Technical Report

Massachusetts Division of Marine Fisheries
Technical Report TR-46

An Assessment of River Herring Stocks in Massachusetts

G. A. Nelson, P. D. Brady, J. J. Sheppard, M. P. Armstrong

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

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Commonwealth of Massachusetts
Deval Patrick, Governor
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Richard K. Sullivan, Jr., Secretary
Department of Fish and Game
Mary B. Griffin, Commissioner
Massachusetts Division of Marine Fisheries
Paul Diodati, Director

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 20-27 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 0.21 in recent years. Similar reductions in proportions of repeat spawners were observed for blueback herring in the Monument River. Results from the statistical catch-at-age model, and estimates of total instantaneous mortality from age, repeat spawner, and length data showed that total mortality of alewife in the Monument River during the late 1990s increased by at least 20% compared to the earlier part of the time series. Potential causes of the declines in size, increases in total mortality and population declines are discussed.

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 from freshwater to marine systems and vice versa (Mullen et al., 1986). River herring provide recreational and cultural benefits to citizens who value them for food and bait.

In recent years, river herring abundance in several runs throughout Massachusetts have 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. In addition, the National Marine Fisheries Service has listed blueback herring and alewife as "species of concern". 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.

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 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 10.5^{o}C , 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 13.9^{o}C. 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 for most of the summer, juvenile herring begin their migration to the ocean in July. 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 3 to 5 years of age and the fish return to their natal streams utilizing their olfactory sense to guide them to home waters.

Description of Management Units

Herring runs in Massachusetts are managed directly by DMF or by local town governments with DMF oversight.

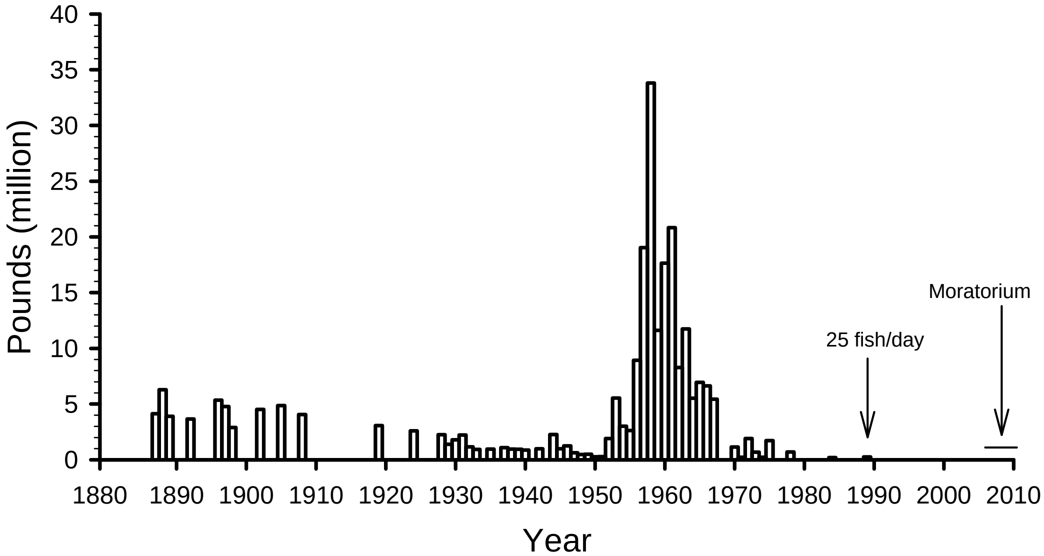

Figure 1. Massachusetts commercial landings of river herring, 1887-2010.

Fisheries Descriptions

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 were only a very small fraction of the historical highs and most harvest occurred using dipnets and beach seines. 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

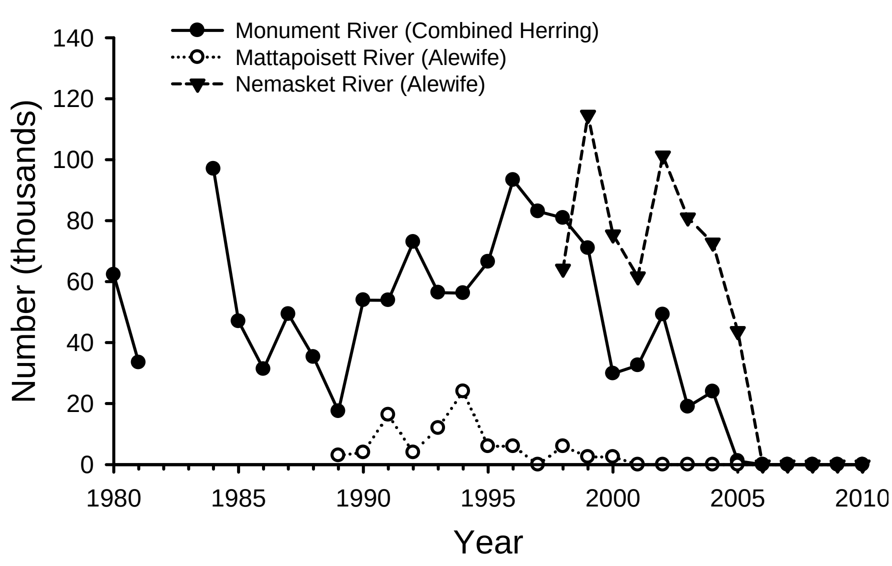

Figure 2. Number of fish removed (for bait, stocking, or scientific samples) from three Massachusetts rivers, 1980-2010.

data from the towns of Middleboro, Bournedale, and Mattapoisett with herring runs on the Nemasket River, Monument River and Mattapoisett River, respectively (Figure 2).

Bycatch in Commercial Fisheries. The issue of river herring bycatch is receiving a lot of attention at this time. 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 and purse seine fisheries for Atlantic herring are becoming 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. 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 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.

Recreational Fishery. Historically, there have been few reports of river herring being taken by recreational anglers for food. More often, river herring were taken for bait. The Marine Recreational Fisheries Statistics Survey (MRFSS) estimates 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.

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 are provided to DMF and harvest ranges from about 1,200 fish to 3,500 fish per year, with removals coming from several rivers.

Fishery Regulations

Currently, the Commonwealth of Massachusetts is in the sixth year of a harvest moratorium for river herring. Beginning in 2005, 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:

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

(2) 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.

(4) 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.

(5) 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.

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. Since the moratorium, effort has been reduced to protect donor populations and approximately 20,000 fish per year have been deposited into five to ten systems. Many of the recent efforts have been with-in system, moving fish upstream past multiple obstructions to the headwater spawning habitat.

Fisheries-Independent Monitoring

Data on alewife and blueback herring in Massachusetts come from mostly historical and/or current work conducted by DMF, University of Massachusetts 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, do 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).

All data are summarized by species and river in Appendix Table 3. 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.

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 began characterizing 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).

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. Biological data are available from 1985 and 1993.

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.

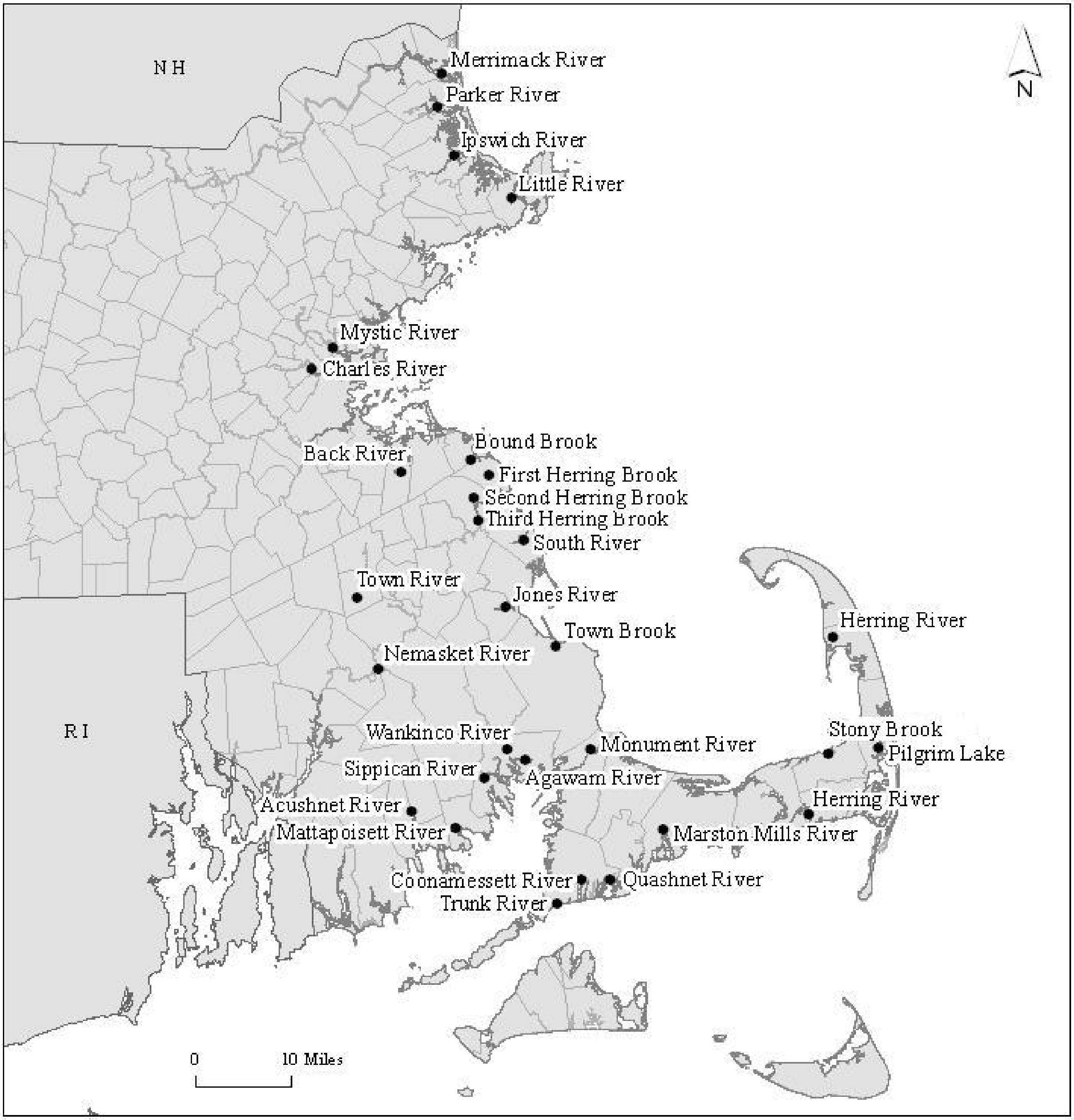

Figure 3. Massachusetts rivers for which historical and/or current data on river herring are available.

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. There are no biological data available.

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 only data available are the number of herring lifted at the Essex and Pawtucket Dam fishlifts since 1983. Data are provided by the US Fish and Wildlife Service.

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 approximately weekly by using a dipnet. All scales are aged using the criteria of Rothschild (1963), Marcy (1969) and Kornegay (1977), and repeat spawners are identified. Fish samples are used to apportion abundance into species- and sex-specific estimates (Brady, 1987). DMF often uses 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) - 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). There are no estimates of run size available.

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 Rideout et al. (1979). Due to high flood waters of 2005 and 2006, a weir failed, making it difficult for alewives to pass. Passage counts since 2005 are probably biased.

There are no current data on population characteristics.

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) - 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). 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.

Data Trends

Data for this assessment were stringently reviewed to provide the most reliable, scientifically-valid estimates of passage or total run size and population characteristics. Therefore, not all data summarized in Appendix Table 3 were used.

<u>Trends in Run Size</u>. 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 4; Figure 4). Some river estimates were deemed unusable 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

<u>Alewife</u> - Passage estimates of alewife showed increasing trends in numbers from 22,000 fish in 1988 to 130,000 fish in 2000 (Appendix Table 4; Figure 4). Passage estimates dropped precipitously through 2004 to 5,385 fish. Passage size has increased gradually to 12,319 fish in 2010 (Appendix Table 4; Figure 4).

Monument River

<u>Alewife</u> - A fluctuating, but increasing trend in total run size was evident from 1980 to 2000, peaking at about 597,937 fish (Appendix Table 4; Figure 4). Thereafter, it dropped precipitously through 2002 to 182,031 fish, and

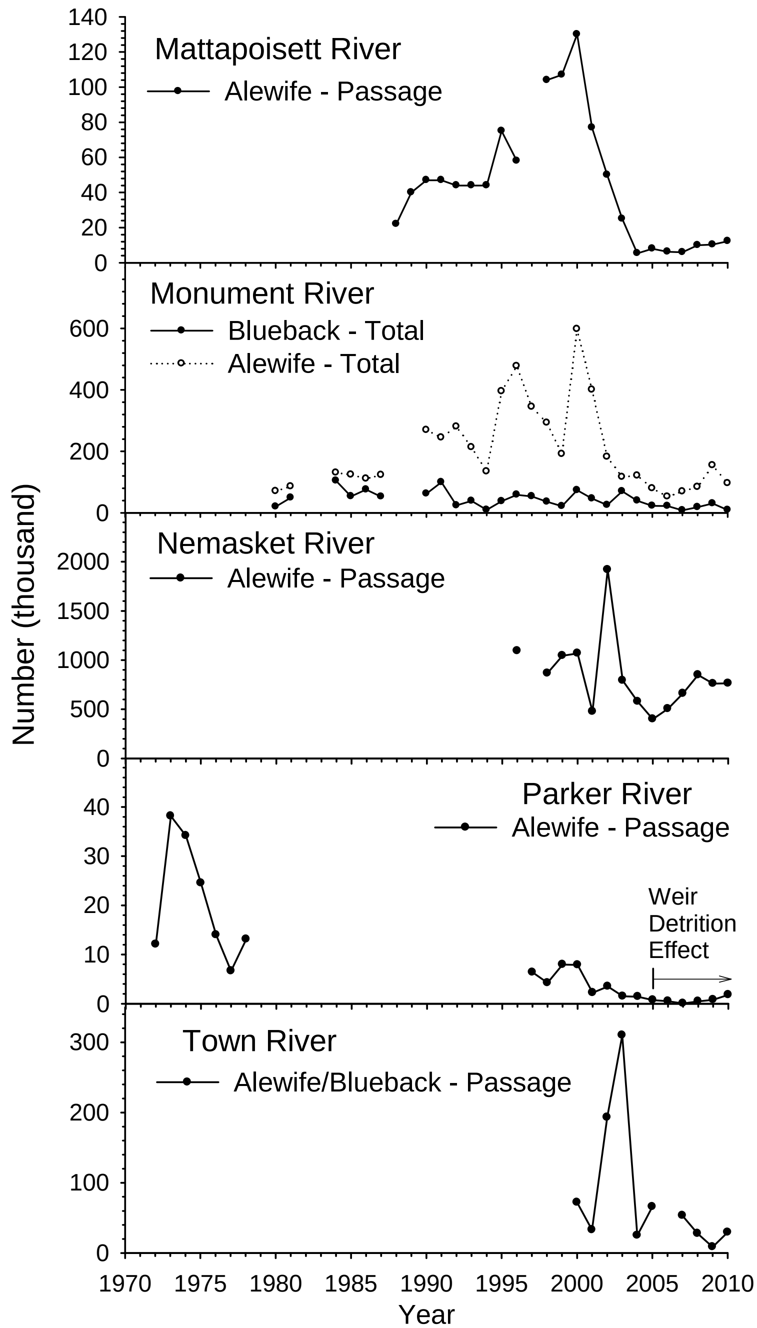

Figure 4. Passage and total run size counts for alewife and blueback herring in five Massachusetts Rivers.

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 119,354 fish. (Appendix Table 4; 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 4; 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 4; Figure 4).

Nemasket River

Alewife - Passage numbers of alewife have fluctuated considerably since 1996 (Appendix

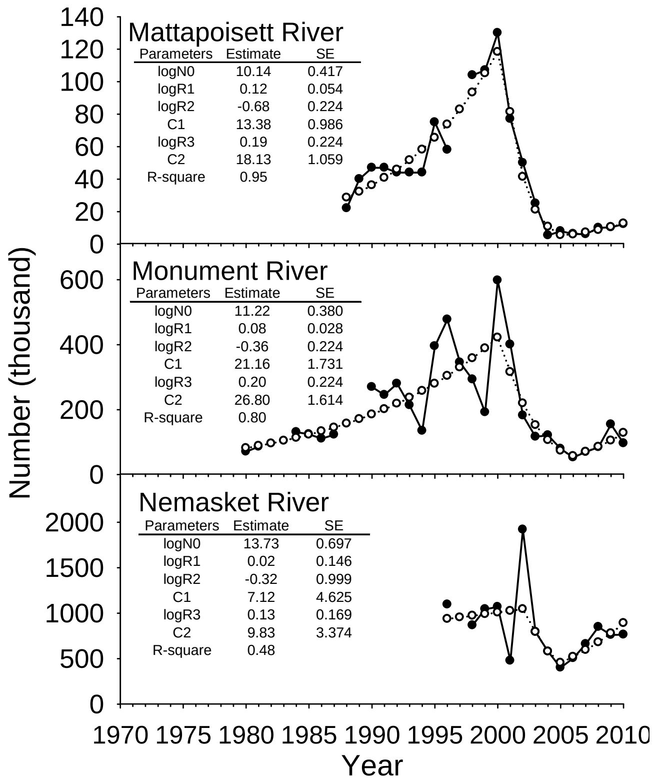

Figure 5. Observed (solid) and predicted (hollow) passage or total run size counts for alewife and blue-back herring in the Mattapoisett, Monument and Ne-masket rivers.

Table 4; Figure 4). Passage numbers averaged 910,000 fish prior to 2002, but following the peak (1.9 million fish), numbers declined through 2005 to 401,000 fish. Since 2008, numbers have increased to 791,150 fish on average (Appendix Table 4; Figure 4).

Parker River

Alewife - Passage counts of alewives 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 slightly.

Town River

Alewife/Blueback - Passage numbers of alewife and blueback herring (combined) have fluctuated considerably since 2000 (Appendix Table 4; Figure 4). Passage numbers were as high 310,000 fish in 2003. In most years, however, passage numbers averaged only 39,373 fish (Appendix Table 4; Figure 4).

A simple population model was fitted to the alewife counts for the Mattapoisett River, Monument River and Nemasket River to estimate the net "reproductive" rates:

$$N_t = N_0 \cdot R^t$$

where N_t is the count at time t, N_0 is estimated initial population size, and R is the net "reproductive" rate. R can be used as an indication that the population has remained stable over time (R=1), has increased (R>1), or has declined (R<1).

The equation was linearized using natural-log transformation:

$$\ln(N_t) = \ln(N_0) + \ln(R) \cdot t$$

To simultaneously estimate the parameters for periods of three different trends in counts, a piecewise regression approach was used. The linear model was fitted separately to data from three periods, but models were linked so that the ending year for the first and second periods were also the intercept for the second and third periods:

$$\ln(N_{1,t}) = \ln(N_{1,0}) + \ln(R_1) \cdot t \quad \text{for } t < C_1$$
$$\ln(N_{2,t}) = \ln(N_{1,0}) + C_1 \cdot (\ln(R_1) - \ln(R_2)) + \ln(R_2) \cdot t \quad \text{for } t \geq C_1 \text{ and } t < C_2$$
$$\ln(N_{3,t}) = \ln(N_{1,0}) + C_1 \cdot (\ln(R_1) - \ln(R_2)) + C_2 \cdot (\ln(R_2) - \ln(R_3)) \cdot t \quad \text{for } t \geq C_2$$

where C_1 and C_2 are the common years of change and other values are as described above. For this three period model, six parameters $ln(N_{1,0})$, $ln(R_1)$, $ln(R_2)$, $ln(R_3)$, C_1 and C_2 were estimated using least-squares.

Matttapoisett River

Alewife - The common times of change (C_1 and C_2) were estimated to be 13.4 (year 2000.4) and 18.1 (year 2005.1), and the estimated net "reproductive" rates was 1.12, 0.50, and 1.20 for the first, second and third periods, respectively. Passage counts in this river increased by 12% per year, on average, during 1988-2000, declined by 50% per year, on average, through 2005 and increased by 20% per year, on average, after 2005 (Figure 5). The high r-square value (0.95) indicated excellent model fit.

Monument River

Alewife - The common times of change (C_1 and C_2) were estimated as 21.2 (year 2000.2) and

26.8 (year 2005.8), and the estimated net "reproductive" rates were 1.08, 0.69, and 1.22 for the first, second, and third periods, respectively. Total counts in this river increased by 8% per year, on average, during 1988-2000, declined by 27% per year, on average, through 2005, and increased by 22% per year, on average, from 2006-2010 (Figure 5). The high r-square value (0.80) indicated good model fit.

Nemasket River

Alewife - The common times of change (C_1 and C_2) were estimated as 7.1 (year 2002.1) and 9.8 (year 2004.8), and the estimated net "reproductive" rates were 1.02, 0.73, and 1.14 for the first, second and third periods, respectively (Figure 5). Passage counts in this river increased by 2% per year, on average, during 1996-2002, declined by 26% per year, on average, through 2004, and increased by 14% per year, on average, from 2005-2010 (Figure 5). The low r-square value (0.48) indicated poor model fit.

Trends in Size Structure. Raw length frequencies available for each river, species and sex are shown in Appendix Tables 5 and 6, and summary statistics for the length distributions are shown in Appendix Tables 7 and 8. 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, and Nemasket rivers (Appendix Tables 7 and 8). Mean total length of both species and sexes from the Monument River declined from 1984 through the mid-1990s (Appendix Table 8; Figure 6). Female and male alewives and blueback herring sampled during 2004-2010 were about 20-27 mm smaller, on average, than alewives and blueback herring of the same sex sampled during 1984-1987 (Appendix Table 8). Mean total length of alewife (sexes combined) in Stony Brook showed a similar decline over time (Figure 6).

Trends In Age Composition. Any available age data regardless of the length of the time series were used in this assessment. Raw data are presented in Appendix Tables 9 and 10. Mean age is presented in Appendix Table 11.

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 9; Figure 7) . Mean ages for female and male alewife in 1991 were 4.6 and 4.3 years, respectively (Appendix Table 11).

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 on the youngest and oldest ages of blueback herring in the run. Mean ages for female and male blueback herring in 1991 were not calculated due to small sample sizes (Appendix Table 11).

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 9; Figure 7) . Mean ages for female and male alewife in 2007 were 4.2 and 4.0 years,

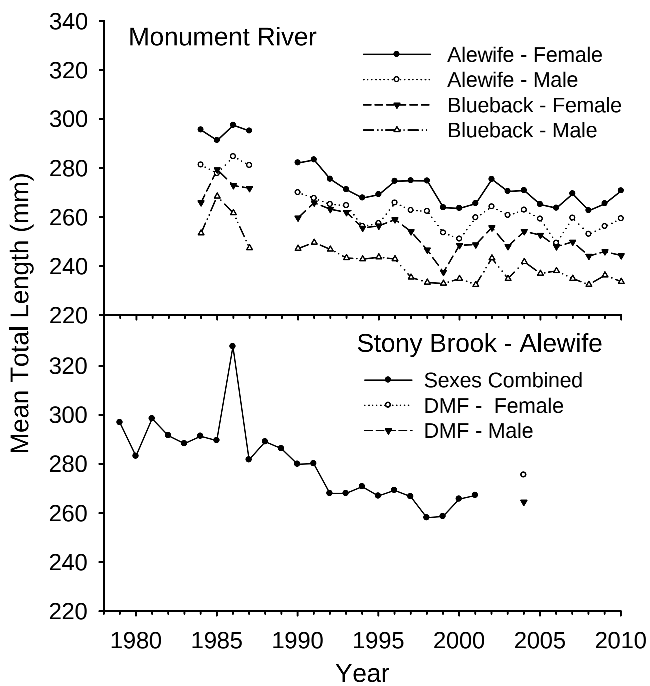

Figure 6. Mean total lengths of alewife and blue-back herring in the Monument River and Stony Brook, 1978-2010.

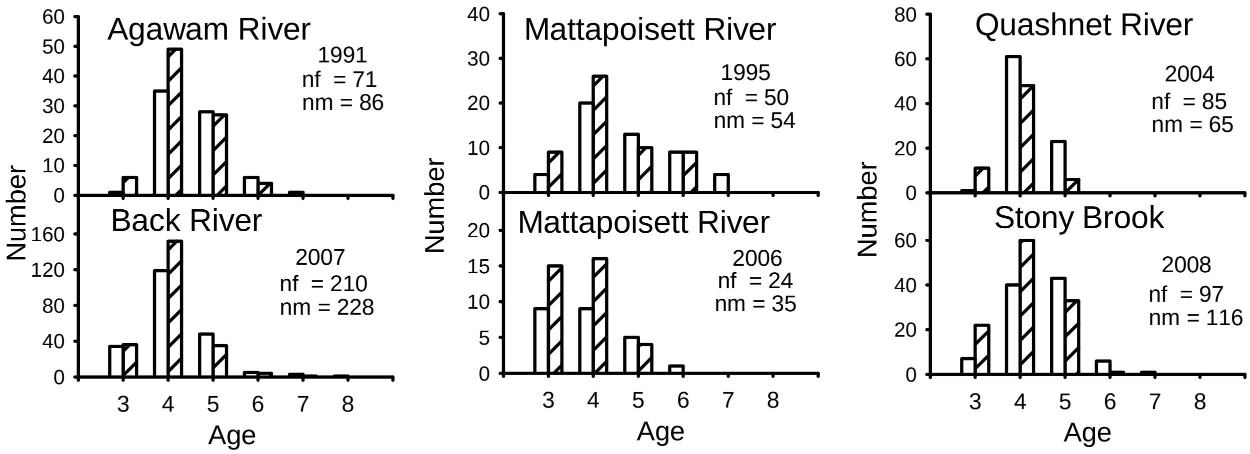

Figure 7. Age structure of alewife by sex (female: hollow bars; male: hash marks) in several Massachusetts rivers from intermittent sampling, 2004-2010. *nf* is female sample size and *nm* is male sample size.

respectively (Appendix Table 11).

Charles River

Blueback - Age samples were available from 1985 and 1993. The youngest and oldest alewives observed in the run were ages 3 and 10, respectively, for females and ages 2 and 7, respectively, for males (Appendix Table 9; Figure 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 11).

