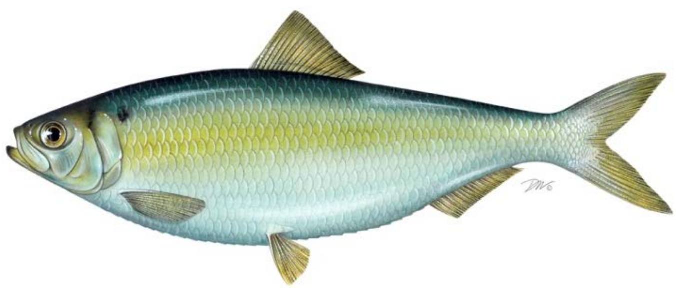
Stock Assessment Report No. 12-02

of the

# Atlantic States Marine Fisheries Commission

# *River Herring Benchmark Stock Assessment Volume I*



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*Working towards healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015*

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# PREFACE

The 2012 Benchmark Stock Assessment of River Herring occurred through an Atlantic States Marine Fisheries Commission (ASMFC) external peer review process. ASMFC organized and held Data Workshops on October 27-28, 2009 and August 23-26, 2010. Assessment Workshops were held on February 28 – March 2, 2011 and August 8 – 10, 2011. Participants of the Data and Assessment Workshops included the ASMFC River Herring Stock Assessment Subcommittee and Technical Committee, as well as invited individuals from state and federal partners. ASMFC coordinated a Peer Review Workshop from March 14 – 15, 2012. Participants included members of the River Herring Stock Assessment Subcommittee and a Review Panel consisting of four reviewers appointed by ASMFC.

This 2012 River Herring Benchmark Stock Assessment Report is divided into two volumes due to its length.

**Volume I includes:**

**Section A – Terms of Reference and Advisory Report of the Peer Review Panel**
**PDF pages 4 – 37**
The Advisory Report provides an summary of the stock assessment results supported by the Review Panel. The Terms of Reference Report provides a detailed evaluation of how each Terms of Reference was addressed by the Stock Assessment Subcommittee. Individual reviewer reports are also available upon request from the ASMFC.

**Section B – Technical Committee Response to Peer Review Report**
**PDF Page 38**
A report from the Technical Committee to the Management Board which clarifies the purpose and use of the Stock Assessment Report's estimates of incidental catch of river herring in response to the Review Panel Report.

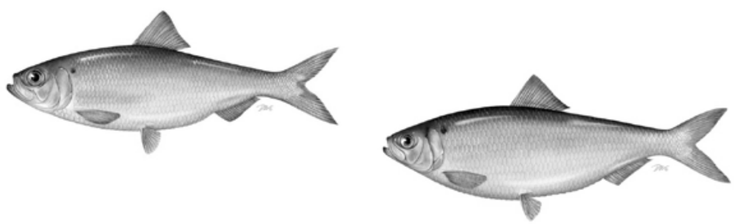
**Section C – 2012 River Herring Stock Assessment Report for Peer Review (Coastwide)**
**PDF Pages 39 – 388**
This report describes the background information, data used, and analysis for the assessment submitted by the Technical Committee to the Review Panel. It contains a coastwide analysis and comparison of river herring populations.

**Volume II includes:**

**Section D – 2012 River Herring Stock Assessment Report for Peer Review (Maine through Florida)**
This report describes the background information, data used, and analysis for the assessment submitted by the Technical Committee to the Review Panel. This volume contains a detailed description and summary of river herring populations by jurisdiction or watershed unit.

# Section A

# Terms of Reference & Advisory Report of the River Herring Stock Assessment Peer Review




Prepared by the
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Peer Review Workshop conducted on
March 14-15, 2012
Raleigh, North Carolina


**Atlantic States Marine Fisheries Commission**

*Working towards healthy, self-sustaining populations for all Atlantic coast fish species*
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## Preface

*Summary of the ASMFC Peer Review Process*

The Stock Assessment Peer Review Process, adopted in October 1998 and revised in 2002 and 2005 by the Atlantic States Marine Fisheries Commission (ASMFC or Commission), was developed to standardize the process of stock assessment reviews and validate the Commission's stock assessments. The purpose of the peer review process is to: (1) ensure that stock assessments for all species managed by the Commission periodically undergo a formal peer review; (2) improve the quality of Commission stock assessments; (3) improve the credibility of the scientific basis for management; and (4) improve public understanding of fisheries stock assessments. The Commission stock assessment review process includes an evaluation of input data, model development, model assumptions, scientific advice, and a review of broad scientific issues, where appropriate.

The Benchmark Stock Assessments: Data and Assessment Workshop and Peer Review Process report outlines options for conducting an external peer review of Commission managed species. These options are:

1. The Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC) conducted by the National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC).
2. The Southeast Data and Assessment Review (SEDAR) conducted by the National Marine Fisheries Service, Southeast Fisheries Science Center (SEFSC).
3. The Transboundary Resources Assessment Committee (TRAC) reviews stock assessments for the shared resources across the USA-Canada boundary and is conducted jointly through the National Marine Fisheries Service and the Canada Department of Fisheries and Oceans (DFO).
4. A Commission stock assessment Peer Review Panel conducted by 3-5 stock assessment biologists (state, federal, university). The Commission Review Panel will include scientists from outside the range of the species to improve objectivity.
5. A formal review using the structure of existing organizations (i.e. American Fisheries Society, International Council for Exploration of the Sea, or the National Academy of Sciences).

Twice annually, the Commission's Interstate Fisheries Management Program (ISFMP) Policy Board prioritizes all Commission managed species based on species management board advice and other prioritization criteria. The species with highest priority are assigned to a review process to be conducted in a timely manner.

In March 2012, the Commission convened a Stock Assessment Peer Review Panel comprised of scientists with expertise in stock assessment methods and/or diadromous species and their life history. The review of the river herring stock assessment was conducted at the Doubletree Brownstone Hotel in Raleigh, North Carolina from March 14 - 15, 2012. Prior to the Review Panel meeting, the Commission provided the Review

Panel Members with an electronic copy of the 2012 River Herring Stock Assessment Report.

The review process consisted of an introductory presentation of the completed 2012 stock assessment by river system and from a coast wide perspective. Each presentation was followed by general questions from the Panel. The second day involved a closed-door meeting of the Review Panel during which the documents and presentations were reviewed and a report prepared.

The report of the Review Panel is structured to closely follow the terms of reference provided to the stock assessment team.

## Acknowledgements

The Peer Review Panel thanks the members of the River Herring Stock Assessment Subcommittee and Shad and River Herring Technical Committee, as well as staff of the Atlantic States Marine Fisheries Commission, particularly Patrick Campfield, for support during the review process.

