3	73	225	25.6
2007	42	227	10.5	30	218	9.4	73	223	10.9
2008*									
2009	34	216	31.2	39	233	16.2	73	225	25.6
2010	13	234	9.7	15	248	24.8	28	241	20.2
2011	111	220	11.6	69	237	20.7	180	227	17.8
2012	20	257	7.8	1	292	N/A	21	258	10.9
2013	49	231	8.5	56	242	11.2	105	237	11.4
2014	51	236	11.0	89	249	16.2	140	244	15.8
2015	139	240	11.3	176	251	11.8	315	241	12.9

**Due to low flows, fish were not collected in this area*

Table 17.13 Age composition (no) of blueback herring collected by fishery independent sampling below the Pinopolis Dam on the Cooper River, SC.

Sexes Combined							
Age	1975	1977	1978	1979	1980	1981	1982
2	45	4	3	12		12	
3	103	52	12	33	21	109	10
4	154	152	121	195	30	69	49
5	18	80	25	136	29	227	53
6				3	19	29	11
7						8	2
Mean	3.45	4.07	4.04	4.22	4.46	4.39	4.57
Males							
Age	1975	1977	1978	1979	1980	1981	1982
2				8			
3				15			
4				102			
5				58			
6							
7							
Mean				4.15			
Females							
Age	1975	1977	1978	1979	1980	1981	1982
2				4			
3				18			
4				93			
5				78			
6				3			
7							
Mean				4.30			

Table 17.14 Number at age of blueback herring collected in fishery independent sampling by pound and gill net (GN, PN) and seine (SN) in the lower Santee River, SC.

Sexes Combined				
	GN	PN	SN	GN
Age	1977	1978	1979	1985
1	0	3	0	0
2	0	7	0	0
3	7	18	17	2
4	110	44	17	65
5	15	74	19	245
6	0	6	14	105
7	0	0	5	14
Mean Age	4.1	4.3	4.6	5.1

Males				
	GN	PN	SN	GN
Age	1977	1978	1979	1985
1	0	3	0	0
2	0	6	0	0
3	3	9	17	2
4	54	24	11	48
5	5	35	9	186
6	0	1	5	61
7	0	0	0	5
Mean Age	4.0	4.1	4.0	5.1

Females				
	GN	PN	SN	GN
Age	1977	1978	1979	1985
2	0	1		0
3	4	9		0
4	56	20	6	17
5	10	39	10	59
6	0	5	9	44
7	0	0	5	9
Mean Age	4.1	4.5	5.4	5.3

Table 17.15 Age composition (%) of blueback herring collected in fishery independent sampling by gillnet (GN), seine (SN), pound net (PN) in the lower Santee River, SC.

Males									
	GN	PN	SN	GN	GN	GN	GN	GN	GN
Age	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.08	0.00	0.00	0.01	0.00	0.00	0.00	0.00
3	0.05	0.12	0.40	0.02	0.06	0.12	0.07	0.03	0.01
4	0.87	0.31	0.26	0.74	0.16	0.43	0.36	0.59	0.16
5	0.08	0.45	0.21	0.23	0.71	0.15	0.44	0.34	0.62
6	0.00	0.01	0.12	0.00	0.06	0.25	0.12	0.04	0.20
7	0.00	0.00	0.00	0.01	0.00	0.05	0.01	0.00	0.02
Mean Age	4.0	4.1	4.0	4.2	4.8	4.7	4.6	4.4	5.1
Females									
	GN	PN	Seine	GN	GN	GN	GN	GN	GN
Age	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.06	0.12	0.00	0.01	0.02	0.05	0.02	0.00	0.00
4	0.80	0.27	0.20	0.64	0.14	0.37	0.22	0.37	0.13
5	0.14	0.53	0.33	0.31	0.75	0.15	0.47	0.51	0.46
6	0.00	0.07	0.30	0.03	0.09	0.43	0.29	0.11	0.34
7	0.00	0.00	0.17	0.01	0.00	0.00	0.00	0.01	0.07
Mean Age	4.1	4.5	5.4	4.4	4.9	5.0	5.0	4.8	5.3

Table 17.16 Frequency of repeat spawn of male blueback herring from the Santee River in SC.

	Spawn Marks	Age 2	3	4	5	6	7	Totals	% Virgin	% Repeat
1978										
	0	9	9	23	13			54		
	1			2	19			21		
	2				3	1		4		
	Totals	9	9	25	35	1		79	68.4	31.6
1979										
	0		17	10	8	2		37		
	1							0		
	2							0		
	Totals	0	17	10	8	2		37	100.0	0.0
1980										
	0	1	1	49	12			63		
	1				4	2	1	6		
	2							0		
	Totals	1	1	49	16	2	1	69	91.3	8.7
1981										
	0	2	29	14	24	1		70		
	1			2	25	2		29		
	2				1	1		2		
	Totals	2	29	16	50	4	0	101	69.3	30.7
1982										
	0		15	41	6	3		65		
	1				8	1		9		
	2				1	10	2	11		
	Totals	0	15	41	15	14	2	85	76.5	23.5
1983										
	0		9	34	34	11	1	88		
	1			1	4	1		6		
	2				2		1	2		
	Totals	0	9	35	40	12	2	96	91.7	8.3

Table 17.77 Frequency of repeat spawn of female blueback herring from the Santee River in SC.

	Spawn Marks	Age						Totals	% Virgin	% Repeat
		2	3	4	5	6	7			
1978										
	0	1	9	19	22	1		52		
	1				15	4		19		
	2				1			1		
	Total	1	9	19	38	5	0	72	72.2	27.8
1979										
	0			6	10	5		21		
	1				4	2		6		
	2						3	0		
	Total	0	0	6	14	7	3	27	77.8	22.2
1980										
	0		1	39	18	9	1	67		
	1			1	3	3	3	7		
	2				1	2		3		
	3						1	77		
	Total	0	0	1	4	5	4	87	77.0	23.0
1981										
	0		6	15	36	5		62		
	1				12	2		14		
	2						1	0		
	Total	0	6	15	48	7	1	76	81.6	18.4
1982										
	0		7	36	10	9	1	62		
	1				2	13	1	15		
	2				2	13	1	15		
	Total	0	7	36	14	35	3	92	67.4	32.6
1983										
	0		5	24	34	12		75		
	1			3	6	11		20		
	2				5			5		
	3				1	2		100		
	Total	0	0	3	12	13	0	125	60.0	40.0

Table 17.88 Mean fork length at age (mm) of blueback herring, sexes combined, collected by fishery independent sampling below the Pinopolis Dam on the Cooper River, SC.

	Age						
Year	1	2	3	4	5	6	7
1975		206	236	261	284		
1976							
1977		234	243	247	254		
1978		220	240	261	289		
1979		198	241	260	277	298	
1980			234	261	266	277	
1981		199	215	222	280	310	319
1982			229	243	254	266	268
All years		242	267	253	309	326	333

Table 17.99 Mean fork length at age (mm) of blueback herring collected by fishery independent gill net sampling below the Wilson Dam on the Santee River, SC.

	Age						
Year	1	2	3	4	5	6	7
Males							
1980	137	197	227	245	256	270	272
1981	133	192	227	247	258	263	282
1982	134	191	227	246	259	264	269
1983	139	185	220	239	254	263	270
1984	125	182	218	237	248	258	
Mean FL	134	189	224	243	255	264	273
Females							
1980	134	200	232	253	266	278	283
1981	134	198	233	256	270	279	295
1982	136	195	234	255	270	278	284
1983	142	186	221	245	262	273	
1984	123	179	216	238	254	268	274
Mean FL	134	192	227	249	264	275	284

Table 17.20 Mean fork length (mm) at age (yrs) of young blueback herring from the Cooper and Santee Rivers, SC.

Cooper River		Santee River	
Age (yrs)	Length	Age (yrs)	Length
0.67	79.0	0.42	44.6
		0.50	48.0
		0.50	47.4
		0.75	55.3

Table 17.21 Von Bertanlanffy growth parameters based on fork length (mm) of blueback hering collected by fishery independent sampling below the Pinopolis Dam on the Cooper River and the Wilson Dam on the Santee River, SC.

	Cooper River	Santee River	
Parameter	Sexes combined	Male	Female
L-infinity	286.5	267.6	281.0
K	0.630495073	0.6721946	0.610289
t0	0.164542792	0.1417377	0.118728

Table 17.22 Estimates of total instantaneous mortality (Z) for blueback herring of the Cooper River, SC.

	Z	SE
1975	2.15	
1977	0.64	
1978	1.58	
1979	2.09	1.14
1980	0.23	0.16
1981	1.67	0.31
1982	1.64	0.05

Table 17.23 Estimated number of blueback herring harvested from the Santee-Cooper Rediversion Canal, minimum population size, and maximum exploitation rate (u).

Year	Estimated Harvest (No.)	Minimum Population Size	Relative Exploitation	Scalar M-R LCI w/o 1988	3 Year Running Average
1990	9,408	80,408	0.12	0.006	
1991	72,251	472,251	0.15	0.008	
1992	674,510	1,263,510	0.53	0.028	0.014
1993	1,329,762	1,674,762	0.79	0.042	0.026
1994	947,489	1,245,489	0.76	0.040	0.036
1995	1,520,642	2,081,642	0.73	0.038	0.040
1996	1,948,191	3,400,476	0.57	0.030	0.036
1997	1,045,464	1,222,278	0.86	0.045	0.038
1998	1,320,134	1,432,600	0.92	0.048	0.041
1999	884,793	1,067,591	0.83	0.043	0.045
2000	991,001	1,686,587	0.59	0.031	0.041
2001	178,532	2,040,547	0.09	0.005	0.026
2002	0	421,459	0.00	0.000	0.012
2003	384,038	470,947	0.82	0.043	0.016
2004	66,150	101,695	0.65	0.034	0.026
2005	257,544	432,728	0.60	0.031	0.036
2006	55,125	160,254	0.34	0.018	0.028
2007	372,645	421,988	0.88	0.046	0.032
2008	0	8,503	0.00	0.000	0.021
2009	526,260	965,006	0.55	0.029	0.025
2010	511,560	729,310	0.70	0.037	0.022
2011	276,360	612,570	0.45	0.024	0.030
2012	138,915	176,032	0.79	0.041	0.034
2013	246,225	360,085	0.68	0.036	0.034
2014	383,082	554,282	0.69	0.036	0.037
2015	165,375	410,006	0.40	0.021	0.031

Table 17.24 Age zero blueback herring collected by electrofishing from several SC rivers.

Year	Winyah Bay	Santee River	Cooper River	Edisto River	Combahee River
2001	0	4	0	0	0
2002	0	84	24	0	0
2003	0	787	0	2	0
2004	11	NS	0	0	0
2005	12	NS	0	1	0
2006	7	NS	26	0	0
2007	3	NS	1	0	1
2008	3	NS	1	6	0
2009	16	NS	2	1	0
2010	2	NS	0	0	0
2011	4	NS	0	0	0
2012	2	NS	0	0	0
2013	11	NS	6	0	2
2014	86	NS	13	0	0
2015	88	NS	11	1	1

NS – Not Sampled

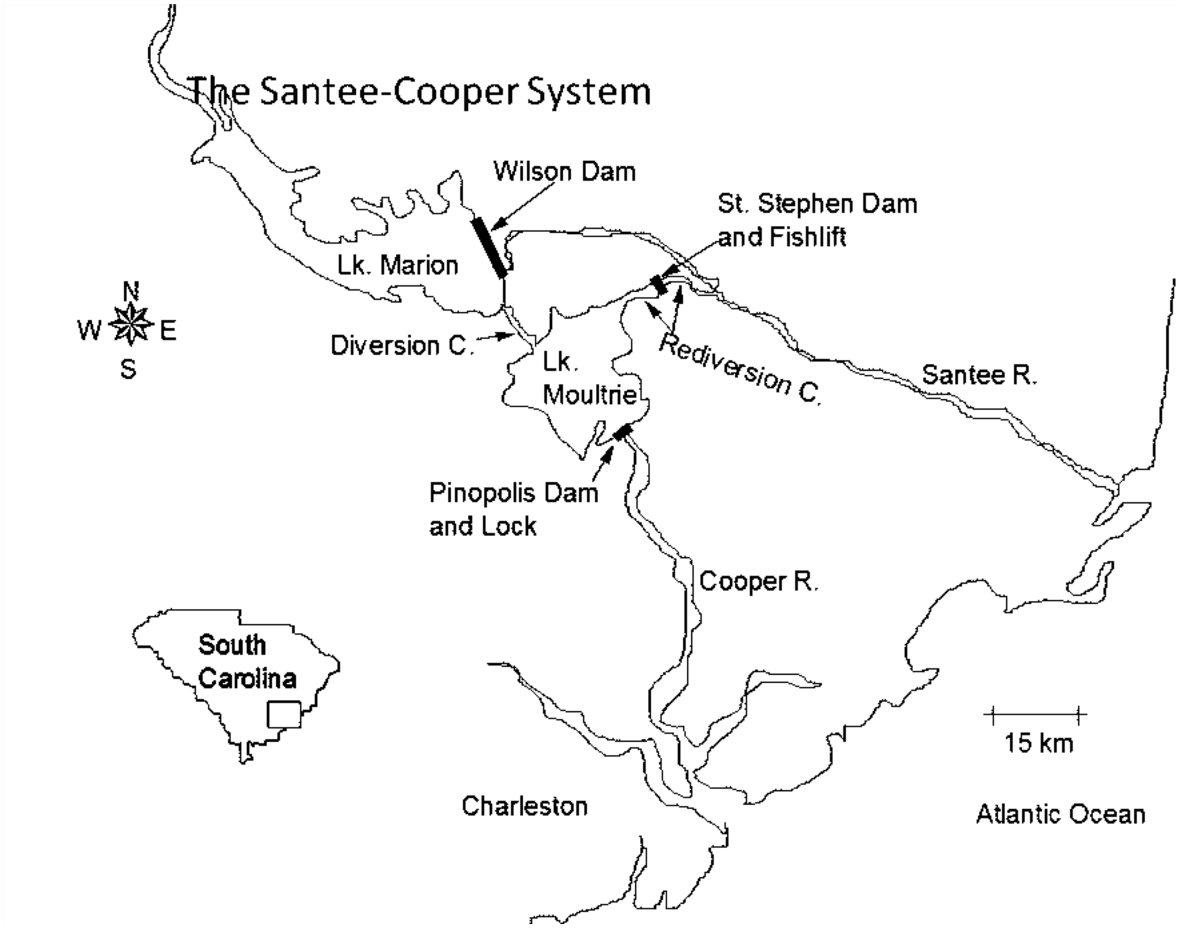


Figure 17.4 Santee-Cooper Rivers complex in South Carolina.

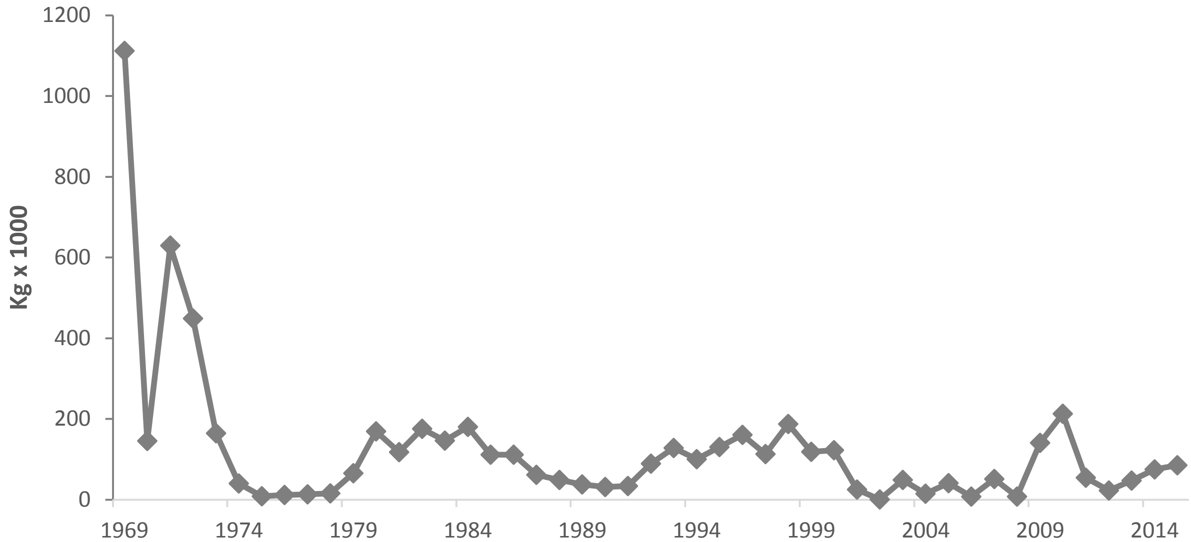


Figure 17.5 Reported landings (kg) of blueback herring taken in the commercial fishery in South Carolina, 1969-2015.

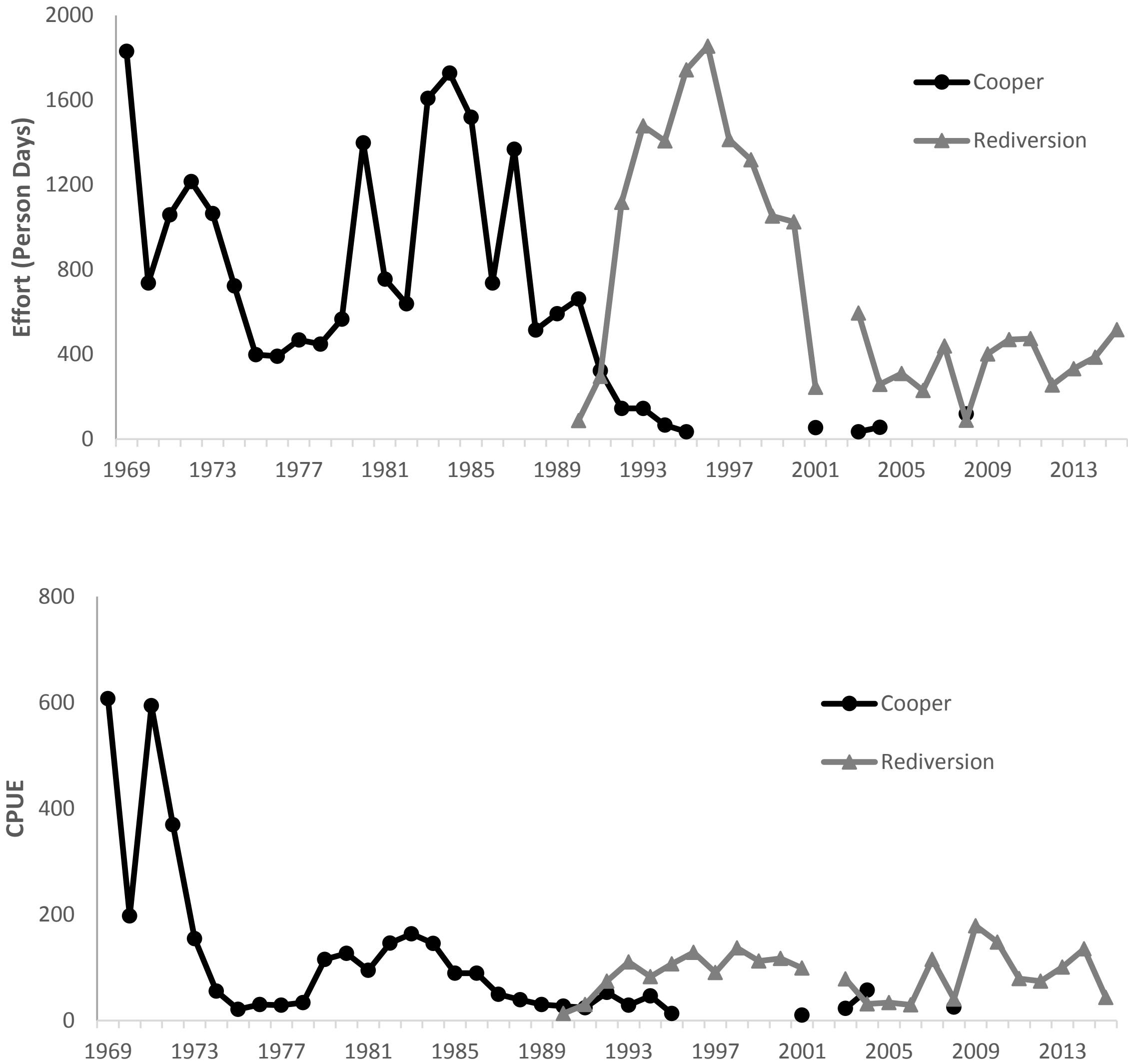


Figure 17.6 Estimated effort (person days, top) and CPUE (bottom) in the commercial fishery for blueback herring in the Cooper River and the Santee-Cooper Rediversion Canal, SC.