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 9; Figure 7). 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 11) 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 10; Figure 9). Ages 4-5 were the most abundant age-classes in the spawning run. From 1993-2006, the youngest and oldest individuals observed on the run were generally age 3 and 6 for both sexes, respectively, although older ages were observed infrequently (Appendix Table 10; Figure 9). Ages 7 and 8 were observed in larger samples from 2007-2010. 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 1993-2010 indicated a decline in mean age over time (Appendix

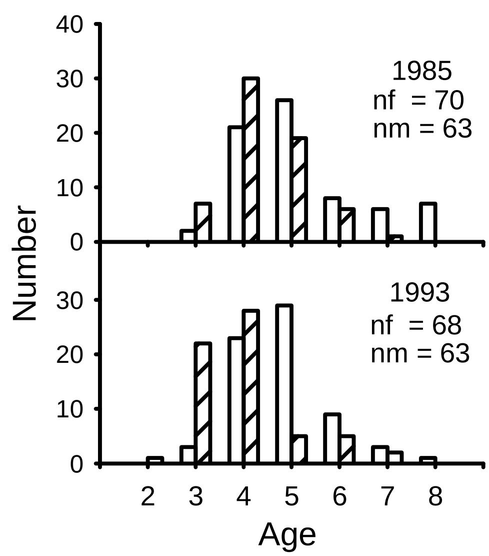

Figure 8. Age structure of Charles River blueback herring by sex (female: hollow bars; male: hash marks), 1985 and 1993. *nf* is female sample size and *nm* is male sample size.

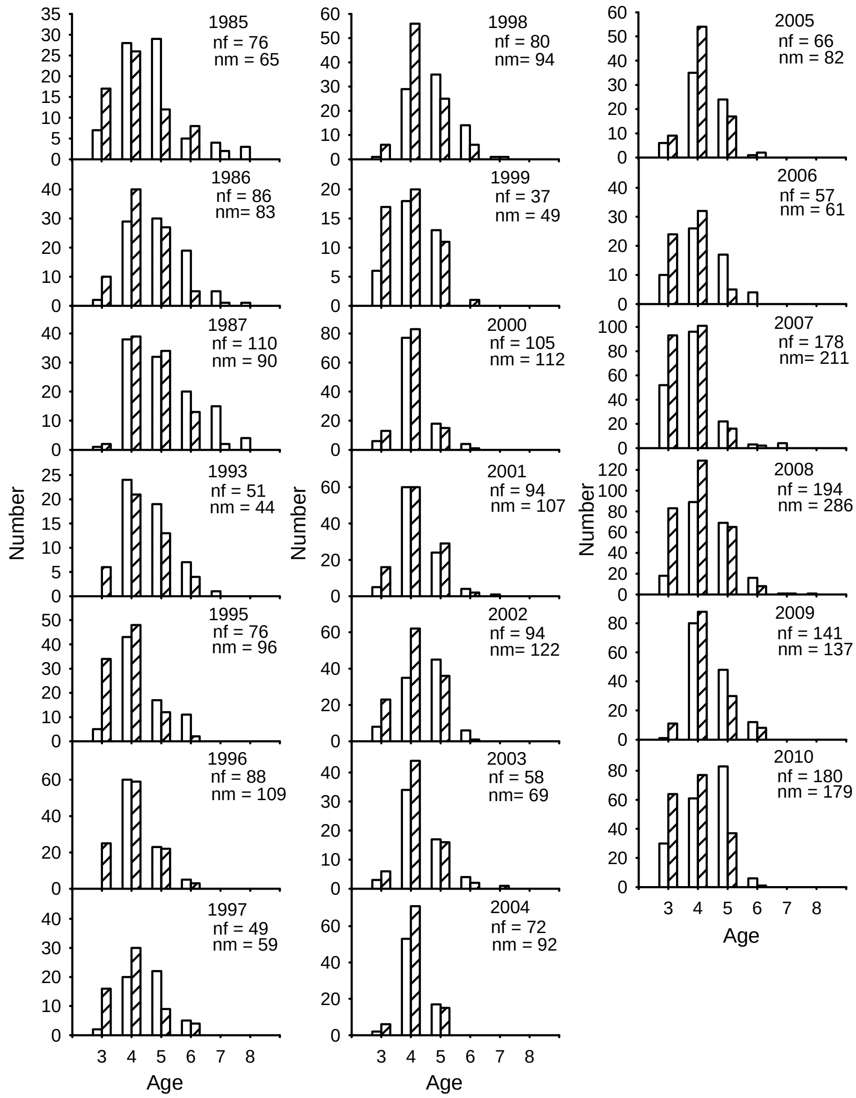

Figure 9. Age structure of Monument River alewife by sex (female: hollow bars; male: hash marks), 1985 – 2010. *nf* is female sample size and *nm* is male sample size.

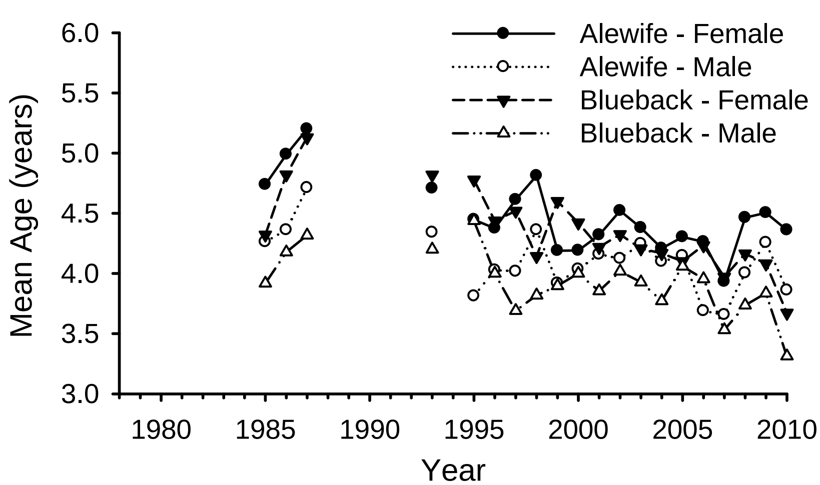

Figure 10. Mean age of Monument River alewife and blueback herring by sex, 1985-2010.

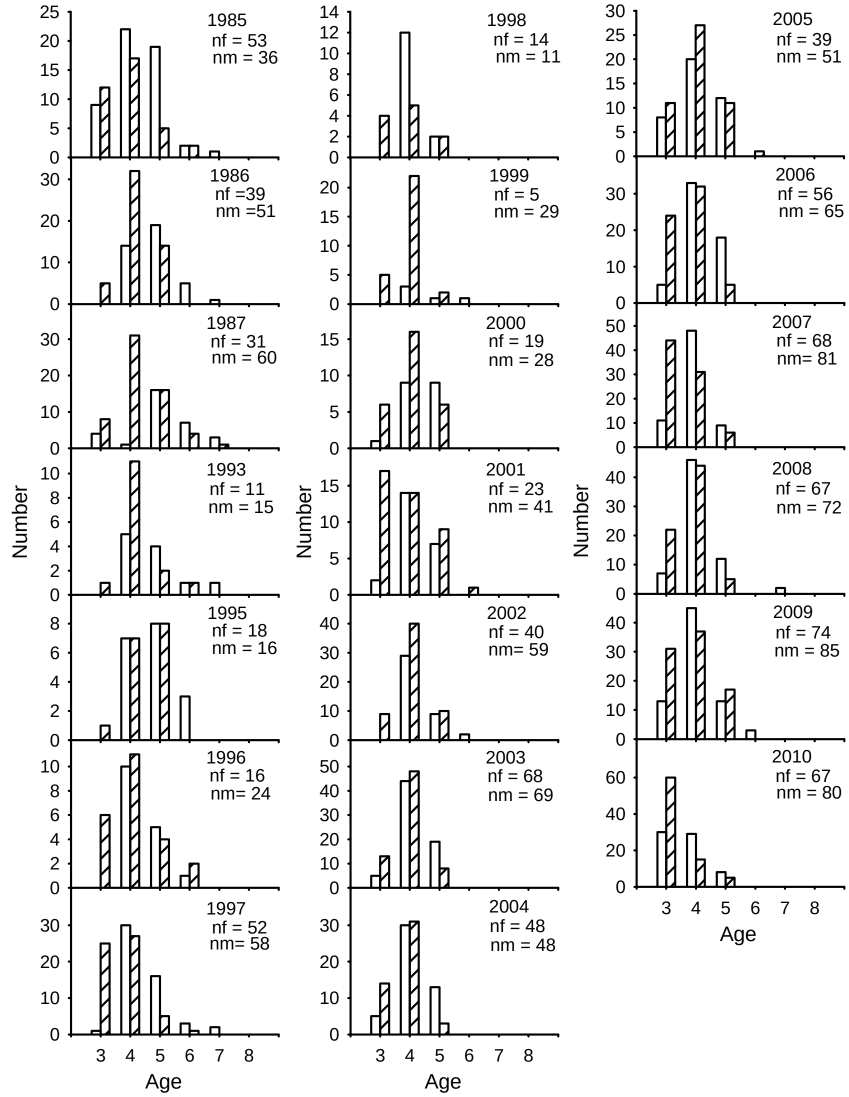

Figure 11. Age structure of Monument River blueback herring by sex (female: hollow bars; male: hash marks) determined from sampling, 1985-2010. *nf* is female sample size and *nm* is male sample size.

Table 11; Figure 10).

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 10; Figure 11). Ages 4-5 were the most abundant age-classes in the spawning run. From 1993-2010, 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 10; Figure 11). 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 1993-2010 indicated a decline in mean age over time (Appendix Table 11; Figure 10).

Mystic River

Alewife - Age compositions of both sexes of alewife from 2004-2010 were comprised of ages 2-7 with peak numbers occurring mostly at ages 4 and 5 (Appendix Table 9; Figure 12). Mean age ranged from 3.9 to 4.7 years for females and from 3.5 to 4.3 years for males (Appendix Table 11).

Blueback - Age samples for blueback herring were available from 2005-2010. The youngest and oldest individuals of both sexes observed in

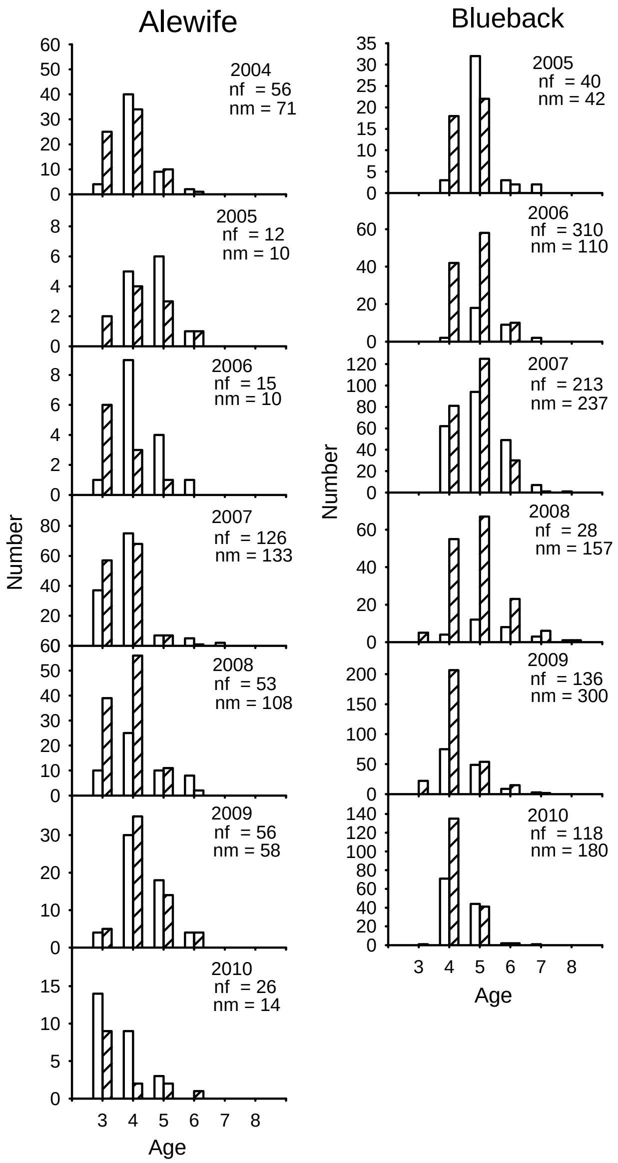

Figure 12. Age structure of Mystic River alewife and blueback herring by sex (female: hollow bars; male: hash marks), 2004-2010. *nf* is female sample size and *nm* is male sample size.

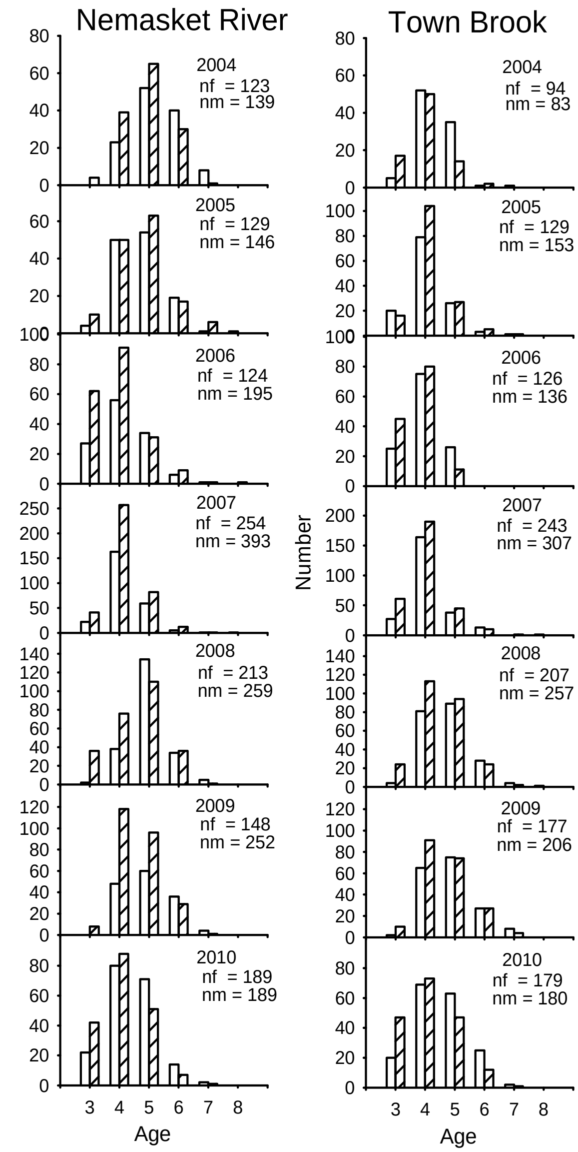

Figure 13. Age structure of Nemasket River and Town Brook alewife by sex (female: hollow bars; male: hash marks), 2004-2010. *nf* is female sample size and *nm* is male sample size.

the run were age 3 and 8, respectively (Appendix Table 9; Figure 12). Ages 4 and 5 were the most abundant age-classes. Mean age ranged from 3.4 to 4.4 years for females and from 3.2 to 3.8 years for males (Appendix Table 11).

Nemasket River

Alewife - The youngest and oldest individuals of both sexes observed in the run during 2004-2010 were age 3 and 8, respectively (Appendix Table 9; Figure 13). Ages 4-5 were the most abundant age-classes. Mean age ranged from 4.2 to 5.3 years for females, and from 4.0 to 4.9 years for males (Appendix Table 11).

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). 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 (Figure 14). Average age from 1971-1978

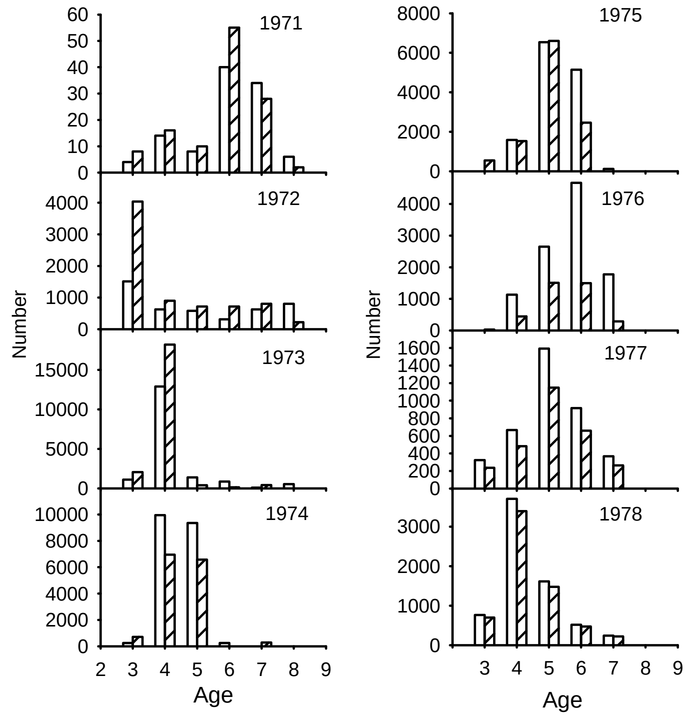

Figure 14. Age structure of Parker River alewife by sex, 1971-1978. The age structure of the total run for each year is shown (expanded from samples) except 1971 ((female: hollow bars; male: hash marks)

ranged from 4.3 to 6.0 years for females, and from 4.0 to 5.7 for males (Appendix Table 11).

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 9; Figure 7). 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 11).

Blueback - No description of the age composition is made because only 8 individuals were aged (Appendix Table 9).

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 9; Figure 7). 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 11).

Town Brook

Alewife - The youngest and oldest individuals observed in the run during 2004-2010 were age 3 and 8 for females and age 3 and 7 for males, respectively (Appendix Table 9; Figure 13). Age 4 was the most abundant age-class for both sexes. Mean age ranged from 4.0 to 4.9 years for females and from 3.8 to 4.6 years for males (Appendix Table 11).

Blueback - No description of the age composition is made because only 9 were aged (Appendix Table 9).

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 15). Unfortunately, data from 1984-1987 were not available for historical comparison. Although variable, mean length-at-age of alewife for ages 3-5 of both sexes declined in the mid-1990s and increased through 2003. Since 2004, mean length-at-age has been variable without trends (Figure 15). Mean length-at-age for blueback herring has varied without trend (Figure 15).

Trends in Proportions of Repeat Spawners. The frequencies of new and repeat spawners determined by reading spawning checks on scales are listed in

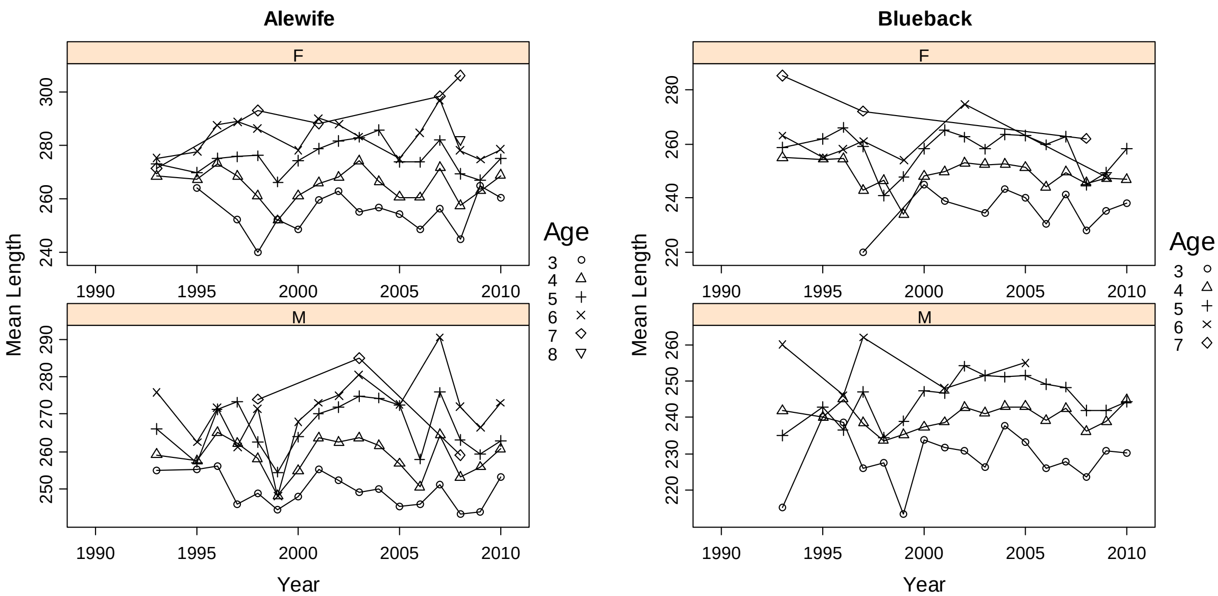

Figure 15. Mean length-at-age of alewife and blueback herring by year and sex for the Monument River, 1990-2010.

Appendix Table 12 and 13 by species, river, sex and year. The proportions that repeat spawners comprised the total samples are given in Table 1.

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 and 0.44 in 1993. For males, the proportions were 0.49 in 1985 and 0.25 in 1993 (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 -2010, proportions of repeat spawners ranged from 0.01-0.41, but most were ≤0.29. Since 2003, the proportions of repeat spawners have been ≤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 -2010, proportions of repeat spawners ranged from 0.00-0.27, but most were ≤0.20. Since 2003, the proportions of repeat spawners have been ≤0.14.

Mystic River

Alewife - The estimated proportions of repeat spawners for females varied widely without trend (0.00 in 2006 to 0.36 in 2004) (Table 1). However, the proportions of repeat spawners for males remained consistent at 0.3-0.32 in 2004-2005, but declined to <0.21 during 2006-2010.

Table 1. Proportion of repeat spawners in alewife and blueback herring samples by sex, river and year. *=not calculated due to small sample size.

Alewife

Female

River	1986	1987	1991	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
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
Mystic														0.36	0.08	0.00	0.13	0.25	0.29	0.15
Nemasket														0.43	0.29	0.10	0.13	0.22	0.30	0.23
Quashnet														0.07						
Stony														0.21						
Town														0.14	0.18	0.08	0.17	0.29	0.31	0.21

Male

River	1986	1987	1991	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
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
Mystic														0.32	0.30	0.00	0.07	0.16	0.21	0.14
Nemasket														0.44	0.29	0.10	0.12	0.20	0.17	0.16
Quashnet														0.05						
Stony														0.12						
Town														0.17	0.12	0.04	0.23	0.32	0.32	0.17

Blueback

Female

River	1985	1986	1987	1991	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Agawam				*																	
Charles	0.54				0.44																
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
Mystic																0.03	0.16	0.15	0.36	0.12	0.15
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
Agawam				*																	
Charles	0.49				0.25																
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
Mystic																0.06	0.21	0.18	0.27	0.13	0.13
Quashnet															*						
Town																*					

Blueback - The estimated proportions of repeat spawners for female and male blueback herring varied without trend (range: 0.03 in 2005 to 0.36 in 2008 for females; 0.06 in 2005 to 0.27 in 2008 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).

Trends in Total Instantaneous Mortality Rates.

Age and repeat spawner data

The Chapman-Robson survival estimator (Chapman and Robson, 1960; Murphy, 1997) was applied to the annual age- and repeat-spawner 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. For repeat spawner data, the new spawners (0) were assumed fully-recruited. Only Z estimates made from data with three or more age-classes (including first fully-recruited age) were deemed valid. All methods were programmed in *R*.

Length data

The Beverton-Holt (BH) length-based Z estimator (Beverton and Holt, 1957) was applied to all available length data. The equation for Z is

$$Z = \frac{K(L_\infty - \overline{L})}{\overline{L} - L_c}$$

where K and L_∞ are the growth and asymptotic length, respectively, for a von Bertalanffy growth equation, Lc is the length-at-first capture (smallest size of the youngest age at which animals are fully-vulnerable to fishery and sampling gear) and L bar is the mean length of fish $\geq Lc$. The population is assumed to be in equilibrium after any change in mortality. K and L_∞ were estimated from mean length-at-age data available in Mayo (1974; back-calculated mean lengths) for alewife and in Collette and Klein-MacPhee (2002) for blueback herring. The standard von Bertalanffy growth equation was fitted to the growth data, but L_∞ was fixed to the maximum observed length in each study to ensure that it was not underestimated due to incomplete sampling of the population. Estimates of L_∞, K, and Lc are given in Table 2.

Table 2. Von Bertalanffy growth parameters and L_c for alewife and blueback herring by sex.

Species	Sex	L_{oo} (mm TL)	K	L_c(mm TL)
Alewife	Female	355	0.41	240
	Male	340	0.45	235
Blueback	Female	330	0.41	230
	Male	320	0.39	220

If the population is not in equilibrium, the Z estimates will be biased. To deal with this situation, an alternative Beverton-Holt estimator that accounts for non-equilibrium conditions (Gedamke and Hoenig, 2006) was also applied to the length data. In this method, a Z is estimated for each period of mortality change along with the year of that change using maximum likelihood. Akaike's Information Criterion (AIC) values are compared to determine the model structure that best describes variability in the length data. The same input parameters as the equilibrium method are required. The non-equilibrium method was programmed in *R* and the function *optim* was used to find the parameters that minimized the negative log-likelihood. This method was applied to data only from the Monument River because of the shortness of the time series for other rivers.

Estimates of Z from the age, repeat spawner (rps), and length data by species and sex are given in Appendix Table 14 and are plotted in Figures 16-19. 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. The resulting estimates of Z from the Gedamke and Hoenig (2006) method and years in which mortality changed for the Monument River are presented in Table 3. Estimates for each river are summarized below:

Agawam River

Alewife - Z estimates for females in 1991 ranged from 0.71 (BH) to 0.96 (age), while those for males ranged from 0.91 (BH) to 1.18 (age) (Appendix Table 14; Figure 17).

Blueback - Z estimates for females in 1991 ranged from 0.81 (age) to 0.86 (BH). The valid single estimate of Z for males was 1.31 (BH) (Appendix Table 14; Figure 16). There were no valid estimates from repeat spawner data.

Back River

Alewife - Z estimates for females in 2007 ranged from 0.66 (BH) to 1.99 (rps), while those for males ranged from 0.77 (BH) to 1.64 (age) (Appendix Table 14; Figure 16).