## Introduction

'River herring' is the collective term for two of the anadromous alosine herrings: the alewife, *Alosa pseudoharengus*, and the blueback herring, *A. aestivalis*. These are closely related species, sharing many physical characteristics and broadly overlapping in range (Collette and Klein-Macphee 2002).

'River herring' is also a misleading misnomer, for the anadromous shads spend most of their lives at sea. However, they concentrate in spawning aggregations in rivers, and it is there that traditional fisheries are prosecuted. Furthermore, young fry use riverine, lacustrine, and estuarine habitats as nursery grounds. Thus, these species are recognized for connecting inland watersheds to marine ecosystems, transporting production from one realm to the other and back again at different life stages.

River herring are not as well documented in historical fisheries as were their larger congener the American shad; however, new analyses based on historical accounts suggests that their abundances far exceeded that of American shad (Hall et al. *in press*). Prior to exploitation by Western European colonists, populations of river herring in large river systems likely ran in the hundreds of millions; coastally this would have translated into annual spawning runs in the billions. Seaward emigrating young-of-year also encountered a gauntlet of marine predators (Stevenson 1899); hence these young fish presented a clear trophic link between inland and marine production.

Today, these linkages are largely broken. Stocks of river herring are greatly depleted compared to the early 17$^{th}$ century baseline, as well as compared to that of the late 19$^{th}$ century. As well, many genotypes are probably extirpated (Chapman 1895), most of them without documentation.

Reviewing the recent history of this species pair from 1950 when harvests began to be reported consistently, river herring are depleted. This most recent decline appears to have begun in a period of large, offshore harvests by a combination of foreign and U.S. fleets (River Herring Stock Assessment Report).

This report reviews components of the recent stock assessment of river herring conducted by the Stock Assessment Subcommittee (SASC). Data collection, standardization of indices, trend analyses, and stock assessment models were undertaken by the SASC, and uncertainties quantified. The Panel commends the SASC on the comprehensive approach and points out some places for improvement in the following sections. The Peer Review Panel concurs with the SASC conclusions, that river herring stocks are depleted, that ocean bycatch is an issue, and that recovery will require management on multiple fronts (e.g., fishery management, watershed management) and will need to be responsive to factors beyond human control (e.g., climate change).

**Terms of Reference for the River Herring Stock Assessment Peer Review**

**1. Evaluate the justification for inclusion or elimination of available data sources.**

The River Herring Stock Assessment Subcommittee (SASC) cast a wide net to collect and synthesize data from as broad a variety of sources as possible. The approach was inclusive rather than exclusive, and uncertainties and caveats were noted.

For inland/coastal information, 57 systems (mostly rivers) were included in the coast-wide assessment (Table 1). Nine categories of fisheries independent and dependent information were considered by the SASC. Most of the valid information was for northern systems; much information was lacking, particularly in southern states. It was noted that few state surveys actually target river herring per se. Some of the better count data were at fish passage facilities. For select data sets, a change in sampling methodology was a concern, as it limited utility of a data set for temporal trend analysis. Overall, however, there were sufficient data to undertake many of the analyses presented by the SASC.

Historical and modern catch data were obtained state by state and for the entire U.S. coast. NOAA Fisheries maintains data from 1950 onward, while pre-1950 data were from a combination of federal and state sources. Although the first reported catches dated from 1887, both the SASC and the Peer Review Panel noted that large data gaps occur prior to 1950 due to incomplete reporting by state. As an example, the U.S. Fisheries Commission reported river herring harvests in 1892 as coming solely from Massachusetts (3,651,000 lbs or 1,659.5 MT). On the other hand, the New York Times, which reported a great deal on fisheries in the 19th century, listed additional 1892 harvests of river herring from New York, Delaware, Maryland, and North Carolina totaling 19,932 MT – thus, the total harvest for that year was well over 20,000 MT or a factor of 12 larger than reported in U.S. statistics (NYT 1895). The Panel recognizes the difficulties in estimating catch from historical sources, but encourages the SASC to pursue these avenues in the future.

A problem with catch data is that these are generally reported only as 'river herring' or even as 'alewife'. Parsing out the species can be done by making reasonable assumptions about range distributions (cf. Limburg and Waldman 2009). However this was not done for the assessment.

Recreational catch data were not used because the only data source, NOAA's Marine Recreational Information Program, does not collect data in fresh water where most recreational fishing for river herring occurs. Additionally, there was concern about species misidentification in this dataset.

Trend analyses were conducted on most datasets, including catch-per-unit-effort data (loess smoothed, 11 rivers), run size estimates (23 rivers), young-of-year indices (13 rivers as well as lower Chesapeake Bay and Albemarle Sound), miscellaneous young-of-year, juvenile, and adult surveys (4 rivers), 19 trawl surveys, as well as the biological (mean length, maximum age) and population level (total mortality, Z, computed by age or by repeat spawning marks) information. The Panel noted that while the catch rate series were standardized for effort, analyses of these data would have benefited from use of Generalized Linear Modeling approaches which would have allowed more in-depth exploration of the trends in the data as well as their uncertainties. Further comments on the uncertainties in the trend analyses are evaluated in ToRs 3 and 4.

Indices of run sizes based upon visual or electronic counters were available for six states for differing time periods preceding the 2010 surveys. Cluster analyses of three time intervals were conducted (1984-2010, 1999-2010, and 2003-2010) to explore temporal and spatial trends in run size. The first time period allowed for the longest time series to be analyzed but was restricted to 10 rivers (3 Maine, 4 New Hampshire, and 1 each in Massachusetts, Rhode Island, and Connecticut). A reduction in the time period (1999-2010) allowed more recent trends to be examined, increasing the analysis to 15 rivers (3 Maine, 6 New Hampshire, 3 Massachusetts, 2 Rhode Island and 1 Connecticut). The final time series (2003-2010) allowed the inclusion of 19 rivers (4 Maine, 6 New Hampshire, 3 Massachusetts, 3 Rhode Island and 3 Connecticut).

Although the run sizes in most rivers examined exhibited a decline, no geographic relationships could be detected by the cluster analysis. The data from 2003-2010 did show some promise as a geographic predictor of a latitudinal relationship and additional (future) analysis will be needed to bear this out. A problem with analysis of run counts is that the data are subject to both natural (i.e. spring rainfall) and anthropogenic modifications (i.e. river diversion or fishway modification) in upstream accessibility that can be acute or long term. Other confounding factors include the location of any obstruction or fishery component downstream of the census location and the absence of data on whether or not river herring use specific spawning locations within a river.