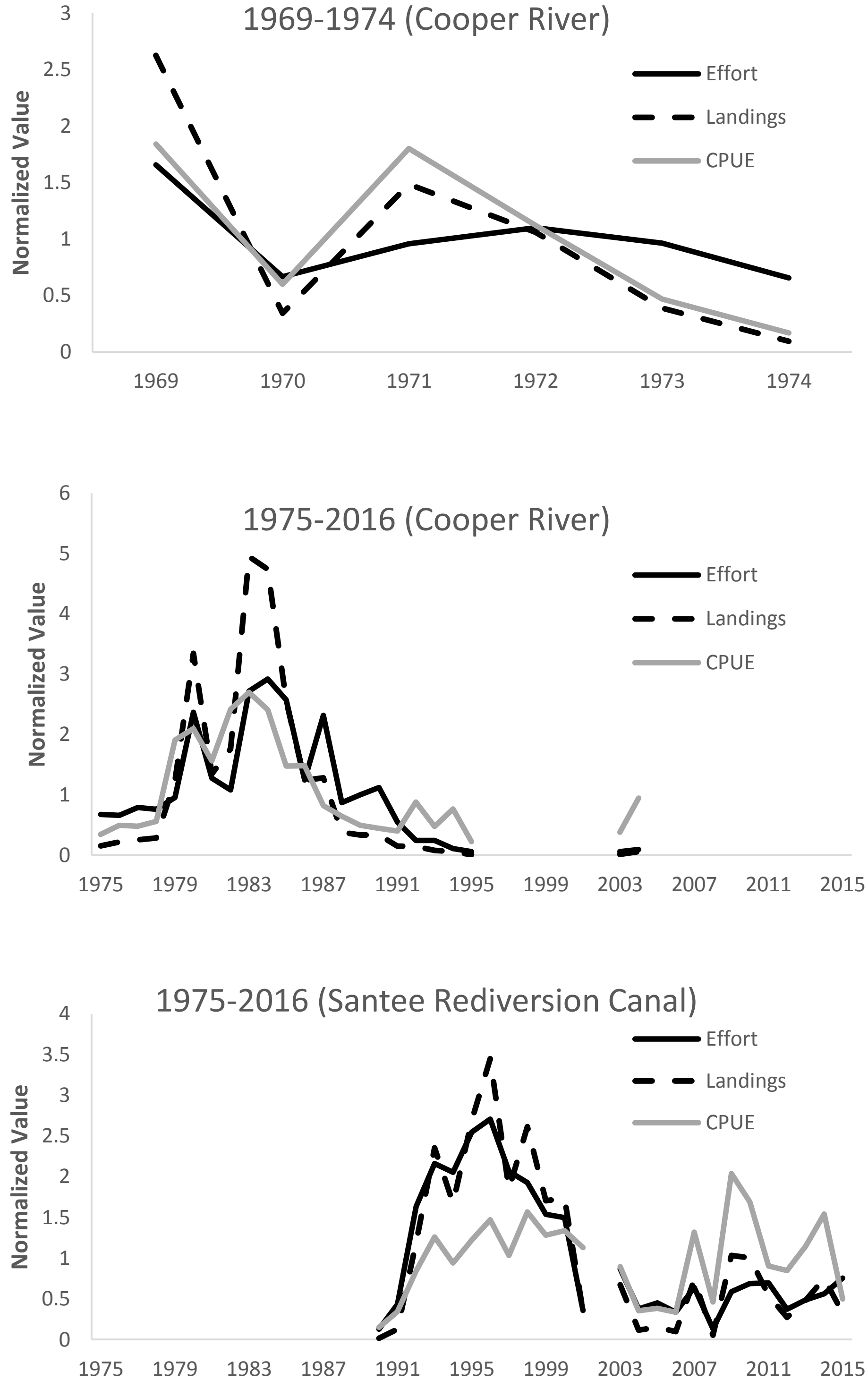


Figure 17.121 Normalized effort (Man days), landings (kg x 1000) and CPUE for the commercial fishery for BBH in the Cooper River (top, 1969 – 1974 and middle, 1975 – 2015) and the Santee-Cooper Rediversion Canal, SC (bottom, 1990 - 2015). River specific data normalized as ratio of annual data divided by long-term mean.

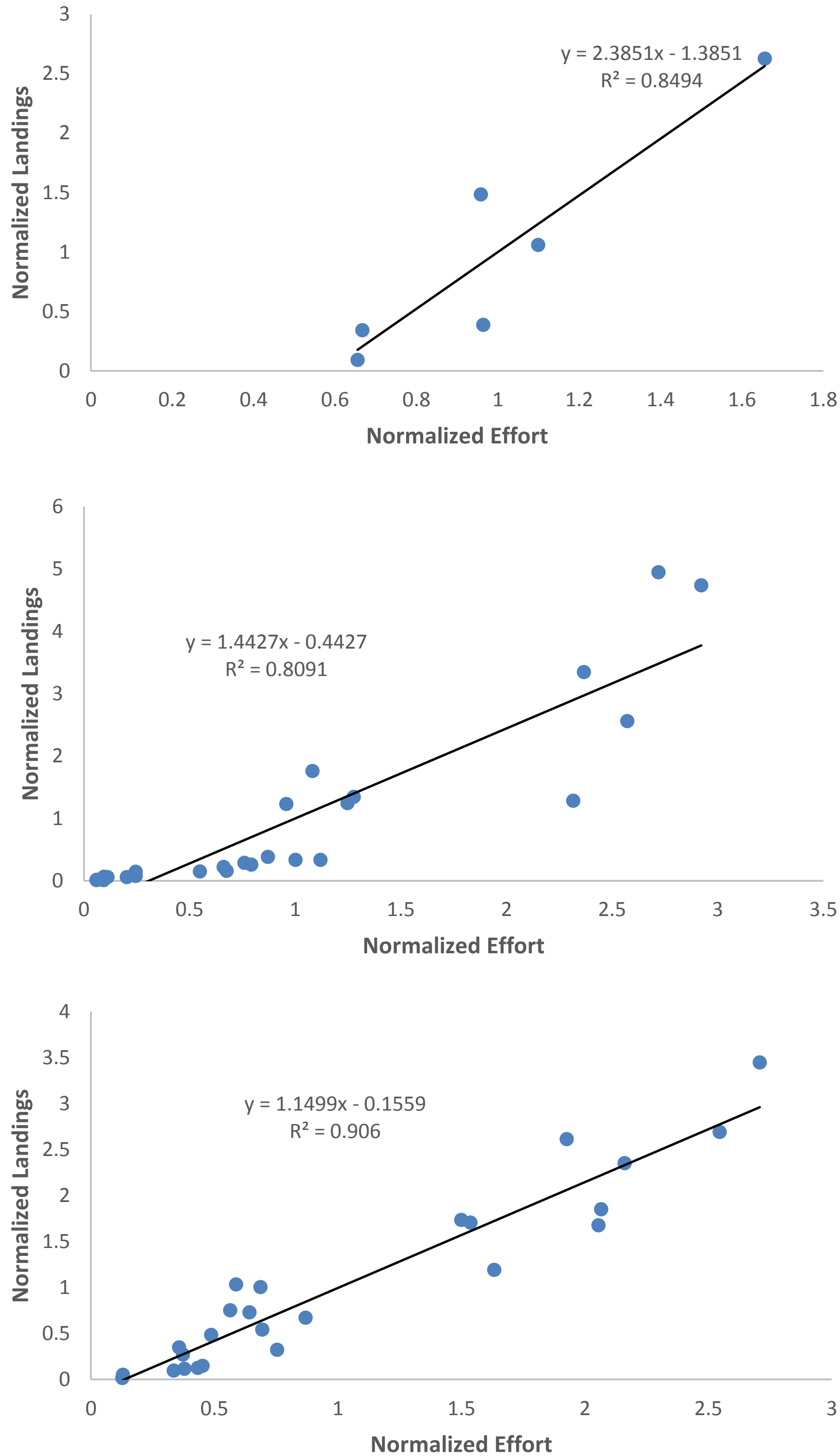


Figure 17.8 Normalized effort vs normalized landings in the commercial fisheries of the Cooper River (top, 1969 – 1974, and middle, 1975 – 2015) and the Santee River (bottom, 1990 – 2015).

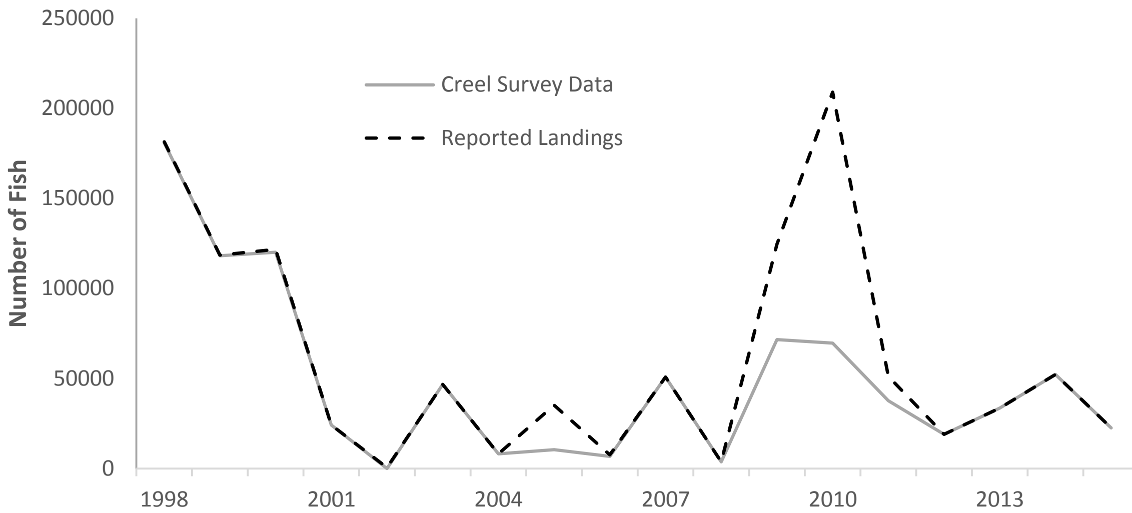


Figure 17.7 Creel survey data and reported landings of blueback herring in the Rediversion Canal of the Santee River, 1998-2015.

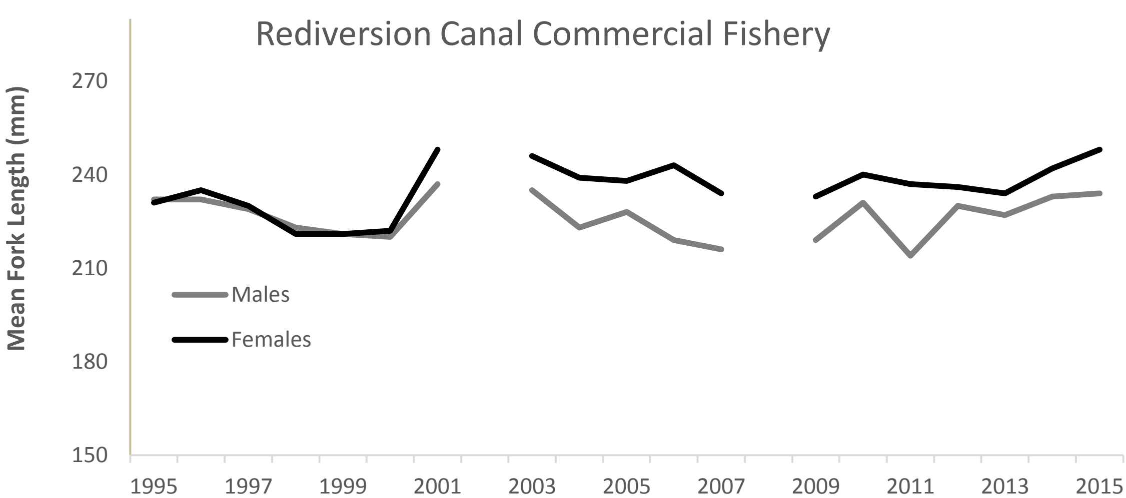


Figure 17.8 Mean fork length (mm) of blueback herring taken in the commercial fishery below the St. Stephen Dam on the Santee-Cooper Rediversion, 1995-2015.

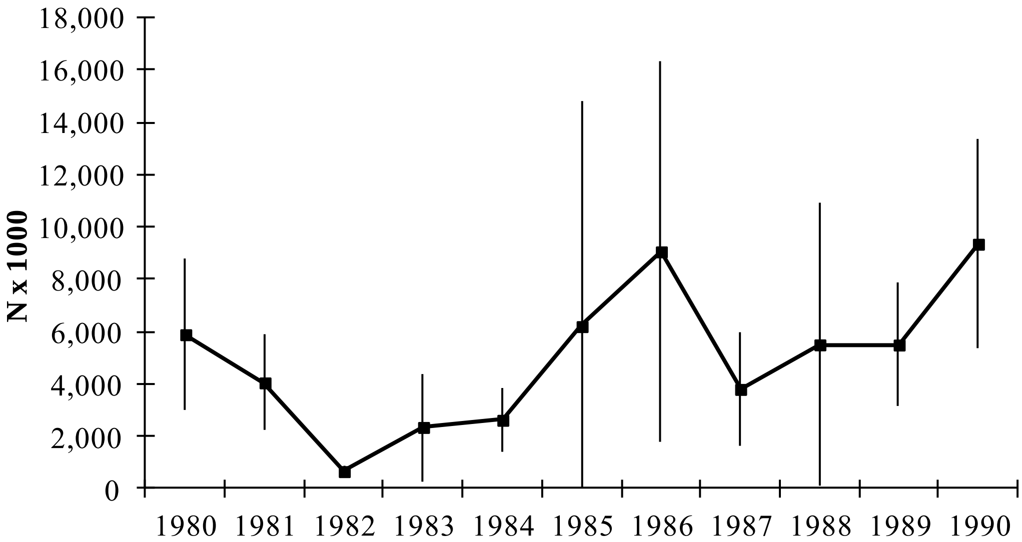


Figure 17.9 Population estimates of blueback herring in the Santee River, SC. Vertical lines denote 95% confidence interval, 1980-1990.

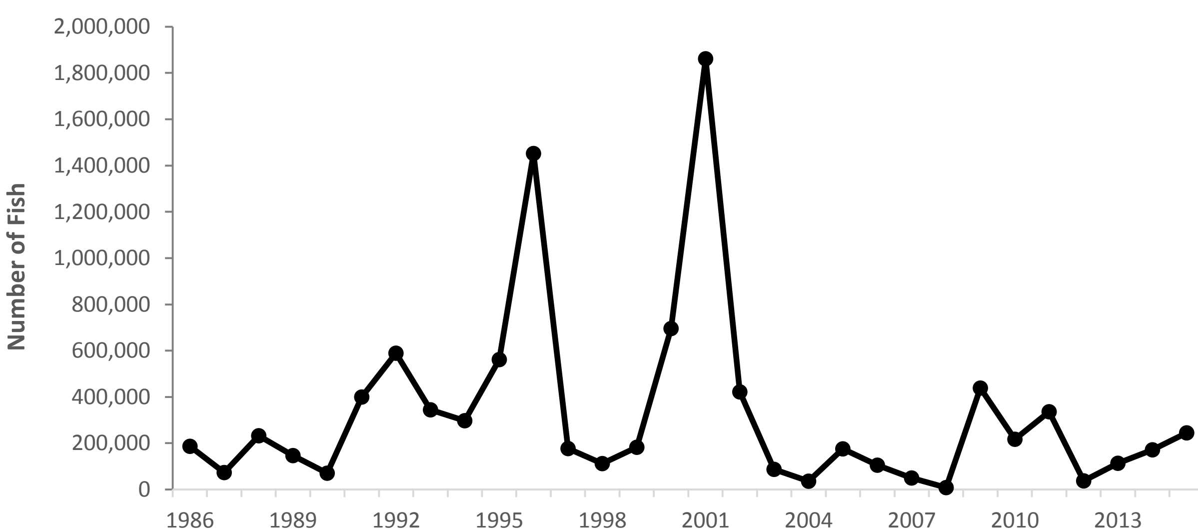


Figure 17.10 Number of blueback herring lifted over the St. Stephen Dam on the Santee-Cooper Rediversion Canal, SC, 1986-2015.

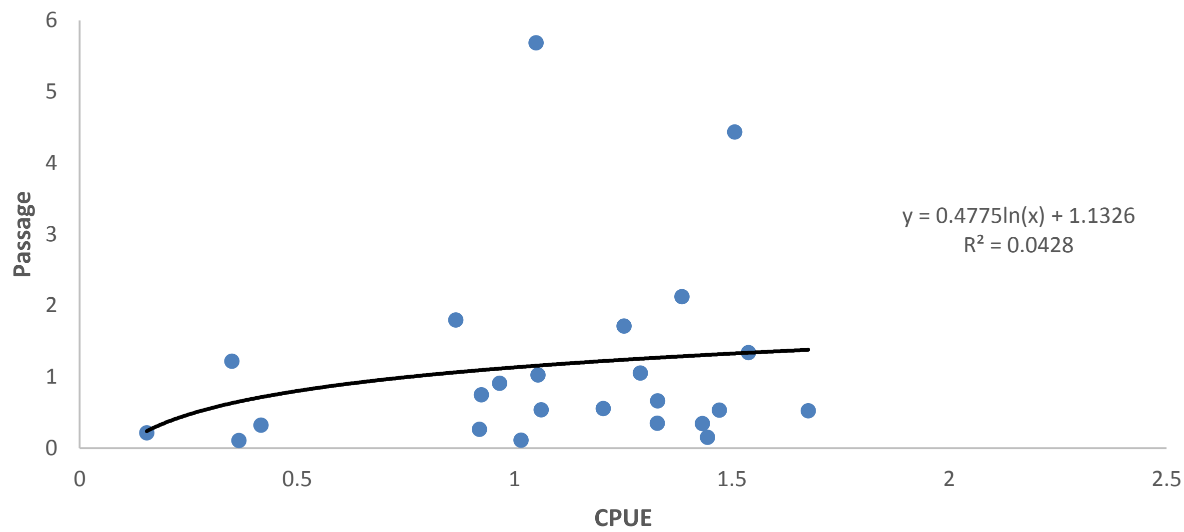


Figure 17.11 Relationship between normalized CPUE of blueback herring in the Santee-Cooper Rediversion Canal commercial fishery and normalized passage numbers in the St. Stephens Dam Fish Lift.

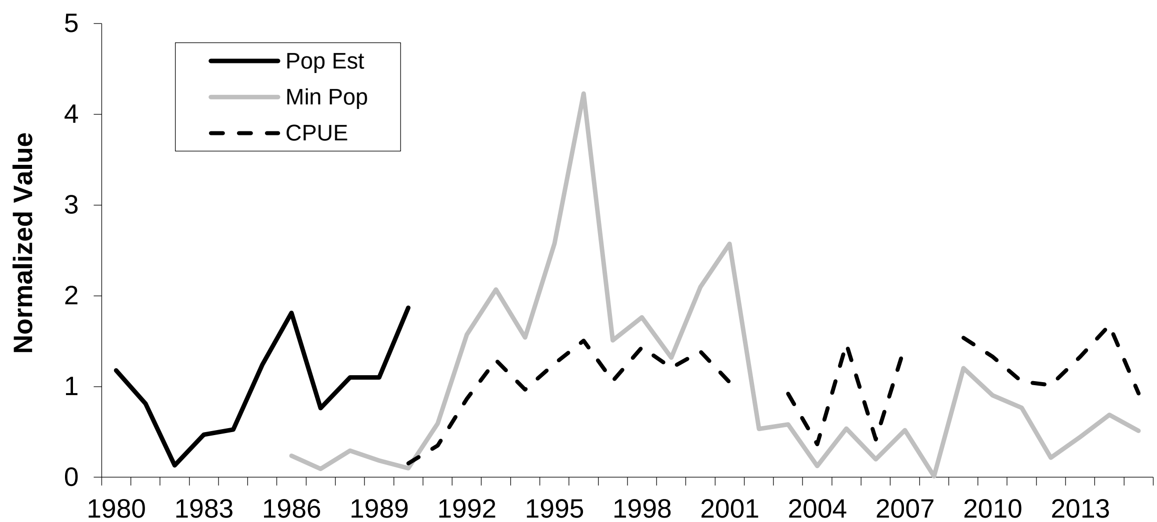


Figure 17.12 Available abundance indices for blueback herring on the Santee River and Santee-Cooper Rediversion Canal, South Carolina. CPUE as kg per man day in the commercial fishery. Passage and population estimates in numbers. All data normalized as annual value / time series mean.

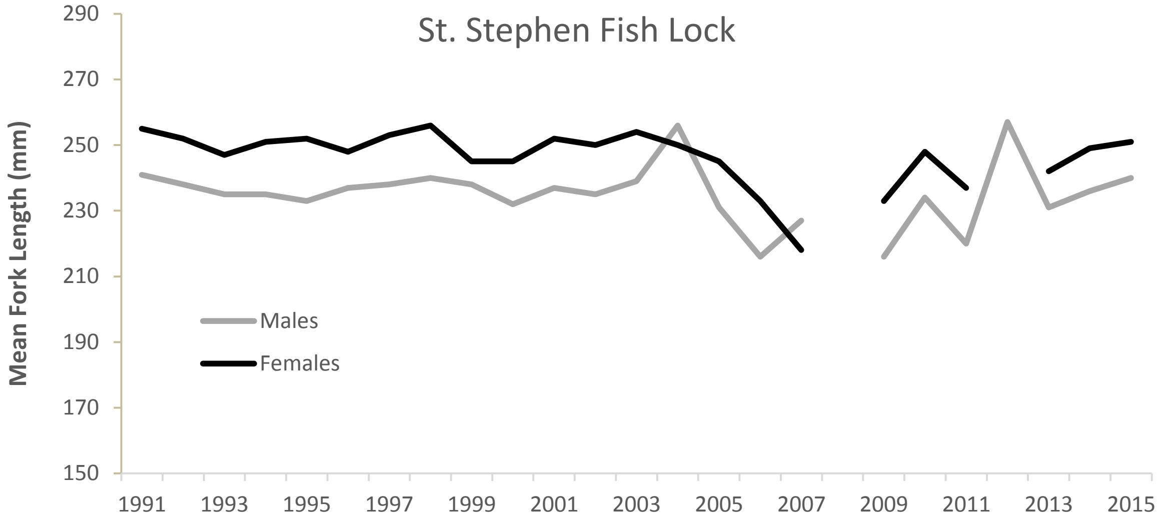
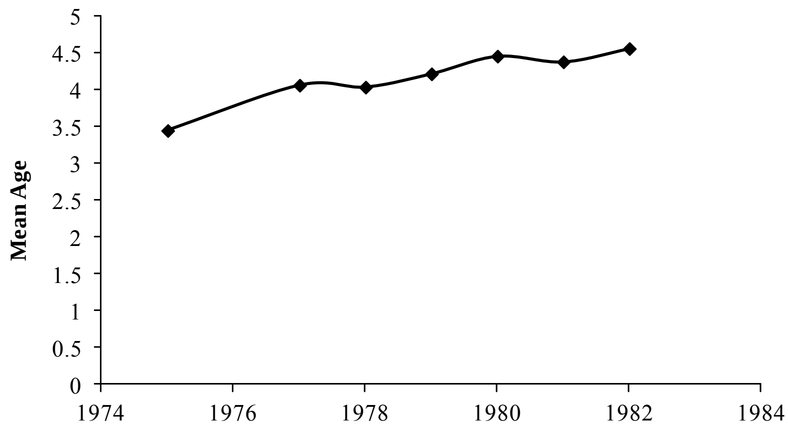


Figure 17.13 Mean fork length (mm) of blueback herring taken in the commercial fishery below the St. Stephen Dam on the Santee-Cooper Rediversion, 1991-2015.