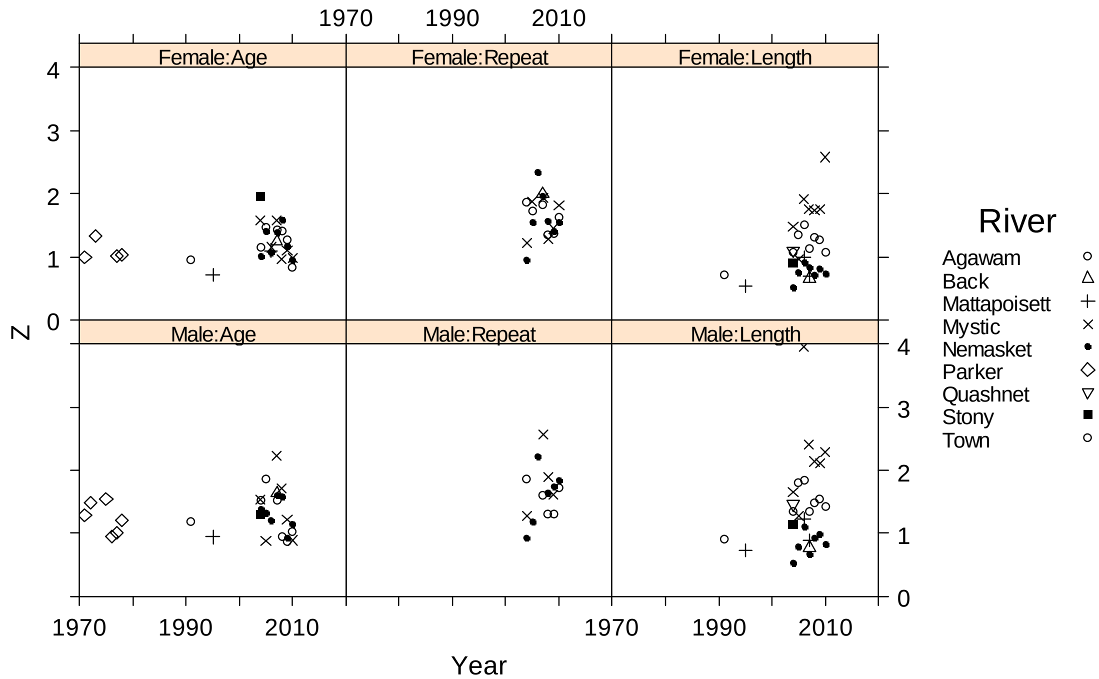

Figure 16. Estimates of instantaneous total mortality from age, repeat spawner and length data for alewife in Massachusetts rivers, 1971-2010. The Chapman-Robson survival estimator was applied to age and repeat spawner frequency data, and the Beverton-Holt estimator was applied to length data.

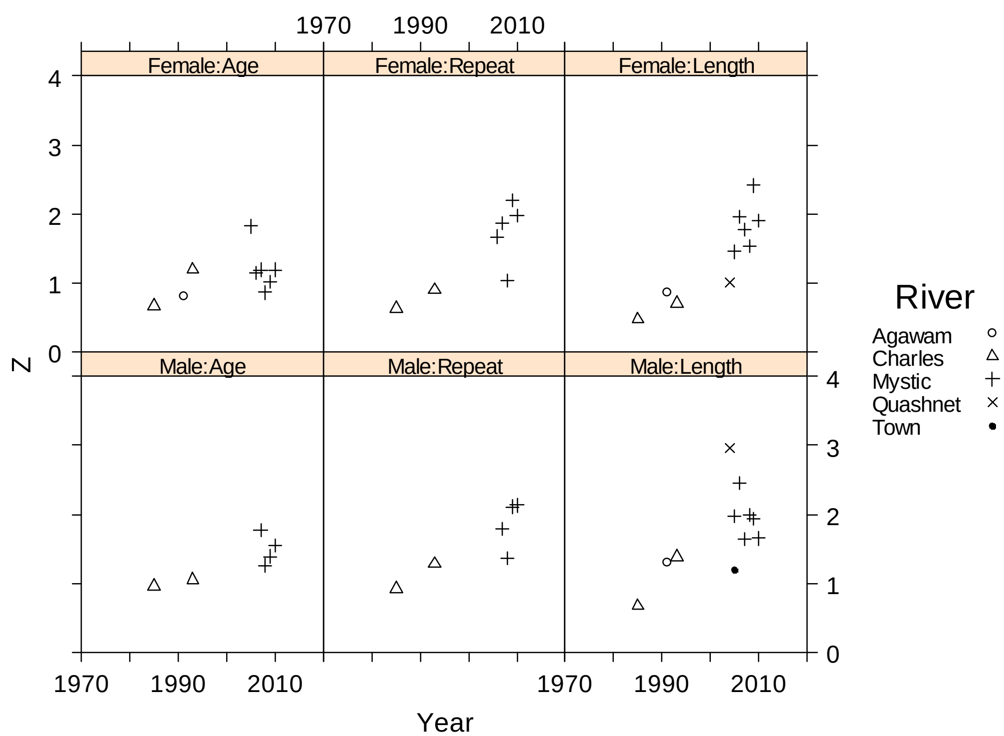

Figure 17. Estimates of total instantaneous mortality (Z) from age, repeat spawner, and length data for blueback herring in several Massachusetts rivers, 1985-2010. The Chapman-Robson survival estimator was applied to age and repeat spawner frequency data, and the Beverton-Holt (BH) estimator was applied to length data.

Charles River

Blueback - Z estimates for females in 1985 ranged from 0.47 (BH) to 0.67 (age), while those for males ranged from 0.67 (BH) to 0.96 (age) (Appendix Table 14; Figure 17). In 1993, Z estimates for females ranged from 0.7 (BH) to 1.19 (age), while those for males ranged from 1.05 (age) to 1.38 (BH) (Appendix Table 14; Figure 17).

Mattapoisett River

Alewife - Z estimates for females in 1995 ranged from 0.54 (BH) to 0.72 (age). During 2006-2007, Z estimates ranged from 0.7 (BH) to 1.1 (age); no estimates were available from rps data (Appendix Table 14; Figure 16). For males, Z estimates in 1995 ranged from 0.73 (BH) to 0.94 (age). During 2006-2007, BH Z estimates ranged from 0.89-1.22 and are the only ones available (Appendix Table 14; Figure 16).

Monument River

Alewife - For 1985-1987, Z estimates from age and rps frequency data ranged from 0.76 (age data) to 1.04 rps for females and from 0.84 to 1.12 (age) for males (Appendix Table 14; Figure 18). For 1993-2010, Z estimates from age and rps frequency data ranged from 0.87 (age) to 2.53 (rps) for females and from 1.02 (age) to 2.82 (rps) (Appendix Table 14; Figure 18). Estimates of Z from repeat spawner data tended to be higher than estimates derived from age data (Figure 18). Comparison of Z estimates from age and repeat spawner data showed an increase in total mortality over time series for both sexes, although estimates for female alewife from age data showed a slight decline in Z after 2000 (Figure 18).

An increasing trend in total instantaneous mortality was also observed in the BH Z estimates for both sexes (Appendix Table 14; Figure 18). Z values for 1984-1987 were about half of those estimated for the same time period using age and rps data. As the year of the time series increased, mortality approached levels estimated using age and repeat spawner data (Figure 18). Comparison of AIC values from the GH method indicated that the best model for female alewife assumed two mortality changes

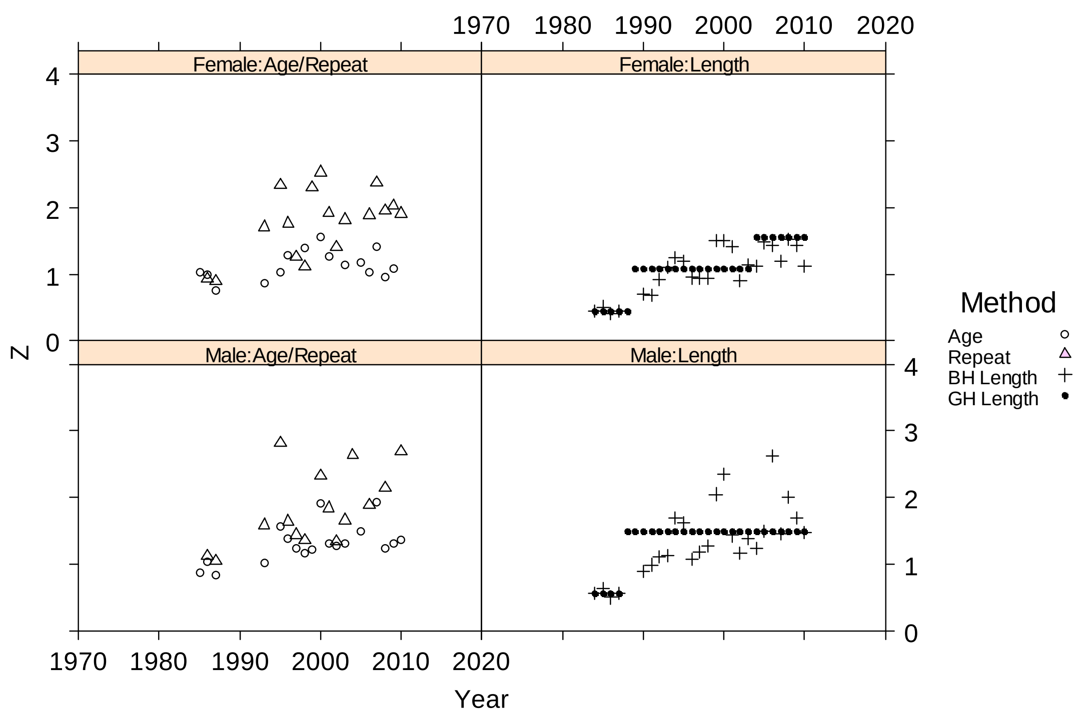

Figure 18. Estimates of total instantaneous mortality (Z) from age, repeat spawner, and length data for alewife in the Monument River, 1984-2010. The Chapman-Robson survival estimator was applied to age and repeat spawner frequency data, and the Beverton-Holt (BH) and Gedamke-Hoenig (GH) length-based mortality estimators were applied to length data.

Table 3. Results of the non-equilibrium estimation of Zs following Gedamke and Hoenig (2006) for Monument River alewife and blueback herring.

Female Alewife

Parameter	Estimate	SE	t
Z1	0.45	0.031	14.52***
Z2	1.09	0.054	20.18***
Z3	1.56	0.117	13.33***
Y1	1988.7	0.404	14.13***
Y2	2003.6	0.957	21.51***
SD	40.29	5.699	7.07**
AIC	221.8		

Male Alewife

Parameter	Estimate	SE	t
Z1	0.57	0.055	10.36***
Z2	1.49	0.07	21.28***
Y1	1988	0.401	15.03***
SD	46.62	6.598	7.06***
AIC	225.1		

Female Blueback

Parameter	Estimate	SE	t
Z1	0.58	0.045	12.88***
Z2	1.27	0.087	14.60***
Z3	2.1	0.269	7.81***
Y1	1988.7	0.545	10.55***
Y2	2005.1	0.897	24.59***
SD	28.34	4.003	7.08***
AIC	204.3		

Male Blueback

Parameter	Estimate	SE	t
Z1	0.66	0.06	11.78***
Z2	1.08	0.09	11.49***
Z3	1.85	0.13	14.34***
Y1	1985.40	0.56	4.31***
Y2	1995.10	0.72	16.80***
SD	28.03	4.00	7.00***
AIC	181.10		

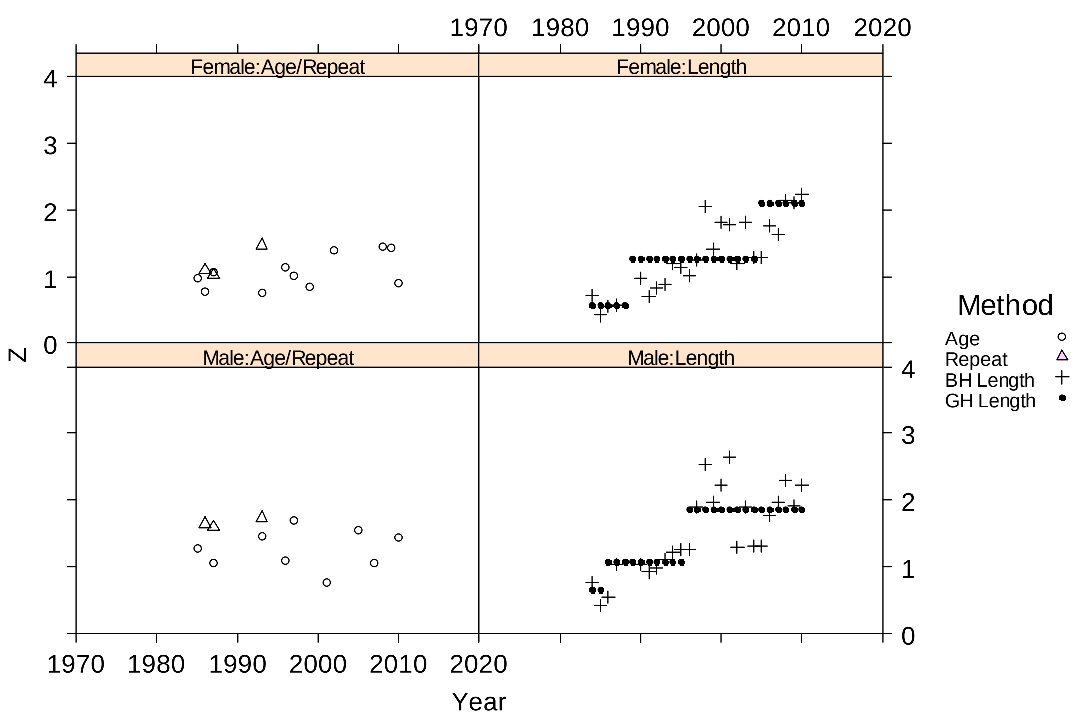

Figure 19. Estimates of total instantaneous mortality (Z) from age, repeat spawner, and length data for blueback herring in the Monument River, 1984-2010. The Chapman-Robson survival estimator was applied to age and repeat spawner frequency data, and the Beverton-Holt (BH) and Gedamke-Hoenig (GH) length-based mortality estimators were applied to length data.

(1989 and 2004) over the time series (Table 3). For male alewife, the best model assumed mortality changed once (1988) (Table 3). For female alewife, Z was estimated to be 0.45 prior to 1989, 1.09 during 1989-2003, and 1.56 after 2004 (Table 3). For male alewife, Z was estimated to be 0.57 prior to 1988, and 1.49 thereafter (Table 3).

Blueback - For 1985-1987, Z estimates from age and rps frequency data ranged from 0.98 (age) to 1.49 (age) for females and from 1.06 (age) to 1.64 (rps) for males (Appendix Table 14; Figure 19) For 1993-2010, Z estimates from age and rps frequency data ranged from 0.75 (age) to 1.54 (age) for females and from 0.76 (age) to 1.73 (rps) for males (Appendix Table 14; Figure 19). Estimates of Z from repeat spawner data tended to be higher than estimates derived from age data (Figure 19). Comparison of Z estimates from age and repeat spawner data showed no trend in total mortality over time series for both sexes (Figure 19).

An increasing trend in total instantaneous mortality was observed in the BH Z estimates for both sexes (Appendix Table 14; Figure 19). Some Z values for 1984-1987 were about half of those estimated for the same time period using age and rps data. As the year of the time series increased, mortality approached and exceeded levels estimated using age data (Figure 19). Comparison of AIC values from the GH method indicated that the best model assumed mortality changed twice (female: 1989 and 2005; male: 1985 and 1995) over the time series (Table 3). For female blueback, estimates of Z were 0.58 prior to 1989, 1.27 during 1989-2004, and 2.10 thereafter. For males, estimates of Z were 0.66 prior to 1985, 1.08 during 1985-1994, and 1.85 thereafter (Table 3).

Mystic River

Alewife - Z estimates for females during 2004-2010 ranged from 0.96 (age) to 2.58 (BH) (Appendix Table 14; Figure 16). For males, Z estimates during 2004-2010 ranged from 0.88 (age) to 3.96 (BH)(Appendix Table 14; Figure 16).

Blueback - Z estimates for females during 2004 -2010 ranged from 0.86 (age) to 2.41 (rps) (Appendix Table 9; Figure 17). For males, Z estimates during 2004-2010 ranged from 1.26 (age) to 2.46 (BH)(Appendix Table 14; Figure 17).

Nemasket River

Alewife - Z estimates for females during 2004-2010 ranged from 0.51 (BH) to 2.35 (rps) (Appendix Table 14; Figure 16). For males, Z estimates during 2004-2010 ranged from 0.54 (BH) to 2.21 (rps)(Appendix Table 14; Figure 16).

Quashnet River

Alewife - Only one Z for each sex was available. For 2004, Z (BH) was 1.10 for females and 1.46 for males (Appendix Table 14; Figure 16).

Blueback - Only one Z for each sex was available. For 2004, Z (BH) was 1.01 for females and 2.96 for males (Appendix Table 14; Figure 17).

Stony Brook

Alewife - Z estimates for females during 2004-2010 ranged from 0.90 (BH) to 1.96 (age) (Appendix Table 14; Figure 16). For males, Z estimates during 2004-2010 ranged from 1.14 (BH) to 1.30 (age)(Appendix Table 14; Figure 16).

Town Brook

Alewife - Z estimates for females during 2004-2010 ranged from 0.84 (age) to 1.87 (rps) (Appendix Table 14; Figure 16). For males, Z estimates during 2004-2010 ranged from 0.87 (age) to 1.87 (rps)(Appendix Table 14; Figure 16).

Blueback - The Z estimate in 2005 for male blueback herring was 1.20 (Figure 17). No estimates were made for females because of low sample sizes (Appendix Table 14).

Increasing trends in total mortality over time were evident for Monument River alewife using the three types of data (e.g., age, repeated spawner frequency, and length data), but similar trends were evident using the length data only for blueback. It is difficult to conclude if total mortality of river herring increased in the other rivers as well due to the shortness of the time series of data and variability in the Z estimates among rivers.

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 1978-2010 and were generally lower south of Cape Cod.

A Stock Assessment Model for Alewife

A forward-projecting age-structured statistical catch-at-age (SCA) model for the Monument River alewife stock was constructed and is used to estimate age-3 abundance and natural mortality rates during 1980-2010 from total in-river catches, escapement counts, and escapement age composition.

Model Structure. The structure of 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 natural mortality rates and field estimates of 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 (2), *d* is the number of maturity phases (2), *y* is the number of years and *A* is the oldest age group (age 8+). The number of year classes in the model was 6, representing ages 3 through 8+.

The cohort dynamics of the model is a hybrid of the Gaspereau River model in Gibson and Myers (2003a). The model incorporates the *immature* and *mature* phases by sex of the alewife's life history and assumes the year begins at the start of spawning. Mature individuals of each age move into the Monument River where they are intercepted and removed for harvest, and escapement counts are made upriver of the catchment basin. Biological samples for length, sex, and age are collected from escapement fish. The model allows natural mortality values to be specified for each year, age, sex and maturity phase or allows natural mortality to be estimated for each sex, two periods over the time series, or combinations of the two. If the estimation of natural mortality is chosen, then the resulting estimates are interpreted as including all remaining mortality aside from natural mortality (e.g., bycatch mortality).

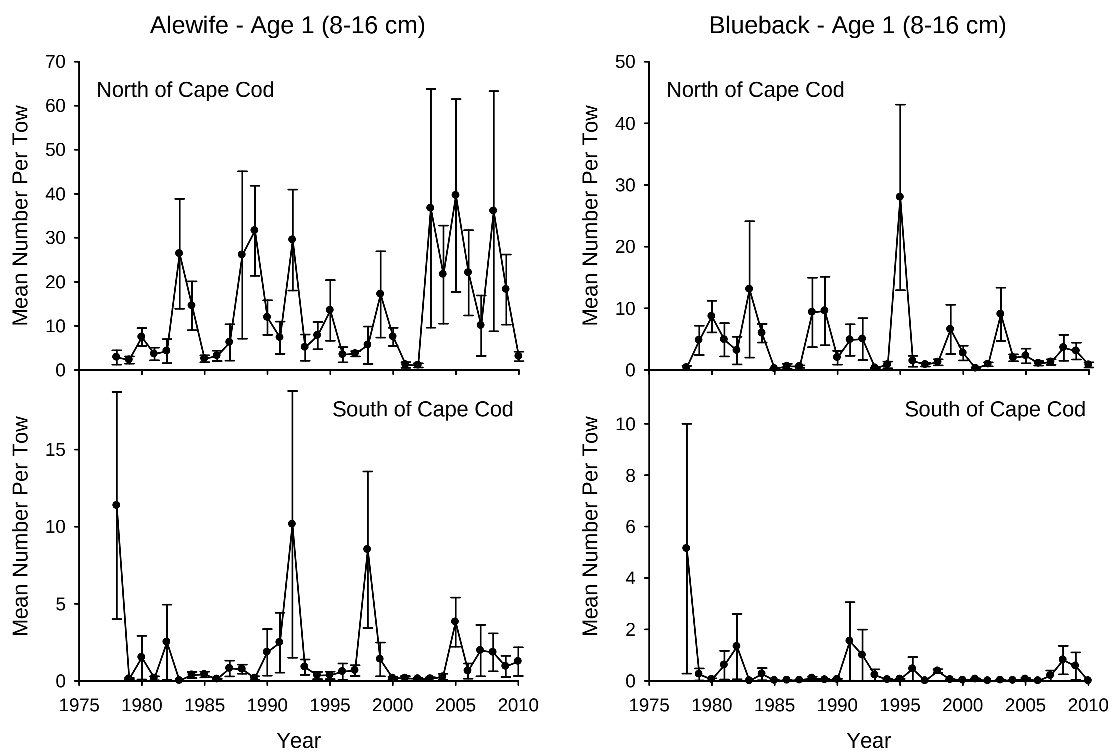

Figure 20. Indices of relative abundance (stratified mean number per tow) for age-1 alewife and blueback herring north and south of Cape Cod from the spring Massachusetts inshore bottom trawl survey, 1978-2010. Whiskers are +/-1 standard error.

Table 4. Population dynamics equations used in the alewife SCA model.

Population Model	Symbol	Equation
Age-3 numbers	$\hat{R}_y$	$\hat{R}_y = \hat{\bar{R}} \cdot \exp^{\hat{e}_y}$
Sex-specific age-3 numbers	$\hat{N}_{s,d,y,3}$	Female Immature: $\hat{N}_{1,1,y,3} = \hat{R}_y \cdot f \cdot (1-p_{1,y,3})$ Female Mature: $\hat{N}_{1,2,y,3} = \hat{R}_y \cdot f \cdot p_{1,y,3}$ Male Immature: $\hat{N}_{2,1,y,3} = \hat{R}_y \cdot (1-f) \cdot (1-p_{2,y,3})$ Male Mature: $\hat{N}_{2,2,y,3} = \hat{R}_y \cdot (1-f) \cdot p_{2,y,3}$
1980 abundance-at-age (4-8+)	$\hat{N}_{s,d,1980,a}$	Immature: $\hat{N}_{s,1,1980,a} = \hat{N}_{s,1,1980,a-1} \cdot \exp^{-M_{s,1,1980,a-1}} \cdot (1-p_{s,1980,a})$ Mature: $\hat{N}_{s,2,1980,a} = \hat{N}_{s,2,1980,a-1} \cdot (1-u_{1980}) \cdot \exp^{-M_{s,2,1980,a-1}} +$ $\hat{N}_{s,1,1980,a-1} \cdot \exp^{-M_{s,1,1980,a-1}} \cdot p_{s,1980,a}$
Abundance-at-age (4-7)	$\hat{N}_{s,d,y,a}$	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: $\hat{N}_{s,2,y,a} = \hat{N}_{s,2,y-1,a-1} \cdot (1-u_{y-1}) \cdot \exp^{-M_{s,2,y-1,a-1}} +$ $\hat{N}_{s,1,y-1,a-1} \cdot \exp^{-M_{s,1,y-1,a-1}} \cdot p_{s,y,a}$
Plus-group abundance-at-age	$\hat{N}_{s,d,y,8+}$	Immature: $\hat{N}_{s,1,y,8+} = \hat{N}_{s,1,y-1,a-1} \cdot \exp^{-M_{s,1,y-1,a-1}} \cdot (1-p_{s,y,a}) +$ $\hat{N}_{s,1,y-1,8+} \cdot \exp^{-M_{s,1,y-1,8+}} \cdot (1-p_{s,y,a})$ Mature: $\hat{N}_{s,2,y,8+} = \hat{N}_{s,2,y-1,a-1} \cdot (1-u_{y-1}) \cdot \exp^{-M_{s,2,y-1,a-1}} +$ $\hat{N}_{s,1,y-1,a-1} \cdot \exp^{-M_{s,1,y-1,a-1}} \cdot p_{s,y,a} +$ $\hat{N}_{s,2,y-1,8+} \cdot (1-u_{y-1}) \cdot \exp^{-M_{s,2,y-1,8+}}$
Predicted removals-at-age	$\hat{C}_{s,y,a}$	$\hat{C}_{s,y,a} = \hat{N}_{s,2,y,a} u_y$
Predicted total removals	$\hat{C}_y$	$\hat{C}_y = \sum_s \sum_a \hat{C}_{s,y,a}$
Predicted escapement-at-age	$\hat{E}_{s,y,a}$	$\hat{E}_{s,y,a} = \hat{N}_{s,2,y,a}(1-u_y)$
Predicted total escapement	$\hat{E}_y$	$\hat{E}_y = \sum_s \sum_a \hat{E}_{s,y,a}$
Predicted escapement age composition	$\hat{P}_{s,y,a}$	$\hat{P}_{s,y,a} = \frac{\hat{E}_{s,y,a}}{\sum_a \hat{E}_{s,y,a}}$
Female spawning stock biomass	SSB_y	$SSB_y = \sum_a \hat{N}_{1,2,y,a} \cdot (1-u_y) \cdot w_{1,2,y,a}$
Fishing mortality	$\hat{F}_y$	$\hat{F}_y = -\log_e(1-u_y)$

Given the above dynamics, population numbers-at-age by sex and maturity phases are calculated through time by using cohort survival models (Table 4). Number of age-3 alewife at the beginning of spawning season (R_y) are directly estimated in the model and these estimates are partitioned into sex-specific (s) (1=female; 2=male) and maturity phase (d)(1=immature; 2=mature) estimates of age-3 abundance ($N_{s,d,y,3}$) using the proportion female (f) and mature proportions-at-age (p_a)(derived outside of the model)(Table 4). Number of age-3 alewife (R_y) in the population is modeled as a log-normal deviation (independent and identically distributed normal random variables with zero mean and constant variance and are constrained to sum to zero over all years) from average abundance (R bar) (Table 4). This formulation differs from the original Gibson and Meyers model which linked recruitment via a Beverton-Holt equation.