Length data were available from eight states (Maine, New Hampshire, Massachusetts, New York, Maryland, North Carolina, South Carolina, and Florida) along with the National Marine Fisheries Service Bottom Trawl survey. Sex-specific trends in length over time were examined for Maine through South Carolina; however large gaps in the Florida time series (1973-2001) prevented its inclusion. Although sampling methods were inconsistent between rivers, all trend analyses were based on within system sampling so gear selectivity should not have been a concern.

The trend analysis of the length data found a negative relationship in 4 of 10 rivers for alewife and 5 of 8 for blueback herring. The SASC noted significant trends were more common in times series that began in 1990 or earlier, and hence the length of the time series may be a confounding factor. The potential for a geographic bias may also be present for the two species because the number of rivers sampled was not even between regions. Of the six rivers where significant trends were found, only two were from New England while 8 of the 12 rivers examined were from this region. Evidence for this concern may also be seen in the results of the NEFSC Bottom Trawl survey where coast-wide trends were seen in alewife and "to a lesser extent in the blueback." It should be noted that Marcy (1969; cited as an ageing reference by SASC) notes a latitudinal trend in size that was apparent in the late 1960's. The panel realizes the SASC does not have the power to control data collection but encourages all attempts to obtain data from the under or non-represented states (regions).

River herring age data, determined by scales, were used for maximum age, length-at-age analyses, age at maturity, and associated mortality estimates. Potential problems with growth differences precluded use of length keys to develop age estimates.

All states cited the methods of Cating's (1953) study of ageing shad scales as part of the methodology for ageing their river herring. Several problems with the use of Cating's method have been discussed in recent years (McBride et al. 2005 and Duffy et al. 2011). Most recently Duffy et al. (2011) found that Cating's method does not reliably account for shad ages over large latitudinal ranges. Some of the discrepancy lies in the use of transverse grooves to establish the freshwater zone and ages one to three. They concluded transverse groove formation is more closely related to scale size (fish size) rather than a function of age. This would create a latitudinal interpretation problem that becomes more acute as the trends in decreasing length noted above develop.

The SASC clearly noted the weaknesses of using ages determined by scales:

> "These protocols have not been validated with known-age fish, and there have not been many efforts to standardize river herring ageing across states. As with any ageing method, there is the potential for bias both between labs and within labs over time as personnel change and methods are not consistently standardized."

Additionally, the Panel recognized that in the absence of validation (using known age fish) or alternate aging structures (i.e., otoliths) there were no alternatives. The Panel felt strongly that there is a need to develop a standardized, validated ageing process to reliably provide vital life history data.

Overall, the Panel concluded the SASC adequately justified the inclusion and exclusion of the available data in its analysis.

| State | River | Time series | By species | Harvest | Age |
|---|---|---|---|---|---|
| ME | Damariscotta | 1943-2010 | | ● | |
| | St. George | 1943-2010 | | ● | |
| | Union | 1975-2010 | | ● | |
| | Orland | 1943-2010 | | ● | |
| | Androscoggin | 1983-2010 | ● | | ● |
| | Sebasticook | 2000-2010 | ● | | ● |
| | Merrymeeting Bay/Tribs | 1979-2009 | ● | | |
| | Gulf of Maine | 2000-2010 | ● | | |
| NH | Exeter/Squamscott | 1991-2010 | ● | ● | ● |
| | Lamprey | 1991-2010 | ● | ● | ● |
| | Winnicut | 1991-2010 | ● | ● | ● |
| | Oyster | 1991-2010 | ● | ● | ● |
| | Cocheco | 1991-2010 | ● | ● | ● |
| | Taylor | 1991-2010 | ● | ● | ● |
| | Great Bay Estuary | 1997-2010 | x | | |
| MA | Mattapoisett | 1988-2010 | ● | ● | o |
| | Monument | 1980-2010 | ● | ● | o |
| | Nemasket | 1996-2010 | ● | ● | o |
| | Parker | 1971-1978, 2000-2010 | ● | ● | o |
| | Town | 2000-2010 | | ● | |
| | Agawam | 2006-2010 | | ● | o |
| | Back | 2007-2010 | ● | ● | ● |
| | Charles | 2008-2009 | | ● | ● |
| | Mystic | 2004-2010 | ● | | ● |
| | Quashnet | 2004 | ● | | ● |
| | Stony Brook | 1978-2004 | ● | | o |
| RI | Gilbert Stuart | 1981-2010 | | | ● |
| | Nonquit | 1999-2010 | | | ● |
| | Buckeye Brook | 2003-2010 | | | |
| | Pawcatuck | 1988-2010 | | | x |
| | Ocean waters | 1979-2010 | | | |
| | Naragansett Bay | 1988-2010 | | | |
| | Coastal ponds | 1992-2010 | | | |
| CT | Bride Brook | 1966-1967, 2003-2011 | ● | | |
| | Connecticut River | 1975-2011 | ● | | |
| | Farmington River | 1976-2011 | ● | | |
| | Thames River | 1996-2011 | ● | | |
| NY | Hudson | 1975-2010 | ● | o | o |
| DE, NJ, PA | Delaware River | 1980-2010 | o | o | o |
| | Delaware Bay | 1966-2010 | o | o | o |
| MD | Nanticoke | 1959-2010 | o | | o |
| | Susquehanna | 1972-2010 | o | | |
| | Chesapeake Bay | 1959-2010 | | | o |
| MD, VA, DC | Potomac River | 1959-2010 | | ● | |
| VA | James | 1966-2010 | o | ● | o |
| | Rappahannock | 1966-2010 | o | ● | o |
| | York | 1966-2010 | o | ● | o |
| NC | Albemarle Sound | 1972-2009 | | o | |
| | Chowan River | 1972-2009 | ● | ● | ● |
| SC | Wynah Bay | | | | |
| | Santee-Cooper | 1969-2010 | o | ● | o |
| | Savannah River | | | | |
| | Ashley-Combahee-Edisto Basin | | | | |
| GA | Altamaha River | 2010 | | | |
| | Ogeechee River | 2010 | | | |
| | Savannah River | 2010 | | | |
| FL | St. John's River | 2001 -2010 | ● | | |

| Length | Weight | Repeat Spawner | FI Adult | FI JAI | FD CPUE |
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**Table 1**. Summary of available data and data quality by state, river, or other system (from SASC). Dark grey cells with filled circles indicate data sets available for the entire time series of interest; medium grey cells with open circles had partial data sets available; and light grey cells with “x” indicate data sets not reliable enough to use for the assessment. Blank cells indicate no data.