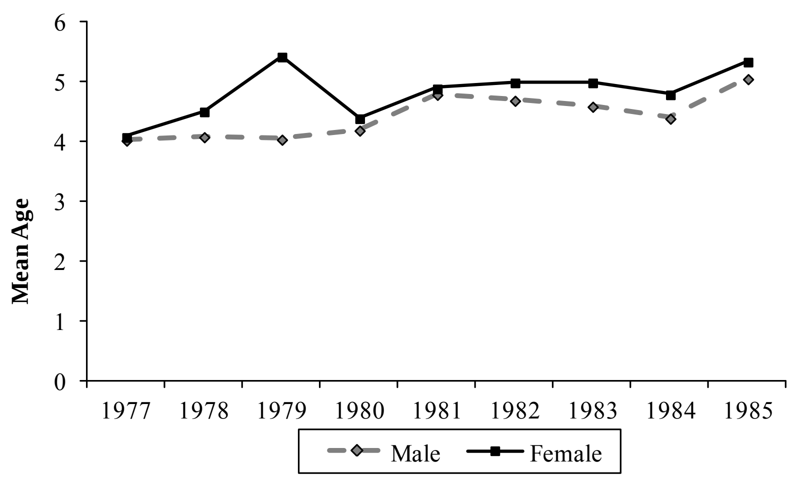


Figure 17.14 Mean age of blueback herring collected from the Santee River (bottom, male and female) and Cooper River (top, sexes combined) prior to rediversion in 1985.

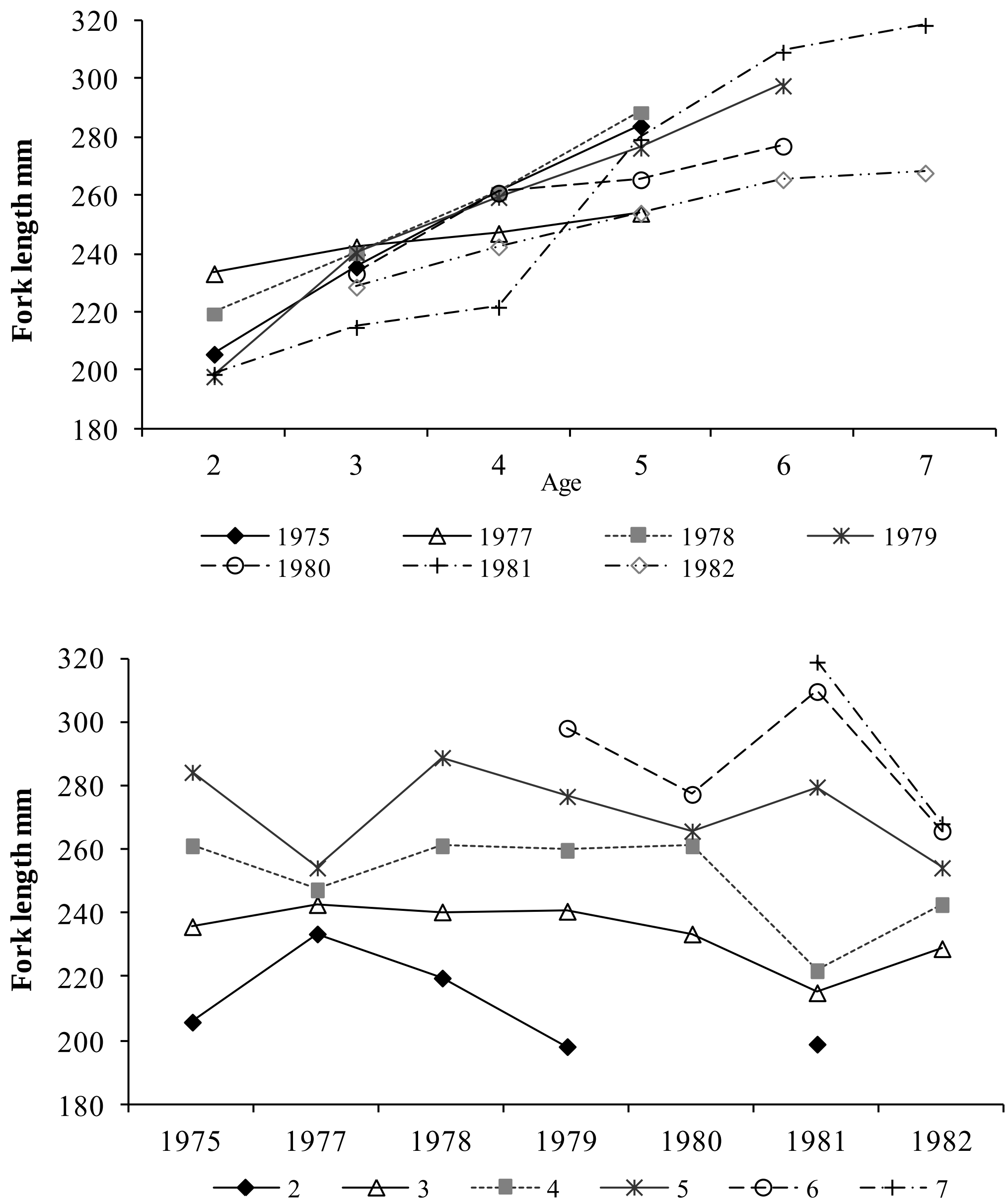


Figure 17.95 Mean fork length (mm) (bottom) and length at age (top) of blueback herring collected from the Cooper River in SC. Lengths for sexes were combined.

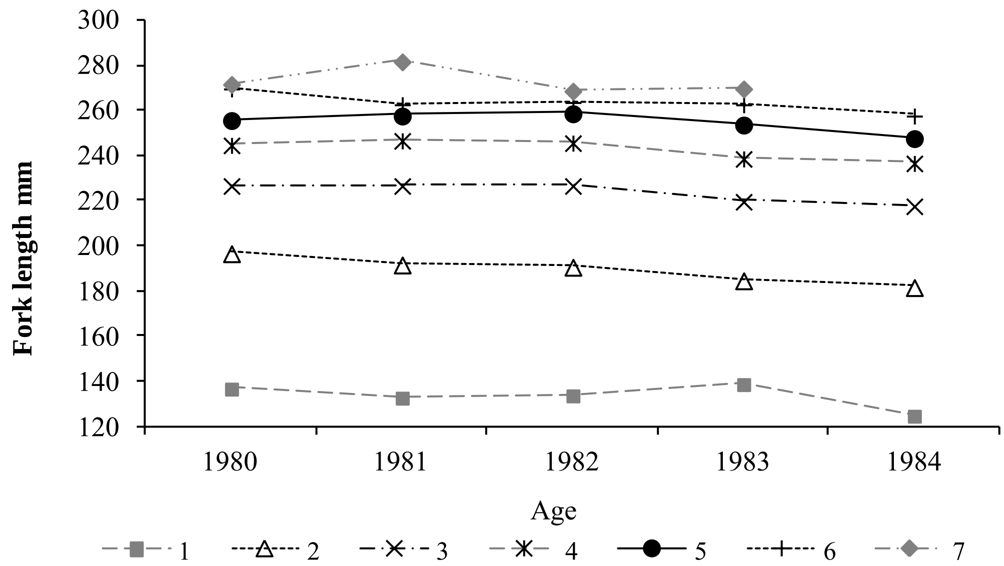


Figure 17.106 Mean fork length (mm) at age of male blueback herring from the Santee River, SC.

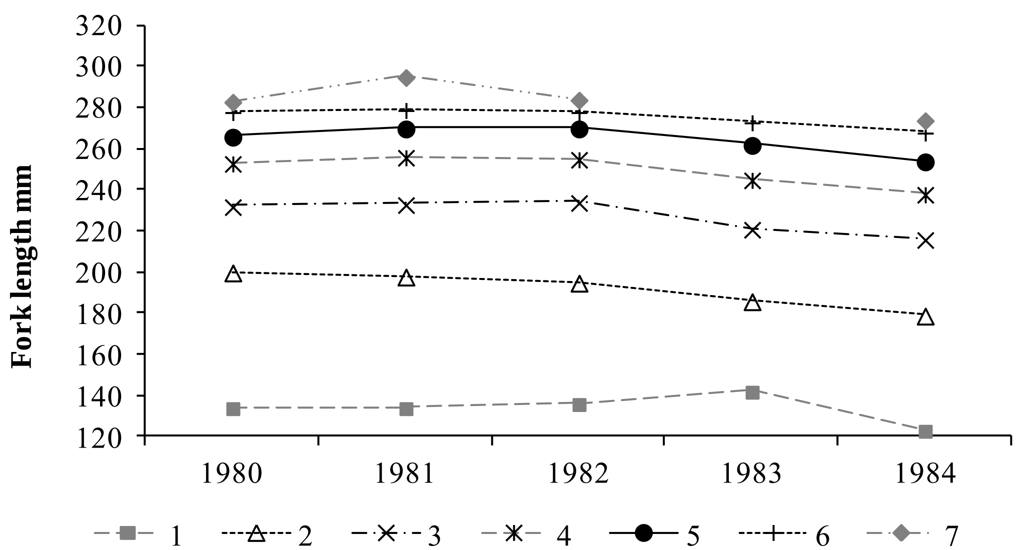


Figure 17.117 Mean fork length (mm) at age of female blueback herring from the Santee River, SC.

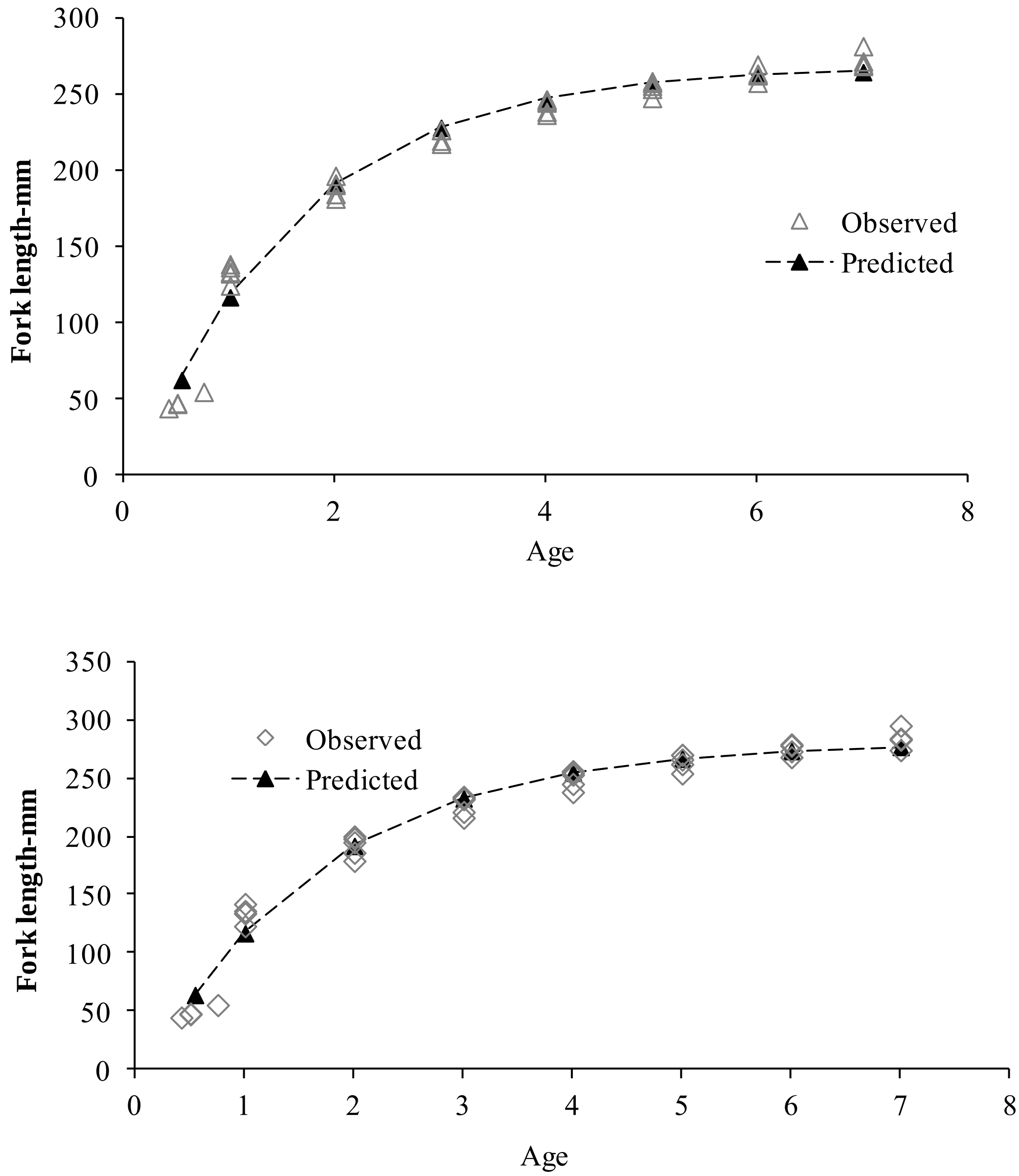


Figure 17.128 Growth curves for male (top) and female (bottom) blueback herring from the Santee River.

Appendix. Summary of current regulations on take of blueback herring in South Carolina.

General

There is no commercial fishing activity for herring in the Ashley, Edisto, Combahee, Coosawhatchie, and Savannah Rivers or in State territorial Atlantic Ocean waters.

Season

The open season is 15 February - 15 April in the rivers draining into Winyah Bay, the Ashley River, and Charleston Harbor. The open season in the Santee River is 15 February - 1 May. The open commercial season for the Rediversion Canal of Santee River and the Tailrace Canal of Cooper River is 1 March - 1 May of each year. There is no closed season for the commercial take of herring in the Santee-Cooper Lakes with legal gears in open areas.

Harvest Limits

The allowable daily take of herring (including the allowable by-catch)for net fisheries is 10 US bushels per boat in the Tailrace Canal of the Cooper River, 250 lbs per boat in the Santee-Cooper Lakes, and 10 US bushels per boat in the Rediversion Canal. There are no other caps or quotas in effect for commercial herring fisheries in South Carolina.

Gears

Approved commercial gears are anchored (set or stationary) and drift gill-nets in all open riverine waters seaward of dams, with the exceptions of open portions of the Santee and Cooper River where other gears are allowed. Circular drop-nets up to six feet in diameter, lift-nets and cast-nets are the only gears allowed in the upper Tailrace Canal of the Cooper River and in the open portions of the Rediversion Canal of the Santee River. Lift-nets, cast-nets, and hook & line may be used within the Santee-Cooper Lakes and cast-nets and/or hook & line are legal gear in other inland reservoirs. Legal minimum mesh size for gill-nets is 2 1/2" stretched mesh in all State waters open to such gear. The length of any gill-net may not exceed one half of the width of the waterway where it is fished. Gill-nets may not be fished within 200 yards of any previously deployed net. Regulatory changes implemented in 2001 restricted net lengths to a maximum of 200 yards in freshwaters and 300 yards in inland marine waters.

Lift Periods

There is a weekly 84-hour lift period in effect for all waters of the Winyah Bay system during the open gill-netting season. The Ashley River and Charleston Harbor have no weekly lift period during open gill-netting season. The use of nets in the Cooper River Tailrace Canal is allowed only from sunrise until 10:00. Fishing with nets in the Rediversion Canal is allowed from 7:00 PM - 12:00 midnight EST or 8:00 PM – 12:00 midnight EDT, with no lift period. Portions of several rivers are closed to commercial gear.

Actual regulations can be found at: http://www.scstatehouse.gov/code/t50c005.htm, under Title 15.

18 Status of River Herring in Georgia and Florida

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Executive Summary

The St. Johns River, Florida harbors the southernmost spawning run of Blueback Herring *Alosa aestivalis* on the Atlantic coast of the United States. The run is currently not harvested by either commercial or recreational anglers and no harvest has been recorded since the 1960s. Limited landings data and anecdotes suggest that the Blueback Herring run in the St. Johns River was large in the past. There are no long time series of either fishery dependent or fishery independent data for this stock. Modern abundance indices are not directly comparable to the limited historical data because gears used and sampling methods differ. Available data, though limited in scope, suggest that modern Blueback Herring abundance is low in the St. Johns River, Florida. Spawning adults are smaller than those collected by researchers in 1972 and 1973. Blueback Herring were much more abundant than American shad *Alosa sapidissima* in fishery independent samples in 1972 and 1973 and are now the less abundant in contemporary sampling within the St. Johns River even with shad abundance also historically low.

Due to the limited amount of data on river herring in Georgia, information collected from the state of Georgia has been included with the state of Florida. Inclusion of this data in no way implies that these stocks are genetically similar or should be treated as one management unit. The St. Mary's River on the Georgia/Florida border is known to have historically contained a blueback herring run but no data are available for an assessment of the St. Mary's. Additional populations of blueback herring have been reported in Georgia include the Altamaha and Ogeechee Rivers, as well as the Savannah River on the Georgia/South Carolina Border. For information on river herring in the Savannah River refer to Section *X* (South Carolina).

18.1 INTRODUCTION

Blueback Herring were likely an important fishery in Florida in the 19th and early 20th centuries but the available catch data are unreliable. Landings of 'alewife' are reported up to a peak around 1 million pounds in the early 20th Century. However, 'alewife' were often the combined landings of Blueback Herring, hickory shad (*Alosa mediocris*), and menhaden (*Brevoortia* spp.). It is unclear what proportion of these was herring though herring were harvested and salted for market at the time. By the mid-20th Century, herring harvest was limited to bycatch in other fisheries that was sold as crab and catfish bait (Williams et al., 1975). In Georgia, historically the Blueback Herring fishery was minimal to non-existent, especially when compared to the American and hickory shad fisheries.

In Georgia there is currently no known commercial or recreational fishing for Blueback Herring while in Florida various gear restrictions have effectively eliminated all commercial harvest of blueback herring and there is no known recreational fishing for them. River herring were largely ignored until the approval of Amendment 1 of the Shad and River Herring Fishery Management Plan in 1999 which required monitoring of American shad stocks. Since the spawning and nursery habitats of the American shad and blueback herring overlap (Williams and Bruger 1972) this allows the collection of data on the relative abundance, size structure, and sex ratio of blueback herring in addition to the targeted sampling for American shad. In Florida, current data are collected using electrofishing for adults and pushed trawls pushed trawls for juveniles and so are not quantitatively comparable to the two years of data provided by Williams et al. 1975 from seine and surface trawl collections. The only inference on historic and modern abundance of Blueback Herring is derived from the abundance of Blueback Herring relative to American shad in fishery independent samples. Sampling that targets adult American shad in Georgia has not yielded any data on Blueback Herring.

18.2 MANAGEMENT UNIT DEFINITION

There is no active management of Blueback Herring in Georgia or Florida. Blueback Herring are known to occur in Florida in the St. Johns and St. Mary's rivers, which would presumptively be two independent management units.

18.3 REGULATORY HISTORY

18.3.1 Georgia

There are no laws regarding the recreational take of river herring in Georgia's rivers. Castnets can be utilized to capture landlocked blueback herring for bait within Georgia reservoirs.

18.3.2 Florida

Blueback Herring have not been specifically regulated in the St. Johns River, Florida. Gear restrictions in other fisheries have affected Blueback Herring catch. New pound net licenses were no longer issued for the St. Johns River after 1982. Existing pound net licenses were non-transferable (FAC 68A-23.003) and no pound nets are operating on the St. Johns River, Florida. The Florida Constitution was amended by voter referendum to prohibit entanglement nets larger than 500ft^2 in state waters. This net ban became effective on July 1, 1995 (Art. X, Sec. 16).

As of January 1, 1997 hook and line is the only permissible gear for all *Alosa* in Florida (FAC 68B-52.001). Recreational anglers must possess a valid saltwater fishing license in order to retain anadromous species in fresh water.