The initial population abundance-at-age for ages 4-8+ in 1980 for each sex and maturity phase ($N_{s,d,1980,a}$) is calculated by assuming a static stock (Table 4). M is the natural mortality rate in 1980 for sex s, maturity phase d, and age a, and u is the exploitation rate which is assumed known (calculated from catch/(catch+escapement)).

Population abundance-at-age for ages 4-7 ($N_{s,d,y,a}$) and the plus-group ($N_{s,d,y,8+}$) are calculated in the remaining years by using similar cohort equations (Table 4).

The program was designed to accept user-inputted M values specified by year, sex, and age or to allow estimation of M by sex (2 estimates), two periods (2 estimates), and sex and two periods (4 estimates). The estimates of M were applied to both immature and mature fish. If M is estimated, then the parameter represents "all mortality other than in -river fishing".

The annual proportions of fish mature at each age and sex were calculated from repeat-spawner frequency data collected in the Monument River. Due to the small sample sizes of repeat-spawner data and missing data in some years, the averages of proportions mature-at-age from all years were used. The resulting proportions-at-age for each sex were:

	Age					
Sex	3	4	5	6	7	8+
Female	0.102	0.729	0.983	1	1	1
Male	0.275	0.86	0.993	1	1	1

Total removals of alewife are one set of data from which age-3 abundances and natural mortality rates are estimated. Total removals in numbers includes harvested fish and fish taken for transplant to other rivers. The equation for removals-at-age is given in Table 4 and it requires estimates of annual numbers of mature fish at each sex and age and exploitation rates (assumed known). 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 through the predicted total removals equation (Table 4).

Escapement counts and age structure are the second set of data from which age-3 abundances and natural mortality are estimated. Count data were available from 1980-1981, 1984-1987, and 1990-2010. Escapement age data were available only from years 1985-1987, 1993, and 1995-2010. A multiple regression model that predicts well total abundance in the Monument River from lagged autumn monthly cumulative rainfall data was used to fill-in missing escapement data for 1982, 1983, 1988 and 1989 after subtracting removal estimates from the prediction. The equation for escapement numbers-at-age is given in Table 4 and it requires estimates of annual numbers of mature fish at each sex/age and exploitation rates. All predictions are stored in an array of dimensions s x y x A-2. Estimated escapement-at-age values are then compared to the observed total escapement and to proportions of escapement numbers-at-age through the predicted total escapement and age composition equations (Table 4).

Female spawning stock biomass (SSB) is calculated from mature female numbers that escaped harvest and mean weight-at-age for mature females (Table 4). Calculated mean weights-at-age are provided in Appendix Table 15.

Fishing mortality rates were calculated from the calculated exploitation rates assuming a Type I fishery (Table 4).

For total removals and escapement numbers, lognormal errors are assumed and the generalized concentrated likelihood ($-L_l$)(Parma 2002; Deriso et al. 2007) was calculated (Table 5). CV_y is the coefficient of variation for the observed removal or escapement numbers in year y, n_C and n_E are the number of years, and λ_C and λ_E are the relative weights (Parma 2002; Deriso et al., 2007).

For escapement age composition data, a multinomial error likelihood ($-L_p$) is assumed ($n_{y.s}$ is

Table 5. Likelihood functions for removals and escapement data.

Negative Log-Likelihood	Symbol	Equation
Lognormal total removals and escapement	$-L_l$	$$-L_l = 0.5*(n_C + n_E)*\ln\left(\frac{RSS_C + RSS_E}{n_C + n_E}\right)$$ where $$RSS_C = \lambda_C \sum_y \left(\frac{\log_e(C_y + 1e^{-5}) - \log_e(\hat{C}_y + 1e^{-5})}{CV_{c,y}}\right)^2$$ $$RSS_E = \lambda_E \sum_y \left(\frac{\log_e(E_y + 1e^{-5}) - \log_e(\hat{E}_y + 1e^{-5})}{CV_{E,y}}\right)^2$$
Multinomial escapement age composition	$-L_p$	$$-L_p = \lambda_p \sum_y \sum_s - n_{s,y} \sum_a (P_{s,y,a} + 1e^{-5}) \cdot \ln(\hat{P}_{s,y,a} + 1e^{-5})$$ where λ_p is a user-defined weighting factor.
Effective sample size	$\hat{\bar{n}}_s$	$$\hat{\bar{n}}_s = \frac{\sum_y \hat{n}_{s,y}}{d_{s,y}}$$ where $$\hat{n}_{s,y} = \frac{\sum_a \hat{P}_{s,y,a}(1 - \hat{P}_{a,y,a})}{\sum_a (P_{s,y,a} - \hat{P}_{s,y,a})^2}$$ and $\hat{P}_{s,y,a}$ is the predicted proportion-at-age a in year y for sex s from the escapement numbers, $P_{s,y,a}$ is the observed proportion-at-age, and $d_{s,y}$ is the number of years of data for escapement series.

the effective number of fish of sex s aged in year y and $P_{s,y,a}$ is the observed proportions of escapement numbers-at-age)(Table 5). Effective sample size is estimated using iterative procedures of McAllister and Ianelli (1997). The formula for the average effective sample size is provided in Table 5. 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 ($-L_l$–L_p) is used by the autodifferentiation routine in AD Model Builder to search for the "best" age-3 abundance and "natural" mortality parameters 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. Average age-3 abundance is minimized in phase 1, abundance deviations are minimized in phase 2, and, if estimated, "natural" mortality is minimized in phase 3.

Model fit for all components was checked by using standardized residual plots and root mean square errors. Equations for standardized residuals (r) for log-normal (total removals and escapement) and multinomial (age composition) errors are given in Table 6 (n is the total number of total removals or escapement values). For escapement age composition data, standardized residuals required the average effective sample size for each sex (Table 6). Equations for root mean square error (RMSE) are given in Table 6.

Table 6. Diagnostic functions for removals and escapement data.

Diagnostics	Symbol	Equation
Standardized residuals (lognormal)	$r_{C,y}$ or $r_{E,y}$	$r_{C,y}=\frac{\log_e(C_y+1e^{-5})-\log_e(\hat{C}_y+1e^{-5})}{\sqrt{\log_e(CV_y^2+1)}}$ $r_{E,y}=\frac{\log_e(E_y+1e^{-5})-\log_e(\hat{E}_y+1e^{-5})}{\sqrt{\log_e(CV_y^2+1)}}$
Standardized residuals (age composition)	$r_{s,y,a}$	$r_{s,y,a}=\frac{P_{s,y,a}-\hat{P}_{s,y,a}}{\sqrt{\frac{\hat{P}_{s,y,a}(1-\hat{P}_{s,y,a})}{\hat{n}_s}}}$
Root mean square error	$RMSE$	Total removals $RMSE_C=\sqrt{\frac{\sum_y r_{C,y}^2}{n}}$ Total escapement $RMSE_E=\sqrt{\frac{\sum_y r_{E,y}^2}{n}}$

Reference Points. Fishing mortality and female spawning stock biomass 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 derived the $F_{40\%}$ and $F_{20\%}$ reference points (fishing mortality rates that reduces 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 biomass).

The YPR and SPR analyses follow the model adapted by Gibson and Myers (2003c) for alewife and the equations are shown in Table 7. Here, 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 (SS_9) was calculated to match the maximum observed age in Massachusetts (9: observed in Parker River) for female alewife (Table 7).

YPR and SPR were calculated for a set of Fs that ranged from 0 to 5 with 0.01 increment. 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 $SPR_{F=0}$. Only data from 1990 were used to calculate SPR

Table 7. Reference points equations used in the alewife SCA model.

Reference Point Calculations	Symbol	Equation
Yield-Per-Recruit (kg)	YPR_F	$YPR_F = \sum_{a=3}^{\max a} SS_a w_a (1 - e^{-F})$ where SS_a is given by: $SS_3 = p_3$ $SS_4 = SS_3 e^{-M_{m,3}-F} + (1-p_3)e^{-M_{i,3}} p_4$ $SS_5 = SS_4 e^{-M_{m,4}-F} + (1-p_3)(1-p_4)e^{-M_{i,3}-M_{i,4}} p_5$ $SS_6 = SS_5 e^{-M_{m,5}-F} + (1-p_3)(1-p_4)(1-p_5)e^{-M_{i,3}-M_{i,4}-M_{i,5}} p_6$ $SS_7 = SS_6 e^{-M_{m,6}-F} + (1-p_3)(1-p_4)(1-p_5)(1-p_6)e^{-M_{i,3}-M_{i,4}-M_{i,5}-M_{i,6}} p_7$ $SS_8 = SS_7 e^{-M_{m,7}-F} + (1-p_3)(1-p_4)(1-p_5)(1-p_6)(1-p_7)e^{-M_{i,3}-M_{i,4}-M_{i,5}-M_{i,6}-M_{i,7}} p_8$ and for the plus-group, one additional SS_a was calculated to match the maximum observed age in Massachusetts (9: observed in Parker River) for female alewife: $SS_9 = SS_8 e^{-M_{m,8}-F} + (1-p_3)(1-p_4)(1-p_5)(1-p_6)(1-p_7)(1-p_8)e^{-M_{i,3}-M_{i,4}-M_{i,5}-M_{i,6}-M_{i,7}-M_{i,8}} p_8$
Spawning Biomass-Per-Recruit Analysis (kg)	SPR_F	$SPR_F = \sum_{a=3}^{\max a} SS_a w_a e^{-F}$
Beverton-Holt S-R Equation (linearized)	BH	$\log_e(\hat{R}_y) = \log_e(\hat{a}) + \log_e(SSB_{y-3}) - \log_e(1 + \hat{a}SSB_{y-3}/\hat{R}_0) + \varepsilon$
Equilibrium spawning stock biomass, recruits and catch	SSB^*, R^* and C^*	$SSB^* = \frac{(\hat{a}SPR_F - 1)\hat{R}_0}{\hat{a}}$ $R^* = \frac{\hat{a}SSB^*}{1 + (\hat{a}SSB^*/\hat{R}_0)}$ $C^* = R^* \cdot YPR_F$
Minimum threshold SSB	$SSB_{20\%}$	$SSB_{20\%} = 0.2\frac{(\hat{a}SPR_{F=0} - 1)\hat{R}_0}{\hat{a}}$

and YPR values in order to develop historical estimates of reference points 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-3}) from the recruitment-spawner 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 (Table 7) was fit externally to the age-3 recruitment numbers (R_y) and corresponding spawning stocking biomass (SSB_{y-3}). 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 & c). The BH equation was fitted to the recruitment-spawner data using non-linear least-squares regression. Only estimates of recruitment from 1986 -2009 and SSB from 1983-2006 are used to estimate the S-R relationship to eliminate the influence and possible bias of the static stock abundance estimates during the first year (1980) and the slight retrospective bias near the terminal (see below).

For a given level of F, the equilibrium spawning biomass (SSB*), corresponding number of recruits, and equilibrium yield is calculated by using the BH a and R_0 parameters (Table 7). 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 $1/SPR_F = a$. The minimum threshold biomass ($SSB_{20\%}$) was calculated as 20% of the equilibrium female spawner biomass in the absence of fishing (Table 7).

Base Configuration and Results. Initial runs of the model were conducted to examine the impact of different structures (i.e., M by sex, M by period, and M by sex and period) for the estimation of M. Iterations of effective sample sizes and adjustments of CVs for the total escapement and catch series were made for each model run. To pick a "best" model, two sets of analyses were run. For the models that estimated sex-specific, and sex- and period-specific Ms, each was balanced by changing the CVs and effective sample sizes. For each set of fixed CVs and effective sample sizes, the structure of M estimation was changed to the alternate M structures. AIC values were then compared to determine the "best" model. The run in which M was estimated for two time periods (1980-1999, 2000-2010) was deemed "best" and was selected as the base run.

Table 8. Likelihood components with respective contributions in base model run.

Likelihood Components	Weight	RSS
Total Escapement	1	30.31
Total Catch	1	28.30
Escape Age Comps	0.5	2118.36
Total Likelihood		1058.48
Number of Estimates		34.00
AIC		2184.95
Catch RMSE	1.00178	
Escape. RMSE	1.00404	

Comparison of model outputs revealed an imbalance between the total escapement numbers and escapement age composition (escapement data were not predicted well after 2000), indicating possible conflict between the two sources of data. Since we believe that the total escapement numbers have less error than the age composition data, the likelihood contribution of the latter was downweighted by 50%.

The female sex proportion (f) used in the base model run was 0.5. Adjustments of CVs for the total escapement and catch series to obtain an RMSE value near 1.00 were 0.24 and 0.25, respectively. The average effective samples sizes for female and male catch age composition were set to 35 and 54, respectively, based on the original non -downweighted model results.

Resulting contributions to total likelihood are listed in Table 8. The converged total likelihood was 1,058.5. In total, 34 parameters were estimated in the model. The resulting estimates of recruitment and natural mortality are given in Table 9. Graphs depicting the observed and predicted values for total removals and total escapement numbers, and standardized residuals are shown in Figure 21. Plots of observed and predicted catch age composition (proportions) and bubble plots of standardized residuals for each sex, year, and age

Table 9. Parameter estimates and associated standard deviations of base model configuration.

Year	Age-3 Numbers	SD	CV
1980	106,470	17,853	0.17
1981	233,590	67,736	0.29
1982	233,215	75,958	0.33
1983	211,212	47,539	0.23
1984	172,468	31,486	0.18
1985	152,850	25,667	0.17
1986	108,386	24,672	0.23
1987	34,198	42,112	1.23
1988	137,850	95,503	0.69
1989	135,910	108,851	0.80
1990	463,473	138,290	0.30
1991	287,307	71,359	0.25
1992	230,117	50,134	0.22
1993	126,704	36,012	0.28
1994	400,817	71,006	0.18
1995	511,492	81,786	0.16
1996	364,369	64,074	0.18
1997	338,133	58,663	0.17
1998	226,499	46,247	0.20
1999	602,272	85,479	0.14
2000	623,160	103,539	0.17
2001	293,244	54,294	0.19
2002	233,287	40,142	0.17
2003	213,768	33,855	0.16
2004	123,789	22,391	0.18
2005	91,913	18,388	0.20
2006	155,500	27,657	0.18
2007	182,634	32,368	0.18
2008	214,165	38,230	0.18
2009	93,836	24,591	0.26
2010	124,145	41,284	0.33

Period	M	SD	CV
1980-1999	0.701	0.052	0.075
2000-2010	1.150	0.049	0.043

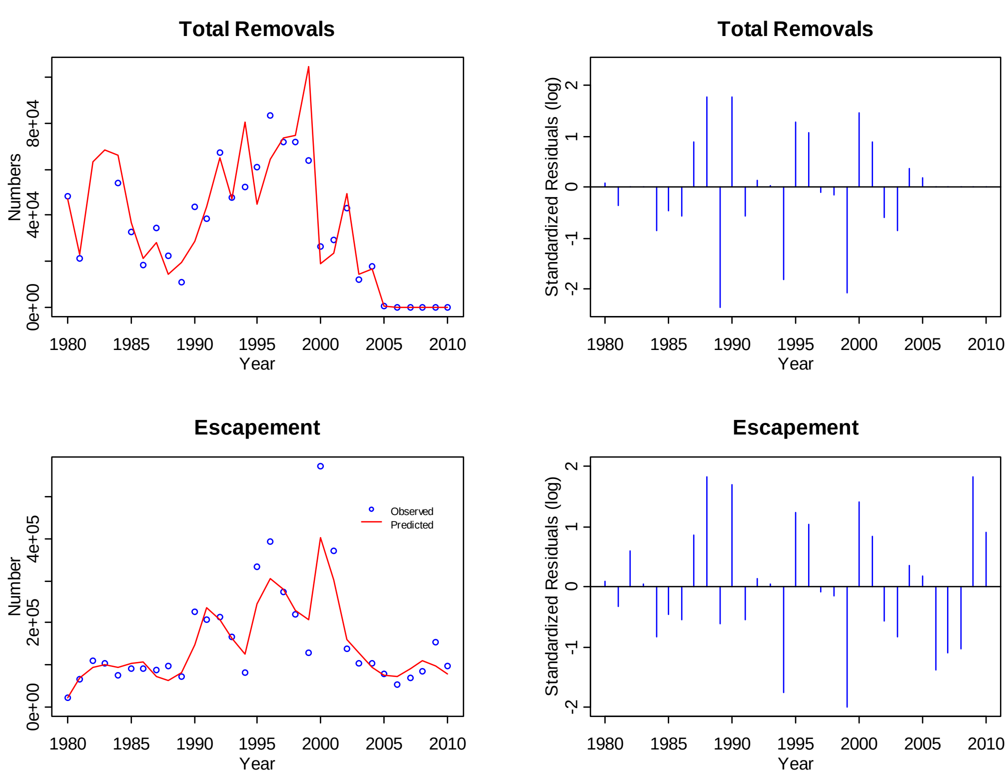

Figure 21. Comparison of observed and predicted total removals and escapement numbers and standardized residuals for Monument River alewife.

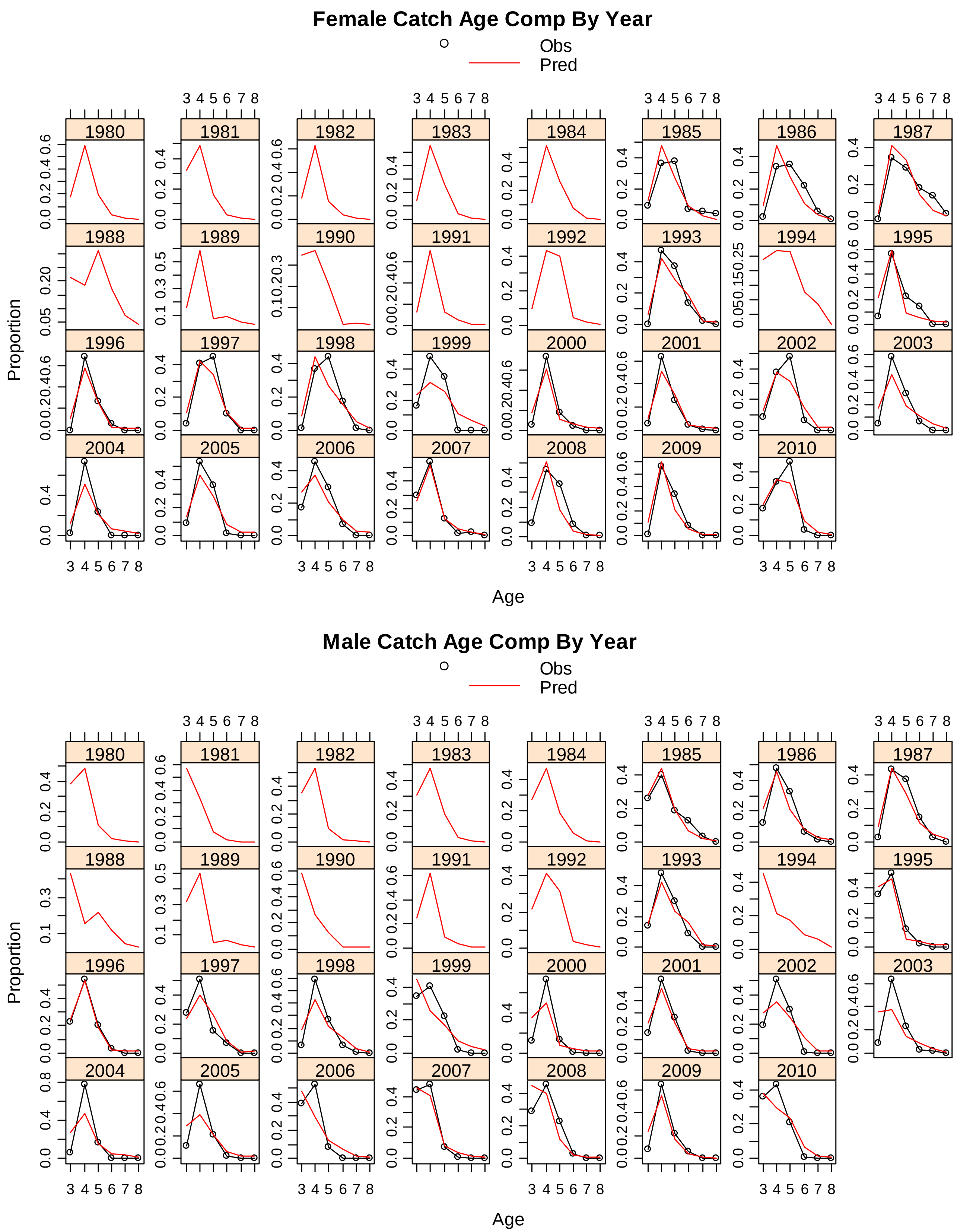

Figure 22. Observed and predicted escapement age composition (proportions) for Monument River alewife by sex, age, and year.

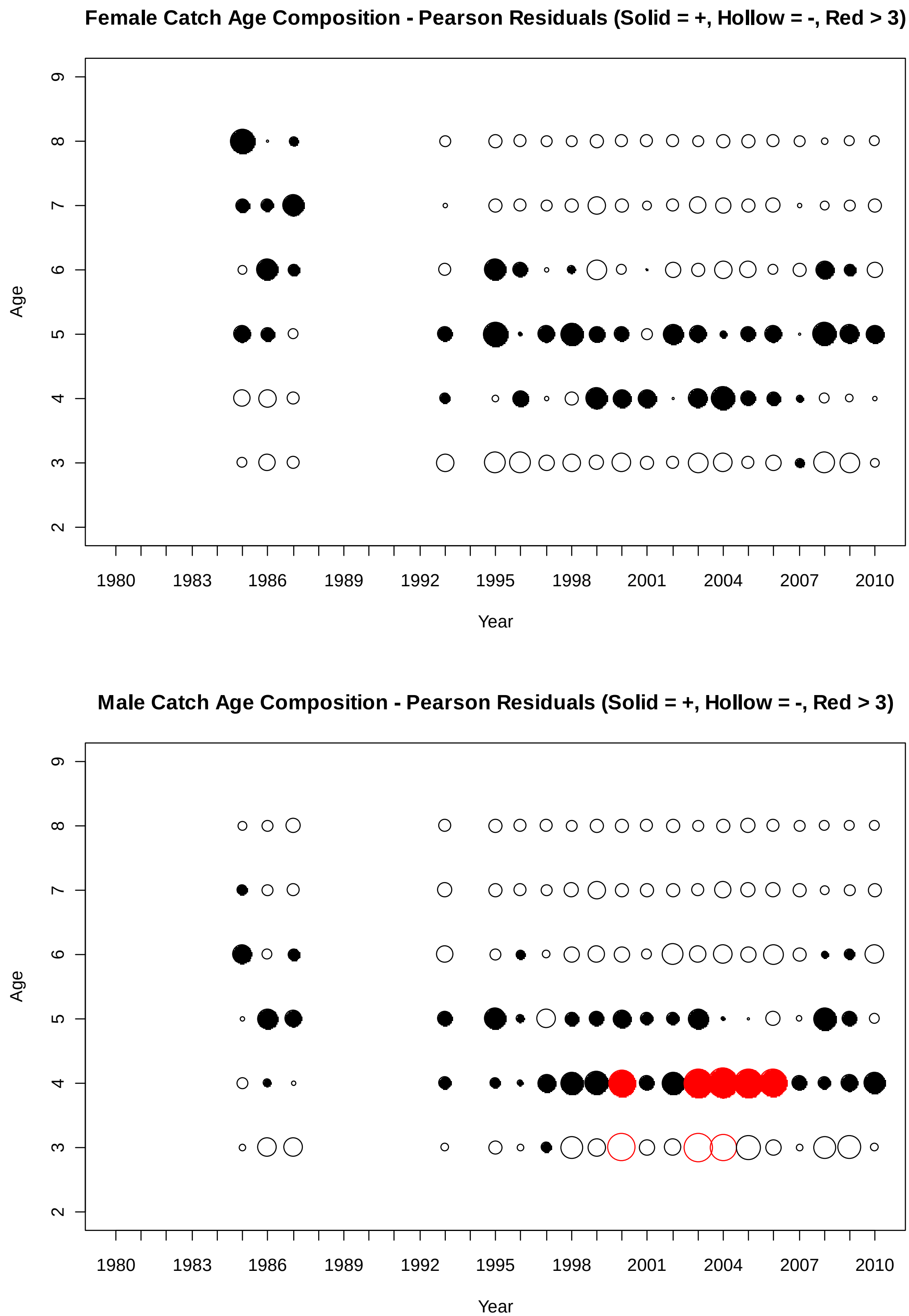

Figure 23. Bubble plots of standardized residuals of catch age composition by sex, year, and age for Monument River.

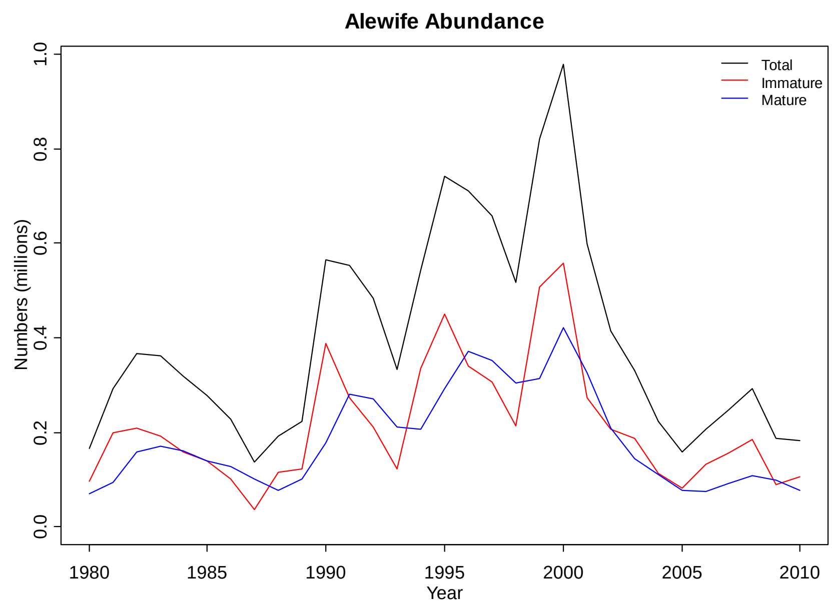

Figure 24. Population abundance estimates for the Monument River alewife stock.

are shown in Figures 22 and 23. The model fit the observed total catch and total escapement (Figure 21) well, but the fit to the escapement age composition was poor in several cases (Figures 22 and 23). This was due to the downweighting of the escapement age composition data. Based on coefficients of variation, many estimates were precise (CVs≤0.20)(Table 9).