**2. Evaluate the estimates of ocean bycatch of river herring and the methods used to develop estimates.**

For many years, incidental bycatch in marine fisheries was a known but unquantified mortality source for river herring and shad, and was identified as a high priority in the most recent American shad stock assessment review (ASMFC 2007). For the current river herring assessment, incidental catch - defined as alosines brought aboard and either retained (landed) or discarded at sea - was quantified for the first time. The purpose was to compare the magnitudes of incidental catch from all sources to reported commercial catches.

Data were obtained from the Northeast Fishery Observer Program (NEFOP) and were quantified by fleet for 14 different gear types (see pg. 19 of the stock assessment report), by year, season, geographic area, gear group, and mesh size for each species. Bycatch was estimated by taking the ratio of bycatch weight to caught weight as reported on ships by a NEFOP observer, and then adjusting these by the weight of the sold catch as reported by dealers, which is considered a more accurate weight.

Bycatch was assessed from 1989–2010. However, methodologies changed in 2005 for subsampling bycatch in high-volume midwater trawls and became better estimations. Hence, midwater trawl incidental catches are only included for 2005–2010. Coefficients of variation (CVs) were calculated following Wigley et al. (2007).

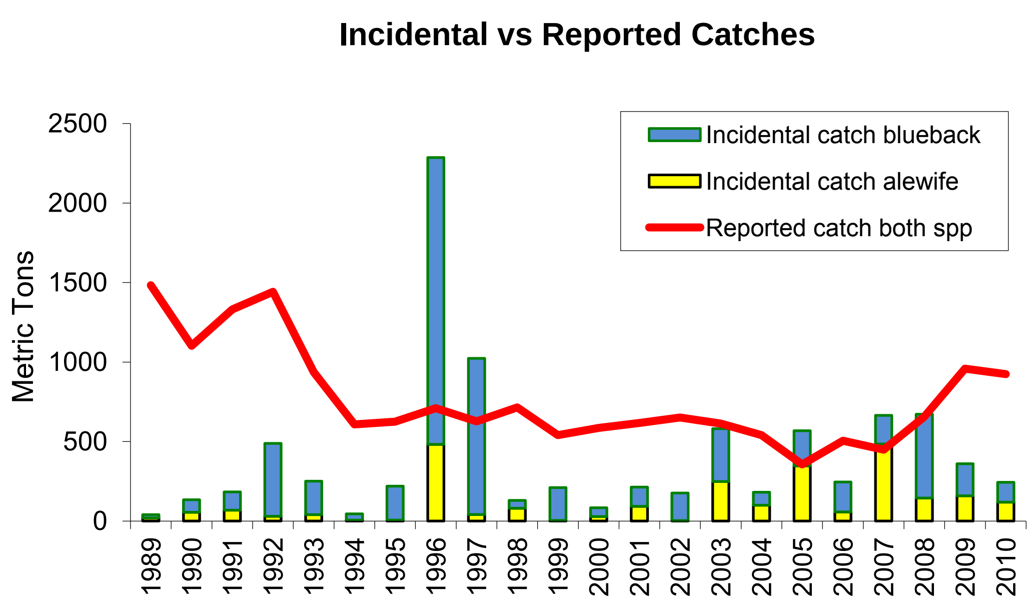


Figure. 1. Incidental catches of blueback herring and alewife, all gears and fleets reported by NEFOP observers, compared to total reported catches, 1989-2010. CVs not shown. Midwater trawl bycatch only included from 2005 onward.

Alewife bycatch ranged from a low of 2.72 MT in 2002 to 482 MT in 1996, with CVs ranging from 0.2–3.86 (20%–386%). Blueback herring bycatch ranged from 19.6 MT in 1989 to a high also in 1996 of 1803.4 MT, with CVs ranging from 0.2 to 2.1. Incidental marine catch estimates came close to or exceeded total reported commercial catches in 6 out of 22 years (Figure 1). Incidental catches occurred in all seasons, but tended to be highest during October – March. Midwater trawl catches were about equally proportioned between New England and Mid-Atlantic statistical areas, although New England small-mesh trawls took more incidental catch than Mid-Atlantic ones. Overall, New England incidental catches formed the larger part of the total (56%).

An unknown fraction of incidental catch is reported as 'landed catch' and thus the actual incidental bycatch reported as alewife and blueback herring is likely a bit lower than shown in Figure 1. However, an additional category of bycatch, called 'Herring – Unknown' (2.1 – 328 MT during this period) likely also includes river herring.