18.4 ASSESSMENT HISTORY

McBride et al. (2010) described the 2002 – 2005 spawning runs of Blueback Herring in the St. Johns River including feeding, reproduction, sex ratio, and size distribution. Overall, McBride el al. (2010) concluded that the stock is persistent, but its status is unknown and the smaller individual sizes evident today suggest that this population could be experiencing higher mortality now than a few decades ago. The Benchmark Stock Assessment for River Herring in 2012 extended the electrofishing dataset from McBride et al. (2010) from 2005 through 2010 and introduced a juvenile pushnet survey dataset for the St. Johns River. Recent data suggest that the St. Johns River population of Blueback Herring is of high priority for conservation due to unique genetics and apparent demographic changes (Palkovacs et al. 2013).

18.5 STOCK-SPECIFIC LIFE HISTORY

Blueback Herring in Florida are iteroparous and spawn in the St. Johns River from January to late March and occasionally early April (Williams et al. 1975, McBride et al. 2010). They spawn in the St. Johns River mature as early as age three for males and age four for females. Males mature slightly earlier with a greater proportion of males than females being age four. The majority of males mature by age five and females by age six. Mature male blueback herring collected from the 1972 and 1973 runs were age three to eight with ages five and six being 83.4% to 77.7% of the population in 1972 and 1973 respectively. Mature female blueback herring collected from the 1972 and 1973 runs were age four to eight and age six was most common (Williams et al. 1975)

18.5.1 Fecundity

Fecundity estimates of blueback herring in the Altamaha River Georgia were 120,000 – 400,000 eggs per female with a mean of 244,00 eggs per female (Street 1970).

Fecundity for blueback herring in the St. John’s River was reported in Williams et al, 1975. It was estimated that blueback herring contained 151,000 to 349,000 eggs with a mean of 262,024 (N = 24) based off of:

$$F = (110.4198 + 0.7183*Wt) * 1000$$

F = Fecundity, Wt = total weight

18.6 HABITAT DESCRIPTION

18.6.1 Georgia

The Altamaha is one of the largest rivers within Georgia. The Altamaha River forms at the confluence of the Oconee and Ocmulgee Rivers and flows unobstructed for 137 miles to the Atlantic Ocean (Godwin and Adams, 1969). There is no information available on the use of this habitat by river herring at any life stage.

18.6.2 Florida

Spawning occurs in the St. Johns River between river kilometer (rkm) 200 and 375 as well as in some tributaries such as the Wekiva River, Dunn's Creek, and Black Creek, although most spawning appears to occur along the main river (Williams et al., 1975, McBride et al., 2010). The St. Johns River is entirely coastal and drops a total of 9.1 m over its entire 499km length. Most of that drop occurs upstream of river kilometer 314 (McLane 1955). The head of the tide is generally at Lake George (rkm 199). Weak tides can reach as far as the Lake Monroe outlet at river kilometer 266 during low flow. The St. Johns River has a "southern river flow pattern" (Kelly and Gore 2008) in which low flow typically occurs from late winter into early summer and high flows occur in the late summer and early fall corresponding to a summer wet season. The floodplain is rarely inundated during the spawning season. Available habitats along the 175 km of river where spawning has been documented are diverse and include several broad lakes.

The St. Johns River is a large meandering channel averaging three to six meters deep and about 80 meters wide from rkm 200 to 266, between lakes George and Monroe. It is bounded almost entirely by bottomland hardwood floodplain forest and has numerous oxbows and sloughs known as "dead rivers". There are three shallow lakes connected to this stretch; Lake Dexter (1902 acres), Lake Woodruff (2200 acres), Lake Beresford (800 acres). This stretch is at sea level during low flow and is weakly (< 4 cm) affected by lunar tides when flow is below 4000 cubic feet per second. Flow rarely reverses on flood tides but instead slows while the river backs up. Wind events can cause the flow to stop or reverse for a period of days at low flows (Kroening 2004). Substrates are a mix of sand and detritus muck with sand prominent along bluffs and scoured bends and deep muck in backwaters. The littoral zone is generally vegetated and fringed by trees, emergent vegetation such as *Nuphar lutea*, or submerged vegetation such as eelgrass *Vallisneria Americana*. This stretch was altered between 1884 and 1945 for navigation improvement. Numerous bends were cut off by dug channels thus straightening the channel and creating artificial oxbows. Sandbars were removed to establish a minimum depth of 12 feet between Palatka and Sanford (USACE 2011).

The St. Johns River passes through Lake Monroe (9400 acres) between rkm 266 and 276. Lake Monroe is a round shallow basin averaging two meters in depth. The river braids through seasonally flooded marsh and wet prairie upstream of Lake Monroe between river kilometers 276 and 306. Sand is the dominant substrate in the main river channels with organic detritus dominant in backwater sections. Emergent *Nuphar lutea* fringes much of this stretch of river. The river passes through Lake Harney (6200 acres) between rkm 306 and 314. Lake Harney, like Lake Monroe, is a round shallow basin. Both lakes have sandy bottoms and are usually fringed with submerged vegetation dominated by eelgrass and sometimes hydrilla.

There the river is braided through extensive wet prairie upstream of Lake Harney where the majority of the fall in elevation occurs. Substrate in the channel varies from find sand to peat. There is a weir at rkm 415 but this is upstream of any documented spawning location for blueback herring and the highest density of eggs and larvae and spawning adults collected in previous studies were well downstream of this location in the 30 km reach between Lake Monroa and Lake Harney (Williams et al. 1975, McBride et al. 2010).

Blueback Herring have been documented to spawn in both lentic and lotic habitats (Walsh et al. 2005), both which are extensive in the St. Johns River. Spawning may occur in some of the lakes through which the St. Johns River passes but specific habitat selection has not been delineated for this system.

Juveniles reside in the river until late fall or early winter, generally between rkm 125 and 305, with the range gradually shifting downstream to below rkm 125 from late summer to winter. Some Blueback Herring may over winter far upstream near the spawning grounds in low flow and/or warm years (Williams et al. 1975). The habitat upstream of rkm 200 is described above. Downstream of rkm 200, the St. Johns River is a tidal freshwater estuary that includes 40,000 acre Lake George at the upstream end between rkm 182 and 200. Lake George is approximately 18 km long by 10.5 km wide and averages 3 m deep. Below Lake George the tidal freshwater reach varies in width from 0.18 km to 2 km and has an average tide range of 0.33 m.

It is not known what habitat(s) in the St. Johns are most beneficial to Blueback Herring spawning. New physical habitat alteration is not an imminent threat and most activities on the flood plain center around restoration and protection. As much as 62 percent of the floodplain upstream of Lake Harney was drained for agriculture by the 1970s and much water was diverted out of the basin. Habitats in the primary spawning area, though, remain largely intact. Efforts to restore the upper river floodplain and a natural hydro-period are underway (St. Johns River Water Management District 2007).

18.7 RESTORATION PROGRAMS

There are no restoration programs in Georgia or Florida.

18.8 AGE

No age data are currently available.

18.9 FISHERIES DESCRIPTIONS

There is no directed fishery (commercial or recreational) in Florida. Gear restrictions preclude there being any fisheries operating where bycatch is likely.

There is no evidence that a directed fishery (commercial or recreational) has ever existed for river herring Georgia's rivers or coastal waters. A 1999 creel survey conducted by the South Carolina Department of Natural Resources at the New Savannah Bluff Lock and Dam documented the only known recreational harvest of blueback herring in Georgia's rivers. This survey was conducted from February 1, 1999 through June 30, 1999 and anglers harvested an estimated total of 95 blueback herring. During this same time period anglers harvested an estimated 3,828 American shad. The extremely low blueback herring harvest numbers seem to indicate that anglers targeting American shad incidentally harvested these fish. The Army Corps of Engineers closed public access to the lock and dam in 2014, thus essentially eliminating the recreational shad fishery on Georgia's side of the river.

18.10 FISHERIES INDEPENDENT MONITORING

18.10.1 Data Collection Methods

18.10.2 Spawning stock surveys

18.10.2.1 Seine Survey

In-migrating adult Alosa species were collected in the St. Johns River, FL by seine in 1972 and 1973. The seine was a 306m commercial herring seine (6 cm stretched mesh) fished two to three nights per month from January to March at rkm 152. Blueback herring were enumerated and subsampled for biological data, age and fecundity. Juveniles were collected by seine and towed surface trawl throughout the year in 1972 and 1973 (Williams et al. 1975).

18.10.2.2 Electrofishing Survey

Adult Alosa species were collected on the spawning grounds in the St. Johns River by electrofishing beginning in 2001. In 2001 and 2002 sampling was haphazard 10 minute transects. The sampling protocol was standardized beginning in 2003. Standard sampling occurred from January to April in each year. Ten random transects were sampled in two representative river sections lying between rkm 278 and 357. One section is referred to as the "Creel Area". The other section is referred to as "Upstream" and combines two sub-areas. The Creel Area lies between river kilometers 274 and 297 as measured from the river mouth and falls between Lake Monroe and Lake Harney. "Upstream" includes four transects in a six kilometer reach between Lake Harney and Puzzle Lake (rkm 314-320) and six transects in 12 km of river bracketing State Road (SR) 50 near Christmas, Florida (rkm 345-357) (Figure 1). In 2009 and 2010, peak-season trips were made to various tributaries in search for spawning locations of Alosa species outside the mainstem of the St. Johns River (Figure 2). These locations included spring fed streams, blackwater creeks, and back channels in the braided section of the St. Johns River.

Sampling was conducted using an 18-foot aluminum boat outfitted with a Smith-Root GPP 9.0 electrofisher using two four-dropper Wisconsin rings. Pulsed direct current (60 Hz) was used at 340 or 680 volts depending on water conductivity. Amperage was standardized for effective power transfer and the electricity was cycled 25 seconds on by 5 seconds off. Sampling lasted for 10 minutes of "on pedal" in each transect and targeted open water. The boat path meandered between the center of the channel and the two-foot depth contour or outer edge of vegetation where channel width exceeded 50 meters. The entire navigable channel was covered where channel width was less than 50 m. Electrofishing direction was downstream with boat speed about 1-2 mph faster than ambient current. Two netters were used for all samples in the St. Johns River for catch per unit effort (CPUE) samples.

Fish collected were held live, processed between transects, and then released except when retained for biological sampling. Sex, total length (TL) (mm), and weight (g) were recorded for all *Alosa spp.* collected. From 2003 to 2005 scales and otoliths were retained but aging has not been attempted. River herring are present primarily in February and March so CPUE for the adult index is calculated from sampling conducted in these months.

18.10.3 Juvenile Surveys

18.10.3.1 Pushnet Survey

A bow mounted pushnet was constructed in 2006 to begin developing a juvenile abundance index for Alosa species in the St. Johns River, Florida. The sample gear consisted of a 5.3 m aluminum boat used to push a modified four panel Cobb trawl mounted on a rigid frame. The net opening was 1.2 m high X 1.5 m wide. The body was 3 m deep and constructed of 19 mm stretched mesh knotless nylon. The cod end was 2 m deep and constructed of 12.7 mm stretched mesh knotless nylon

Pushnet sampling was haphazard in 2006 while the gear was being tested for efficacy in the river. Sampling was expanded to cover the entire nursery zone during the spring, summer, and early fall of 2007 through 2009. The nursery zone was sampled monthly from March to September. Sampling consisted of 48 five-minute tows at randomly selected stations between Warner Point and Lake Harney which corresponds to river kilometers 125 and 305, respectively. The river was stratified into 10 km blocks with 3 samples selected in each block to ensure sample coverage throughout the nursery zone in a sampling month. Sampling occurred on four consecutive nights starting 45 minutes after sunset with 12 stations visited each night along a 40 km river reach. Juveniles appear to be most vulnerable to the gear for the longest period of time between Lake George and Lake Monroe. Therefore, a 40 km reach was selected from rkm 210 to 250 for annual monitoring (Figure 3). In 2010 this stretch was sampled biweekly from the end of March until September. Twelve stations were visited each night with three randomly selected in each 10 km block. The index is calculated as the geometric mean of April through July catches. A second sampling reach in tidal freshwater between rkm 125 and165 was added in 2011 (Figure 3) and bi-weekly sampling has occurred in this reach from April through July in each year since.

Distance pushed through the water was measured using a General Oceanics 2030R mechanical flowmeter mounted between the inner and outer vertical bars of the frame. Tow speed was standardized with the motor at 2000 rpm corresponding to a speed of approximately 2.6 statute miles per hour in still water.

Catch per tow was standardized to the average volume of a five-minute tow in the survey to date using the formula:

$$SC_i = C_i*(686m^3/V_i)$$

where SC_i = standardized catch in the ith tow. C_i = catch of the ith tow. V_i = volume of the ith tow and volume = net aperture area * distance towed.

18.10.3.2 Seine Survey

In 2010, Georgia Department of Natural Resources initiated juvenile Alosine sampling on the Altamaha, Ogeechee, and Savannah rivers to prepare for the implementation of ASMFC Amendment 3. Juvenile Alosines were sampled utilizing a 50' seine pulled along the edges of sandbars in each of the three rivers.

Low numbers of blueback herring are captured from the Altamaha and Savannah rivers each year during the seine survey. The highest geometric means recorded since 2010 were 1.8 herring/haul for the Altamaha River and 2.0 herring/haul for the Savannah River. No blueback herring have ever been collected from the Ogeechee River in the seine survey.

18.11 ASSESSMENT APPROACHES AND RESULTS

18.11.1 Relative Abundance

Adult herring were far more abundant in the St. Johns River, FL, 9.7 and 7.4 times, than American Shad in seine samples in 1972 and 1973 but shad were more numerous in modern electrofishing samples, often by greater than a factor of 10 (Figure 4) even though the American Shad population is at low abundance (McBride and Holder 2008). There is no trend in the CPUE of Blueback Herring in the electrofishing survey. The CPUE is low with a high standard error (Table 3). We do not know whether or not electrofishing is selective for American Shad relative to Blueback Herring or whether by focusing on the primary river channels sampling is missing areas where herring aggregate in this system. Winter-spring time electrofishing in small tributaries and along the littoral zones of larger lakes for other monitoring has not detected blueback herring. To date they are primarily encountered in the main stem of the river when electrofishing for American shad. Electrofishing CPUE has been low and without trend since 2003 (Table 3, Figure 4).

American shad were more abundant than Blueback Herring in all years of standard sampling (Figure 4). Tributary sampling to date has located mature blueback herring only in the Wekiva River and in Haw Creek at very low densities.

18.11.2 Trends in Juvenile Abundance

Previously, in the St. Johns River, FL, Williams et al. 1975 reported 355.3 and 268.3 Blueback Herring per seine haul during January – March in 1972 and 1973 respectively. Subsequent juvenile sampling in those years yielded 1,983 blueback herring in 1972 and 4,050 blueback herring in 1973.

The CPUE of juvenile Blueback Herring was greatest in 2006 during testing of the new gear in the rkm 210-250 river reach (Table 5). Since then, catches have been lower under the standard protocol with catches of juvenile American shad being similar to or exceeding the catch of blueback herring (Figure 5). The CPUE of YOY Blueback Herring has been erratic in the rkm 210-20 reach from 2006 through 2016 (Figure 5). There has been an increase in the CPUE of YOY in the tidal freshwater rkm 125-165 river reach during the 2007 to 2016 time (Figure 5).

While catch rates are not comparable between the different gears it is apparent that the proportion of each species present has changed. Juvenile herring were six to seven times more abundant than American Shad in 1972 and 1973 samples. Juvenile American Shad were as or more abundant than juvenile blueback herring in most years sampling with a pushed trawl. The geographic and temporal coverage was similar between the 1972-73 sampling and modern sampling. There is no reason to believe that the pushed trawl is more selective for American shad relative to herring than the surface trawls and seines used in 1972 and 1973.

18.11.3 Trends in Size

Blueback Herring collected from the St. Johns River, FL in 1972 and 1973 were larger than those collected in modern sampling (Table 4, McBride et al. 2010). Although the gears are different and were fishing different sections of the river there isn't reason to believe that either gear was size selective. Electrofishing tends to bias towards larger individuals when there is a measurable selectivity difference between sizes. The reduced mean length of adult blueback herring during 2001-2017 as compared to the runs in 1972 and 1973 could point to a demographic shift. Demographic change has recently been documented for an alewife *Alosa pseudoharengus* run. A comparison of Alewife from 1966-1967 to alewife from 2003-2006 in Bride Brook, Connecticut showed a reduction of mean length, mean age, age of recruitment, and the proportion of repeat spawners in the modern runs (Davis and Schultz 2009). Mean age of the run in Bride Brook declined from 5-7 year to 3-4 years. The mean size of blueback herring spawning in the St. Johns River in 2001-2016 corresponds to age 3-4 fish in the 1972 and 1973 runs during which 2.9% and 17% of males and 0.6% and 9.6%. of females were age 4 in those years. The majority of spawning herring in 1972 and 1973 were older than age 4. Such a shift in demographics can be the result of increased mortality.

We have no modern age data so we cannot confirm that the change in size is reflective of reduced growth or age truncation in the St. Johns River population.

Females were larger than males and both males and females were smaller than males and females collected in 1972 and 1973 (Table 4, McBride et al. 2010).

18.11.4 Trends in Lengths at Age

Length at age is reported in Williams et al. 1975 (Table 1).

18.11.5 Potential Sources of Increased Mortality and other Threats

No fisheries target blueback herring in Florida and Georgia. No fisheries are operating in the rivers that are likely to encounter blueback herring as bycatch. Any additional source of fishing mortality of sub-adults or adults is probably remote to the St. Johns River such as those in the Atlantic mackerel and Atlantic herring fisheries in the northeast (Harrington et al. 2005). The shrimp trawl fishery is the most likely fishery in Georgia waters that may inadvertently capture river herring. However, no bycatch of herring has ever been reported from this fishery.

New surface water withdrawals of up to 262 million gallons per day (mgd) for consumption are being sought from the St. Johns River basin to accommodate a projected population growth in the region from 4.4 million people to 7.3 million people by 2030. The withdrawal may reduce average daily discharge by 7.8 percent with 155 mgd projected to come from three locations along the spawning grounds of Blueback Herring and other Alosines. The effects of this withdrawal on water quality and ecology as well as possible impingement/entrainment of early life stages have been reviewed with recommendations made to avoid adverse impacts on Alosines (Miller et al. 2012a, 2012b).

Some of the water in the spawning and nursery habitats are currently considered impaired due to non-attainment of standards for several water quality parameters including nutrient loads and dissolved oxygen. Various actions are underway to attempt to mitigate these issues (Florida Department of Environmental Protection FDEP 2005). The trend in water quality during the last two decades has generally been a slow decline with chlorophyll a, total nitrogen, total phosphorous, and total suspended solids increasing in the middle St. Johns River (Keller et al. 2004). High water is commonly associated with dissolved oxygen levels well below 5 mg/l but high water typically occurs during September-November upstream of the nursery zone. The tidal freshwater portion from Lake George to the river mouth are also subject to summer and fall algae blooms and hypoxia events common in systems with high nutrient loading (Magley and Joyner 2008). It is not known if the downstream water quality is affecting the ability of juveniles to emigrate successfully in years when algae blooms are intense and persistent. Basin management action plans for implementation of TMDLs for relevant criteria have been established for the middle and lower St. Johns River (FDEP 2008, FDEP 2012). The BMAP for the lower river has resulted in some progress toward meeting nutrient TMDLs (FDEP 2013).

18.12 BENCHMARKS

Data are insufficient to establish a benchmark for Georgia or Florida.

18.13 CONCLUSIONS AND RECOMMENDATIONS

The reduced size of adults might indicate increased mortality remote to the St. Johns River. The age structure of the returning adults needs to be determined in order to establish whether the reduced size is a result of a change in growth or age structure of returning adults. Knowing the age structure of the spawning stock would also be helpful in determining if the JAI is reflective of year class strength.

Water quantity and quality are potential threats to both spawning success and juvenile growth and survival to out-migration in the St. Johns River. As noted in the habitat section, alosines spawn during the dry season in the St. Johns River when water levels are typically low. This may make them particularly sensitive to withdrawals. Data are needed on habitat selection by adults for spawning in order to assess how habitat might be affected by proposed water withdrawals and changes in average stage.

Juvenile monitoring should continue to assess whether any changes in water quality or habitat impact annual juvenile abundance.

There is no Blueback Herring fishery in Florida therefore there are no possible fishery interventions that would improve the population of Blueback Herring in the St. Johns River, Florida. The source of at-sea mortality needs to be determined and reduced and water quality problems within the St. Johns River should be addressed if blueback herring population of the St. Johns River is to increase.

Neither measure of adult or juvenile abundance is conclusive and it may be a stretch to base the assessment of Blueback Herring abundance on the relative abundance of Blueback Herring as compared to the relative abundance of American Shad in common samples. However, the low adult relative abundance of blueback herring in electrofishing samples corresponds to what appears to be low relative abundance of juveniles in trawl gear. Blueback herring were the most abundant alosine in the St. Johns River, Florida in past decades (Hale et al. 1985, Moody 1961, Williams et al. 1975). Taken in aggregate these indices do point to low blueback herring abundance relative to historic levels in the St. Johns River.