The abundance estimates of the Monument River alewife by sex, maturity state, year and age are given in Appendix Table 16. Prior to 1989, alewife total abundance (3+) was low and average about 259,000 fish (Figure 24). Although variable, total abundance increased to 979 thousand fish by 2000. Total abundance declined steadily to 157,448 fish by 2005 (Figure 24). Since 2006, total abundance has averaged only 222,000 fish (Appendix Table 16). Age-3 abundance followed similar patterns as total abundance (Table 9). Age-3 numbers were low prior to 1989 (average = 154,000 fish), increased and peaked at about 511,492 fish in 1995 (1992 year-class), declined to 226,499 fish in 1998, increased to its peak of 623,160 fish in 2000, and declined to its second lowest level of 91,913 fish by 2005 (2002 year-class). Since 2006, age-3 numbers have averaged about 154,000 fish.

µ and F Mortality Rates. Exploitation rates (µ) for alewife in the Monument River before the 2005 moratorium ranged as high as 0.68 in 1980 to as low as 0.04 in 2000 (Table 10). Exploitation steadily declined over the time series (Table 10). Since the moratorium, exploitation rates have been zero. Corresponding fishing mortality (F) rates are listed in Table 10. F was highest during the early 1980s and averaged 0.42 per year. It steadily declined over the time series and averaged 0.15 from 2001-2004.

Natural Mortality. The period estimates of "natural" mortality, which includes all other sources of mortality not accounted for, were 0.70 for 1980-1999 and 1.15 for 2000-2010, indicating that mortality increased by 64% after 1999 (Table 9).

Spawning Stock Biomass. Estimates of female spawning stock biomass (SSB) for alewife by age are provided in Appendix Table 17. Prior to 1989, female SSB (3+) was low and averaged about 6,566 kilograms (Figure 25). Although variable, female SSB increased steadily to 25 thousand kilograms by 1996 and remained high but variable through 2001. Female SSB declined steadily from about 13 thousand kilograms in 2002 to its lowest value of about 5,235 kilograms in 2006. (Figure 25). Since 2007, female SSB has averaged only 6,901 kilograms (Figure 25).

Retrospective Analysis. Small retrospective bias was evident in estimates of age-3 abundance,

Table 10. In-river exploitation rates (μ) and equivalent fishing mortality rates for the Monument River.

Year	mu	F
1980	0.68	1.15
1981	0.25	0.28
1982	0.40	0.51
1983	0.40	0.51
1984	0.41	0.53
1985	0.26	0.31
1986	0.17	0.18
1987	0.28	0.33
1988	0.19	0.21
1989	0.19	0.21
1990	0.16	0.18
1991	0.16	0.17
1992	0.24	0.27
1993	0.22	0.25
1994	0.39	0.49
1995	0.15	0.17
1996	0.17	0.19
1997	0.21	0.23
1998	0.25	0.28
1999	0.33	0.40
2000	0.04	0.05
2001	0.07	0.08
2002	0.24	0.27
2003	0.10	0.11
2004	0.15	0.16
2005	0.01	0.01
2006	0.00	0.00
2007	0.00	0.00
2008	0.00	0.00
2009	0.00	0.00
2010	0.00	0.00

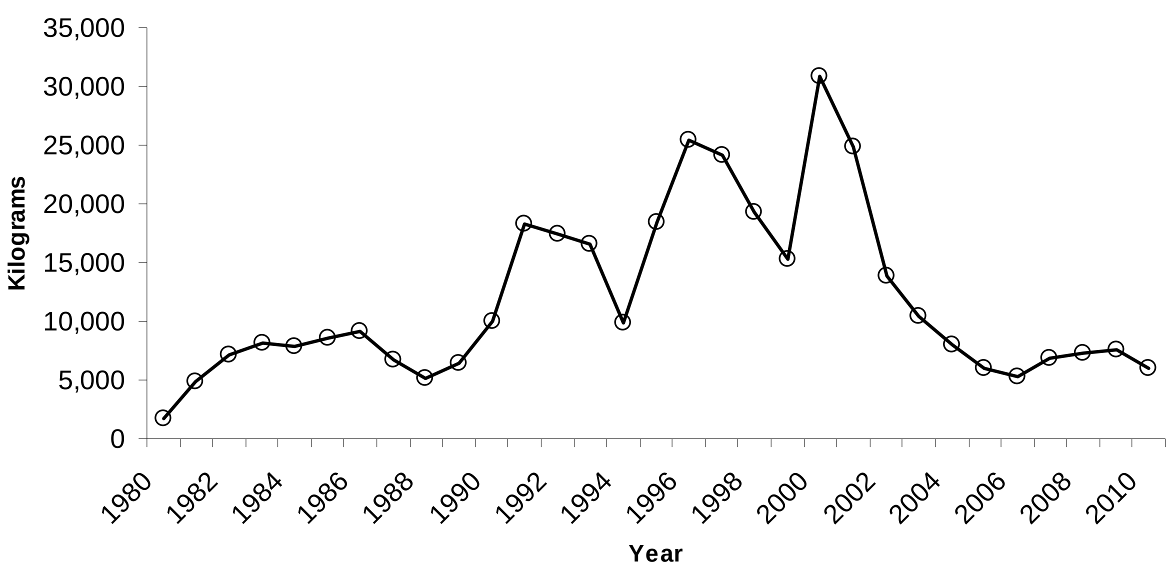

Figure 25. Estimates of female spawning stock biomass (kilograms) for Monument River alewife.

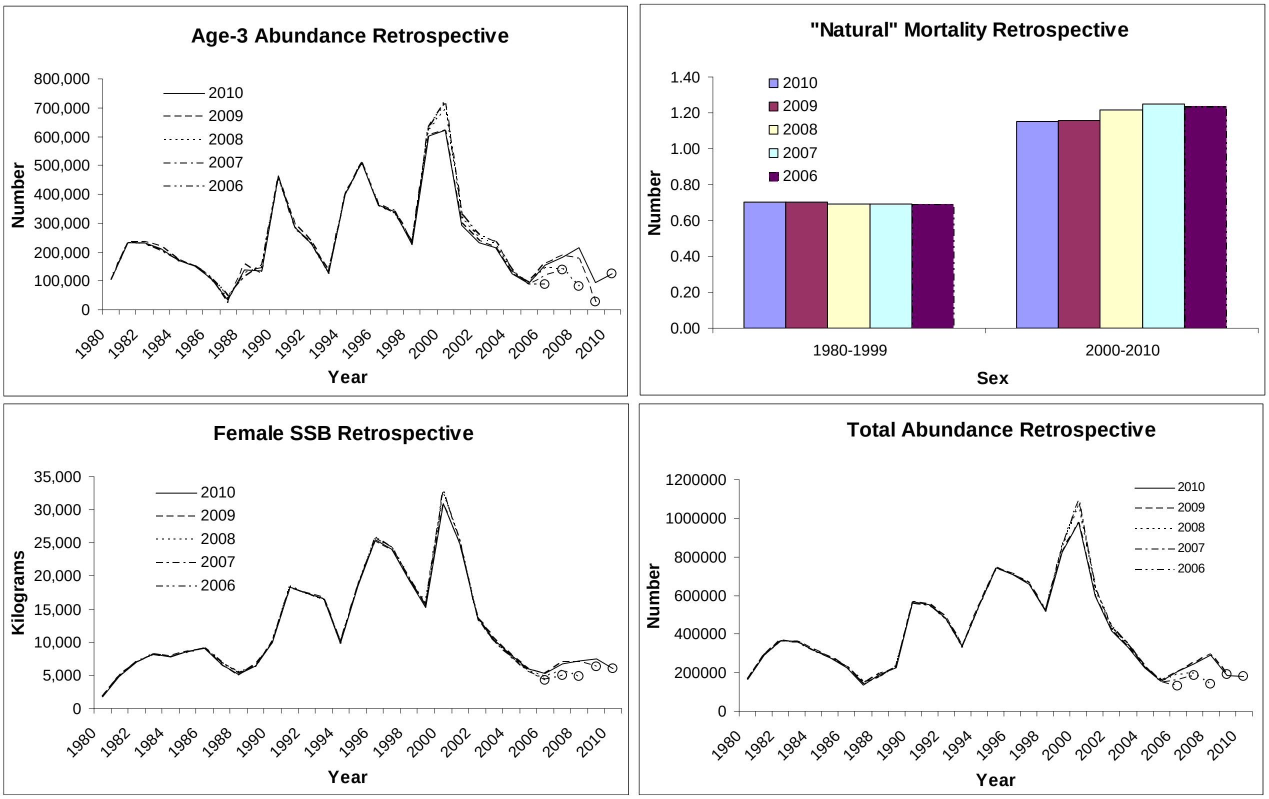

Figure 26. Retrospective analyses for age-3 abundance, "natural" mortality, and female spawning stock biomass, and total population abundance estimates for the Monument River.

"natural" mortality estimates, female SSB, and total population abundance. There was a consistent underestimation of the terminal year values of age-3 numbers, female SSB and total population abundance, but a consistent overestimation of "natural" mortality values in the second period (Figure 26).

Reference Points. The fit of the Beverton-Holt stock-recruitment equation to the age-3 abundance and female SSB is shown in Figure 27. A plot of the residuals indicated reasonable model fit (Figure 27). The estimates of a and R_0 are 36.34 (SE=19.45) and 441,316 fish (SE=242,454), respectively. Both estimates were imprecise (CVs >0.5) (Figure 27). Reference points generated from YPR, SPR and the production model are shown in Table 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 1.07 (Figure 28). The fishing mortality that reduced the female spawning biomass to 40% and 20% of the level without fishing was 0.54 and 1.06, respectively (Figure 28).

From the spawner-recruit data, F_{med} was estimated to be 0.70. From the production model, the fishing mortality rate that produces maximum sustainable yield, F_{msy}, was 0.55 and corresponding spawning stock bass, SSB_{msy}, was 19,297 kilograms. SSB_{msy} was higher than the 20% of the equilibrium spawner biomass, $SSB_{20\%}$ (13,577 kilograms) (Table 11). Current female spawning stock biomass (8,256 kilograms) is 31% of SSB_{msy}. The fishing mortality rate that drives the population to extinction, F_{col}, was 1.29. The relationships between the reference points from the production model are shown with the SR data in Figure 29. The estimates of F_{msy} and F_{col} are considerably lower than those estimated for

Table 11. Reference points derived from YPR, SPR and production model methods.

Method	Basis	Estimate
Yield Per Recruit	F0.1	1.07
	Fmax	5
Spawner Per Recruit	F40%	0.54
	F20%	1.06
	Fmed	0.7
Production Model	Fcol	1.29
	Fmsy	0.55
	SSBmsy	19297
	SSB20%	13577

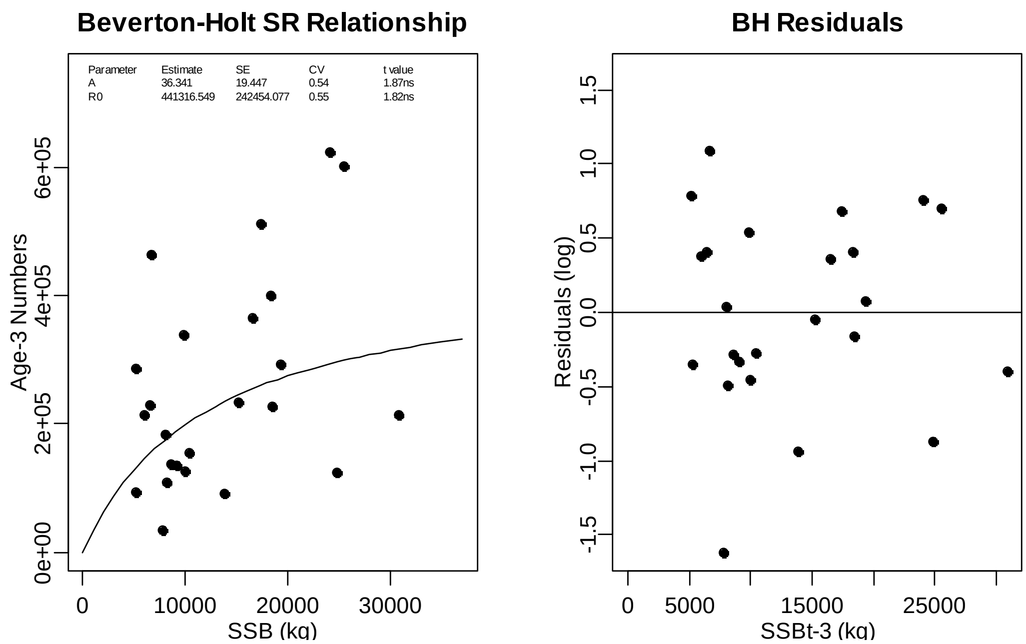

Figure 27. Beverton-Holt stock-recruitment relationship for the Monument River alewife. Estimates of *a* and R_0 are provided in the first graph, and residuals are shown in the second graph.

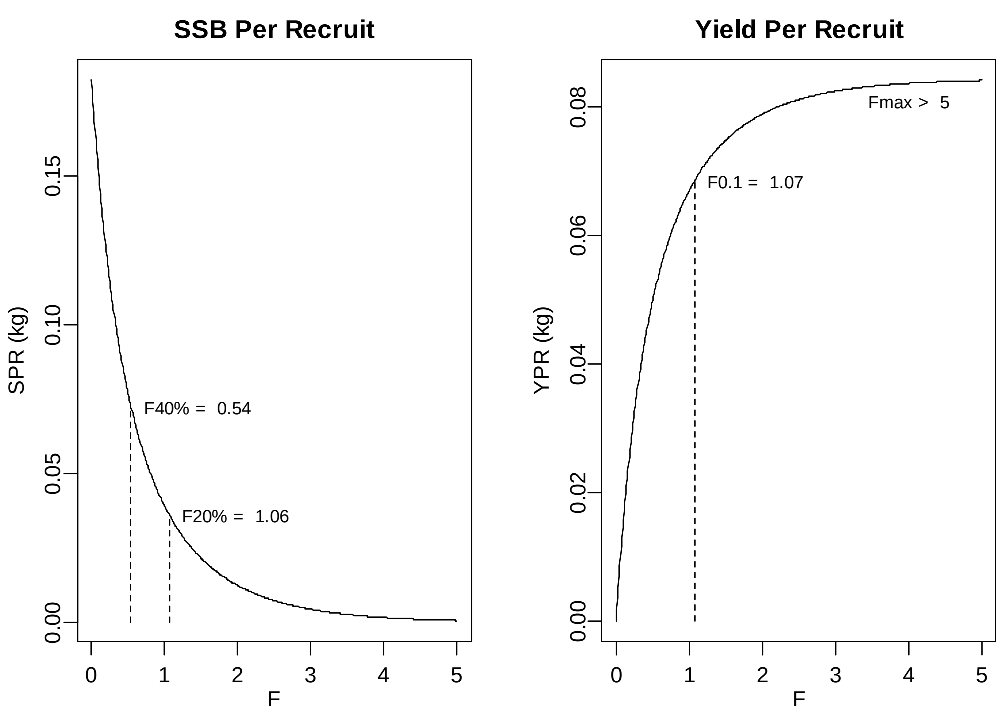

Figure 28. Results of spawning biomass-per-recruit and yield-per-recruit and analyses for Monument River alewife.

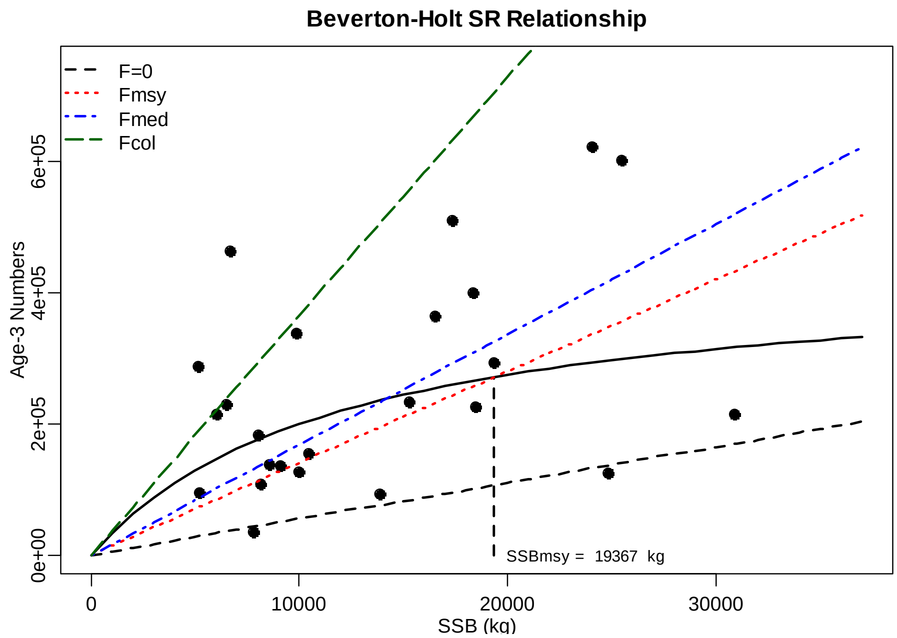

Figure 29. Production model reference points for Monument River alewife.

alewife (F_{msy}>1.0; F_{col}>1.82) in three Canadian rivers by Gibson and Myers (2003b). The in-river fishing mortality rates exceeded F_{msy} and other reference points only during the beginning of the time series (Table 10).

The reference points based on the overall S-R relationship may be over-estimating the alewife's current ability to respond to changes in mortality. Examination of period-specific S-R points revealed that, since 1998, the number of fish surviving to age -3 has dropped but has remained constant at about 190,000 fish regardless of the level of female spawning stock biomass (Figure 30). This suggests

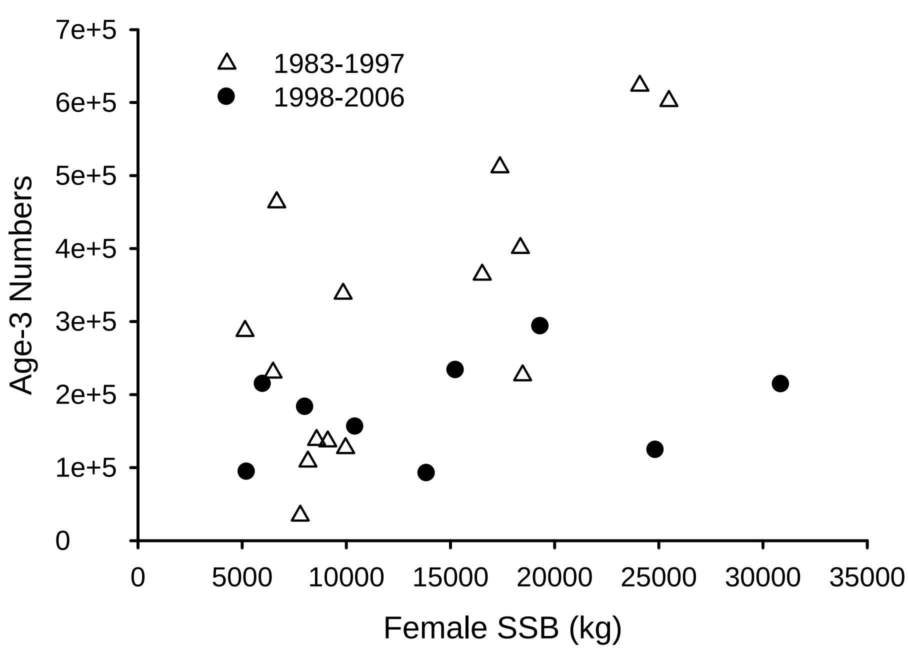

Figure 30. Plot of S-R data for Monument River alewife with year-classes symbolized by time periods (1983-1997 and 1998-2006).

that the reference points for alewife's in its current survival regime may be lower.

Sensitivity Analyses. Sensitivity analyses were conducted to determine the influence of assumed-known input values on the resulting estimates of age-3 abundance, female SSB, natural mortality rates, and total population abundance. The sensitivity of the base model output to changes in the female sex ratio, CVs of total removals and escapement numbers, average effective sample size, and the ratio used to downweight the escapement age composition were examined. The following changes in input parameters were made:

Female sex ratio	±0.1
CVs and effective sample sizes	±20%
Downweight Ratio	±0.1

For changes in female sex ratio, the CVs and effective sample sizes were re-balanced before downweighting.

Changing the female sex ratio by ±0.1 had little impact on the estimates of age-3 abundance, natural mortality or total population abundance (Appendix Figure 1). The ±0.1 change had the biggest impact on female SSB (Appendix Figure 1). On average, female SSB increased by 237% with a 0.1 increase in the sex ratio, while female SSB decreased by 222% with a 0.1 decrease in the sex ratio (Appendix Figure 1).

Changing the CVs of the total removals and escapement numbers by ±20% had little impact on the estimates of age-3 abundance, natural mortality, female SSB or total population abundance (Appendix Figure 2).

Changing the average effective sample sizes had variable impacts on the estimates of age-3 abundance, natural mortality, female SSB or total population abundance. Increasing the average effective sample sizes by 20% increased and decreased specific values of the age-3 estimates between –44 and +23%, while decreasing the average effective sample size by -20% increased and decreased specific values of the age-3 estimates between –100 and +244% (Appendix Figure 3). Changes in female SSB (range: -19.0 to 28%), total abundance (range: -49.0 to 63.0%), and natural mortality estimates (range: -0.6 to 3%) were less dramatic (Appendix Figure 3).

Changing the downweight ratio had also variable impacts on the estimates of age-3 abundance, natural mortality, female SSB or total population abundance. Increasing the downweight ratio by 0.1 increased and decreased specific values of the age-3 estimates between –44and +24%, while decreasing the downweight ratio by 0.1 increased and decreased specific values of the age-3 estimates between –100 and +224% (Appendix Figure 4). Changes in female SSB (range: -20.0 to 29%), total abundance (range: -49 to 63.0%), and natural mortality estimates (range: -0.6 to 3.0%) were less dramatic (Appendix Figure 4).

Comparison of Total Instantaneous Mortality Estimates. Total instantaneous mortality estimates (Z) were derived by adding the annual F values (Table 10) to the respective period estimates of "natural" mortality. These values were compared to Z estimates derived using the Chapman-Robson survival estimator on age data (see *Trends in Total Instantaneous Mortality*). In addition, Z reference points (i.e., Z_{col} and $Z_{20\%}$) were calculated by adding the "natural" mortality estimate for 1980-1999 to the F reference points presented in Table 11. Comparison of the Z estimates showed that the Z estimate derived in this model were comparable to the Z derived using the Chapman-Robson estimator on age data for female and male alewife (Figure 31). The Chapman-Robson-based estimates showed increased mortality starting in the mid-1990s, while the SCA model, due to the model configuration, showed increased mortality after 1999 (Figure 31). Except for two estimates of male alewife Z, most Z estimates were well below the Z reference points (Figure 31). This indicates that, although there was an increase in total mortality, the increase was not high enough to collapse the stock of alewife in the Monument River.

Potential Causes of Population Declines and Increased Mortality

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

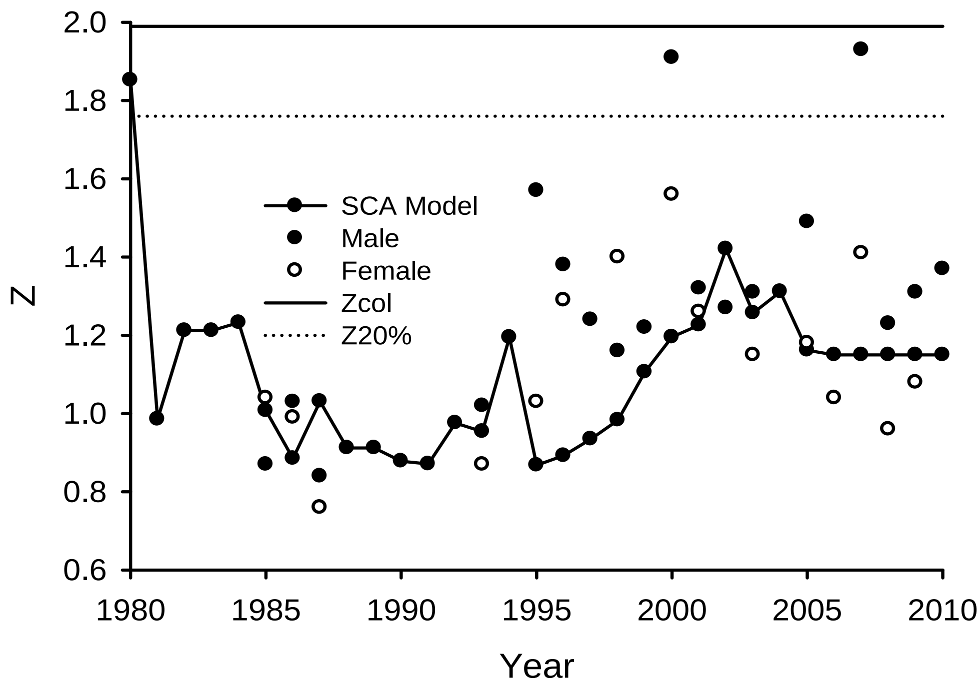

Figure 31. Comparison of Z estimates derived from the SCA model and those derived from raw age data using the Chapman-Robson survival estimator for Monument River alewife. Also, shown are the Z reference points (Zcol and Z20%).