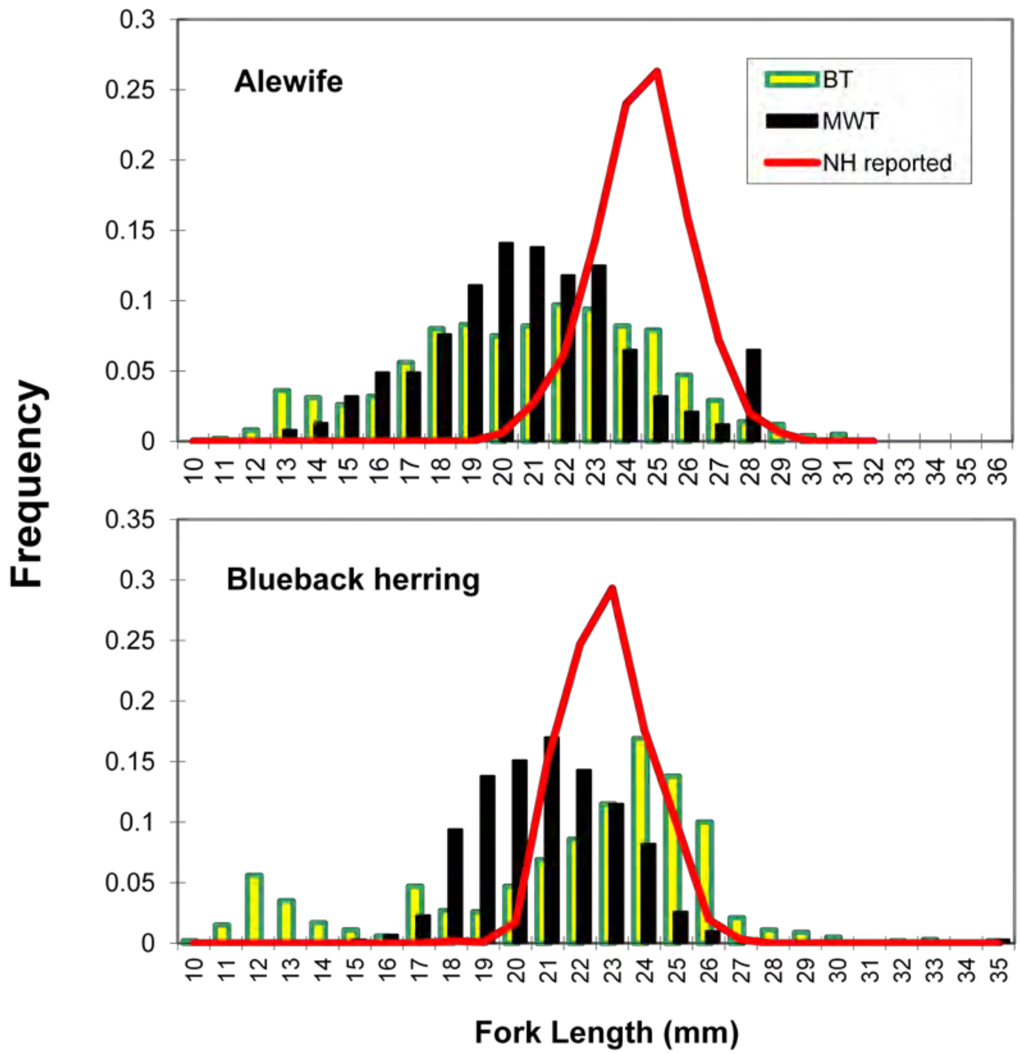


Figure 2. Length frequency distributions of alewife and blueback herring captured in bottom trawls (BT), midwater trawls (MWT), and compared to the spawner length frequency in New Hampshire. Data are from 2005-2010 added together.

Observers also record the sizes of incidentally caught river herring. It is noteworthy, even if expected, that a far broader range of sizes of both species were caught at sea than is the case in inland fisheries (Figure 2, using New Hampshire inland catches as a typical example of spawner size frequencies). For both species, large proportions of immature individuals were captured at sea. This is cause for concern.

Overall, the Panel considered the approach used by the SASC to assess incidental catches of river herring as reasonable and followed established protocols. Uncertainties were acknowledged. The Peer Review Panel encourages the assessment team to work to reduce uncertainties going forward, noting that CVs were lower in later years of the data presented. This likely is due to improvements in midwater trawl subsampling, among other things.

**3. Evaluate the methods and models used to estimate population parameters (e.g., Z, biomass, relative abundance) and biological reference points, including but not limited to:**

- **a. Evaluate the choice and justification of the preferred model(s) or method(s) of calculation. Was the most appropriate model or method chosen given available data and life history of the species?**
- **b. If multiple models were considered, evaluate the analysts' explanation of any differences in results.**
- **c. If appropriate, evaluate model parameterization and specification (e.g. choice of CVs, effective sample sizes, likelihood weighting schemes, calculation/specification of M, stock-recruitment relationship, choice of time-varying parameters, plus group treatment).**
- **d. Evaluate the diagnostic analyses performed, including but not limited to:**
  1. **Sensitivity analyses to determine stability of estimates and potential consequences of major model assumptions**
  2. **Retrospective analysis**

Besides examining trends in fishery-dependent and -independent indices of abundance, the SASC pursued three main categories of analyses to estimate population parameters. The first consisted of the estimation of river-specific total mortality (Z). Associated with this was derivation of Z reference points based upon a Spawner per Recruit (SPR) analysis. The second category consisted of the estimation of both river-specific and coast-wide exploitation rates (u). The third category consisted of two sets of population models, one set for specific rivers (Monument, Chowan and Nanticoke) and a second set for the coast-wide stock.

*Total Mortality (Z)*

Age frequency information was available for many of the coast's rivers from a variety of fishery-dependent and -independent sources (see ToR 1). The Chapman-Robson (1960) survival estimator, which is comparable to catch curve analysis but less biased, was applied to the annual age frequency data to provide a total mortality estimate by river, species, sex and year. Assumptions were made that sampling was representative of the abundance of each age class, the first age of full recruitment was the age class with the highest frequency, and selectivity for all full recruited ages was one. Z estimates were made from data with three or more age classes, including the first fully recruited age. Trends in the derived estimates were indicated through linear or loess smoothers. The method depends on the accuracy of the ages which was raised as an issue during the assessment. It is also influenced by many of the same issues that affect catch curve analysis, such as potential violation of selectivity assumption as well as variability due to recruitment events. If these are not severe, the method can provide an adequate estimate of annual total mortality along with estimates of uncertainty (CV) for each component of the coastal river herring complex.

A similar analysis of total mortality trends was conducted using the repeat spawner data available for each stock component. Estimates were made from data where three or more repeat spawner classes, including the first fully-recruited class, were deemed valid. This analysis was undertaken to avoid the problem of ageing inaccuracies. The other issues encountered in the age-specific analysis would apply here as well. The Panel was concerned that while this analysis would address the ageing issue, others may be present. Specifically, skip spawning, while not considered likely by the SASC, would produce biased (high) estimates of Z. Interestingly, the repeat spawner Z estimates tended to be higher than the age-based ones, consistent with this potential problem. And, if spawning checks and scale rings were annual, both estimates should be highly correlated, which was not the case. On balance, the Panel preferred the age-based Z estimates notwithstanding the potential ageing uncertainties.

Total mortality reference points were developed to compare to the annual Z estimates using Spawning Stock Biomass per Recruit (SRP) software available in the NMFS assessment toolbox. State-specific estimates of spawner weight-at-age were developed, in some cases converting length-at-age to weight-at-age using state-based length-weight relationships. Fishing and natural mortality were assumed to occur consistently throughout the year, so the fraction of both that elapsed before spawning was estimated by each state based on the month with the highest run count (if available) by species. Fishing selectivity was assumed to be 1 for all ages and represented both in-river adult fishing and juvenile ocean catches. It also includes other sources of mortality such as that due to passage and predation. The SPR model provides estimates of spawning biomass per recruit for a range of fishing mortalities as a percent of the maximum possible ($F$ = 0). The Panel considered the methodology appropriate for use with river herring.

*Exploitation rates*

Exploitation rates (u) were estimated for five New England rivers by dividing the in-river harvest by the total run size (escapement plus harvest) for a given year. This method relies on the quality of escapement and harvest data. If these are reasonably accurate, the method is appropriate. Its utility is limited by the data available, a point highlighted by the fact that estimates were calculated for only five of the over 50 rivers along the coast.