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Table 1. Mean total length (TL) at age as reported in Williams et al. 1975. Lengths here converted from fork lengths (FL) using the equation: TL = 1.1458*FL – 1.2495

	Female		Male	
Age	N	Mean TL	N	Mean TL
3			1	237
4	2	262	6	268
5	45	276	69	269
6	65	289	66	279
7	39	295	12	284
8	3	302		

Table 2. Mean catch per seine haul of blueback herring and American shad in 1972 and 1973. N is the number of nights. One to four seine hauls were made during a sampling night but Williams et al. 1975 only reports a mean catch rate for a given night and not the catch in each haul.

	blueback herring			American shad		
Year	N	Mean fish/haul	SE	N	Mean fish/haul	SE
1972	6	355.3	85.0	6	36.8	2.8
1973	6	268.3	36.5	6	71.3	13.7

Table 3. Electrofishing CPUE (geometric mean) of Blueback Herring on the spawning ground in the St. Johns River Florida during February and March. Few stations were visited over a short period of the spawning season in 2001 and 2002.

Year	Mean Catch per Sample	SE	Number of Stations
2001	4.63	0.32	16
2002	0.19	0.12	18
2003	0.20	0.06	60
2004	0.58	0.12	105
2005	0.11	0.03	124
2006	0.19	0.05	80
2007	0.11	0.04	81
2008	0.20	0.05	70
2009	0.32	0.07	90
2010	0.53	0.15	51
2011	0.16	0.07	54
2012	0.09	0.03	60
2013	0.44	0.08	70
2014	1.54	0.14	70
2015	0.86	0.12	80
2016	0.46	0.46	80

Table 4. Mean total length (mm) and mean weight (g) of male and female Blueback Herring collected from the St. Johns River. Mean weight for 1973 and 1972 is estimated by applying the weight/length relationships reported in Williams et al. 1975 to the lengths reported therein. FWC discontinued collection of weights in the field during routine monitoring of Alosa on the spawning grounds in 2011.

	Male					Female				
YEAR	N	LENGTH	SD	WEIGHT	SD	N	LENGTH	SD	WEIGHT	SD
1972	743	273		161.91		1322	286		218.31	
1973	939	266		150.93		1044	280		204.25	
2001	45	253	10.13	132.02	24.96	20	264	9.99	156.27	26.90
2002	2	255	21.21	135.65	31.18	4	267	9.81	157.30	19.62
2003	5	236	7.64	106.42	19.60	11	266	13.18	154.25	39.35
2004	92	250	7.43	126.12	19.54	103	260	7.55	141.98	19.08
2005	7	245	16.41	119.64	25.20	12	266	6.12	137.24	16.98
2006	23	242	10.98	106.71	18.36	14	257	6.98	135.79	20.58
2007	15	257	32.93	144.27	85.40	12	263	11.41	151.17	41.73
2008	21	250	8.28	130.86	15.69	14	257	8.73	151.29	19.11
2009	42	244	7.16	117.14	16.45	24	258	9.31	133.67	17.59
2010	61	250	7.05	123.34	18.44	25	263	8.18	159.56	28.48
2011	11	249	11.00			10	255	13.60		
2012	3	246	4.04			8	266	6.93		
2013	21	242	8.87			30	252	9.87		
2014	123	253	6.87			55	263	6.87		
2015	41	256	9.07			80	270	9.96		
2016	57	248	9.70			27	261	9.80		

Table 5. The geometric mean catch per tow of juvenile Blueback Herring collected by nocturnal pushnet during April to July from 2006 through 2016 in the St. Johns River, Florida between river kilometer 210 and 250.

Year	Number of hauls	Number of fish	Geometric Mean	SD	SE	Zero hauls
2006	22	349	10.04	1.83	0.39	1
2007	46	846	2.95	3.73	0.55	20
2008	48	209	1.41	2.15	0.31	32
2009	48	201	1.13	2.18	0.31	43
2010	96	522	1.23	2.36	0.24	59
2011	96	722	3.01	2.25	0.23	27
2012	60	96	1.07	0.92	0.12	20
2013	72	371	1.43	2.28	0.27	37
2014	60	1944	8.84	3.91	0.46	5
2015	72	133	0.67	1.19	0.14	42
2016	72	181	1.11	1.5	0.18	36

Table 6. The geometric mean catch per tow of juvenile Blueback Herring collected by nocturnal pushnet during April to July from 2007 through 2016 in the St. Johns River, Florida between river kilometer 125 and 165.

Year	Number of hauls	Number of fish	Geometric Mean	SD	SE	Zero hauls
2007	33	83	1.45	1.27	0.22	11
2008	48	118	1.21	1.23	0.18	16
2009	46	21	0.25	0.61	0.09	36
2010	12	43	1.55	2.02	0.58	6
2011	24	30	0.68	1.04	0.21	14
2012	60	176	0.91	1.55	0.20	32
2013	72	272	2.16	1.45	0.17	18
2014	96	953	3.35	2.80	0.29	29
2015	84	532	3.08	1.94	0.21	18
2016	72	1730	5.06	3.87	0.46	20

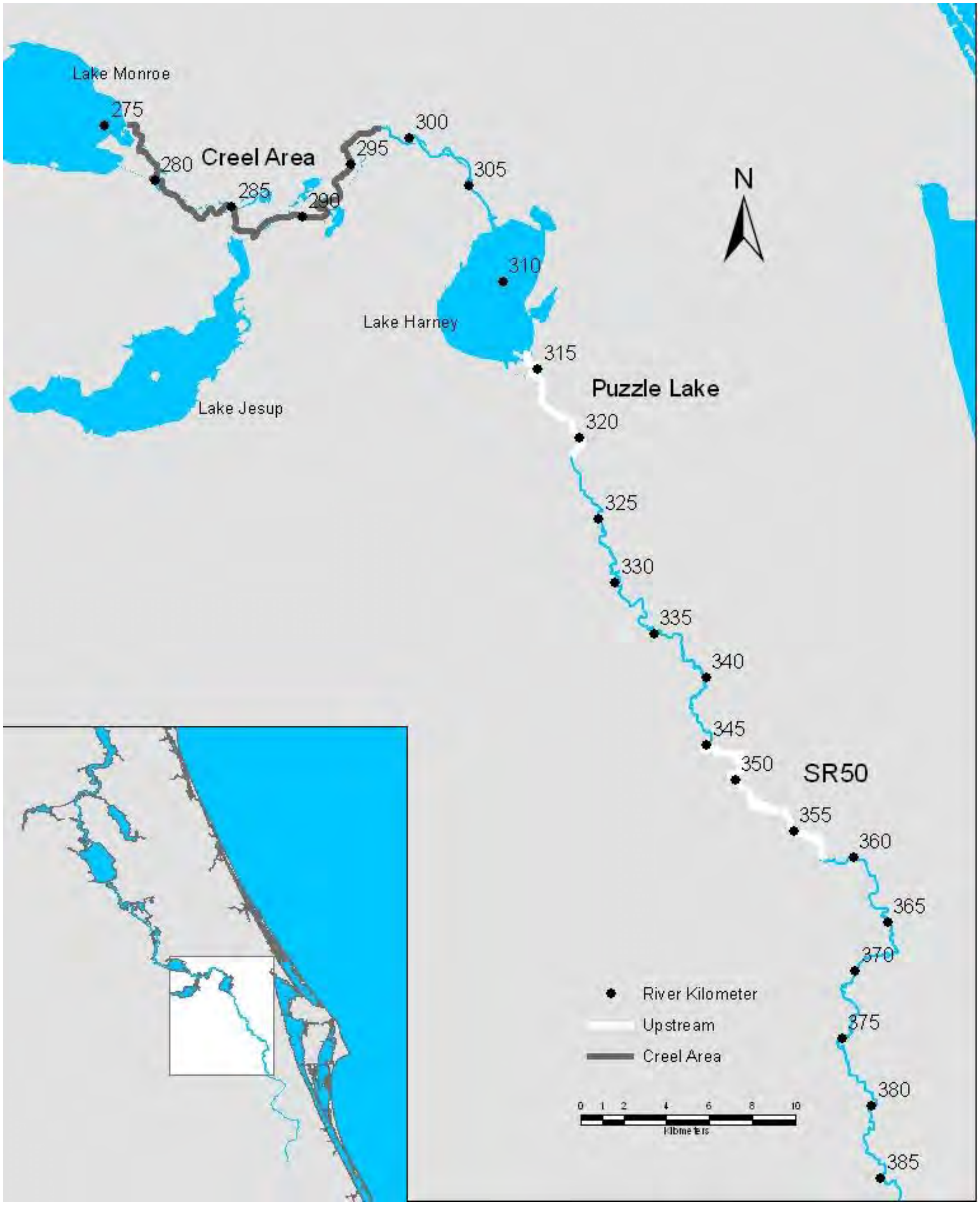


Figure 1. Map of areas sampled in the St. Johns River for monitoring of the spawning runs of adult American shad and other *Alosa* species. Numbers refer to kilometers upstream from the river mouth.

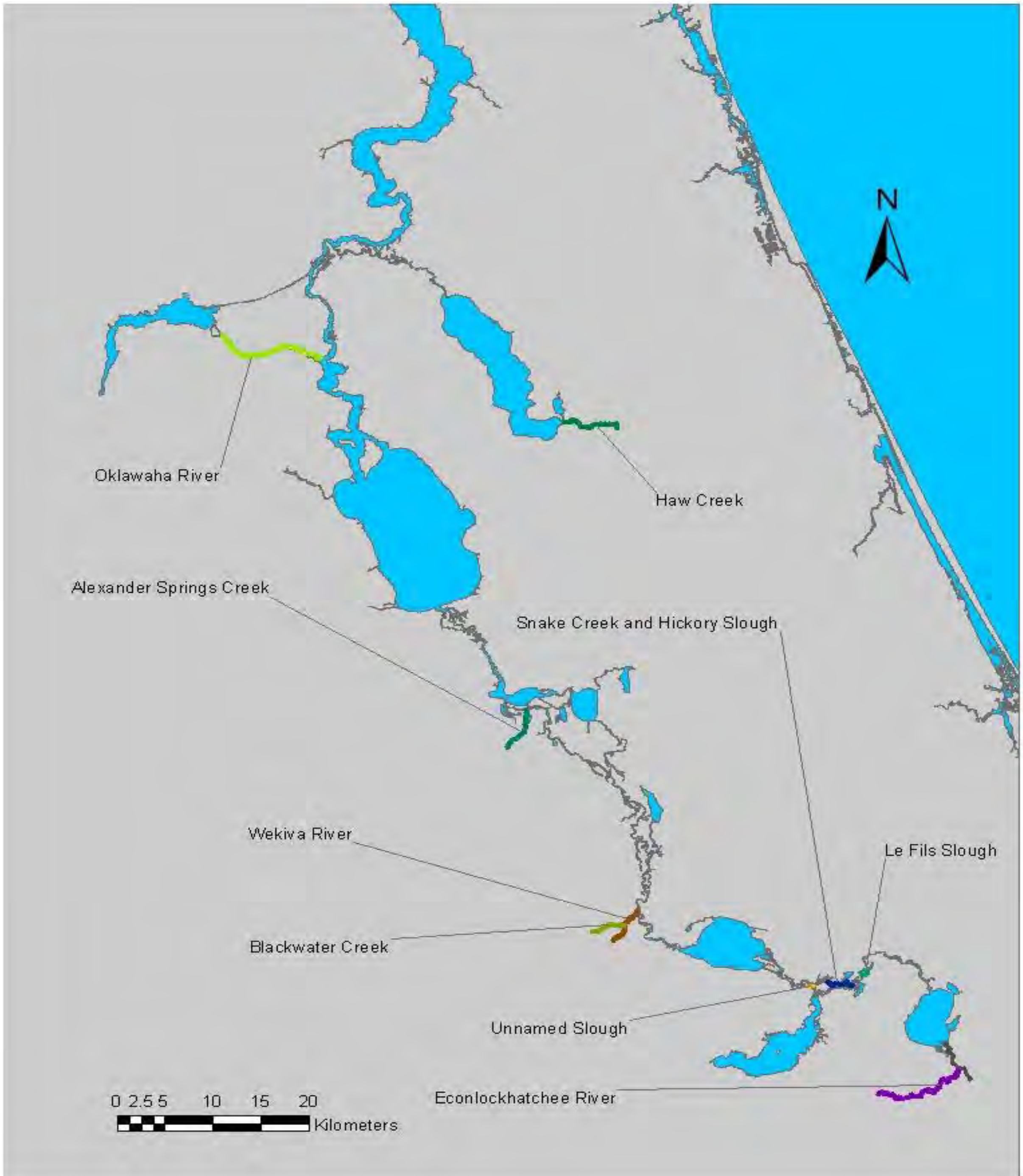


Figure 2. Map of targeted tributaries of the St. Johns River for monitoring of the spawning run of adult American shad and other *Alosa* species.

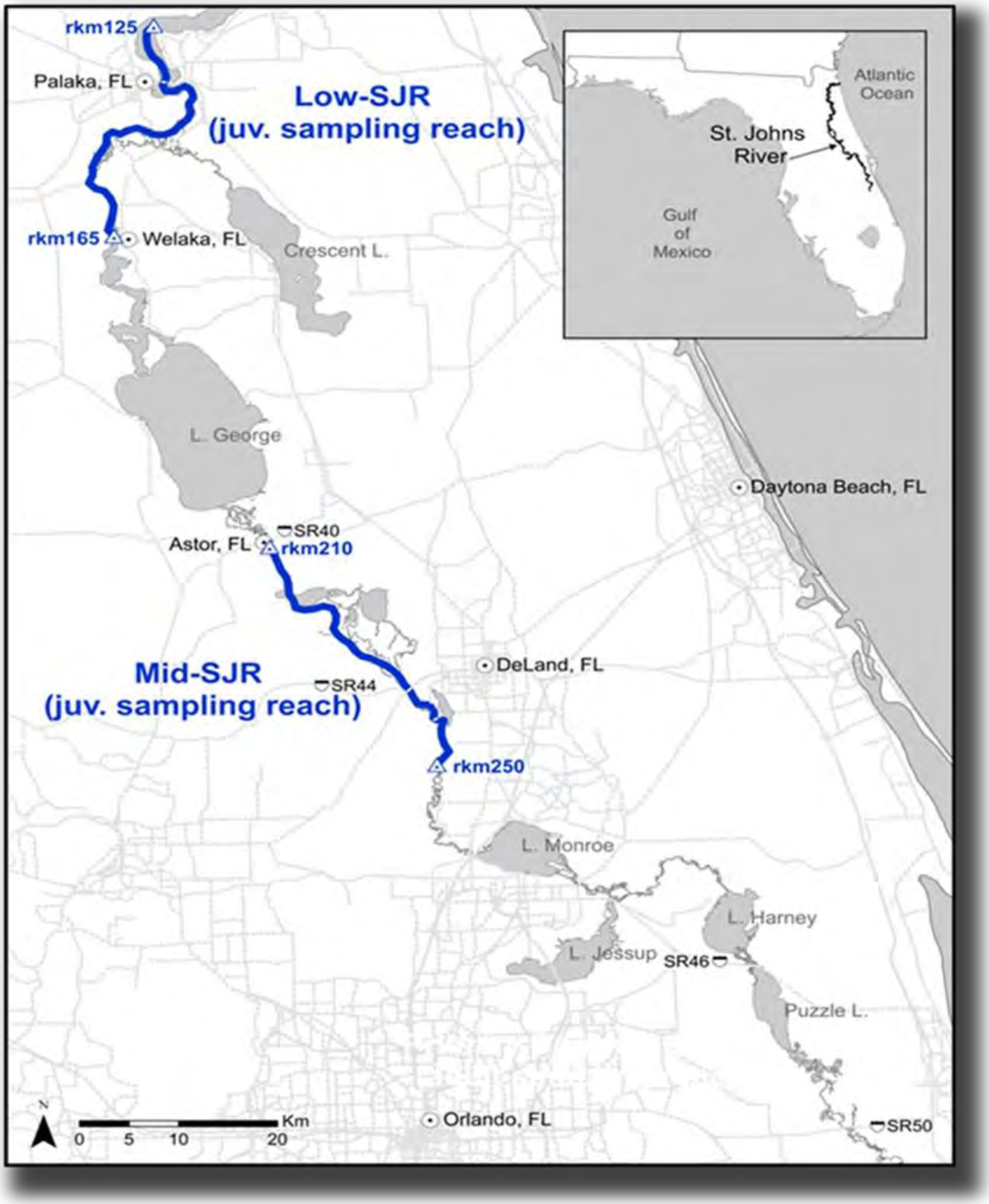


Figure 3. Middle and lower St. Johns River juvenile sample zones. Tidal freshwater extends from river kilometer 30 to Lake George. The "Low-SJR" sample reach is entirely in tidal freshwater. The river bottom of the reach between Lake George and Lake Monroe is below sea level but flow is dictated by river discharge with flow reversal only by wind driven sloshing in Lake George during period of very low discharge. The "Mid-SJR" sampling reach is a dark water river flowing between bottomland hardwood swamps.

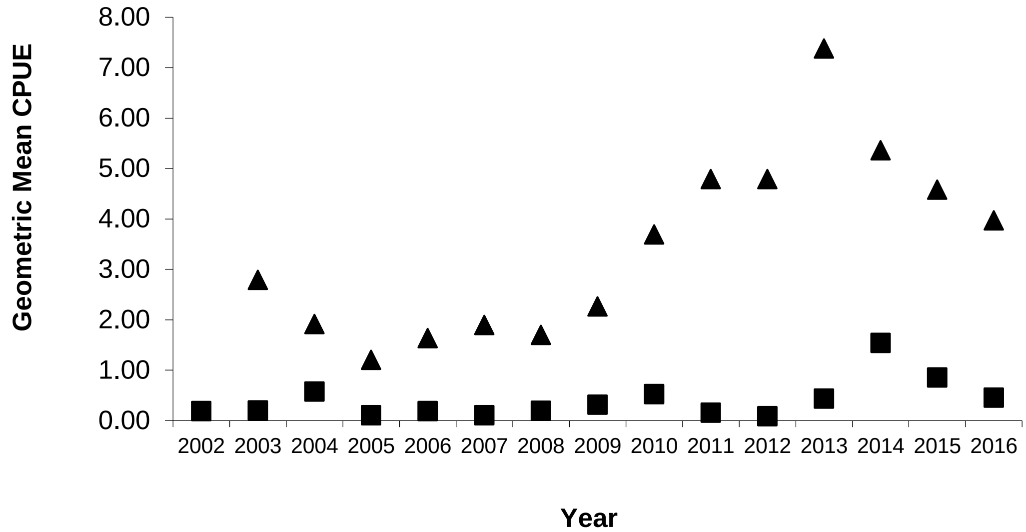
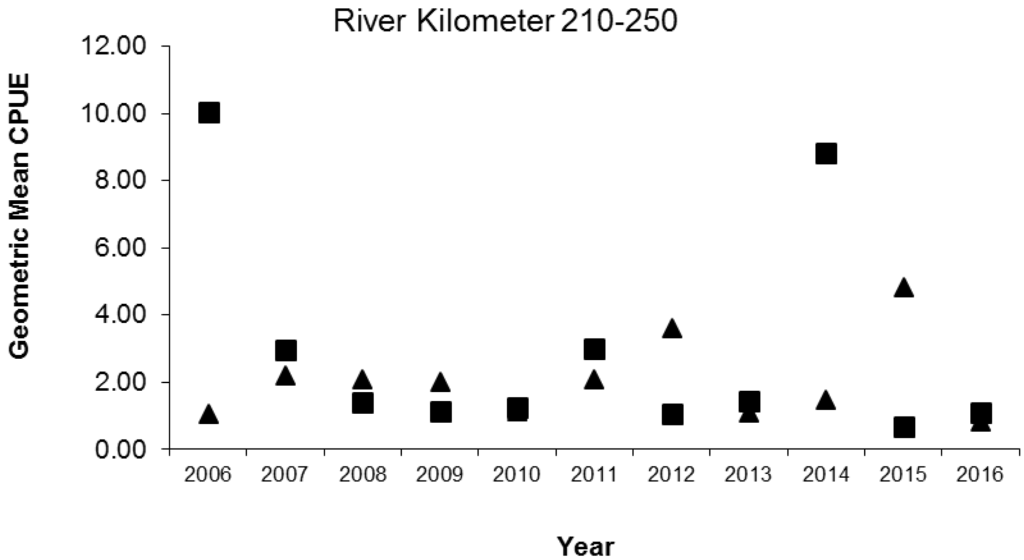


Figure 4. The geometric mean catch per sample of Blueback Herring (squares) and American Shad (diamonds) from standardized 10 minute electrofishing transects on the spawning grounds during January, February, and March in each year



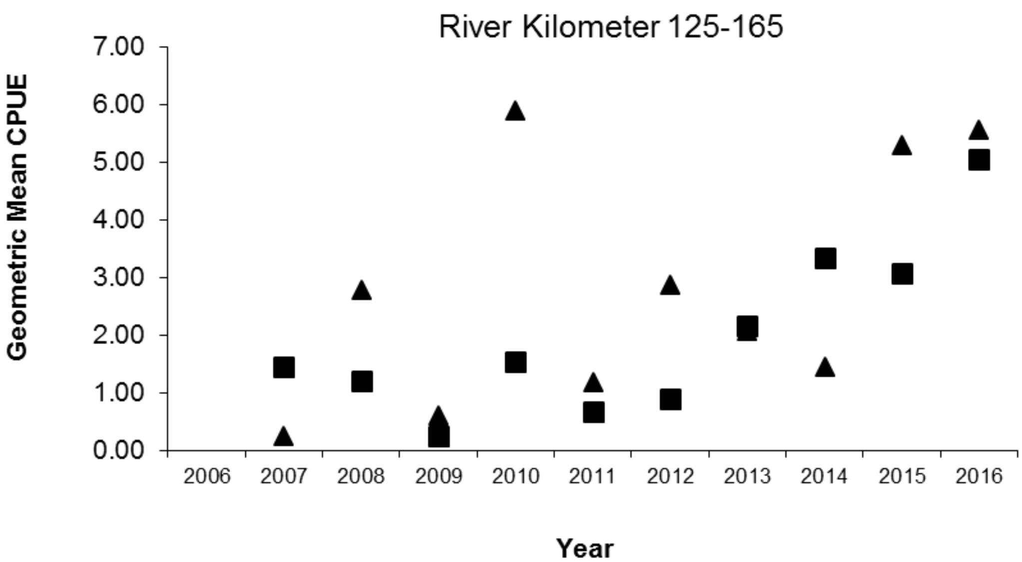


Figure 5. Geometric mean catch per 5-minute pushnet sample of juvenile Blueback Herring (squares) and American Shad (triangles) during April to July from 2006 through 2016 between river kilometer 210 and 250 and from 2007 through 2016 between river kilometer 125 and 165.