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 . Support for a change in carrying capacity is evident in the stock-recruitment data for Monument River alewife (Figure 30). Since 1998, the number of fish surviving to age-3 dropped but has remained constant at about 190,000 fish regardless of the level of female spawning stock biomass (Figure 30). This suggests that survival declined and a plot of the number of age-3 fish divided by the corresponding female spawning stock biomass shows that this occurred through the mid-2000s (Figure 32). The cohorts with lowest survival were the 1998 and 1999 year-classes (Figure 32). These fish were age-3 in 2001 and 2002 and their low numbers contributed to the decline in population abundance as they aged.

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. To investigate whether trends in abundance of Monument River alewife may be correlated with rainfall, we regressed total alewife abundance against monthly cumulative rainfall from July through December lagged 3, 4, 5 and 6 years in the past (abundance in the run is comprised mostly of ages 4, 5 and 6). Stepwise multiple regression was used to select the significant monthly data that best predicted the total abundance. Results are shown in Figure 33 and suggest that the survival of ages 4 and 5 fish when they were juveniles is positively dependent on rainfall during the fall months of September, November and December.

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*), and seals (*Phoca vitulina*). Striped bass, in particular, may have impacted river herring as strong, negative correlations

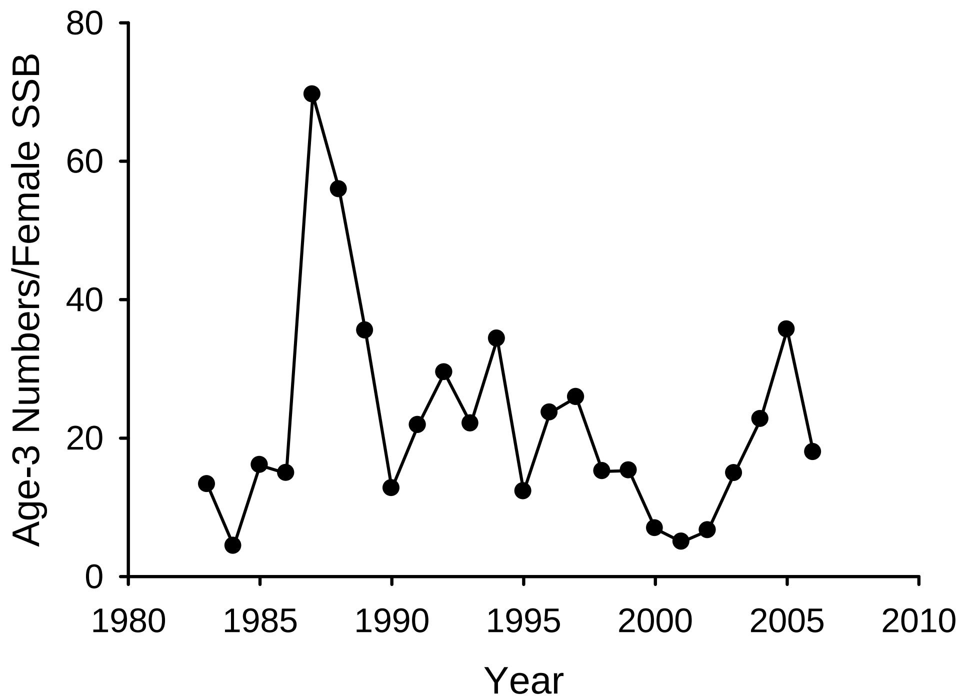

Figure 32. Plot of survival ratios (age-3 numbers divided by female SSB) for Monument River alewife.

$$A = -241074 + 27998 S_{t-4} + 20351 S_{t-5} + 33495 N_{t-4} + 22594 N_{t-5} + 23580 D_{t-4} - 148757 I_{2006-2010}, r^2 = 0.77$$

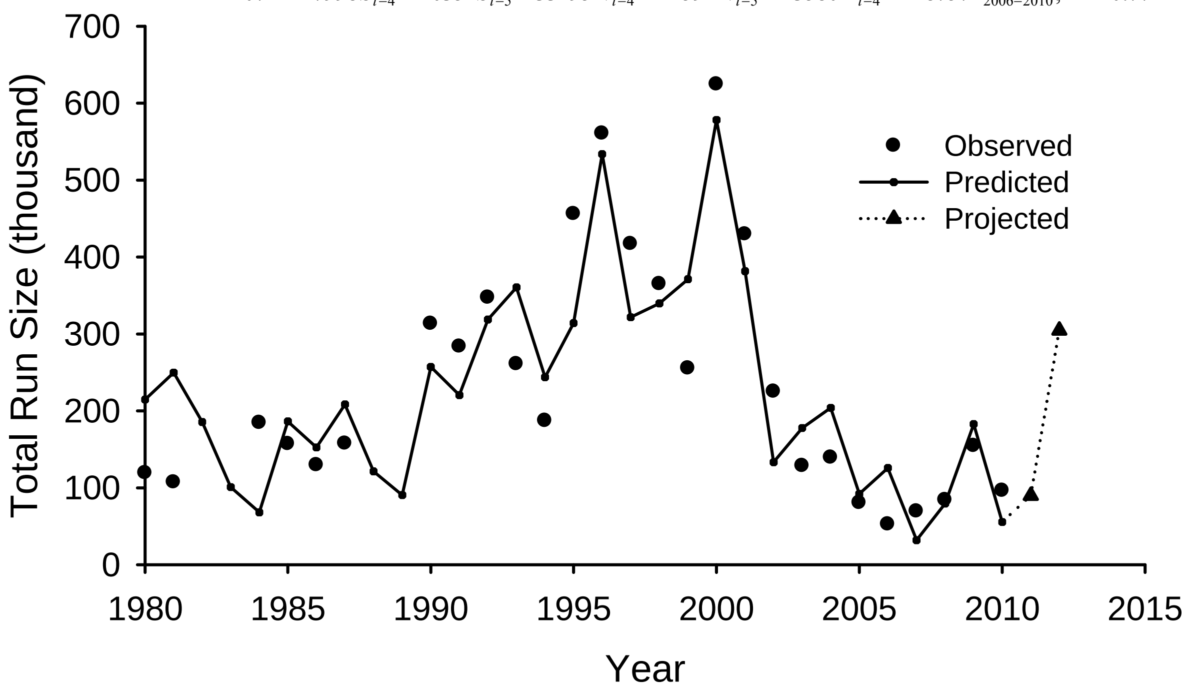

Figure 33. Prediction of Monument River alewife total abundance using monthly cumulative rainfall from Onset, Massachusetts lagged 4 and 5 years.

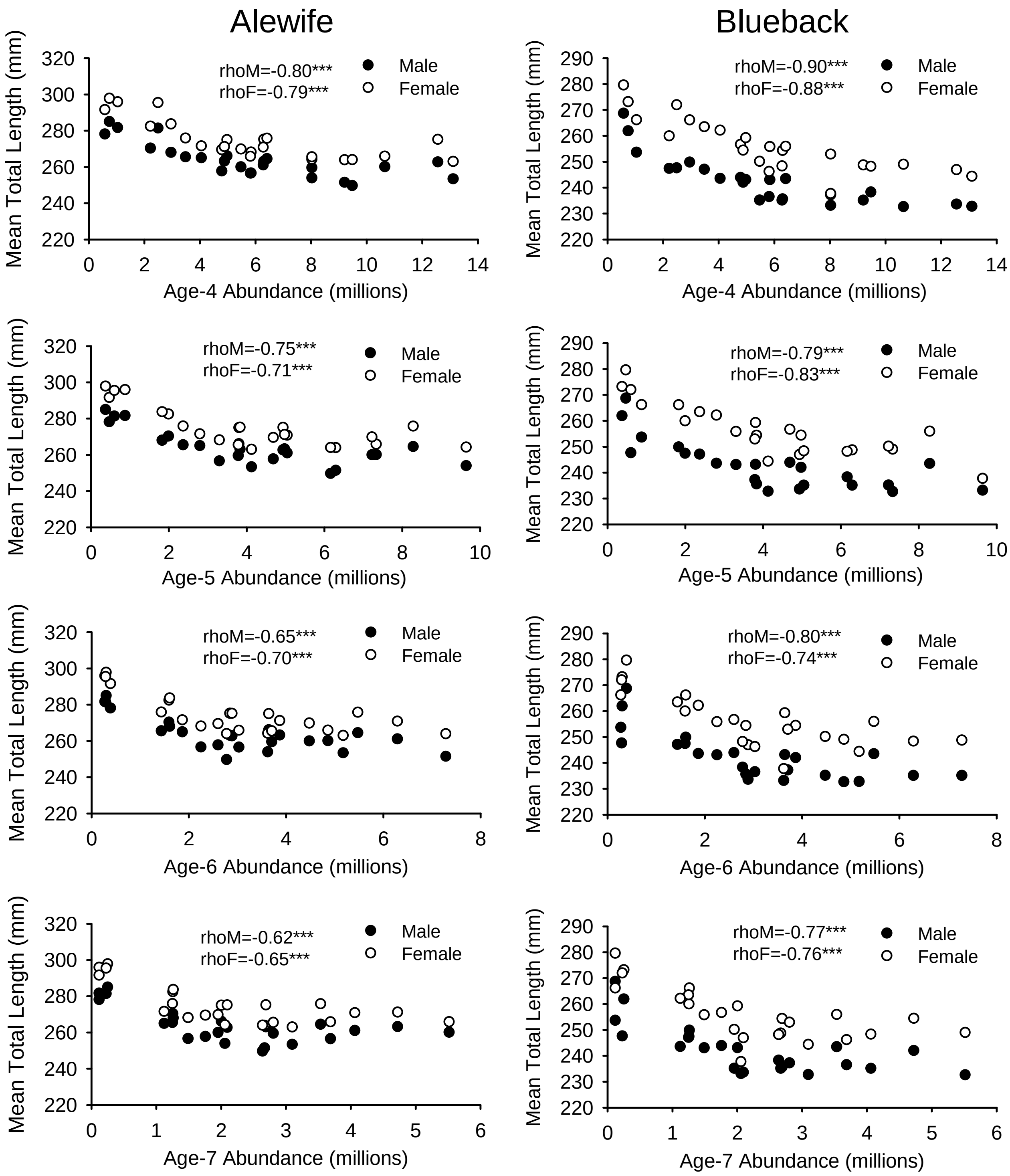

Figure 34. Mean length for male and female alewife and blueback herring from the Monument River versus striped bass coastwide abundance for ages 4-7 lagged one year.

(Spearman rho) between average sizes of female and male alewife and blueback herring from the Monument River and striped bass coast-wide abundance are evident (Figure 34).

Bycatch in Fisheries - It is indeed possible that bycatch in several fisheries off Massachusetts may be impacting river herring stocks since fisheries like the Atlantic herring fishery began in the late 1990s and total mortality was shown to increase during that time, at least in the Monument River. However, river-specific impacts are impossible to assess at this time because there is no information on river-stock composition from the bycatch.

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.

Watershed Alterations - Many rivers in Massachusetts continue to be severely degraded by water withdrawals, transport of wastewater out of the watershed, and loss of water inputs due to development within the watershed. Such conditions affect the passage and spawning of adults and survival of young.

Summary

1. Count data for three (Parker, Monument and Mattapoisett Rivers) of the five rivers used to estimate trends in passage and total run size indicated a precipitous decline in alewife abundance after 2000. Such a decline was not observed in the Nemasket River, but passage counts after 2002 declined by 26% per year through 2005. The decline in alewife abundance in the Monument River was due to two consecutive years of low recruitment of age-3 fish. Abundance has slowly increased 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.

2. Size data from the Monument River and Stony Brook indicated that the average total lengths of alewife and blueback herring have declined over time. Herring in the Monument River are currently about 20-27 mm smaller than herring sampled during 1984-1987.

3. The average age of alewife and blueback herring in the Monument River has declined over time. The maximum age of both species is 1-2 years less than the maximum ages observed during 1985-1987.

4. 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 0.21 in recent years. Similar reductions in proportions of repeat spawners were observed for blueback herring in the Monument River.

5. Results from the statistical catch-at-age model, and estimates of total instantaneous mortality from age, repeat spawner, and length data showed that the total mortality of alewife in the Monument River increased during the late 1990s.

Acknowledgements

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Appendix Table 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 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 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 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

Appendix Table 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.

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 3. Summary of time series of fisheries-independent data for river herring in Massachusetts.

Run	Species	Enumeration Method	Counts	Length Data	Weight Data	Sex Data	Age Data	Repeat Spawn Data	Source	Comments
Acushnet River	Alewife/ Blueback	Trap (2005 - present) Electronic (2008 - present) Video (2008)	Total and combined escapement (2005 - present)	Alewife (2005-2010) Blueback (2008-2009)	Alewife (2005-2010) Blueback (2008-2009)	Alewife (2005-2010) Blueback (2008-2009)	Alewife (2005-2010) Blueback (2008-2009)	Alewife (2005-2010) Blueback (2008-2009)	MADMF CSBB USGS	Census
Agawam River	Alewife/ Blueback	Electronic	Combined Passage (2006 - present)	1991	1991	1991	1991	1991	Wareham MADMF CSBB	
Back River (Combined)	Alewife/ Blueback	Visual Video (2008-2009)	Combined Passage 1977-78; 1984, 1986 - present	Alewife 2007	Alewife 2007	Alewife 2007	Alewife 2007	Alewife 2007	Weymouth MADMF UMASS	No statistical design (Visual counts)
Bound Brook	Alewife	Visual	Passage (2010)	None	None	None	None	None	NSRWA	No statistical design
Charles River	Blueback herring	Video (2008-2009	Combined Passage (2008-2009)	1985; 1993	1985; 1993	1985; 1993	1985; 1993	1985; 1993	MADMF UMASS	
Connecticut River (Holyoke)	Blueback	Fishlift/ Video	Total and combined Passage (1967 - present)	None	None	None	None	None	USFWS	Census
Coonamessett River	Alewife/ Blueback	Visual	Combined Passage (2005 - present)	None	None	None	None	None	Falmouth DNR	
1st Herring Brook	Alewife	Visual	Passage (2005 - 2006)	None	None	None	None	None	NSRWA	No statistical design
2nd Herring Brook	Alewife	Visual	Passage (2005 - 2006)	None	None	None	None	None	NSRWA	No statistical design
3rd Herring Brook	Alewife/ Blueback	Visual	Combined Passage (2003, 2005 - 2006)	None	None	None	None	None	NSRWA	No statistical design
Herring Brook	Alewife/ Blueback	Visual	Combined Passage (2010)	None	None	None	None	None	NSRWA	No statistical design
Herring River (Wellfleet)	Alewife/ Blueback	Visual	Combined Passage (2007 - present)	None	None	None	None	None	MADMF APCC	Stratified random design
Herring River (Harwich)	Alewife/ Blueback	Visual	Combined Passage (2007 - present)	None	None	None	None	None	APCC	Stratified random design
Ipswich River	Alewife/ Blueback	Visual Trap	Combined Passage (2000 - present) Total combined Passage. (2006 - 2008)	None	None	None	None	None	IRWA MADMF	No statistical design prior to 2005 Census (trap)
Jones River	Alewife/ Blueback	Visual	Combined Passage (2005 - present)	None	None	None	None	None	JRWA	
Little River	Alewife/ Blueback	Visual	Combined Passage (2000-2002; 2005; 2009)	None	None	None	None	None	MA Audubon	Counts to be continued under 8 Towns and the Bay
Marston Mills River	Alewife/ Blueback	Visual	Combined Passage 2006 - present	None	None	None	None	None	Watershed Association	Stratified random design

Appendix Table 3 cont.

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Run	Species	Enumeration Method	Counts	Length Data	Weight Data	Sex Data	Age Data	Repeat Spawn Data	Source	Comments
Mattapoisett River	Alewife	Electronic counter	Combined Passage (1987 - 2010)	1995; 2006 - 2007	1995; 2006 - 2007	1995; 2006 - 2007	1995; 2006 - 2007	1995; 2006 - 2007	AA MADMF	
Merrimack River	Alewife/ Blueback	Fishlift/ Video	Combined Passage (1983 - Present)	None	None	None	None	None	USFWS	High water affected counts from 2005-2007
Monument River	Alewife/ Blueback	Electronic Visual Video (2008-2009)	Total and combined escapement: 1980-81; 1984-1987; 1990 - present	Both spp.: 1984 - 1987, 1990 - 2010	Both spp.: 1984 - 1987, 1993, 1995 - 2010	Both spp.: 1984 - 1987, 1990 - 2010	Both spp.: 1984 - 1987, 1993, 1995 - 2010	Both spp.: 1984 - 1987, 1993, 1995 - 2010	MADMF UMASS (video)	Census
Mystic River	Alewife/ Blueback	None*	None*	Alewife (2004-2010) Blueback (2005-2010)	Alewife (2004-2010) Blueback (2005-2010)	Alewife (2004-2010) Blueback (2005-2010)	Alewife (2004-2010) Blueback (2005-2010)	Alewife (2004-2010) Blueback (2005-2010)	MADMF	Future site for fish counting using electronic counter
Nemasket River	Alewife	Visual	Passage 1996; 1998 - present	1996, 2000, 2004 - 2010	1996, 2000, 2004 - 2010	1996, 2000, 2004 - 2010	1996, 2000, 2004 - 2010	1996, 2000, 2004 - 2010	MLHFC MADMF	No statistical design
Parker River	Alewife	Visual	Passage (1972 - 1978; 2000 - Present)	1971-1972	None	1971-1978	1971-1978	None	Mayo (1974), UMASS PRCWA	Detrition of weir affected counts in 2006-2007
Pilgrim Lake	Alewife	Visual	Combined Passage (2007 - present)	None	None	None	None	None	APCC	Stratified random design
Quashnet River	Alewife/ Blueback	None	None	Both sp.: 2004	Both sp.: 2004	Both sp.: 2004	Both sp.: 2004	Both sp.: 2004	MADMF	
Sippican River	Alewife	Electronic Counter	Combined Passage (1995-2002; 2006)	None	None	None	None	None	AA MADMF	Counter not installed from 2003-2005 & 2007 (high water) 2008 & 2009 (counter was used to replace failed counter on Matt. River; 2010 (plans to replace existing ladder)
South River	Alewife/ Blueback	Visual	Combined Passage (2006, 2008, 2010)	None	None	None	None	None	NSRWA	No statistical design
Stony Brook	Alewife/ Blueback	Visual	Combined Passage 2007 - present	Alewife (2004)	Alewife (2004)	Alewife (2004)	Alewife (2004)	Alewife (2004)	MADMF APCC	Stratified random design
Town Brook	Alewife/ Blueback	Visual (2008 - present) Video (2008 - 2009)	Combined Passage (2008 - present)	Alewife (2004-2010) Blueback (2004)	Alewife (2004-2010) Blueback (2004)	Alewife (2004-2010) Blueback (2004)	Alewife (2004-2010) Blueback (2004)	Alewife (2004-2010) Blueback (2004)	MADMF Plymouth UMASS	No statistical design
Town River	Alewife/ Blueback	Electronic Counter	Combined Passage (2000 - present)	None	None	None	None	None	Bridgewater	
Trunk River	Alewife	Visual	Escapement (2009, 2010)	None	None	None	None	None	Falmouth	No statistical design
Wankinco River	Alewife/ Blueback	Electronic Counter	Combined Passage (2007 - present)	None	None	None	None	None	Wareham MADMF CSBB	
Ocean North of Cape Cod	Alewife/ Blueback	Trawl Survey	Age-1 Relative Abund: 1978-2010	Both sp.: 1978-2010	Agreggate for both spp.: 1978 - 2010	None	None	None	MADMF	
Ocean South of Cape Cod	Alewife/ Blueback	Trawl Survey	Age-1 Relative Abund: 1978-2010	Both sp.: 1978-2010	Agreggate for both spp.: 1978 - 2010	None	None	None	MADMF	

Appendix Table 4. Passage, total and removal numbers of river herring from select Massachusetts rivers.

	Mattapoisett River		Monument River			Nemasket River	
	Alewife		Blueback	Alewife	Combined	Alewife	
Year	Passage	Removals	Total Count	Total Count	Removals	Passage	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	22,000	0			35,280		
1989	40,000	3,000			17,520		
1990	47,000	3,960	62,397	269,502	53,950		
1991	47,000	16,320	99,646	245,151	53,880		
1992	44,000	3,960	24,017	280,001	73,002		
1993	44,000	12,000	39,117	213,249	56,380		
1994	44,000	24,000	9,665	134,590	56,210		
1995	75,000	6,000	37,912	395,201	66,513		
1996	58,000	6,000	59,008	477,432	93,339	1,094,860	
1997			53,855	345,074	83,045		
1998	104,000	6,000	36,210	292,970	80,881	866,538	64,200
1999	107,000	2,500	21,754	191,516	70,973	1,043,906	114,632
2000	130,000	2,500	73,902	597,937	29,859	1,069,000	75,426
2001	77,000	0	46,478	400,422	32,552	476,779	61,668
2002	50,000	0	25,530	182,031	49,211	1,919,000	101,302
2003	25,000	0	70,181	116,718	18,990	793,000	80,971
2004	5,385	0	39,602	121,184	23,954	578,000	72,763
2005	8,000	0	22,944	79,483	1,192	401,000	43,741
2006	6,270	0	22,192	52,472	0	505,000	0
2007	6,011	0	8,140	69,385	0	659,880	0
2008	9,987	0	18,532	84,196	0	848,848	0
2009	10,356	0	30,536	154,532	0	760,717	0
2010	12,319	0	9,358	96,355	0	763,884	0

Appendix Table 4 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			53,173		89				
2007	60	13,996	30,252	100,473	2,788		53,315			
2008	485		33,383	30,429	8,246		27,783	1,525		
2009	800		19,197	36,354	6,539		8,596	906	23,537	31,589
2010	1,800		71,026	30,057	10,665		29,465			
	Detrition of stream weirs affected 2006-2007									

Appendix Table 5. 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

Mystic 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	1				6				1					
220	7			1	3		6	2	1	1	2			
230	16	8	2		3	2	29	6	21	7	6	3	1	
240	10	6			9	7	44	28	28	8	13	8	7	8
250	12	8	3	2	1	5	35	36	25	11	27	22	2	10
260	12	15	2	2	2	7	10	26	28	14	13	15	2	7
270	9	15	2	4		7	12	21	3	9	1	12	2	
280	3	4		2		1	3	10	1			4		
290	1							3		2				
300			1	1				2		1		1		1
310														
320														
330														
340														
Total	71	56	10	12	24	29	139	134	108	53	62	65	14	26

Nemasket 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							1							
220									1					
230			1		1								1	
240	1		6	2	19	1	1		14		4	1	2	
250	10	1	25	7	51	9	21	15	47	9	74	7	29	8
260	20	9	30	21	59	35	84	51	76	17	106	30	81	27
270	23	16	40	40	40	43	131	76	64	66	77	72	96	62
280	35	31	19	25	18	19	96	67	39	67	40	51	51	78
290	34	28	17	19	6	14	45	29	17	33	11	23	15	45
300	14	29	9	10	2	2	14	14	1	15	1	6	1	5
310	2	11		6	1	4		2		5		1		6
320		2					1	1		1				
330														
340														
Total	139	127	147	130	197	127	394	255	259	213	313	191	276	231

Appendix Table 5 cont.

Alewife

Quashnet River

TL mm	2004 M	2004 F	2005 M	2005 F	2006 M	2006 F	2007 M	2007 F	2008 M	2008 F	2009 M	2009 F	2010 M	2010 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

TL mm	2004 M	2004 F	2005 M	2005 F	2006 M	2006 F	2007 M	2007 F	2008 M	2008 F	2009 M	2009 F	2010 M	2010 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

Town Brook

TL mm	2004 M	2004 F	2005 M	2005 F	2006 M	2006 F	2007 M	2007 F	2008 M	2008 F	2009 M	2009 F	2010 M	2010 F
190														
200														
210	1								1					
220	1		3	1	5				3	1	1			
230	5	2	8	3	10	4	9	2	10	3	13	1	6	1
240	12	1	33	9	27	12	43	6	43	16	35	14	45	4
250	16	12	62	32	50	23	74	32	83	35	82	42	85	25
260	25	20	30	44	34	46	108	78	70	74	70	56	85	64
270	22	40	14	31	11	36	60	73	31	49	37	63	44	79
280	3	16	4	13		5	15	40	12	20	7	22	9	38
290		3		9		2		14	4	6		11	3	14
300		1		1			1			3		3		2
310													1	
320								1						
330														
340														
Total	85	95	154	143	137	128	310	246	257	207	245	212	278	227

Agawam

TL mm	1991 M	1991 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

Appendix Table 5 cont.