Relative exploitation rates were estimated for the coast-wide river herring population by dividing the annual estimate of total catch by an index of total biomass. A coast-wide rather than regional or river-based estimate was calculated due to the inability to partition incidental catch to region or river. The total catch was calculated from the total reported landings, NAFO landings reported from other countries, plus incidental catch (see ToR 2). An index of total annual river herring biomass was based on the minimum swept area biomass of the 1976-2010 spring NEFSC bottom trawl survey. The spring survey was used as river herring are more readily caught during the spring than during the fall. This method has been used in other data-poor situations and is part of the AIM package in the NMFS assessment toolbox. It can produce adequate trends in relative exploitation as long as its assumptions are not severely violated. Here, the catch comes from both freshwater and marine environments while the biomass index is only from the latter at one time of the year (spring). The age/size composition of the catch and survey index may be very different. There is evidence that the size composition of the freshwater landings and marine incidental catch are different (ToR 2) but no evidence on survey size composition was provided. The Panel considered that while the results were interesting, they require further verification of the approach's assumptions before being used.

*Population Models*

A Statistical Catch at Age (SCAA) model was developed for each of the Monument (MA), Nanticoke (MD), and Chowan (NC) rivers. The choice of these rivers was based upon a combination of data availability and modeling expertise. While not necessarily planned, it is fortunate these three rivers were chosen as they span the geographic range of river herring along the coast. The Monument model was for alewife, the Chowan model was for blueback herring, while the Nanticoke model was for both species. The three models differed significantly in a number of details but overall were innovative implementations. The Monument model used escapement for catch and did not depend upon offshore incidental bycatch, which was incorporated into the model as a component of natural mortality (*M*). Two time blocks were used to capture significant changes in the fishery and population. The model fits to the data were good with no obvious issues. It was the most advanced SCAA implementation of the three models.

The Chowan model had the same general structure as the Monument's, but did not produce as good a fit to the observations. During the review meeting, the SASC indicated this model, while still good, required further development. The SCAA models (each species) for the Nanticoke River were the least developed of the three. Not only was it acknowledged that incidental catch needed to be incorporated before its acceptance, but the fits to the observations exhibited strong residual patterns.

Overall, while none of these models are appropriate to inform management decisions at the coast-wide scale, the Panel considered the SCAA models as innovative and strongly urged further developments. In addition, they provide platforms for the study of alewife and blueback herring population dynamics at both the river and coast-wide scale. For instance, these models could be used to examine river herring-habitat relationships in each river and how these might influence reference points. Comparison of the findings of these models may provide insight on how river-based processes vary along the coast. Further, the model outputs, e.g. biomass and reference points, can be compared to evaluate whether or not each river population is mixing in the one or many discrete offshore ‘pools’. The Panel encourages efforts to expand these models to other rivers as data and resources permit.

A depletion-based stock reduction analysis (DB-SRA) was developed for the coast-wide river herring population. It employed the Pella-Tomlinson production function rather than the hybrid function developed by Dick and MacCall (2011). The model inputs included catch (including incidental bycatch), the model shape parameter (n), exploitation at MSY ($U_{MSY}$), the carrying capacity (K) and the ratio of 2010 to virgin biomass ($B_{2010}$/K ratio). Due to the long history of this fishery, initial biomass was set at 75% of K. Multiple draws were made by the SASC using different distributions of the n, $U_{MSY}$ and K parameters to determine a value of K which provides an expected $B_{2010}$/K ratio. The SASC informed the Panel that the latter ratio was based on an analysis of catch and run count data which gave a general indication it was on the order of 10%. The base model assumed n=2, $U_{MSY}$ = 0.1, $B_0$/K = 0.75 and $B_{2010}$/K = 0.1. Sensitivity runs (ToR 4) were conducted to explore the model’s behavior to changes in the data inputs. Also, changes were made to the catch history to examine the impact of historical misreporting. The model outputs indicated K was robust to data inputs, except catch, being in the order of 634 kt – 707 kt. $U_{MSY}$ was also relatively stable across input options, varying from 0.055 – 0.073 while $B_{MSY}$ varied from 312Kt – 355kt.

In a Pacific Fishery Management Council–sponsored workshop to explore assessment methods for data-poor stocks (Dorn, 2011), the DB-SRA was determined to provide reasonable estimates of key population parameters, including stock status, given a range of uncertain data inputs and assumptions. However, as acknowledged by the SASC, the river herring model is strongly constrained by the input assumption on $B_{2010}$/K. Thus, in this case, current status is largely influenced by what is assumed to be current status. The Panel also noted that $U_{MSY}$ of 0.06 appears to be unrealistically low and may be due to a mis-specified production function. This is complicated by the fact that the dynamics of two species (alewife and blueback herring) are being jointly modeled.

In summary, the Panel concurred with the SASC that the DB-SRA model did not adequately model river herring stock conditions and should not be used to assess status. On the other hand, it is a valuable heuristic tool to explore the possible dynamics of the resource and guide future modeling efforts which more explicitly incorporate observational informational as part of an optimization process.

**4. Evaluate the methods used to characterize uncertainty in estimated parameters. Ensure the implications of uncertainty in technical conclusions are clearly stated.**

For important parameters and trends estimated, the characterization of uncertainty by the SASC varied across approaches. Uncertainty arises throughout the assessment process in the estimation of various quantities, including: catch (both landed and discarded), indices of abundance, trends in the indices, mortality rates, biological reference points, and population biomass.

In general, the uncertainty in the indices of abundance was not well characterized. Estimates of CPUE from the various fisheries-dependent and -independent surveys were calculated as the total catch divided by the measure of effort. The Panel felt using a more statistical approach was warranted to account for uncertainty in these indices in relation to covariates (e.g. estimating CPUE using a GLM).

The ARIMA model used to estimate temporal trends attempts to reduce observation uncertainty in a time series by assuming point estimates are part of an autoregressive process. The resulting fit has a variance below the variance of the fitted time series, and is an accepted way to characterize trends in noisy data over time (Helser and Hayes, 1999). In addition to the fitting of the ARIMA model, the stock assessment team accounted for additional uncertainty in the fit by computing the probability of being below the reference point (the 25th percentile of the fitted series), along with the statistical level of confidence (at the 80% level). The probability and associated confidence limits were calculated using a bootstrap approach. The Panel felt that calculating statistical levels of confidence around the estimated probability was a useful approach. However, there was some concern over the sensitivity of the ARIMA model fits to the first year in the series, and that additional smoothing techniques might be employed in conjunction with the ARIMA model to fits where conclusions in trends are sensitive to the early time period.

Estimating total mortality rates (Z) relied on the ability to age river herring using scales. The SASC acknowledged there is a large amount of uncertainty in the ageing process using scales, although it is not possible to quantify this uncertainty at present. Total mortality was also estimated using repeat spawner marks, which the SASC believed might be a less biased approach to estimated Z. Estimates of uncertainty in Z estimates were not presented in assessment. The Panel agreed that estimates of uncertainty for these values should be provided, particularly in Table 2 of the assessment that summarizes Z in relation to reference points by system.