19 Trends in Alewife and Blueback Herring from the Northeast Fisheries Science Center Bottom Trawl Surveys

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Objectives

The Northeast Fisheries Science Center (NEFSC) bottom trawl surveys are conducted in both the spring and fall and sample from Maine through North Carolina (Azarovitz et al 1997). These surveys were used to investigate trends in alewife and blueback herring relative abundance and biomass, and mean length.

Methods

Data collected during the NEFSC bottom trawl surveys were used to derive seasonal relative abundance and biomass indices. The surveys follow a stratified random sampling design with strata defined primarily by depth and stations allocated approximately in proportion to stratum area (Azarovitz 1981). Inshore (8-27 m) and offshore strata (27-366 m) have been most consistently sampled by the research vessels *Albatross IV* and *Delaware II* since the fall of 1975 and spring of 1976. Prior to these time periods, either only a portion of the survey area was sampled or a different vessel and gear were used to sample the inshore strata (Azarovitz 1981). Accordingly, seasonal alewife and blueback herring relative abundance indices were derived from these trawl surveys for 1975-2015 in the fall and 1976-2015 in the spring.

Through 2008, standard bottom trawl tows were conducted for 30 minutes at 6.5 km/hour (3.5 knots) with the *Albatross IV* as the primary survey research vessel (Despres-Patanjo et al. 1988). However, vessel, door and net changes did occur during this time, resulting in the need for conversion factors to adjust survey catches for some species. Conversion factors were not available for net and door changes, but a vessel conversion factor for alewife was available to account for years where the RV *Delaware II* was used. A vessel conversion factor of 0.58 was applied to alewife weight-per-tow indices. Alewife number-per-tow indices did not require a conversion factor (Byrne and Forrester 1991).

In 2009, the survey changed primary research vessels from the *Albatross IV* to the *Henry B. Bigelow*. Due to the deeper draft of the *Bigelow*, the two shallowest series of inshore strata (8-18m depths) are no longer sampled. Concurrent with the change in fishing vessel, substantial changes to the characteristics of the sampling protocol and trawl gear were made, including tow speed, net type and tow duration (NEFSC 2007). Calibration experiments, comprising paired standardized tows of the two fishing vessels, were conducted to measure the relative catchability between the two vessel-gear combinations and develop calibration factors to convert *Bigelow* survey catches to *Albatross* equivalents (Miller et al. 2010). Species-specific calibration coefficients were estimated for both catch numbers and weights using the method of Miller et al. (2010) (Table 1). The calibration factors were combined across seasons due to low within-season sample sizes from the 2008 calibration studies (less than 30 tows with positive catches by one or both vessels).

Bottom trawl catches of the subject alosid species tend to be higher during the daytime due to diel migration patterns (Loesch et al. 1982; Stone and Jessop 1992). Accordingly, only daytime tows were used to compute relative abundance and biomass indices. In addition, the calibration factors used to convert *Bigelow* catches to *Albatross* equivalents were estimated using only catches from daytime tows.

Daytime tows, defined as those tows between sunrise and sunset, were determined for each survey station based on sampling date, location, and solar zenith angle using the method of Jacobson et al. (2011). Although there is a clear general relationship between solar zenith and time of day, tows carried out at the same time but at different geographic locations may have substantially different irradiance levels that could influence survey catchability (NEFSC 2011). Preliminary analyses (Lisa Hendrickson, NMFS – *unpublished data*) confirmed that river herring catches were generally greater during daylight hours compared to nighttime hours.

Relative abundance and biomass indices

Relative abundance (stratified mean number-per-tow) and biomass (stratified mean kilogram-per-tow) indices, as well as the proportion of positive tows were calculated for alewife and blueback herring using data from NEFSC spring (1976-2015) and autumn (1975-2015) bottom trawl surveys. Survey indices were developed for each species. For both seasons, survey indices were computed for the entire northwest Atlantic coast. For the spring survey, indices were also calculated separately for a northern set and a southern set of survey strata (Figure 127). The two strata sets were used to examine whether general trends in run count differences between northern and southern rivers along the U.S. Atlantic coast were apparent in NEFSC survey indices for similar regions. The geographic boundary between the northern and southern NEFSC survey regions reflects the monthly timing of the spring surveys with April as the median month of sampling in the north and March as the median month of sampling in the south. Also, the boundary between northern and southern regions roughly corresponds to the Hudson Canyon. In the spring of 2014, stations south of Maryland were not sampled due to delays in the survey. Accordingly, the spring survey index in this year is not based on all of the strata incorporated into other years. Fall surveys were not split into northern and southern regions because of very limited catches of river herring in southern strata.

Autoregressive integrated moving average (ARIMA) models developed in the benchmark assessment to assess trends in relative abundance were updated and are discussed in the coastwide assessment report.

Trends in size structure

Length frequencies were calculated seasonally (spring and fall) for the coastwide population as well as northern and southern regions separately. Trends in mean length (fork length, cm) of alewife and blueback herring were updated using a non-parametric Mann-Kendall test for a monotonic trend and are presented in the coastwide assessment report. Data used in this analysis included lengths from daytime tows only.

Age and Growth

Age data for river herring were only available for a limited time period from 1973 – 1987; therefore, von Bertalanffy growth models were not updated for the NEFSC trawl surveys because new data were not available.

Results

Proportion positive tows

The proportion of tows that encountered river herring was greater during the spring than the fall (Figure 128). During the spring survey, there was little trend in the coastwide proportions for alewife but those for blueback increased slightly over the time series. Furthermore, trends in the proportion of positive tows varied between regions. In the case of alewife, northern and southern regions tracked fairly consistently until the mid-1980s, at which point the northern region began to slightly increase, while the southern region showed a slightly decreasing trend (Figure 128).

In contrast, for blueback herring the southern region generally had a higher proportion of positive tows compared to the northern region until the late-1990s. In the early 2000s, northern and southern regions exhibited similar proportions of positive tows; however, the northern region exhibited a slightly higher proportion of positive tows from the late 2000's onward. Fall surveys showed little fluctuation in the proportion of positive tows compared to the spring surveys but generally increased slightly.

Relative abundance indices

Across all regions, alewife number- and weight-per-tow generally varied without trend until the mid-1990s (Figure 129 and Figure 130). In the 2000's, coastwide indices for both seasons as well as northern indices during the spring exhibited an increasing trend. The southern region did not exhibit a consistent temporal trend during the spring surveys, though the greatest catches occurred near the beginning of the time series. Indices since 2010 have exhibited notable interannual variability. Trends in blueback herring number- and weight-per-tow were similar to those for alewife (Figure 131 and Figure 132). Across both seasons, alewives were typically caught in greater abundances than blueback herring. Differences in relative abundance trends among regions could be a consequence of true regional differences in population trends or a distributional shift of the species.

Trends in size structure

Modes of length distributions varied through time for both species. Modes in alewife length frequencies ranged from 10 cm to 28 cm and tended to be slightly lower during the 2000s during coastwide spring surveys (Table 11) but this temporal pattern was not apparent during coastwide fall surveys (Table 12).

Modes in alewife length frequencies in the northern region during spring surveys were also lower during the 2000s (Table 13) but showed no temporal patterns in the southern region (Table 14). Modes in blueback herring length frequencies ranged from 7 to 25 cm and showed no consistent pattern temporally (Table 15 - Table 18).

Survey timing

The benchmark assessment indicated that the timing of the NEFSC bottom trawl surveys changed during 1975-2011. Linear regressions between median Julian day of sampling and year indicated significant relationships across both seasons and regions. Median Julian day significantly decreased with surveys occurring earlier in the year as the time series progressed. This variability in the timing of the trawl surveys may influence the availability of the species to the survey gear. However, across regions and seasons, there was not a consistent significant relationship between median bottom temperature at the time of sampling and year. In the northern region, the relationship between temperature and year was not significant, indicating that the median temperature when the northern region was sampled has not significantly changed even though the survey has occurred progressively earlier. In the southern region, median sampling temperature significantly increased over time in the fall but did not exhibit a significant relationship with year the spring.

Changes in the timing of the trawl surveys make interpretation of regional trends in relative abundance for anadromous species such as river herring difficult. Changes in relative abundance in northern or southern regions could be an artifact of the timing of sampling rather than true population changes. However, even though the median Julian day for the surveys has changed, the bottom temperature encountered while sampling has largely remained the same. One exception is the median temperature of the southern region in the fall; however, fall regional indices were not examined in this analysis. If river herring migratory behavior is governed by water temperature as it is for Atlantic herring (Maravelias and Reid 1997), observed trends in relative abundance may represent changes in river herring population abundance.

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Table 103: Coefficients and associated standard errors used to convert RV *Bigelow* catches of alewife and blueback herring to RV *Albatross IV* equivalents for the 2009-2011 NEFSC bottom trawl surveys.

	Number		Biomass	
Species	**Coefficient**	**SE**	**Coefficient**	**SE**
Alewife	1.05	0.16	0.72	0.11
Blueback herring	0.87	0.17	1.59	0.45

Table 11: Length frequency of alewives from the coastwide NEFSC bottom trawl survey during the spring.

Length	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3					2																																			
4																			1		1																			
5					1								1																											
6		2			1				1	3	4		13	6	1												2			1	5		1			2				1
7	1		7	3	1	1			7	5	6	3	18	27	16	5	3	2	11				2		7	6	4		20	9	25	2	4	31	1	35	1			14
8	7	2	27	8	23	2	1	2	17	7	5	16	5	22	35	22	4	6	39	4	5	5	10	5	78	7	6	10	60	53	59	6	19	89	4	63	12		7	44
9	33	6	63	32	85	1	6	3	43	16	9	13	20	16	37	43	5	35	51	9	6	4	19	6	225	22	5	32	166	102	115	21	51	235	57	167	75	2	19	145
10	27	3	76	18	182	3	31	2	57	18	6	11	33	13	31	31	17	62	52	13	14	11	32	14	363	22	9	112	190	264	208	26	70	239	73	278	175	9	30	193
11	17	13	42	25	207	5	39	1	45	18	15	2	15	5	23	27	24	92	47	9	11	27	63	8	387	32	11	224	163	246	301	22	72	253	90	1298	1756	24	95	119
12	15	4	58	61	419	12	69	2	56	17	11	6	19	7	23	42	20	85	53	14	20	33	97	25	267	84	13	276	91	161	415	17	75	189	55	838	3028	23	114	88
13	25	16	51	62	344	4	101	7	48	14	11	3	19	3	27	45	43	72	119	39	16	41	153	42	109	68	34	187	58	106	558	17	40	135	61	625	1897	49	67	94
14	16	11	80	59	247	3	39	8	30	11	11	5	22	8	22	39	48	98	118	21	24	47	178	135	89	48	28	15	38	93	678	14	28	109	158	201	1012	55	52	53
15	10	6	81	33	183	3	34	14	22	18	21	23	10	21	15	32	20	110	73	27	42	53	146	235	100	55	17	23	55	135	1920	40	66	132	551	180	319	82	71	88
16	6	6	83	27	151	8	23	38	19	30	25	21	17	29	22	24	17	131	39	28	93	34	176	214	35	65	39	25	67	107	1541	56	117	254	686	258	397	266	125	243
17	13	9	65	25	187	13	35	39	15	43	24	30	26	26	29	21	11	157	28	21	197	82	142	430	33	75	79	41	76	59	379	67	92	276	641	152	1303	1123	344	340
18	15	9	43	90	144	34	57	50	31	26	59	47	20	45	16	22	18	94	37	23	294	99	124	402	72	50	133	60	91	36	116	82	58	111	237	96	1208	1769	358	348
19	32	22	48	106	139	62	81	38	39	26	37	74	30	38	16	29	22	84	49	48	150	82	132	168	73	41	73	22	60	35	26	45	34	86	115	177	584	1193	293	191
20	50	22	68	77	117	114	85	29	29	56	38	104	28	31	23	19	134	115	61	82	208	67	119	289	66	34	58	29	66	28	27	48	79	83	133	231	432	470	292	140
21	60	44	59	55	116	99	46	41	26	47	41	96	31	17	30	12	119	76	46	55	159	180	89	150	46	65	119	39	137	34	26	74	67	89	134	127	251	415	397	176
22	72	61	50	61	132	101	64	46	11	35	47	81	25	14	16	27	94	36	48	90	160	182	107	273	66	67	111	68	135	53	25	74	64	92	76	85	158	333	413	261
23	87	79	55	113	145	113	87	36	29	29	49	60	18	10	17	53	92	24	70	94	219	257	171	293	69	46	115	112	43	53	11	68	33	115	53	91	153	263	217	164
24	118	107	55	151	148	134	82	39	34	13	46	54	24	18	28	151	75	33	38	77	210	313	144	205	79	100	108	90	41	71	9	46	37	147	52	63	117	80	127	216
25	131	100	83	262	108	162	94	47	46	15	57	60	16	22	44	97	102	28	31	68	178	123	58	109	50	94	119	89	37	46	11	34	26	127	40	62	121	56	67	175
26	96	163	134	289	160	124	69	54	57	21	55	130	14	30	27	53	40	19	12	35	53	67	31	41	35	53	71	77	55	27	8	23	19	45	21	20	52	47	13	88
27	93	138	139	264	185	127	78	70	45	26	49	54	15	42	41	17	24	17	7	23	20	15	16	18	8	29	28	55	23	17	2	6	8	20	11	13	33	12	5	62
28	84	82	78	238	179	89	47	57	25	16	27	21	8	49	41	21	21	5	6	5	9	15	4	13	2	7	4	11	9	9	1	3	3	7	4	4	8	2	4	13
29	40	37	34	127	69	67	31	36	21	13	10	17	3	16	21	6	10		2	2		2	2	2	1	1	4	5	1	1	2			2			1	3		2
30	17	21	16	48	73	46	26	20	4	7	6	9	1	4	9	3	7	1		1	1	1											1			1				2
31	6	5	2	28	32	18	5	15	2	2	2		2	1	1	1	2				1																			
32	1	1	4	6	7	12	5	6	1		1																													
33		2	1	2	1	3								1																										
34					1	1	3					1	1		1																									
35						1																1																		
36			1		2											1					1																			
37									1																															
46															1																									
47		1																																						

Table 105: Length frequency of alewives from the coastwide NEFSC bottom trawl survey during the fall.

Length	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
8																																							1		
9																																							4		
10																															1				9				6		
11									2						5				1					4											51	8	46		46		
12									2						49			3	4			3		17							2			1	257	16	2		91	3	
13				2					6						147			16	55			3	1	41					1		11				350	42	214		170		55
14					1		1		2	10				2	148			8	64			1	2	91				5		18	40			5	295	61	177		28	25	471
15				11		135	9	12	3	6	1			8	123			4	23			2	2	131	6	17		19	1	30	93		6	28	310	94	162		96	78	818
16				6	1	272	48	12	13	36	9		3	9	15	6	23	4	11		4	5	10	84	30	50	2	70		43	142	19	25	28	174	69	169	12	212	129	1110
17				22		100	43	15	41	26	31	2	8	32	26	16	93	36	10	4	2	5	19	158	47	47	4	37	10	47	122	123	24	35	116	62	440	122	268	182	709
18		6	2	48	4	19	14	12	27	9	63	16	19	38	47	14	72	88	40	7	29	4	24	258	26	71	26	27	34	74	144	278	12	79	258	125	421	191	160	329	534
19		11	1	54	3	7	4	10	12	4	48	12	21	61	70	5	25	83	64	34	81	2	30	210	30	17	50	31	36	44	101	115	15	91	422	230	1124	217	283	404	1150
20		30	5	33	5	17		2	8	2	38	8	17	51	84	11	10	133	101	193	373	3	17	159	7	35	27	25	47	16	44	95	22	97	243	193	513	388	285	478	837
21	1	55	11	35	2	13	6	4	3	6	50	13	8	72	69	26	11	29	109	211	419	11	14	79	7	93	21	38	44	22	51	55	35	26	141	115	199	424	164	690	452
22	2	39	17	47	11	21	39	1	1	4	80	16	11	47	121	52	8	41	44	181	327	13	25	62	8	185	26	100	34	50	39	80	21	61	59	77	261	243	141	832	271
23	27	26	17	58	12	27	93	1	3		94	10	16	34	128	57	5	33	11	74	262	20	22	19	20	331	20	154	32	64	34	93	39	90	17	61	215	177	89	632	244
24	50	12	26	46	17	74	67	4	5	1	68	13	17	37	88	31	5	25	14	88	145	14	7	15	6	256	30	249	39	49	48	114	43	84	11	65	226	98	83	602	148
25	58	7	21	40	28	79	73	5	11		76	27	4	48	44	30	3	10	7	47	57	8	5	15	3	140	55	218	35	16	26	77	34	45	13	36	90	87	70	399	110
26	30	4	20	36	48	93	39	3	1	1	42	17	8	22	13	13	9	8	1	12	34	2		6	5	71	33	128	25	8	9	29	11	39	5	22	45	36	34	150	65
27	9	2	17	33	30	46	16	3	2		12	7	9	14	6	4	5	4		9	12		4	1	3	3	7	73	15	5	4	4	6	15	3	9	25	28	12	78	25
28	5	3	9	24	25	27	39	1	2	2	2	7	6	5	6	3	2	1	1		4					4	2	20	4	1	4	12	1	3	2	5	9	9		27	10
29	1		1	8	15	31	20		3		2	3	1	2	2	3		1		1	1						1	4		1	2			1			1			2	3
30	4		2	6	4	12	7		3	1	2	3	3			1	1	1													1			3							
31				2	2	9			1				1					1																							
32						1				2		1	1																												
33																										3															
34												1																													
36																										3															
38								1																																	

Table 13: Length frequency of alewives from the NEFSC bottom trawl survey in the northern region during the spring.

Length	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
3					2																																			
4																			1		1																			
5					1								1																											
6		1			1				1	3	4		13	6	1												2			1	5		1			2				1
7	1		7	3	1	1			7	5	6	3	18	27	16	5	3	2	2				2		7	6	4		20	9	25	2	4	31	1	35	1			11
8	7	2	27	8	23	2	1	2	17	7	5	16	5	22	34	22	4	5	26	4	3	5	10	5	78	7	6	10	60	53	59	6	19	89	4	63	12		7	42
9	33	5	56	32	85	1		3	43	16	6	13	20	16	37	43	5	35	47	9	3	4	19	6	225	18	5	32	166	102	115	21	51	235	57	167	75	2	19	143
10	22	3	75	18	182	3	1	1	56	16	4	11	33	10	30	31	14	61	49	7	9	10	32	14	363	17	9	112	190	264	208	26	70	239	68	278	175	9	26	185
11	13	13	40	25	207	5	4	1	44	17	13	2	15	4	23	27	24	78	41	7	6	27	62	8	387	22	11	224	163	246	300	22	72	253	77	1298	1756	20	31	116
12	13	4	57	61	419	12	15	2	56	16	8	6	19	7	23	42	20	62	33	14	15	33	94	25	267	35	13	275	91	161	414	16	75	189	43	838	3028	19	28	86
13	23	16	46	62	344	4	24	6	47	12	10	3	19	3	27	45	43	44	30	38	9	40	146	42	109	21	34	187	58	106	557	17	40	135	41	619	1897	35	37	90
14	15	11	73	59	247	3	15	4	28	10	11	5	22	7	22	39	48	51	24	20	16	47	169	135	88	39	28	15	35	93	678	14	25	106	145	174	1012	55	24	49
15	8	6	80	33	183	3	14	4	20	16	21	23	10	17	15	32	20	41	23	24	21	53	135	234	97	51	17	23	54	135	1920	40	38	127	546	157	319	68	36	85
16	3	5	82	27	150	8	18	14	19	25	24	21	17	25	22	23	15	33	14	24	44	34	170	213	35	65	39	25	62	103	1541	56	62	213	677	234	397	253	117	243
17	9	7	64	21	161	10	15	4	11	34	17	24	25	18	27	20	11	42	17	18	38	79	127	428	32	75	79	41	53	47	379	67	39	248	640	141	1303	1123	339	338
18	13	8	42	66	85	17	12	11	30	18	16	28	20	20	16	21	15	34	25	19	39	98	74	398	70	48	133	58	39	24	115	82	44	105	232	87	1207	1679	355	346
19	25	20	44	74	38	35	21	12	36	19	14	45	30	13	15	28	22	30	44	36	28	76	55	165	64	40	73	21	34	12	26	45	31	76	103	141	578	922	291	189
20	45	19	62	46	20	61	19	15	28	54	21	63	28	15	19	16	128	22	50	63	104	51	62	287	57	34	57	29	46	11	22	47	65	76	106	186	430	181	278	133
21	51	42	54	37	9	39	17	31	23	46	30	50	31	12	25	10	109	10	44	46	116	155	50	148	38	59	119	33	39	7	20	72	53	78	111	115	250	181	336	162
22	48	54	46	17	11	16	31	31	7	33	34	36	25	12	13	22	74	12	46	74	132	163	43	260	45	54	109	64	27	7	21	73	54	79	66	65	158	228	287	232
23	58	73	34	15	6	7	55	14	18	25	30	26	17	8	8	47	75	9	60	78	188	236	68	272	43	34	107	75	16	20	10	63	28	92	50	80	153	183	151	147
24	42	79	28	17	13	7	58	5	8	9	33	17	19	14	17	143	56	21	36	64	188	299	65	162	63	80	78	50	19	38	7	41	26	117	47	58	115	64	98	178
25	32	64	46	35	35	16	68	9	9	12	30	24	9	15	29	87	93	19	22	54	167	116	24	86	41	80	94	48	29	18	9	28	24	101	38	55	121	42	47	145
26	28	81	88	55	94	23	51	8	9	11	37	77	11	18	23	46	30	16	11	31	50	64	12	29	31	45	55	48	30	8	8	18	13	33	21	17	52	35	10	79
27	20	81	96	51	99	38	57	18	9	15	35	15	13	23	36	11	19	14	6	21	20	13	8	15	7	25	21	40	17	5	1	2	5	19	11	13	33	12	5	58
28	13	53	60	61	135	38	32	11	5	10	19	8	7	28	36	15	19	4	5	4	8	15		10	2	6	4	10	8	1	1	3	2	5	4	4	7	2	4	13
29	10	30	32	43	60	34	20	4	1	7	8	5	3	11	18	4	10			2		2	2	2	1	1	3	4	1	1	2			1			1	3		2
30	8	18	15	20	68	23	21	3		4	5	4	1	1	7	2	5	1		1	1	1											1			1				2
31		5	2	11	32	8	5		2	2	2		2		1		2				1																			
32	1	1	3		7	7	2		1																															
33		2	1	2		3								1																										
34					1	1	3								1																									
35																						1																		
36			1		2											1					1																			
37									1																															
46															1																									
47		1																																						

Table 14: Length frequency of alewives from the NEFSC bottom trawl survey in the southern region during the spring.