Blueback

Mystic River

TL mm	2004 M	2004 F	2005 M	2005 F	2006 M	2006 F	2007 M	2007 F	2008 M	2008 F	2009 M	2009 F	2010 M	2010 F
190					1				3					
200			2		1		2		6		8			
210					17		1		8		21		3	
220			14	2	41		36	8	43	4	49	3	37	1
230			22	11	37	5	97	50	50	4	145	37	112	25
240			14	13	28	16	70	64	28	5	87	74	105	43
250			5	18	3	8	31	60	14	10	19	29	27	38
260			2	13	1	3	5	25	3	5	1	6	3	10
270				3		1	1	7	2					1
280								3						
290														
300														
310				5										
320														
330														
340														
Total	0	0	59	65	129	33	243	217	157	28	330	149	287	118

Quashnet River

TL mm	2004 M	2004 F	2005 M	2005 F	2006 M	2006 F	2007 M	2007 F	2008 M	2008 F	2009 M	2009 F	2010 M	2010 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

Town Brook

TL mm	2004 M	2004 F	2005 M	2005 F	2006 M	2006 F	2007 M	2007 F	2008 M	2008 F	2009 M	2009 F	2010 M	2010 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

	Agawam		Charles				Nemasket	
	1991		1985		1993		2004	
TL mm	M	F	M	F	M	F	M	F
190								
200					3			
210					10	3		
220	2				16	1	1	
230	2	1	3		7	5	1	
240			16	2	8	4		
250	1		19	10	7	9		
260	2	3	16	20	5	16		
270		2	8	11	4	15		
280			1	14	1	9		
290						2		
300				7		4		
310				3				
320				1				
330				1				
340				1				
Total	7	6	63	70	61	68	2	0

Appendix Table 6. 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
205																											
210																											
215																											
220																											
225											1			1			1								1	1	
230		1									2	1		4		1	3	1					2	1	7	2	
235							2		2		7	2		2	1	9	10	2	2	1	2	2	3	3	20	3	1
240							1	2	2	4	10	2	3	10	4	12	14	2	4	1	4	4	7	14	37	11	15
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
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
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
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
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
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
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
280		14	8	15			14	25	6	6	4	1	8	10	8	3			12	3	4	3		12	5	2	5
285	10	10	14	17			5	8	4	4	4		7	9	2			2	7		2	1		2	3		3
290	16	9	5	9			8	6	3	1			4	6	2						1					1	2
295	14	4	16	7			3	7					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

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
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
245							1				6	2		6	3		4	7		2		0	1	6	13	3	4
250							1	3	1	3	11	3	2	3	1	9	5	7	3	3	2	10	8	12	20	6	3
255							6	5	6	5	10	10	3	7	10	11	16	10	7	1	6	8	8	14	27	22	11
260		3		1			4	6	8	11	15	14	16	13	5	13	17	12	5	1	12	8	8	20	23	28	29
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
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
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
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
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
290	14	14	10	7			22	19	8	3	4	3	5	14	7			1	10	1	4		2	3	2		5
295	18	20	13	9			10	19	4	1	4		7	5	7	1		1	5	1	2		2	4	1		1
300	20	13	5	13			9	13	4		1	1	4	5	4	1		1	2		1			4	1		2
305	17	8	11	8			3	8			1	1	1	2	2										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

Appendix Table 6 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
200																									1		
205							1									1								1			
210														0		1				2		1		2	4	2	5
215							1		1	2	1		1	9		4		1		5	2	1	4	8	12	3	4
220	2			3			7	1		2		1		14	2		3	4	2	3	2	4	7	12	8	10	9
225	7			1			5	2	1		1	1	1	16	2	3	6	8	3	9	3	3	6	10	9	14	18
230	14		1	9			5	3		2	2	3	2	21	1	5	6	13	7	10	6	8	11	13	12	19	18
235	20		2	11			8	1	3		2	1	4	14	4	1	7	7	9	15	14	9	16	12	12	24	13
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
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
250	13	2	3	6			14	14	3	6	3	3	5	8	1		2	1	11	4	5	7	5		1	2	3
255	8	2	5	4			23	11	3		1	1	2	8				1	11	4	1	1	1				
260	15	3	6	1			15	9	3	2	2	1	1	7			1		3		1	1					
265	17	3	9	4			9	3	1		1	1	1	2					1		1						
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

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
205																											
210																											
215																						1					
220	1							1						1		1									1	1	1
225														1		1				1		1	2		4		
230	2						1				3			3				2		3	1	1	4	1	1	3	4
235	2						1	1			1			7			1	1	3	10			6	5	11	7	10
240	4		1	3			1	1			1		2	8	5		5	7	1	6	5	3	6	8	11	14	20
245				1			10	4	2	1	5	5	2	17	7		4	5	6	11	7	4	14	17	18	24	10
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
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
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
265	17	3	4	3			11	4	1	2	3	2	3	13				2	5	3	5	3	2	6	4	3	4
270	17	4	8	2			9	10	2		1	4	2	7			1	1	3		5	3	3				
275	8	8	5	3			7	6	1	2	2		3	8					1	1	1		2	1			
280	7	8	7	4			2	6	2	0	1			3				1	2		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

Appendix Table 7. Sample size (n), mean, and standard deviation (SD) of total length distributions of alewife and blueback herrings by sex collected in nine rivers , 1985-2010.

Alewife - Females

	Agawam			Back			Mattapoisett			Mystic			Nemasket			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
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

Alewife - Males

	Agawam			Back			Mattapoisett			Mystic			Nemasket			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
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

Blueback - Females

	Agawam			Charles			Mystic			Nemasket			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
1985				70	276.8	20.58												
1991	6	262.3	16.71															
1993				68	264.1	20.18												
2004													3	259.0	4.359	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									

Blueback - Males

	Agawam			Charles			Mystic			Nemasket			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
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	5.413			
2005							58	236.1	10.59							7	244.43	9.981
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									

Appendix Table 8. 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						Blueback Herring					
	Female			Male			Female			Male		
Year	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD	n	Mean Length	SD
1984	127	295.6	13.17	96	281.3	14.85	101	265.9	16.17	138	253.4	20.45
1985	104	291.3	12.80	83	277.8	16.72	55	279.4	14.59	36	268.5	16.29
1986	87	297.5	16.51	83	284.6	15.34	43	272.9	12.87	51	261.7	12.44
1987	118	295.1	16.30	99	281.1	14.25	35	271.7	17.32	69	247.4	18.00
1988												
1989												
1990	135	282.1	14.27	124	270.0	13.87	71	259.7	11.65	115	247.2	14.19
1991	161	283.4	15.49	205	267.6	13.34	63	265.9	16.00	64	249.6	11.17
1992	97	275.5	12.54	93	265.2	11.69	14	263.2	13.67	22	246.8	14.35
1993	92	271.2	10.36	79	264.7	11.28	13	261.9	11.09	24	243.3	17.24
1994	122	267.8	14.55	139	256.2	12.65	26	255.6	15.90	23	242.8	11.66
1995	92	269.2	12.45	123	257.4	8.99	21	256.4	9.24	22	243.6	13.64
1996	137	274.6	11.95	197	265.8	10.48	20	259.0	11.19	35	242.9	9.57
1997	174	274.9	12.77	197	262.7	13.97	100	254.1	14.40	124	235.4	13.24
1998	90	274.8	15.27	101	262.3	12.42	18	246.7	6.18	12	233.3	9.85
1999	79	263.9	12.78	131	253.5	10.44	4	237.5	17.56	31	232.9	12.23
2000	117	263.5	12.02	132	251.1	10.58	20	248.5	8.75	37	234.9	9.17
2001	99	265.5	13.01	112	259.7	10.22	28	248.8	11.83	44	232.4	8.92
2002	108	275.4	12.72	133	264.2	11.62	43	255.7	11.10	70	243.2	10.36
2003	44	270.5	11.35	45	260.7	10.80	70	248.1	10.01	76	234.9	11.04
2004	72	270.8	11.59	95	262.4	11.17	49	254.8	10.71	50	242.9	10.07
2005	66	265.1	10.73	82	259.2	11.17	40	251.9	11.82	51	242.4	10.72
2006	58	263.7	14.04	61	249.4	7.89	56	247.9	12.31	65	238.0	9.51
2007	185	269.1	12.88	220	259.4	11.41	69	250.3	10.04	82	235.0	10.55
2008	194	262.6	13.75	286	253.0	12.23	67	244.1	9.52	72	232.5	10.78
2009	157	265.5	9.54	158	256.2	10.23	80	246.0	8.07	92	236.3	8.47
2010	216	270.7	10.70	264	259.4	10.84	67	244.3	9.66	80	233.7	9.20

Appendix Table 9. Age composition of alewife and blueback herring from Massachusetts rivers, 2004-2010.

Alewife

Back River

Age	Female							Male						
	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	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							Male						
	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	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								Male							
	1995	2004	2005	2006	2007	2008	2009	2010	1995	2004	2005	2006	2007	2008	2009	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
Total	50	0	0	24	0	0	0	0	54	0	0	35	0	0	0	0

Stony Brook

Age	Female							Male						
	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	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							Male						
	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
2	1	0	0	0	0	0	0	1	0	0	0	0	0	0
3	4	0	1	37	10	4	14	25	2	6	57	39	5	9
4	40	5	9	75	25	30	9	34	4	3	68	56	35	2
5	9	6	4	7	10	18	3	10	3	1	7	11	14	2
6	2	1	1	5	8	4	0	1	1	0	1	2	4	1
7	0	0	0	2	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	56	12	15	126	53	56	26	71	10	10	133	108	58	14

Town Brook

Age	Female							Male						
	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	5	20	25	27	4	2	20	17	16	45	61	24	10	47
4	52	79	75	164	81	65	69	50	104	80	190	113	91	73
5	35	26	26	38	89	75	63	14	27	11	45	94	74	47
6	1	3	0	13	28	27	25	2	5	0	10	24	27	12
7	1	1	0	0	4	8	2	0	1	0	1	2	4	1
8	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Total	94	129	126	243	207	177	179	83	153	136	307	257	206	180

Nemasket River

Age	Female							Male						
	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	4	27	22	2	0	22	4	10	62	41	36	8	42
4	23	50	56	163	38	48	80	39	50	91	257	76	118	88
5	52	54	34	59	134	60	71	65	63	31	82	110	96	51
6	40	19	6	5	34	36	14	30	17	9	12	36	29	7
7	8	1	1	1	5	4	2	1	6	1	1	1	1	1
8	0	1	0	1	0	0	0	0	0	1	0	0	0	0
Total	123	129	124	251	213	148	189	139	146	195	393	259	252	189

Agawam

Age	Female	Male
	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

Appendix Table 9 cont.

Blueback

Mystic 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	5	22	1
3	0	3	2	62	4	75	71	0	18	42	81	55	207	135
4	0	32	18	94	12	49	44	0	22	58	125	67	54	41
5	0	3	9	49	8	9	2	0	2	10	30	23	15	2
6	0	2	2	7	3	3	1	0	0	0	1	6	2	0
7	0	0	0	1	1	0	0	0	0	0	0	1	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	0	40	31	213	28	136	118	0	42	110	237	157	300	180

Town 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	0	0	0	0	0	0	0	0	2	0	0	0	0	0
4	1	1	0	0	0	0	0	0	4	0	0	0	0	0
5	0	0	0	0	0	0	0	0	1	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	1	1	0	0	0	0	0	0	7	0	0	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	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

Age	Female 1991	Male 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

Age	Female 1985	Female 1993	Male 1985	Male 1993
2	0	0	0	1
3	2	3	7	22
4	21	23	30	28
5	26	29	19	5
6	8	9	6	5
7	6	3	1	2
8+	7	1	0	0
Total		68		63

Appendix Table 10. 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
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	7	2	1	0	5	0	2	1	6	6	5	8	3	2	6	10	52	18	1	30
4	28	29	38	24	43	60	20	29	18	77	60	35	34	53	35	26	97	89	80	61
5	29	30	32	19	17	23	22	35	13	18	24	45	17	17	24	17	22	69	48	83
6	5	19	20	7	11	5	5	14	0	4	4	6	4	0	1	4	3	16	12	6
7	4	5	15	1	0	0	0	1	0	0	1	0	0	0	0	0	4	1	0	0
8	3	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Total	76	86	110	51	76	88	49	80	37	105	94	94	58	72	66	57	178	194	141	180

Male

Age	1985	1986	1987	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	17	10	2	6	34	25	16	6	17	13	16	23	6	6	9	24	93	83	11	64
4	26	40	39	21	48	59	30	56	20	83	60	62	44	71	54	32	100	129	88	77
5	12	27	34	13	12	22	9	25	11	15	29	36	16	15	17	5	16	65	30	37
6	8	5	13	4	2	3	4	6	1	1	2	1	2	0	2	0	2	8	8	1
7	2	1	2	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0
8	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

Blueback

Female

Age	1985	1986	1987	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
2	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
4	22	14	1	5	7	10	30	12	3	9	14	29	44	30	14	33	48	46	45	29
5	19	19	16	4	8	5	16	2	1	9	7	9	19	13	14	18	9	12	13	8
6	2	5	7	1	3	1	3	0	1	0	0	2	0	0	0	0	0	0	3	0
7	1	1	3	1	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	0
8	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

Male

Age	1985	1986	1987	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
3	12	5	8	1	1	6	25	4	5	6	17	9	13	14	8	14	44	22	31	60
4	17	32	31	11	7	11	27	5	22	16	14	40	48	31	33	40	31	44	37	15
5	5	14	16	2	8	4	5	2	2	6	9	10	8	3	9	11	6	5	17	5
6	2	0	4	1	0	2	1	0	0	0	1	0	0	0	1	0	0	0	0	0
7	0	0	1	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
Total	36	51	60	15	16	24	58	11	29	28	41	59	69	48	51	65	81	72	85	80

Appendix Table 11. 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
Agawam	-	-	-	-	-	-	-	-	-	-	-	4.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Back	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.2	-	-	-
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
Mystic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.1	4.7	4.4	3.9	4.3	4.4	3.6
Nemasket	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.3	4.8	4.2	4.4	5.0	5.0	4.4
Parker	6.0	5.2	4.3	4.5	5.3	5.7	5.1	4.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quashnet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.3	-	-	-	-	-	-
Stony Brook	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.5	-	-	-	-	-	-
Town Brook	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.4	4.3	4.0	4.2	4.8	4.9	4.6

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
Agawam	-	-	-	-	-	-	-	-	-	-	-	4.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Back	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	-	-	-
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
Mystic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.8	4.3	3.5	3.6	3.8	4.3	3.6
Nemasket	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.9	4.7	4.0	4.1	4.6	4.6	4.1
Parker	5.7	4.2	4.0	4.5	5.0	5.4	5.1	4.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quashnet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.9	-	-	-	-	-	-
Stony Brook	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.1	-	-	-	-	-	-
Town Brook	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	4.0	3.8	4.0	4.5	4.6	4.2

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
Agawam	-	-	-	-	-	-	-	-	-	-	-	4.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Charles	-	-	-	-	-	-	-	-	5.2	-	-	-	4.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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
Mystic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.1	4.4	4.0	4.5	3.6	3.4
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
Agawam	-	-	-	-	-	-	-	-	-	-	-	4.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Charles	-	-	-	-	-	-	-	-	4.4	-	-	-	4.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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
Mystic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.5	3.7	3.8	3.8	3.2	3.3
Quashnet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
Town Brook	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		*	-	-	-	-	-

Appendix Table 12. 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

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				

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		0	0	24	0	0	0	0		0	0	35	0	0	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

Mystic River

	Female							Male						
RPS	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
0	36	11	15	110	40	40	22	48	7	10	125	91	46	12
1	18	0	0	12	7	14	3	19	3	0	7	16	10	2
2	1	1	0	3	5	2	1	4	0	0	2	0	2	0
3	1	0	0	1	1	0	0	0	0	0	0	1	0	0
Total	56	12	15	126	53	56	26	71	10	10	134	108	58	14

Town Brook

	Female							Male						
RPS	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
0	81	110	116	202	146	122	142	69	134	130	237	174	140	150
1	11	18	10	37	50	50	30	13	17	6	64	70	58	21
2	0	2	0	3	11	5	7	1	2	0	6	13	6	9
3	2	0	0	1	0	0	0	0	0	0	0	0	2	0
Total	94	130	126	243	207	177	179	83	153	136	307	257	206	180

Nemasket River

	Female							Male						
RPS	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
0	70	98	112	218	167	103	146	78	104	176	347	207	208	159
1	31	24	11	30	37	42	35	34	30	15	47	43	38	25
2	21	5	1	3	8	3	8	24	8	3	0	9	4	5
3	1	2	0	1	1	0	0	3	4	1	0	0	2	0
Total	123	129	124	252	213	148	189	139	146	195	394	259	252	189

Agawam

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

Appendix Table 12 cont.

Blueback

Mystic River

	Females							Males						
RPS	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
0	0	36	26	180	18	120	100	0	33	87	195	114	262	156
1	0	0	3	27	6	15	17	0	2	23	37	34	37	22
2	0	1	2	6	3	1	1	0	0	0	5	7	2	1
3	0	0	0	0	1	0	0	0	0	0	0	2	0	0
Total	0	37	31	213	28	136	118	0	35	110	237	157	301	179

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

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	1985	1993
0	32	37	32	47
1	18	18	21	10
2	10	11	10	4
3	3	0	0	2
4	7	0	0	0
Total	70	66	63	63

Appendix Table 13. 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
0	47	62	41	70	72	35	47	33	97	81	67	51	71	61	49	163	165	122	156
1	25	26	9	4	14	9	28	4	7	10	24	3	1	5	8	12	26	17	17
2	12	17	1	2	2	5	5	0	1	3	3	4	0	0	1	3	3	2	7
3	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	86	110	51	76	88	49	80	37	105	94	94	58	72	66	58	178	194	141	180

Male

RPS	1986	1987	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
0	51	53	34	91	83	46	67	43	101	88	84	56	87	79	58	198	250	123	167
1	24	27	9	4	26	8	22	6	10	18	34	10	5	3	3	13	34	14	11
2	8	9	1	1	0	5	5	0	1	1	3	3	1	0	0	0	2	0	1
3	0	1	0	0	0	0	0	0	0	0	1	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

Blueback

Female

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

Male

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

Appendix Table 14. Yearly estimates of instantaneous total mortality (Z) from age-repeat spawner frequency and length data for alewives and blue-back herring from Massachusetts Rivers by sex.

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					0.98	0.95			0.84

Chapman-Robson Z Estimates (Repeat Spawning)

Year	Back	Mattapoisett	Monument	Mystic	Nemasket	Stony	Town
1971							
1972							
1973							
1974							
1975							
1976							
1977							
1978							
1979							
1980							
1981							
1982							
1983							
1984							
1985							
1986			0.93				
1987			0.9				
1988							
1989							
1990							
1991							
1992							
1993			1.714				
1994							
1995			2.34				
1996			1.76				
1997			1.26				
1998			1.12				
1999			2.3				
2000			2.53				
2001			1.92				
2002			1.41				
2003			1.82				
2004				1.22	0.96		1.87
2005				1.87	1.55		1.73
2006			1.89		2.35		
2007	1.99		2.38	1.94	1.97		1.83
2008			1.95	1.28	1.56		1.35
2009			2.03	1.45	1.4		1.37
2010			1.91	1.81	1.54		1.62

Appendix Table 14 cont.

	Beverton-Holt Equlibrium Z Estimates								
Year	Agawam	Back	Mattapoisett	Monument	Mystic	Nemasket	Quashnet	Stony	Town
1971									
1972									
1973									
1974									
1975									
1976									
1977									
1978									
1979									
1980									
1981									
1982									
1983									
1984				0.44					
1985				0.51					
1986				0.41					
1987				0.44					
1988									
1989									
1990				0.71					
1991	0.71			0.68					
1992				0.92					
1993				1.10					
1994				1.25					
1995			0.54	1.20					
1996				0.95					
1997				0.94					
1998				0.94					
1999				1.50					
2000				1.50					
2001				1.42					
2002				0.90					
2003				1.14					
2004				1.13	1.48	0.51	1.10	0.90	1.08
2005				1.48	0.96	0.76			1.35
2006			1.00	1.43	1.92	0.91			1.51
2007		0.66	0.70	1.19	1.76	0.83			1.14
2008				1.53	1.74	0.71			1.31
2009				1.43	1.76	0.81			1.26
2010				1.12	2.58	0.73			1.08

Appendix Table 14 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

Chapman-Robson Z Estimates (Repeat Spawning)

Year	Back	Monument	Mystic	Nemasket	Stony	Town
1971						
1972						
1973						
1974						
1975						
1976						
1977						
1978						
1979						
1980						
1981						
1982						
1983						
1984						
1985						
1986		1.12				
1987		1.05				
1988						
1989						
1990						
1991						
1992						
1993		1.59				
1994						
1995		2.82				
1996		1.64				
1997		1.44				
1998		1.36				
1999						
2000		2.33				
2001		1.84				
2002		1.34				
2003		1.66				
2004		2.64	1.28	0.92		1.87
2005				1.18		
2006		1.89		2.21		
2007			2.57			1.61
2008		2.14	1.89	1.65		1.3
2009			1.62	1.75		1.31
2010		2.69		1.85		1.72

Appendix Table 14 cont.

	Beverton-Holt Equlibrium Z Estimates								
Year	Agawam	Back	Mattapoisett	Monument	Mystic	Nemasket	Quashnet	Stony	Town
1971									
1972									
1973									
1974									
1975									
1976									
1977									
1978									
1979									
1980									
1981									
1982									
1983									
1984				0.57					
1985				0.63					
1986				0.50					
1987				0.57					
1988									
1989									
1990				0.89					
1991	0.91			0.99					
1992				1.11					
1993				1.13					
1994				1.70					
1995			0.73	1.62					
1996				1.08					
1997				1.19					
1998				1.27					
1999				2.05					
2000				2.35					
2001				1.43					
2002				1.16					
2003				1.38					
2004				1.24	1.65	0.54	1.46	1.14	1.34
2005				1.49	1.28	0.79			1.81
2006			1.22	2.62	3.96	1.11			1.84
2007		0.77	0.89	1.46	2.40	0.67			1.34
2008				2.00	2.14	0.93			1.49
2009				1.70	2.11	0.98			1.54
2010				1.48	2.28	0.82			1.43

Appendix Table 14 cont.

Blueback
Females

Chapman-Robson Z Estimates (Age Data)

Year	Agawam	Charles	Monument	Mystic
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			0.90	1.19

Chapman-Robson Z Estimates (Repeat Spawning)

Year	Charles	Monument	Mystic
1971			
1972			
1973			
1974			
1975			
1976			
1977			
1978			
1979			
1980			
1981			
1982			
1983			
1984			
1985	0.63		
1986		1.1	
1987		1.02	
1988			
1989			
1990			
1991			
1992			
1993	0.9	1.47	
1994			
1995			
1996			
1997			
1998			
1999			
2000			
2001			
2002			
2003			
2004			
2005			
2006			1.67
2007			1.86
2008			1.03
2009			2.19
2010			1.97

Beverton-Holt Equlibrium Z Estimates

Year	Agawam	Charles	Monument	Mystic	Quashnet
1971					
1972					
1973					
1974					
1975					
1976					
1977					
1978					
1979					
1980					
1981					
1982					
1983					
1984			0.72		
1985		0.47	0.42		
1986			0.55		
1987			0.57		
1988					
1989					
1990			0.97		
1991	0.86		0.71		
1992			0.83		
1993		0.7	0.88		
1994			1.19		
1995			1.14		
1996			1.01		
1997			1.25		
1998			2.05		
1999			1.41		
2000			1.81		
2001			1.78		
2002			1.19		
2003			1.82		
2004			1.29		1.01
2005			1.28	1.45	
2006			1.76	1.96	
2007			1.63	1.78	
2008			2.15	1.53	
2009			2.11	2.41	
2010			2.23	1.90	

Appendix Table 14 cont.

Blueback
Males

Chapman-Robson Z Estimates (Age Data)

Year	Charles	Monument	Mystic	Town
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	

Chapman-Robson Z Estimates (Repeat Spawning)

Year	Charles	Monument	Mystic	Town
1971				
1972				
1973				
1974				
1975				
1976				
1977				
1978				
1979				
1980				
1981				
1982				
1983				
1984				
1985	0.92			
1986		1.64		
1987		1.6		
1988				
1989				
1990				
1991				
1992				
1993	1.28	1.73		
1994				
1995				
1996				
1997				
1998				
1999				
2000				
2001				
2002				
2003				
2004				
2005				
2006				
2007			1.79	
2008			1.36	
2009			2.11	
2010			2.13	

Beverton-Holt Equlibrium Z Estimates

Year	Agawam	Charles	Monument	Mystic	Quashnet	Town
1971						
1972						
1973						
1974						
1975						
1976						
1977						
1978						
1979						
1980						
1981						
1982						
1983						
1984			0.77			
1985		0.67	0.41			
1986			0.54			
1987			1.03			
1988						
1989						
1990			1.03			
1991	1.31		0.92			
1992			0.98			
1993		1.38	1.11			
1994			1.22			
1995			1.26			
1996			1.25			
1997			1.90			
1998			2.53			
1999			1.96			
2000			2.23			
2001			2.65			
2002			1.29			
2003			1.89			
2004			1.31		2.96	
2005			1.31	1.98		1.20
2006			1.77	2.46		
2007			1.96	1.64		
2008			2.30	1.99		
2009			1.91	1.93		
2010			2.23	1.65		

Appendix Table 15. Mean weights-at-age for female Monument River alewife. Data in highlighted cells were estimated from years with data.

	Age					
Year	3	4	5	6	7	8
1980	0.155	0.175	0.197	0.217	0.236	0.256
1981	0.155	0.175	0.197	0.217	0.236	0.256
1982	0.155	0.175	0.197	0.217	0.236	0.256
1983	0.155	0.175	0.197	0.217	0.236	0.256
1984	0.155	0.175	0.197	0.217	0.236	0.256
1985	0.155	0.175	0.197	0.217	0.236	0.256
1986	0.155	0.175	0.197	0.217	0.236	0.256
1987	0.155	0.175	0.197	0.217	0.236	0.256
1988	0.155	0.175	0.197	0.217	0.236	0.256
1989	0.155	0.175	0.197	0.217	0.236	0.256
1990	0.155	0.175	0.197	0.217	0.236	0.256
1991	0.155	0.175	0.197	0.217	0.236	0.256
1992	0.155	0.175	0.197	0.217	0.236	0.256
1993	0.155	0.212	0.223	0.228	0.225	0.256
1994	0.155	0.175	0.197	0.217	0.236	0.256
1995	0.172	0.177	0.170	0.206	0.236	0.256
1996	0.155	0.185	0.198	0.218	0.236	0.256
1997	0.146	0.181	0.207	0.216	0.236	0.256
1998	0.122	0.165	0.197	0.223	0.240	0.256
1999	0.160	0.156	0.177	0.217	0.236	0.256
2000	0.154	0.177	0.200	0.202	0.236	0.256
2001	0.161	0.174	0.200	0.224	0.200	0.256
2002	0.167	0.183	0.207	0.223	0.236	0.256
2003	0.157	0.186	0.201	0.214	0.236	0.256
2004	0.167	0.181	0.221	0.217	0.236	0.256
2005	0.161	0.171	0.194	0.206	0.236	0.256
2006	0.149	0.169	0.196	0.224	0.236	0.256
2007	0.158	0.188	0.216	0.255	0.254	0.256
2008	0.144	0.165	0.190	0.211	0.254	0.256
2009	0.154	0.174	0.181	0.195	0.236	0.256
2010	0.163	0.179	0.198	0.216	0.236	0.256

Appendix Table 16. Estimates of population abundance of Monument River alewife by sex, maturity state, year, and age.