In the stock assessment approaches (the SCAA for 3 rivers, and the coast-wide assessment using DB-SRA; see ToR 3), uncertainty was characterized in different ways. DB-SRA utilizes a Monte Carlo approach, whereby model inputs are drawn from a specified distribution. It is recognized that when using DB-SRA, specification of these input parameters is often ad hoc by necessity. The SASC specified various distributions for the input parameters, all of which were dome-shaped. In addition to the usual distributional inputs, the SASC also added uncertainty into the catch series, assuming catches early in the time series had higher coefficients of variation. Although estimates of uncertainty in the catch were added in an ad hoc manner, the Panel thought it was a significant inclusion to the model, as catches are often assumed known when using this approach. The Panel felt that uncertainty in the inputs and outputs of the DB-SRA model were generally well characterized, although in the future it might be more appropriate to assume uniform distributions for the input parameters, and then allow the model to reject unrealistic values. In addition, the Panel felt the distribution for $B_{MSY}$ / K was likely too high, being centered at 0.5 and ranging between 0.3 and 0.7. The Panel felt the distribution should have an upper bound closer to 0.5, and be centered around 0.35. Doing so might account for some of the issues in estimates of $F_{MSY}$ (see ToR 3).

As noted in ToR 3, SCAA models were developed for 3 river systems for one or both species of river herring: the Monument River in Massachusetts (alewife only), the Nanticoke River in Maryland (both alewife and blueback herring), and the Chowan River in North Carolina (blueback only). It was acknowledged by the SASC that the models for the Monument and Chowan Rivers were more developed, and the model for the Nanticoke was a work in progress. All assessment models were developed in AD Model Builder (Fournier, 2011). Uncertainty in the inputs in the Monument and Chowan models was accounted for in the likelihood weighting, whereby catch and survey indices of abundance were weighted by their CV. In addition, an iterative reweighting procedure was conducted to account for the potential impacts of the individual likelihood components to the overall model fitting procedure McAllister and Ianelli (1997). Uncertainty in model estimates were reported for all quantities based on the AD Model builder-estimated standard errors in model parameters and derived quantities. The Panel recognized the characterization of uncertainty in the assessments was sound, although the standard errors in the estimates is likely biased low due to various model assumptions (e.g. fixed M, Beverton-Holt recruitment relationship).

In summary, the Panel felt the characterization of uncertainty was variable across approaches. Uncertainty was generally well addressed in the population models (DB-SRA, SCAA models) and in the trend analyses. However, uncertainty was not well accounted for in the calculation of CPUE indices. The Panel recommends using a more statistical framework, such as a GLM, when calculating CPUEs from surveys.

**5. Evaluate recommended estimates of stock biomass, abundance (relative or absolute), mortality, and the choice of reference points from the assessment for use in management; if appropriate, recommend changes or specify alternative estimation methods.**

No estimates of biomass, abundance (relative or absolute), or fishing mortality were recommended by the SASC. All population models considered were in some stage of development. The SCAA models were developed to describe alewife and blueback herring dynamics at the river scale. While they may have utility to inform specific management decisions at this scale, at least two of them require further development. And, their reference points are applicable to the river and not coastal scale. The DB-SRA model of coast-wide river herring dynamics was not considered to provide credible estimates of biomass and fishing mortality. The Panel felt that while the trend in historical biomass estimated by this model is likely close to the truth - relatively high prior to the 1960s after which it declined rapidly - there is considerable uncertainty in more recent trends, with some formulations suggesting a small increase and others indicating relative stability. The DB-SRA model also suggests exploitation was low until the mid-1960s, rapidly rose to a peak in the early 1970s and then, according to the base model, steadily declined until the present. The estimates of both the in-river and relative exploitation rate also exhibited declines during this period, although the detailed patterns are different. Thus, while the Panel agreed biomass is lower than historical levels and fishing mortality has likely declined more recently, the extent of these reductions is highly uncertain. And, the reference points estimated by the DB-SRA were not considered credible and thus are not useful to the determination of stock status.

The SASC provided three reference points based upon total mortality (Z): $Z_{COLLAPSE}$, the amount of mortality that would cause a stock to collapse; $Z_{20\%}$, the amount that would reduce the biomass per recruit to 20% of the unfished stock; and $Z_{40\%}$, reduced biomass to 40% of unfished biomass. A number of $Z_{COLLAPSE}$ estimates were proposed, all being generally based upon the fishing mortality (*F*) at a percent SPR determined by the inverse of the slope at the origin of a Beverton and Holt stock-recruitment relationship. Total mortality is determined by adding an assumed level of natural mortality. Here, an *M* of 1.0 was assumed. Values of $Z_{COLLAPSE}$ for alewife across rivers ranged 2.0 – 3.0 while those for blueback herring for a more limited number of rivers ranged from 1.6 – 3.2. These were well in excess of the annual estimates of age-based Z. The Panel considered the $Z_{COLLAPSE}$ reference point a useful upper limit to total mortality but it must be considered with caution given its dependence on uncertain stock-recruit relationships and assumptions on natural mortality.

The $Z_{20\%}$ and $Z_{40\%}$ reference points are analogous to the widely used $F_{20\%}$ and $F_{30\%}$ proxies of $F_{MSY}$. In the case of river herring, fishing mortality is assumed to include a combination of fishing and other anthropogenic and non-anthropogenic sources of mortality, most of which cannot be quantified. The percentage of maximum spawning potential used for the determination of the mortality reference point is based upon the productivity characteristics of the species, with lower percentages (15 – 20%) sustainable for highly productive species and higher percentages (35 – 40%) used for less productive species. Punt et al. (2008) determined that the percent SPR at MSY is an inverse function of the steepness parameter of the Beverton and Holt stock-recruitment relationship. A meta-analysis of steepness parameters by Myers et al. (1999) indicated the median estimate of steepness for Clupeids (such as alewife and blueback herring) was 0.71. Based on the analysis of Punt et al. (2008), this implies percentages on the order of 35 – 40% are more appropriate for river herring reference points. The Panel thus recommends that $Z_{40\%}$, rather than $Z_{20\%}$, be used as the total mortality reference point.

The $Z_{20\%}$ and $Z_{40\%}$ reference points are very sensitive to assumptions of *M*. The SASC developed two sets of Z reference points based on *M* equal to 0.3 and 0.7. It based these on a comprehensive study of published relationships between natural mortality and growth parameters such as K (Brody growth coefficient), $t_{max}$ (the maximum age), and average temperature experienced during a year (Table 2). These growth parameters were developed with data from 1973-1983. This analysis indicated estimates of *M* based on longevity ($t_{max}$) were much lower than those based on K. The basis for this could not be determined but may indicate that elevated natural mortality is being expressed through changes in growth. The *M* options of 0.3 and 0.7 were considered to bracket the processes implied by this analysis.