Length	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
6		1																																						
7																			9																					3
8															1			1	13		2																			2
9		1	7				6				3								4		3					4														2
10	5		1				30	1	1	2	2			3	1		3	1	3	6	5	1				5									5				5	8
11	4		2				35		1	1	2			1				14	6	2	5		1			10					1				13			4	64	3
12	2		1				54			1	3							23	20		5		3			49		1			1	1			12			4	86	2
13	2		5				77	1	1	2	1							28	89	1	7	1	7			47					1				20	6		14	30	4
14	1		7				24	4	2	1				1				47	94	1	8		9		1	9			3				3	3	12	28			28	4
15	2		1				20	10	2	2				4				69	50	3	21		11	1	3	4			1				28	5	5	24		13	35	4
16	3	1	1		1		5	24		5	1			4		1	2	98	25	4	49		6	1					5	4			55	41	9	25		13	9	
17	4	2	1	4	26	3	20	35	4	9	7	6	1	8	2	1		115	11	3	159	3	15	2	1				23	12			53	28	1	10			5	2
18	2	1	1	24	59	17	45	39	1	8	43	19		25		1	3	60	12	4	255	1	50	4	2	2		2	52	12	1		14	6	6	9	1	90	3	2
19	7	2	4	32	101	27	60	26	3	7	23	29		25	1	1		54	5	12	122	6	77	3	9	1		1	26	23			3	10	12	35	6	271	2	2
20	5	3	6	31	97	53	66	14	1	2	17	41		16	4	3	6	93	11	19	104	16	57	2	9		1		20	17	5	1	14	7	27	45	2	289	14	7
21	9	2	5	18	107	60	29	10	3	1	11	46		5	5	2	10	66	2	9	43	25	39	2	8	6		6	98	27	6	2	14	11	23	12	1	234	61	13
22	24	7	4	44	121	85	33	15	4	2	13	45		2	3	5	20	24	2	16	28	19	64	13	21	13	2	4	108	46	4	1	10	13	10	20		105	126	29
23	29	6	21	98	139	106	32	22	11	4	19	34	1	2	9	6	17	15	10	16	31	21	103	21	26	12	8	37	27	33	1	5	5	23	3	11		80	66	17
24	76	28	27	134	135	127	24	34	26	4	13	37	5	4	11	8	19	12	2	13	22	14	79	43	16	20	30	40	22	33	2	5	11	30	5	5	2	16	29	38
25	99	36	37	227	73	146	26	38	37	3	27	36	7	7	15	10	9	9	9	14	11	7	34	23	9	14	25	41	8	28	2	6	2	27	2	7		14	21	29
26	68	82	46	234	66	101	18	46	48	10	18	53	3	12	4	7	10	3	1	4	3	3	19	12	4	8	16	29	25	19		5	6	11		3		12	3	9
27	73	57	43	213	86	89	21	52	36	11	14	39	2	19	5	6	5	3	1	2		2	8	3	1	4	7	15	6	12	1	4	3	1						4
28	71	29	18	177	44	51	15	46	20	6	8	13	1	21	5	6	2	1	1	1	1		4	3		1		1	1	8			1	2			1			
29	30	7	2	84	9	33	11	32	20	6	2	12		5	3	2			2								1	1						1						
30	9	3	1	28	5	23	5	17	4	3	1	5		3	2	1	2																							
31	6			17		10		15						1		1																								
32			1	6		5	3	6			1																													
33					1																																			
34												1	1																											
35						1																																		

Table 15: Length frequency of blueback herring from the coastwide NEFSC bottom trawl survey during the spring.

Length	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
5																			1	
6										1	3		1			1			7	13
7				1	13	1		3	7	6	16		4		4			3	20	20
8	1		9	8	82	23	27	10	4	48	41		4	1	3	6		8	60	85
9	4	1	71	26	192	169	44	19	25	103	48	1	31	3	2	3		10	38	42
10	16		70	37	187	60	13	24	23	72	10		33	17		8		59	25	14
11	7		25	42	153	8	16	32	12	38	3	1	21	18		3	10	52	22	10
12	10		24	39	122	17	24	25	15	23	3		12	15	2	12	31	56	29	31
13	12	2	28	23	65	5	16	4	17	28		1	11	5	6	14	46	21	8	24
14	2	2	39	36	66	16	3	5	9	37		3	26	3		6	90	32	3	14
15		5	26	50	88	81	8	2	25	12	15	15	19	9	2	2	111	63	11	8
16	4	26	12	173	42	125	20	5	53	22	12	14	11	13	2	4	132	101	14	13
17	5	37	5	424	30	82	15	20	138	69	48	48	9	22	8	12	43	81	7	10
18	13	68	7	225	33	51	14	65	248	38	33	55	7	21	40	13	10	54	4	9
19	15	59	14	77	21	31	7	52	92	19	18	48	4	5	37	3	1	49	4	12
20	19	19	16	76	9	26	4	37	31	10	15	63	4	2	42		5	14	12	7
21	34	6	28	327	14	66	10	31	27	10	4	29	1	2	12	2	2	3	19	16
22	18	11	25	454	21	92	3	13	35	8	4	22	6	4	7	1	4	2	15	14
23	19	14	13	410	26	36	7	12	31	14	3	22	2	1	1		19	3	11	16
24	12	15	17	239	30	14	15	10	40	29	1	20		2	1	1	24	1	11	12
25	8	15	18	188	46	10	11	13	27	35	1	12		2		4	17		18	8
26	1	8	47	163	32	12	5	13	22	19	2	14	1	2		1	19	1	9	9
27	2	3	44	133	12	7	10	8	17	6	2	7	2		2	3	13	1	10	
28		1	23	41	17	9	3	5	4	5	5	4		1	1		10		1	
29		1	8	50	6		3	1	5	3	4	1								1
30	1		2	21				1	2	4					1					
31																				
32			1					1								1				
33											1					3				
34			1													1				
35			1																	
36			1													3				
37			1																	

Length	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
5																				
6			8					3			11		1	1						
7	8	4	34	5				28		9	104		62	5	3	3				5
8	67	21	82	19		2		21	18	27	102		29	18	17	8			1	13
9	48	32	42	18	8	3		32	24	28	173	4	63	25	24	7				55
10	33	46	27	9	10	2		15	27	9	295	2	46	32	29	16	16	1	2	31
11	23	49	23	2	8	3	1	10	24	7	436	7	29	39	18	52	60	6	21	17
12	20	36	16	25	14	10	1	17	24	37	371	7	11	28	23	36	883	10	24	22
13	17	10	9	13	8	28	1	51	24	65	316	12	19	30	45	20	1011	29	32	64
14	22	2	8	17	7	52	1	64	17	58	288	12	11	39	24	138	472	31	23	59
15	32	2	15	41	6	21	1	99	12	35	415	6	6	72	36	28	28	41	18	41
16	45	3	10	28	1	27	9	32	24	13	210	7	6	146	80	30	17	69	15	77
17	64	11	7	17	6	8	8	14	19	15	69	38	6	160	57	30	54	136	71	62
18	37	14	10	16	16	7	8	21	45	22	45	55	6	134	28	18	31	123	119	98
19	16	11	8	15	16	6	10	4	35	11	9	12	12	123	67	46	243	185	265	149
20	6	15	1	27	18	7	5	6	22	11	10	7	24	155	64	37	374	80	368	94
21	6	19	2	19	13	3	11	16	35	2	6	19	18	362	105	44	117	80	288	41
22	6	26	1	13	28	7	11	17	23	2	3	20	30	278	82	55	98	93	118	53
23	5	42	1	12	38	7	44	8	20	3	2	24	12	59	52	67	46	110	51	71
24	12	21		12	66	13	24	17	4	5		6	2	31	24	33	8	48	24	45
25	6	11		11	61	4	11	7	7	4		5	5	13	7	6		8	16	16
26	5	2		9	19		1	3	4	2	1		1	2	1			1	1	5
27	6			1	3	1		1		1								3	1	
28		1	1	2	1															
29				1																
30	2	1																		
31	1																			
32																				
33																				
34																				
35																				
36																				
37																				

Table 109: Length frequency of blueback herring from the coastwide NEFSC bottom trawl survey during the fall.

Length	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1989	1991	1993	1994	1995	1996
9																			
10																			
11																			
12																			
13				4											1				
14				2		3									22				
15				4		66									9	1			
16				4		46										5	1		
17				24		13				1						6	2		
18				31	1	3		1				1							
19				33		3						1					1		
20				32							2	2					3	12	
21				12		1					2					1	9	47	
22	1		3	7							1	2				1	12	18	
23	1		2	4	1						2		3				3	18	
24	3		6	6	1					1	2	1	3		1		3	6	1
25	2		15	8						1	1	2	5	1				6	
26	3	1	34	1			1				1	2	5	2	2				
27	4		29	4	3				2		3	2							
28	2		23	1					1			1							
29			5	4					1		1								
30			2	1															
31			1	1															
33				1															

Length	1997	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
9												1				7			
10												85				6			
11												360				9			
12				1			1			1		195	1	2		16		8	
13	1						11			2	1	39		8		7		37	
14				3			53	2		2	1	8		62	2	6		56	6
15				1			47	1			3			53		6	1	67	7
16	1			16			7	1			2	5		64		3	8	61	6
17				10				2	5	6	1	65	9	270	8	7	18	25	
18	2			6			2	4		3	2	144	22	392	56	3	84	16	2
19	1		1	8	2			7		2	10	231	37	101	31	17	84	82	11
20	3		1	4		2	1	4	5	3	14	150	41	168	7	31	139	86	15
21	7	1	4	2	6	20	5	7	9	11	16	235	33	289	44	39	444	63	38
22	5		3		42	32	3	10		4	2	45	24	191	74	26	1139	130	207
23	2		17	6	96	26	2	3	3		8	61	10	129	45	14	1223	113	178
24	4		12	6	111	23	3	2	7		6	2	1	69	20	3	788	46	130
25	1	3	4	7	78	9			1		4		1	7	9	1	214	34	108
26	2		1	3	6	3		1	1						3	1	47	9	55
27				1	1		3				1							2	21
28																			
29																			
30																			
31																			
33																			

Table 110: Length frequency of blueback herring from the NEFSC bottom trawl survey in the northern region during the spring.

Length	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
5																			1																					
6										1	3		1			1			6	13			8					3			11		1	1						
7				1	13				7	5	13		4		4			2	7	20	2	4	34	5				28		9	104		62	5	2	3				3
8			1	8	82		1	3	1	32	1		2	1	3	6		8	26	82	15	20	82	18		1		21	18	26	99		27	18	14	8			1	8
9			3	26	187		3	2	15	63		1	22	1	2	3		8	12	38	3	31	42	18	8	3		31	14	26	173	4	63	24	10	7				49
10	1		11	37	185		3	1	19	69			29	7		8		23	16	12	10	45	27	9	10	2		14	15	8	295	2	45	32	18	16	16		2	24
11	3		23	41	151	1	9	6	12	36	1	1	13	7		3	1	7	17	9	8	49	23	2	8	3	1	9	13	7	433	7	28	39	15	52	60	1	20	16
12	6		20	37	122	3	16	13	11	21	1		8	5	1	12	6	9	22	30	3	36	16	25	14	10	1	16	20	37	370	7	11	28	18	36	883	7	24	14
13	5	2	28	23	65	1	8	2	11	28			7	3	6	14	5	15	4	24	7	10	9	13	7	28	1	46	17	65	314	12	17	30	45	20	1011	23	30	20
14	1		39	30	66		3	2	9	25		1	19	1		6	1	16	3	12	13	2	8	17	7	52	1	61	16	58	288	12	10	39	24	138	472	31	23	14
15			25	19	85		2	1	10	6	2	2	15		2	2		9	5	5	13	2	15	41	6	21	1	97	9	34	414	6	5	68	36	28	28	41	18	26
16		1	11	5	41		1	1	4	7	2		9			1	1	7	3	7	6	3	10	27	1	27	9	29	11	10	209	3	5	111	80	30	17	62	15	77
17	3		3	17	17			3	1	12	2	3	7				1	4	1	5	1	2	7	13	5	8	8	7	5	5	69	14	1	99	55	14	54	92	63	57
18	7		2	29	11			3	1	14	1	4	5	2	1		3	7	1		2		8	11	9	7	8	3	7	7	45	16	2	22	14		14	45	48	72
19	7		4	23	9		1	2	1	13	2	4	3			1	1	5					7	8	13	2	8		5	1	7	6	2	28	34	18	16	39	100	110
20	2	2	1	10	3			1	6	3	1	3	1					2			1	2		9	10	6	4	3	1		3	2	2	11	28	9	33	51	297	82
21	3	1	2	2			1		14	1		3	1	2						2	4	1	1	4	2		4	3				4	4	8	22	10	18	69	246	28
22	1	1		4	1		1		10			1							1	1	4	1	1	7	1	1	5	1				6	11	7	9	11	20	37	86	7
23	3	1	1	8			1				2										3			5	1		9	1	2	1		9	4	3	6	8	8	24	39	3
24			7	9	3		3				1					1			1		8			8			3	1	1	2		4	1	3	5		5	7	11	2
25	1		8	7	1		2	1								3			9		4			7			1	1		4		3	3	1	1				10	1
26			23	12	3		1			1		2		1		1			6		3	1		5						1			1		1				1	1
27		1	20	12	2		3								2	3		1	6		4			1						1									1	
28			13	11	9	3								1	1				1			1		1																
29			5	6	6		1																	1																
30			1							3					1						2																			
31																					1																			

Table 18: Length frequency of blueback herring from the NEFSC bottom trawl survey in the southern region during the spring.

Length	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
6																			1	
7						1		3		1	3							1	13	
8	1		8			23	26	7	3	16	40		2						34	3
9	4	1	68		5	169	41	17	10	40	48		9	2				2	26	4
10	15		59		2	60	10	23	4	3	10		4	10				36	9	2
11	4		2	1	2	7	7	26		2	2		8	11			9	45	5	1
12	4		4	2		14	8	12	4	2	2		4	10	1		25	47	7	1
13	7					4	8	2	6			1	4	2			41	6	4	
14	1	2		6		16		3		12		2	7	2			89	16		2
15		5	1	31	3	81	6	1	15	6	13	13	4	9			111	54	6	3
16	4	25	1	168	1	125	19	4	49	15	10	14	2	13	2	3	131	94	11	6
17	2	37	2	407	13	82	15	17	137	57	46	45	2	22	8	12	42	77	6	5
18	6	68	5	196	22	51	14	62	247	24	32	51	2	19	39	13	7	47	3	9
19	8	59	10	54	12	31	6	50	91	6	16	44	1	5	37	2		44	4	12
20	17	17	15	66	6	26	4	36	25	7	14	60	3	2	42		5	12	12	7
21	31	5	26	325	14	66	9	31	13	9	4	26			12	2	2	3	19	14
22	17	10	25	450	20	92	2	13	25	8	4	21	6	4	7	1	4	2	14	13
23	16	13	12	402	26	36	6	12	31	14	1	22	2	1	1		19	3	11	16
24	12	15	10	230	27	14	12	10	40	29		20		2	1		24	1	10	12
25	7	15	10	181	45	10	9	12	27	35	1	12		2		1	17		9	8
26	1	8	24	151	29	12	4	13	22	18	2	12	1	1			19	1	3	9
27	2	2	24	121	10	7	7	8	17	6	2	7	2				13		4	
28		1	10	30	8	6	3	5	4	5	5	4					10			
29		1	3	44			2	1	5	3	4	1								1
30	1		1	21				1	2	1										
32			1					1								1				
33											1					3				
34			1													1				
35			1																	
36			1													3				
37			1																	

Length	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
6																				
7	6														1					1
8	52	1		1		1				1	3		2		3					5
9	45	1						1	10	2				1	14					6
10	23	1						1	12	1			1		10			1		7
11	15							1	11		3		1		3			5	1	1
12	17							1	4		1				5			3		8
13	10				1			5	7		2		2					6	2	45
14	9							3	1				1							45
15	19							2	3	1	1		1	5						15
16	39			1				3	13	3	1	4	1	34				7		
17	63	9		4	1			7	14	10		24	5	61	2	16		44	8	5
18	35	14	2	5	7			18	38	15		39	4	113	14	18	17	78	71	25
19	16	11	1	7	3	4	2	4	30	10	2	6	10	95	32	28	227	146	165	39
20	5	13	1	18	8	1	1	3	21	11	7	5	22	144	37	28	341	30	70	13
21	2	18	1	15	11	3	7	13	35	2	6	15	14	354	83	33	99	11	42	14
22	2	25		6	27	6	6	16	23	2	3	14	19	271	72	44	78	56	32	46
23	2	42	1	7	37	7	35	7	18	2	2	15	8	55	46	59	38	86	11	68
24	4	21		4	66	13	21	16	3	3		2	1	28	20	33	3	41	13	42
25	2	11		4	61	4	10	6	7			2	2	11	6	6		8	6	15
26	2	1		4	19		1	3	4	1	1			2				1		3
27	2				3	1		1										3		
28			1	1	1															
29																				
30		1																		
32																				
33																				
34																				
35																				
36																				
37																				

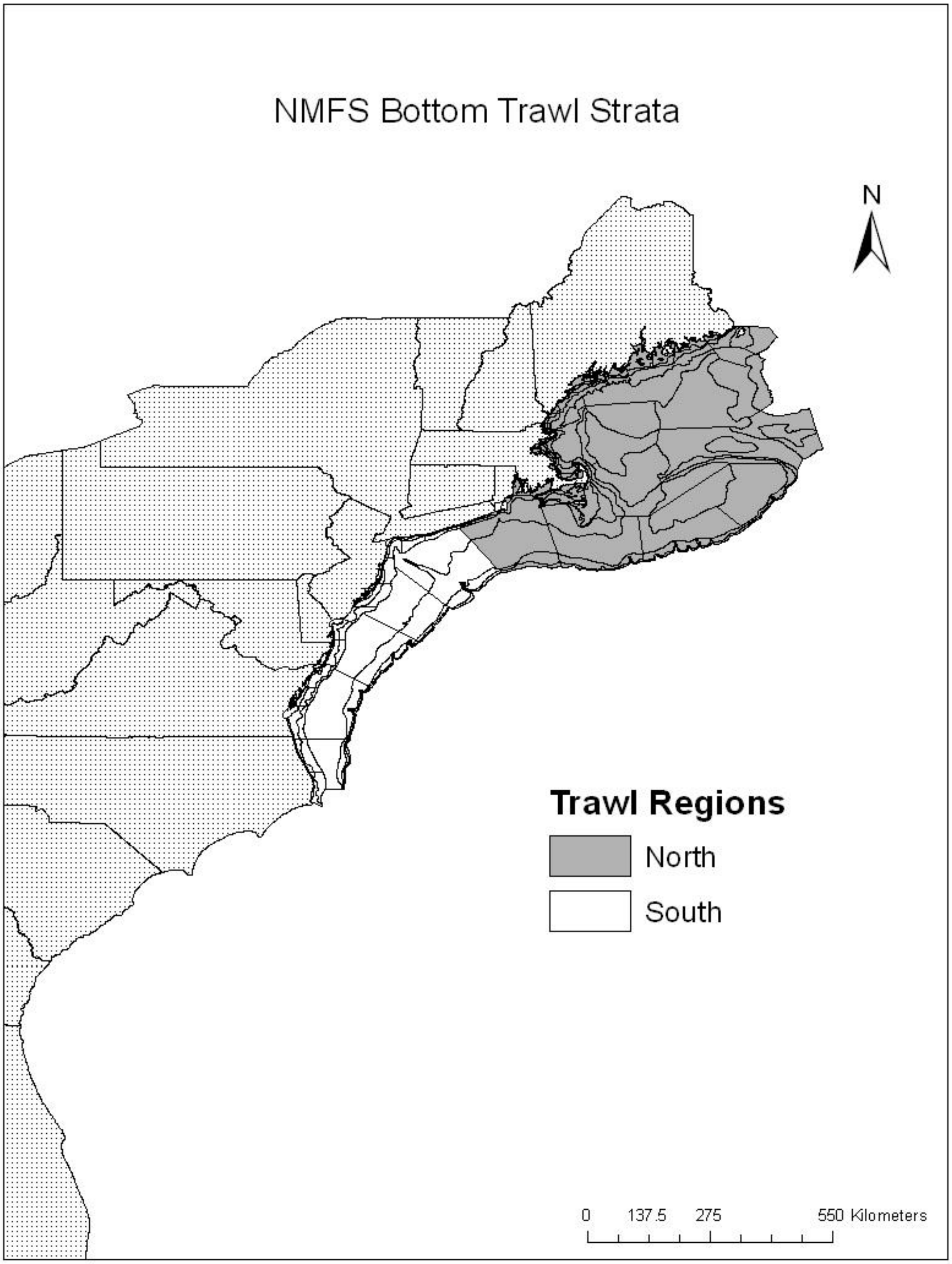

Figure 127: NEFSC bottom trawl survey strata comprising the northern and southern regions. The division between regions reflects the median months of sampling in the spring survey: April in the north and March in the south.