Female Immature

Year	Total	3	4	5	6	7	8
		Age					
1980	54,286	47,805	6,427	54	0	0	0
1981	111,363	104,882	6,427	54	0	0	0
1982	118,869	104,714	14,101	54	0	0	0
1983	109,031	94,834	14,078	119	0	0	0
1984	90,307	77,438	12,750	119	0	0	0
1985	79,148	68,630	10,411	108	0	0	0
1986	57,980	48,666	9,227	88	0	0	0
1987	21,975	15,355	6,543	78	0	0	0
1988	64,014	61,895	2,064	55	0	0	0
1989	69,363	61,024	8,322	17	0	0	0
1990	216,374	208,099	8,204	70	0	0	0
1991	157,048	129,001	27,978	69	0	0	0
1992	120,902	103,322	17,344	236	0	0	0
1993	70,928	56,890	13,891	146	0	0	0
1994	187,733	179,967	7,649	117	0	0	0
1995	253,921	229,660	24,196	65	0	0	0
1996	194,682	163,601	30,877	204	0	0	0
1997	174,078	151,822	21,996	260	0	0	0
1998	122,296	101,698	20,412	186	0	0	0
1999	284,265	270,420	13,673	172	0	0	0
2000	316,271	279,799	36,357	115	0	0	0
2001	155,876	131,667	24,014	196	0	0	0
2002	116,176	104,746	11,300	129	0	0	0
2003	105,032	95,982	8,990	61	0	0	0
2004	63,867	55,581	8,238	48	0	0	0
2005	46,083	41,269	4,770	44	0	0	0
2006	73,387	69,819	3,542	26	0	0	0
2007	88,014	82,003	5,992	19	0	0	0
2008	103,230	96,160	7,038	32	0	0	0
2009	50,423	42,132	8,253	38	0	0	0
2010	59,401	55,741	3,616	44	0	0	0

Female Mature

Year	Total	3	4	5	6	7	8
		Age					
1980	30,694	5,430	18,142	5,981	966	152	24
1981	37,180	11,913	18,142	5,981	966	152	28
1982	66,870	11,894	42,380	9,908	2,260	360	67
1983	75,452	10,772	41,412	19,492	2,976	673	127
1984	72,479	8,796	37,505	19,193	5,861	886	238
1985	63,217	7,795	30,572	17,156	5,656	1,709	328
1986	58,563	5,528	27,667	16,241	6,318	2,065	744
1987	48,064	1,744	19,883	15,921	6,748	2,608	1,160
1988	32,958	7,030	6,175	10,283	5,718	2,407	1,344
1989	43,595	6,931	25,210	3,488	4,160	2,298	1,507
1990	67,293	23,637	24,856	14,189	1,410	1,672	1,529
1991	121,910	14,653	85,083	14,328	5,930	586	1,330
1992	123,100	11,736	52,789	49,259	6,032	2,482	802
1993	98,812	6,462	41,793	28,359	18,687	2,274	1,238
1994	85,934	20,442	23,065	22,876	10,999	7,200	1,353
1995	120,983	26,086	71,278	10,714	6,985	3,330	2,590
1996	164,279	18,583	94,015	41,731	4,531	2,933	2,486
1997	158,893	17,245	66,784	53,584	17,202	1,857	2,221
1998	139,736	11,551	61,683	36,962	21,179	6,758	1,602
1999	129,835	30,716	41,104	33,037	13,924	7,926	3,128
2000	179,313	31,781	107,969	20,274	11,021	4,609	3,659
2001	145,172	14,955	74,215	43,992	6,172	3,335	2,502
2002	92,460	11,898	34,789	29,268	12,979	1,812	1,714
2003	60,983	10,902	27,057	11,923	7,112	3,136	852
2004	48,641	6,313	25,261	10,497	3,412	2,024	1,135
2005	33,209	4,688	14,534	9,373	2,844	920	851
2006	29,352	7,930	10,995	6,034	2,948	890	554
2007	35,840	9,314	18,631	4,585	1,919	934	457
2008	43,077	10,922	21,882	7,766	1,458	608	441
2009	42,830	4,786	25,660	9,121	2,470	462	332
2010	32,204	6,331	11,243	10,696	2,901	782	251

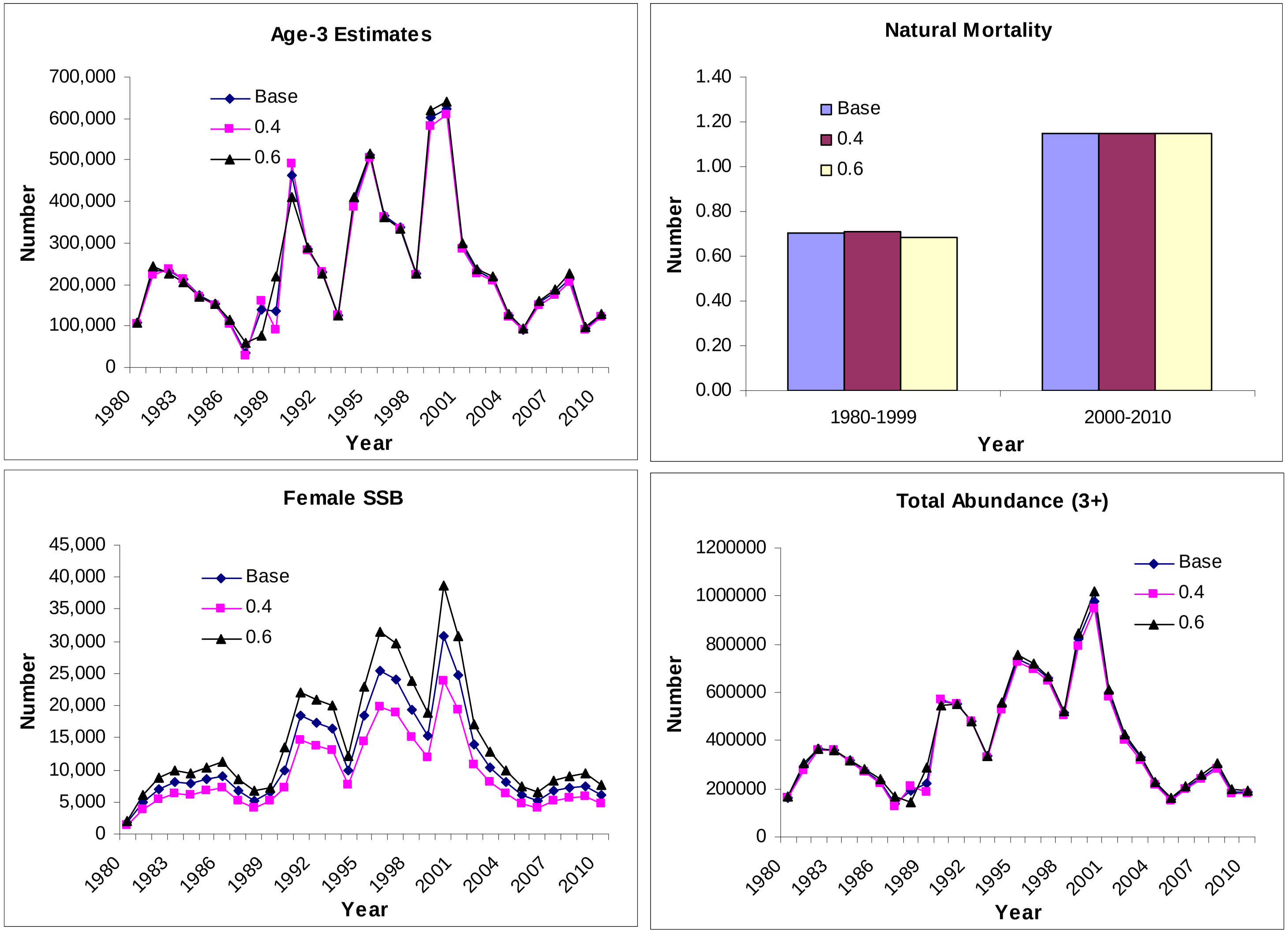
Appendix Table 16 cont.

	Male Immature Age						
Year	Total	3	4	5	6	7	8
1980	41,285	38,595	2,681	9	0	0	0
1981	87,366	84,676	2,681	9	0	0	0
1982	90,431	84,541	5,881	9	0	0	0
1983	82,457	76,564	5,872	20	0	0	0
1984	67,858	62,520	5,318	20	0	0	0
1985	59,769	55,408	4,342	18	0	0	0
1986	43,154	39,290	3,848	15	0	0	0
1987	15,139	12,397	2,729	13	0	0	0
1988	50,841	49,971	861	9	0	0	0
1989	52,741	49,268	3,471	3	0	0	0
1990	171,443	168,009	3,422	12	0	0	0
1991	115,830	104,149	11,669	12	0	0	0
1992	90,692	83,417	7,234	41	0	0	0
1993	51,749	45,930	5,794	25	0	0	0
1994	148,506	145,296	3,190	20	0	0	0
1995	195,519	185,416	10,092	11	0	0	0
1996	144,997	132,084	12,878	35	0	0	0
1997	131,792	122,573	9,174	45	0	0	0
1998	90,651	82,106	8,513	32	0	0	0
1999	224,056	218,324	5,703	30	0	0	0
2000	241,079	225,895	15,164	20	0	0	0
2001	116,350	106,301	10,016	34	0	0	0
2002	89,302	84,566	4,713	22	0	0	0
2003	81,251	77,491	3,749	10	0	0	0
2004	48,317	44,873	3,436	8	0	0	0
2005	35,316	33,318	1,990	8	0	0	0
2006	57,850	56,369	1,477	4	0	0	0
2007	68,708	66,205	2,499	3	0	0	0
2008	80,576	77,635	2,935	6	0	0	0
2009	37,464	34,015	3,442	7	0	0	0
2010	46,518	45,002	1,508	8	0	0	0

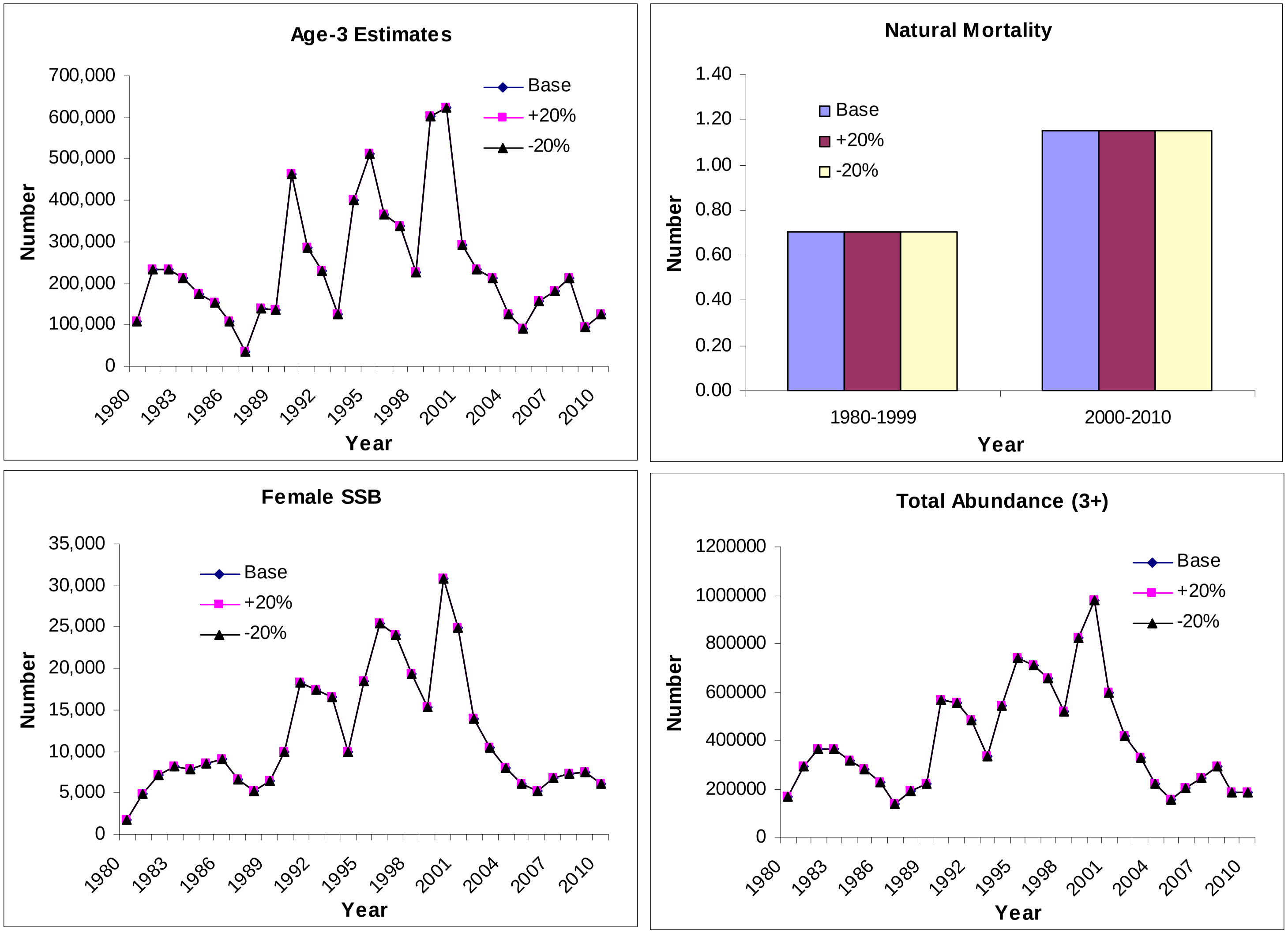
	Male Mature Age							
Year	Total	3	4	5	6	7	8	Total
1980	38,465	14,640	18,764	4,265	674	106	17	164,731
1981	55,947	32,119	18,764	4,265	674	106	19	291,857
1982	90,409	32,067	48,120	8,327	1,597	252	47	366,580
1983	94,925	29,042	45,615	17,221	2,483	475	89	361,865
1984	87,540	23,714	41,312	16,471	5,136	739	168	318,184
1985	75,852	21,017	33,591	14,668	4,814	1,498	265	277,986
1986	68,388	14,903	31,314	14,405	5,365	1,758	644	228,085
1987	51,601	4,702	22,916	14,823	5,954	2,215	991	136,779
1988	44,001	18,954	6,966	9,518	5,294	2,124	1,144	191,813
1989	58,119	18,688	28,937	3,224	3,830	2,127	1,313	223,817
1990	109,814	63,728	28,530	13,338	1,297	1,539	1,383	564,924
1991	158,503	39,505	98,159	13,539	5,548	539	1,214	553,292
1992	148,179	31,641	60,972	46,837	5,673	2,322	734	482,872
1993	112,457	17,422	47,519	26,549	17,677	2,139	1,152	333,947
1994	120,903	55,112	26,309	21,162	10,241	6,811	1,268	543,077
1995	170,513	70,330	78,680	9,538	6,418	3,101	2,446	740,935
1996	205,790	50,101	108,643	38,011	4,011	2,695	2,329	709,748
1997	193,540	46,493	76,885	50,865	15,594	1,644	2,059	658,303
1998	164,012	31,144	70,561	34,723	20,004	6,126	1,454	516,694
1999	183,429	82,813	46,686	30,599	13,010	7,486	2,837	821,585
2000	242,376	85,684	120,562	18,263	10,143	4,306	3,417	979,039
2001	179,969	40,321	87,455	41,253	5,533	3,070	2,337	597,367
2002	117,033	32,077	40,791	28,829	12,124	1,625	1,588	414,971
2003	82,191	29,393	30,783	11,338	6,972	2,929	776	329,457
2004	62,694	17,021	29,468	9,937	3,229	1,984	1,054	223,520
2005	42,840	12,638	16,809	9,023	2,681	870	819	157,448
2006	44,493	21,381	13,030	5,887	2,827	839	529	205,083
2007	55,021	25,112	22,124	4,591	1,866	895	433	247,583
2008	65,691	29,448	25,985	7,793	1,455	591	421	292,574
2009	55,776	12,902	30,471	9,152	2,470	461	320	186,493
2010	45,083	17,070	13,351	10,732	2,901	782	247	183,206

Appendix Table 17. Estimates of female spawning stock biomass (kilograms) for the Monument River alewife.

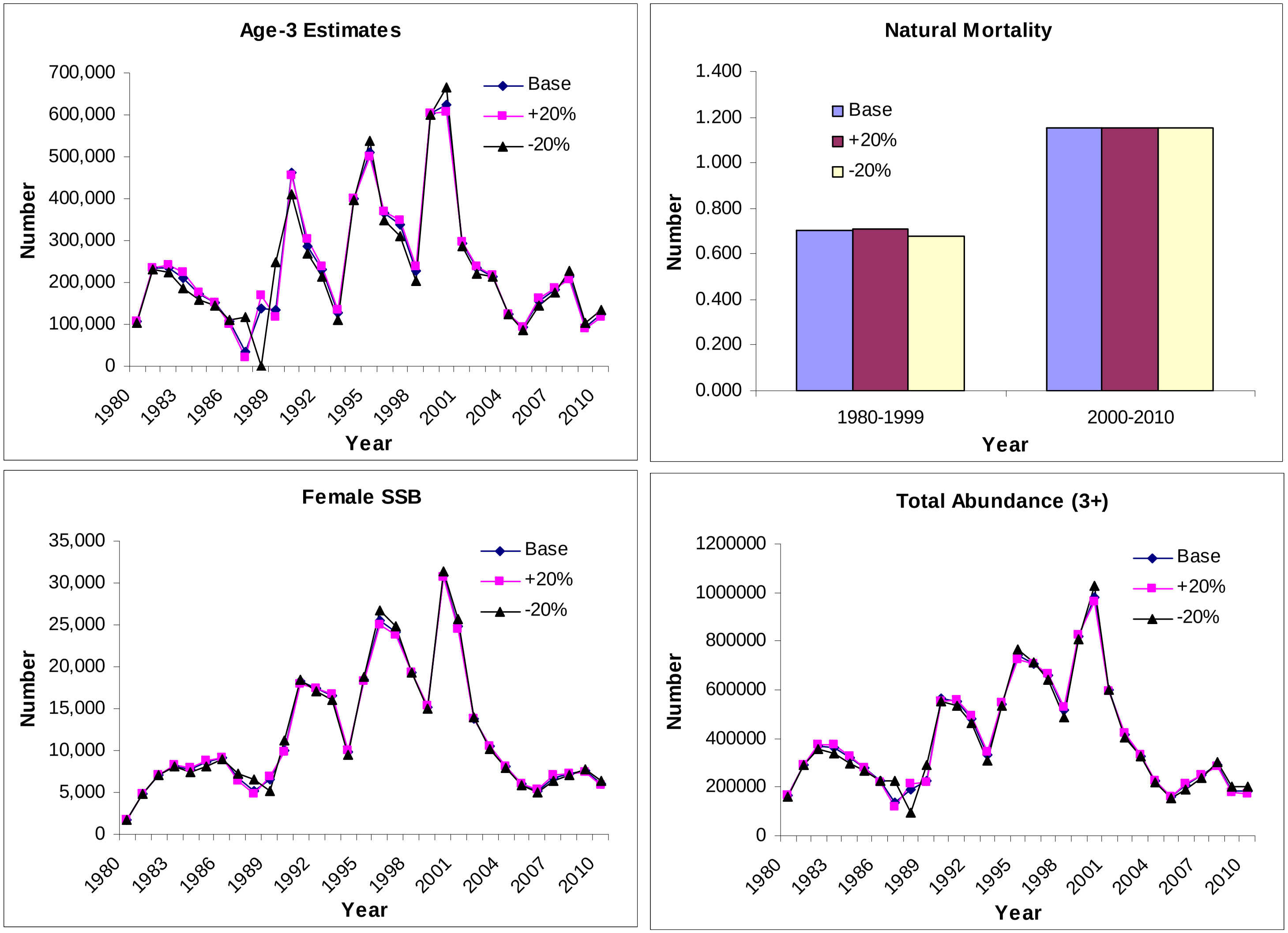
		Age					
Year	Total	3	4	5	6	7	8
1980	1,723	266	1,004	373	66	11	2
1981	4,856	1,390	2,389	887	158	27	5
1982	7,083	1,106	4,450	1,171	294	51	10
1983	8,156	1,002	4,348	2,304	388	95	20
1984	7,789	801	3,858	2,223	748	123	36
1985	8,577	889	3,938	2,487	903	297	62
1986	9,109	713	4,029	2,662	1,141	406	158
1987	6,660	194	2,502	2,255	1,053	443	213
1988	5,143	883	875	1,641	1,005	460	279
1989	6,483	870	3,574	557	731	439	313
1990	9,966	3,068	3,643	2,341	256	330	328
1991	18,350	1,916	12,563	2,382	1,086	117	287
1992	17,372	1,382	7,020	7,374	995	445	156
1993	16,522	778	6,881	4,911	3,309	397	246
1994	9,853	1,934	2,464	2,751	1,457	1,037	211
1995	18,463	3,798	10,679	1,542	1,218	665	561
1996	25,484	2,379	14,366	6,825	816	572	526
1997	24,088	1,994	9,572	8,783	2,942	347	450
1998	19,328	1,063	7,677	5,492	3,563	1,223	309
1999	15,257	3,279	4,278	3,902	2,016	1,248	534
2000	30,874	4,677	18,261	3,875	2,127	1,039	895
2001	24,857	2,232	11,973	8,158	1,282	618	594
2002	13,864	1,516	4,857	4,622	2,208	326	335
2003	10,440	1,538	4,521	2,153	1,367	665	196
2004	8,041	892	3,891	1,974	630	406	247
2005	6,008	746	2,456	1,797	579	214	215
2006	5,235	1,182	1,858	1,183	660	210	142
2007	6,808	1,472	3,503	990	489	237	117
2008	7,234	1,573	3,611	1,476	308	154	113
2009	7,528	737	4,465	1,651	482	109	85
2010	6,038	1,032	2,012	2,118	627	185	64



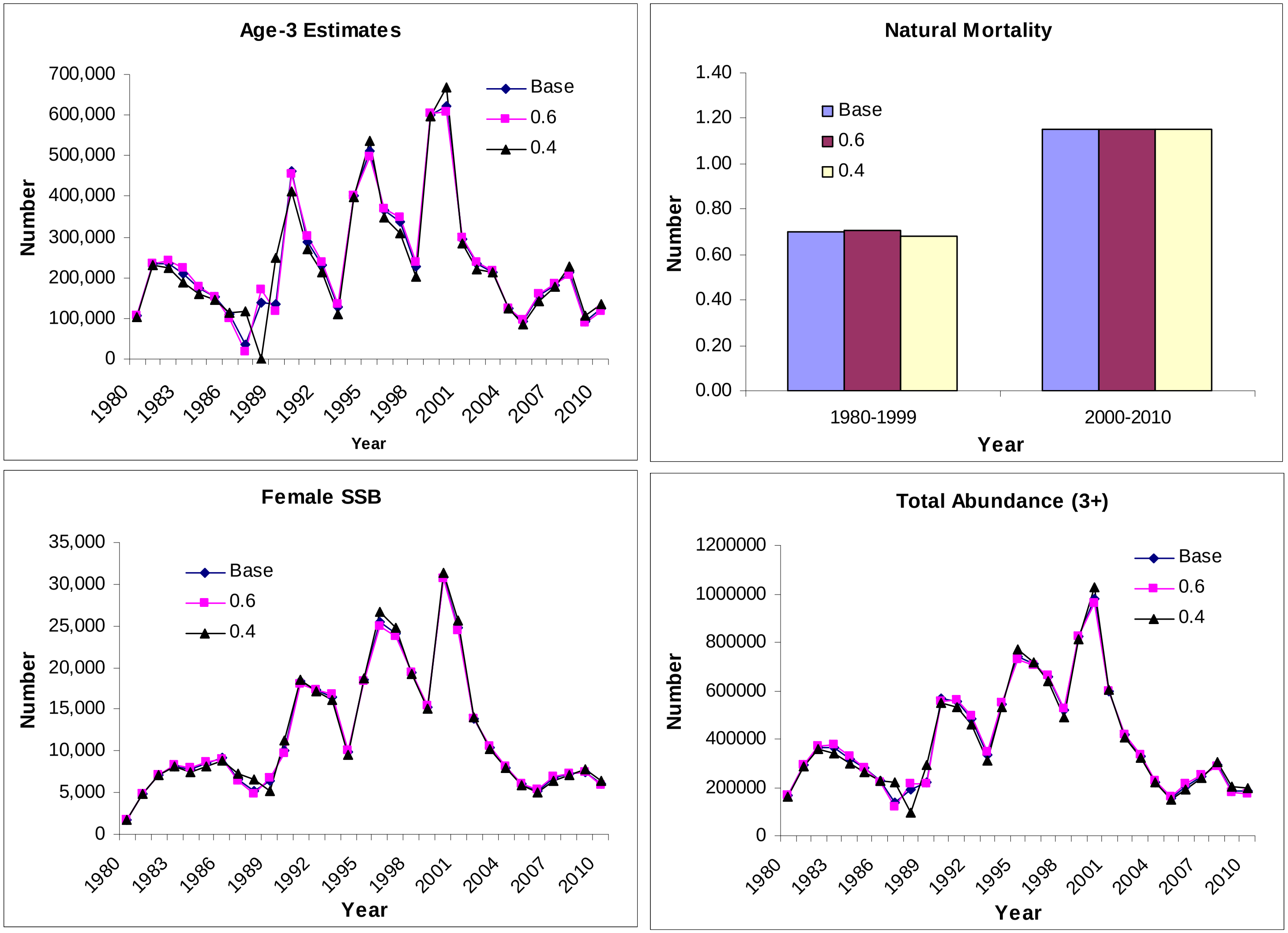
Appendix Figure 1. Sensitivity analysis of input female sex ratio on SCA model output.



Appendix Figure 2. Sensitivity analysis of changing CVs of total removals and escapement numbers by ±20% on SCA model output.



Appendix Figure 3. . Sensitivity analysis of changing average effective sample sizes by ±20% on SCA model output.



Appendix Figure 4. . Sensitivity analysis of changing the downweight ratio of the age composition data by ±0.1 on SCA model output.

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TR-34 Nelson, G. A. 2008. **2007 Massachusetts striped bass monitoring report**.
TR-35 Barber, J. S., K. A. Whitmore, M. Rousseau, D. M. Chosid, and R. P. Glenn. 2009. **Boston Harbor artificial reef site selection and monitoring program.**
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