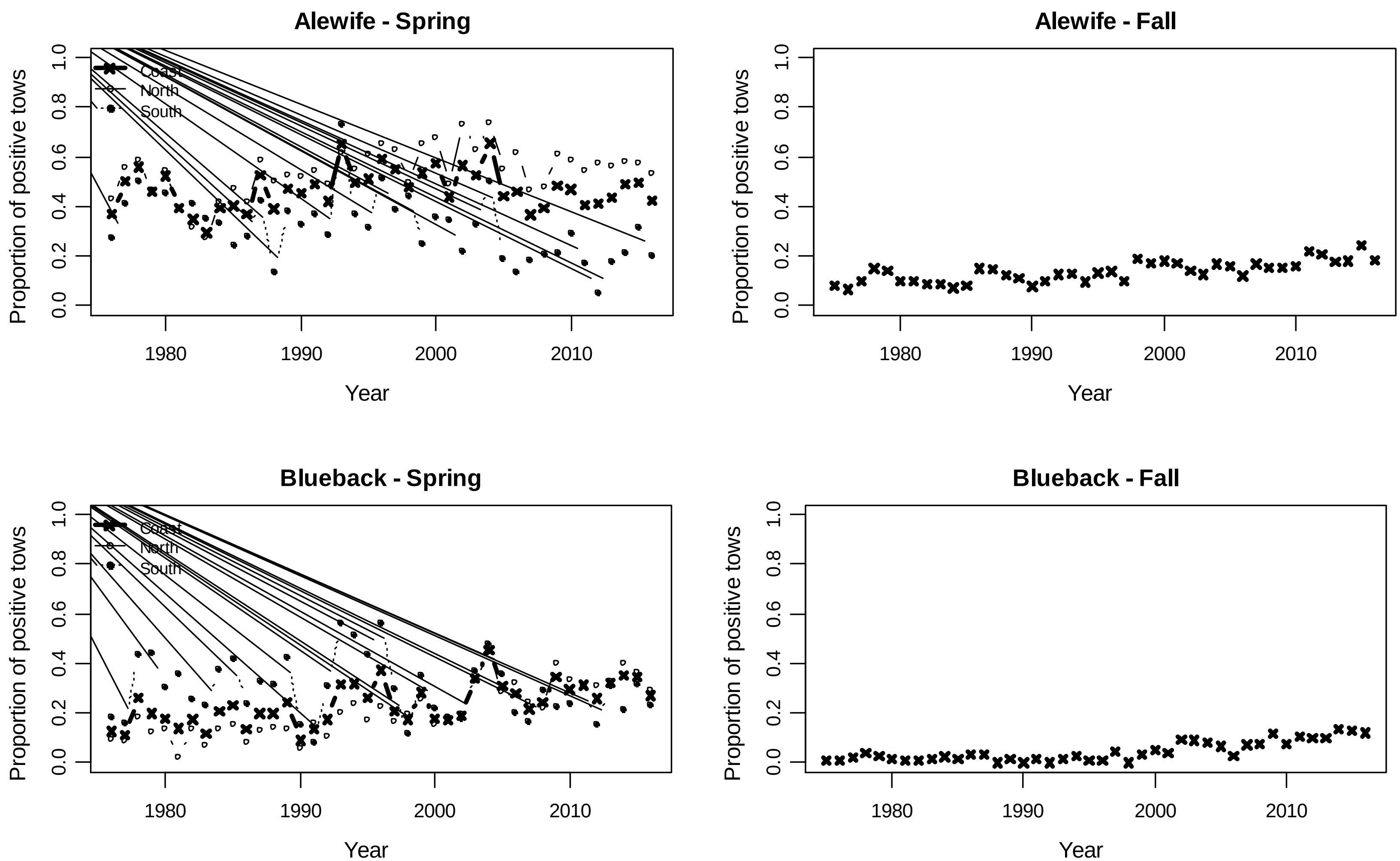

Figure 128: Proportions of positive tows for alewife, blueback herring, and combined species from the NEFSC spring (1976-2011) and fall (1975-2011) bottom trawl surveys. Survey strata were not separated into northern and southern regions for the fall survey.

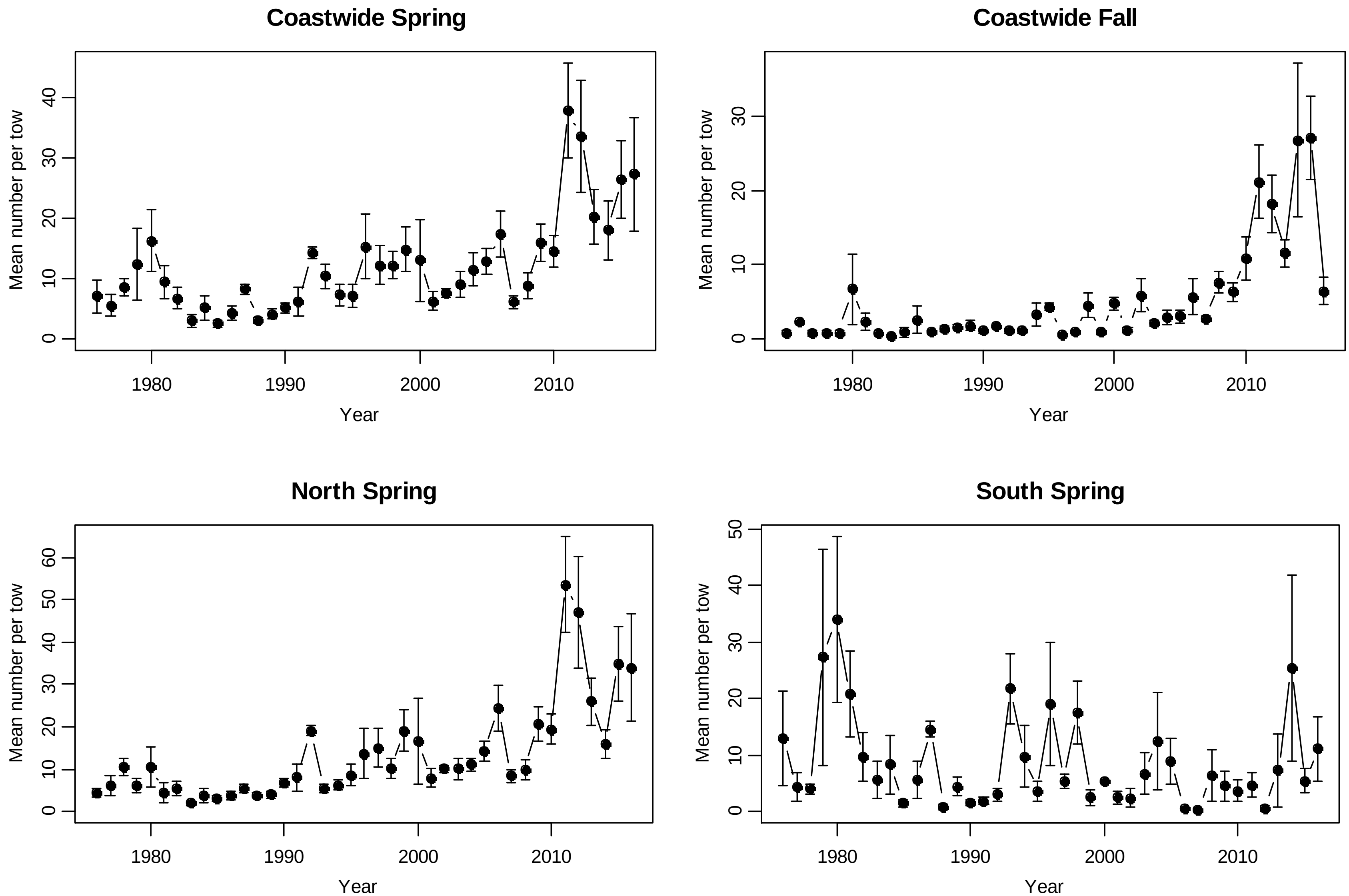

Figure 129: Stratified mean number-per-tow of alewife in the NEFSC bottom trawl surveys. Error bars correspond to one standard error.

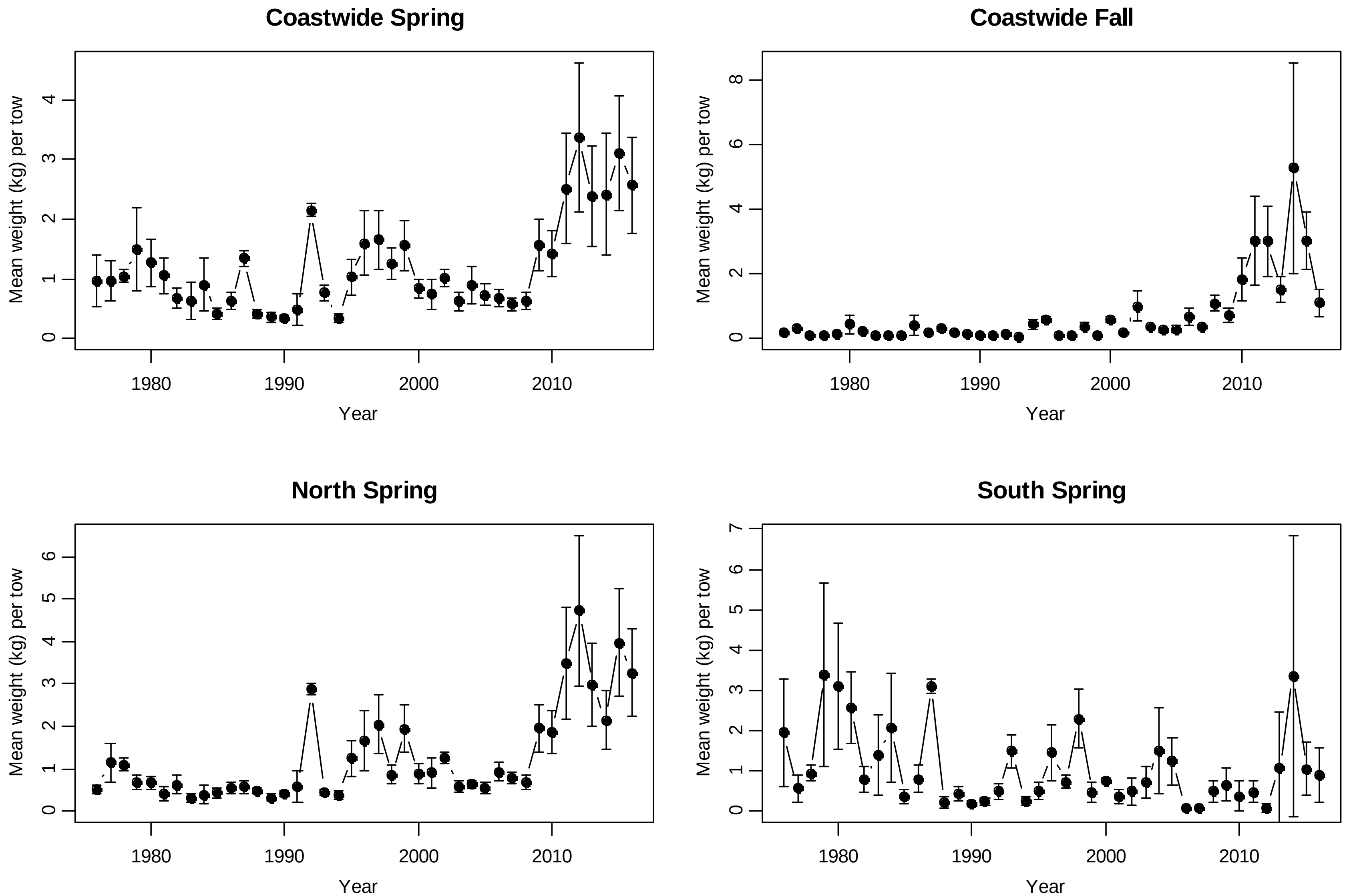

Figure 130: Stratified mean weight (kg)-per-tow of alewife in the NEFSC bottom trawl surveys. Error bars correspond to one standard error.

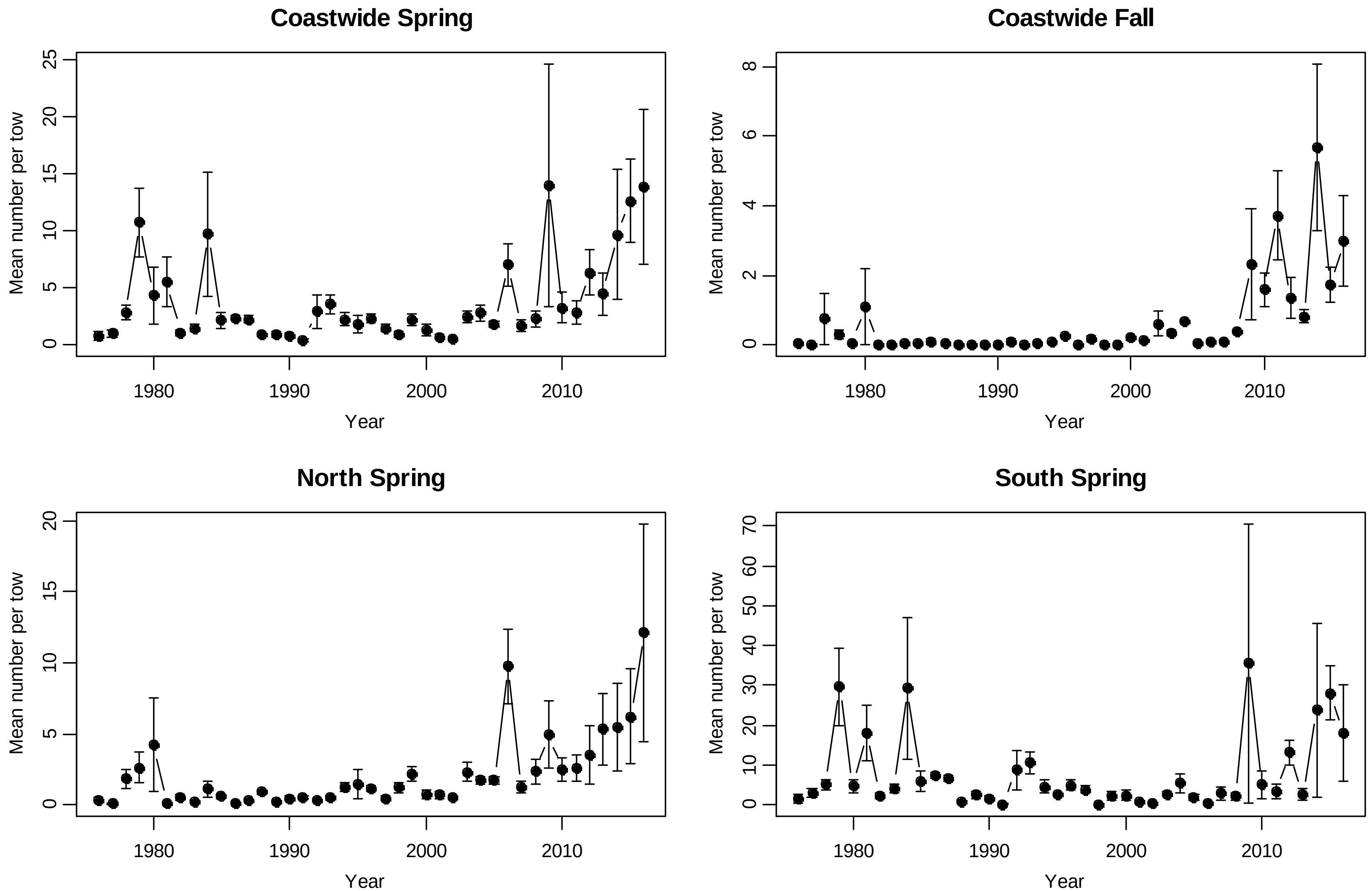

Figure 131: Stratified mean number-per-tow of blueback herring in the NEFSC bottom trawl surveys. Error bars correspond to one standard error.

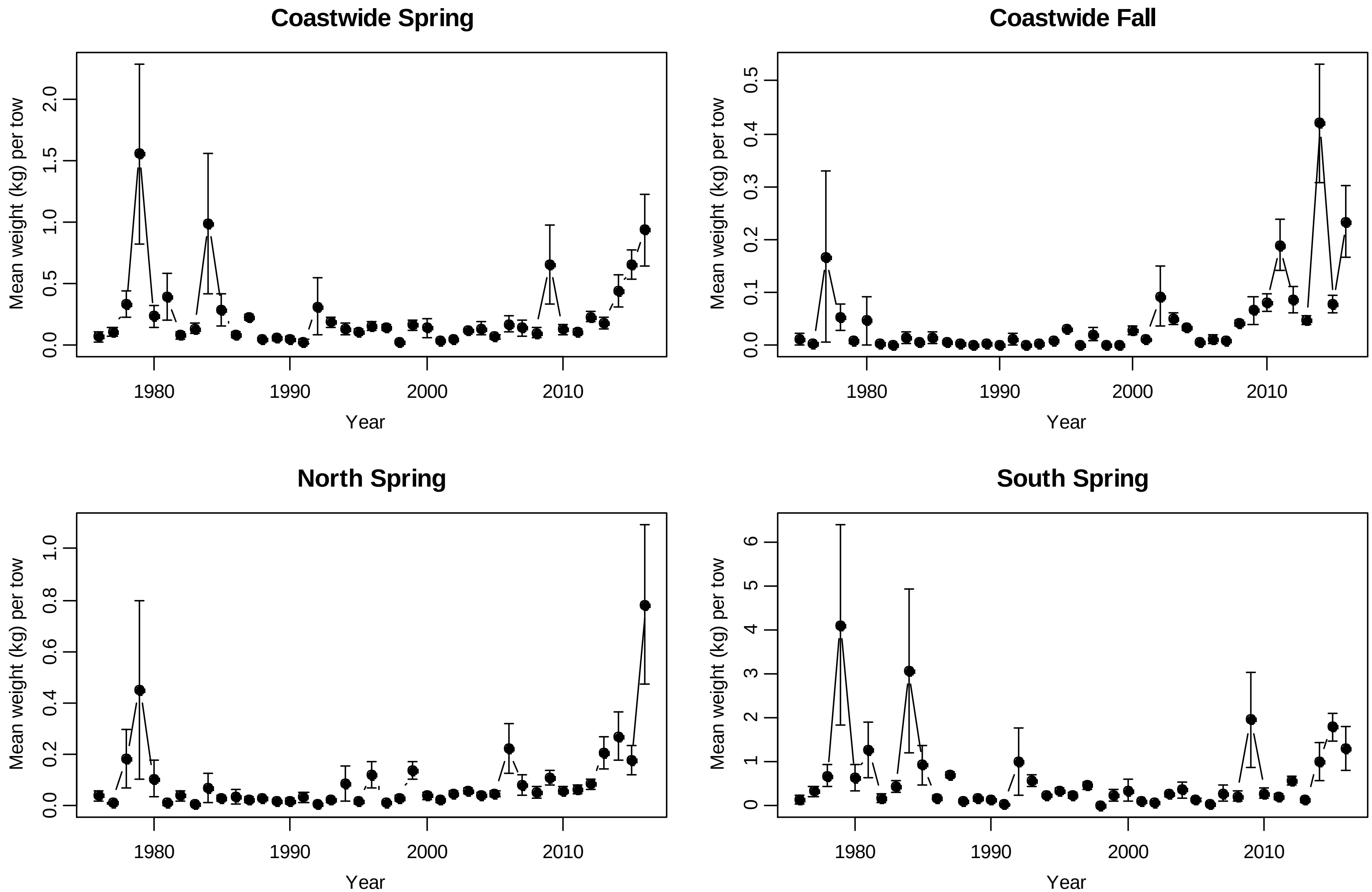

Figure 132: Stratified mean weight (kg)-per-tow of blueback herring in the NEFSC bottom trawl surveys. Error bars correspond to one standard error

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