**Table 2**. Estimates of river herring natural mortality (*M*) developed by the SASC for determination of Z reference points (provided to Panel at review meeting).

| | | Required Parameters | | | | | |
|---|---|---|---|---|---|---|---|
| **Method** | **Equation** | **L_inf** | **K** | **t_max** | **P** | **temp** | **M** |
| Alverson and Carney 1975 | **M** = 3**K**/(exp[0.38***K*****t_max**) − 1] | | X | X | | | 0.164 |
| Pauly 1980 | **M** = exp[−0.0152 + 0.6543*ln(**K**) − 0.279*ln(**L_inf**/10) + 0.4634*ln(**Temp**)] | X | X | | | X | 1.212 |
| Hoenig 1983 (regression) | **M** = exp[1.44 − 0.982*ln(**t_max**)] | | | X | | | 0.401 |
| Hoenig 1983 (rule-of-thumb) | **M** = −ln(**P**)/**t_max** | | | X | X | | 0.382 |
| Ralston 1987 (linear regression) | **M** = 0.0189 + 2.06***K** | | X | | | | 1.234 |
| Jensen 1996 (theoretical) | **M** = 1.50***K** | | X | | | | 0.885 |
| Jensen 1996 (derived from Pauly 1980) | **M** = 1.60***K** | | X | | | | 0.944 |
| Hewitt and Hoenig 2005 | **M** = 4.22/**t_max** | | | X | | | 0.384 |

For $M$ = 0.3, the $Z_{40\%}$ reference point ranged 0.46 – 0.48 for alewife and blueback herring across the rivers along the coast. For $M$ = 0.7, this reference point ranged from 1.11 – 1.15. It is clear the determination of natural mortality is critical to the setting of Z reference points. There is good evidence that total mortality is high. The issue is how much of this is due to fishing and how much due to natural mortality. There is evidence from various sources that fishing mortality has likely been declining over a long period. Some of the growth parameters based on 1973-1983 data suggest $M$ is high. It is possible that due to the depleted state of river herring stocks, multiple sources are causing high apparent natural mortality. These species are forage for many predators and are exposed to many anthropogenic threats (e.g. dams, culverts and other barriers, etc). The Panel considered that $Z_{40\%}$ for $M$ = 0.7, as proposed by the SASC, is a useful reference point against which to measure total mortality.

**6. Evaluate stock status determination from the assessment; if appropriate, recommend changes or specify alternative methods/measures.**

Coast wide status of the stock (biomass and exploitation rates) in relation to management reference points could not be determined. The SASC attempted to estimate coast wide status using the DB-SRA model, but recognized that using estimates of current biomass and exploitation rates were dependent upon the input parameter of $B_{CURRENT}$ / K. The Panel agreed with this conclusion, and also noted estimates of $F_{MSY}$ and historical exploitation rates were likely too low, suggesting that at its peak, the fishery was removing only 20% of the stock per year. While the Panel felt the current DB-SRA model was not to be relied on, it believed this model should be further developed, and may be a useful heuristic tool (see ToR 3**).**

Determination of coast wide status therefore relied on a variety of approaches, including the statistical catch at age models for individual rivers, trend analyses, and estimation of total mortality across rivers. The statistical catch at age models for individual rivers all showed sharp declines in river herring biomass. For the Monument River, alewife spawning biomass declined from a peak of around 35 MT in the mid-1990s to early 2000s to about 7 MT currently. For the Chowan River, spawning biomass of blueback herring declined from a peak of 5225 MT in the early 1980s to a current estimate of 95 MT. The models for alewife and blueback herring in the Nanticoke River, while considered less developed than the other models, suggested similar declines in magnitude, from about 60 and 70 MT in 1989 (for alewife and blueback, respectively), to about 5 MT in recent years for both species.

In addition to the assessment approaches, the SASC explored trends in indices of abundance, mean length, mean length-at-age, and maximum age. In many systems, mean length and maximum age were lower in recent years, and length-at-age for at least one age class showed a decline. For juvenile and adult surveys indices of abundance, trends were variable.

Where total mortality (Z) could be estimated for a river system, it was compared to reference points of $Z_{20\%}$ and $Z_{40\%}$, assuming an *M* of 0.7 (Table 2 in the assessment). These estimates showed that in recent years (2008-2010), the average Z was higher than the $Z_{40\%}$ reference point in all cases, and higher than $Z_{20\%}$ in most cases. The Panel felt the $Z_{20\%}$ reference point was likely too high, and a Z reference point between 35-40% was more appropriate (see ToR 5), such that mortality is likely too high in all systems where Z could be estimated.

Based on the weight of evidence from these approaches, the SASC concluded the coast wide meta-complex of river herring is depleted to near historic lows. The Panel agreed with the SASC conclusion that coast wide, river herring are depleted, and current total mortality rates were too high. The SASC concluded that of the 52 in-river stocks included in their analyses, 22 are depleted, 1 is increasing, and 28 have unknown status (Table 1 in the assessment). The Panel agreed with these general findings.

The SASC and Panel also noted that one stock – the Connecticut River – was not categorized (51 of 52 were assigned to either depleted, increasing, or unknown status categories). The SASC, in conjunction with each jurisdiction's technical committee representation, determined what the most appropriate status determination for each river system. A consensus could not be reached between the SASC and Connecticut's technical committee representation. The Panel agreed with the SASC that the Connecticut River's status was depleted.

The SASC also noted that a northward shift in distribution in both species might be occurring, perhaps in relation to warming water. The SASC noted that for alewife only, stable or increasing trends in juvenile and adult indices of abundance were observed in the northern areas, while stable or decreasing trends were observed in the southern areas. The NMFS trawl survey seemed to support this notion for both species, showing increases in the north and decreases in south.

**7. Review the research, data collection, and assessment methodology recommendations and make additional recommendations as warranted. Clearly prioritize the activities needed to inform and maintain the current assessment, and provide recommendations to improve the reliability of future assessments.**

The Review Panel considered the SASC's research recommendations in four functional categories (population dynamics, monitoring, assessment, and implementation) but maintained their time frame suggestions. Recommendations in the stock assessment and some added by the Panel are ranked as low, moderate, or high priority with comments on justification in Table 3.

**Table 3**. Review Panel evaluation and prioritization of American eel research recommendations. * indicates recommendations added by the Panel.

| Research recommendation | Time period | Priority | Review Panel Comments |
|---|---|---|---|
| **Assessment** | | | |
| *Analyze the consequences of interactions between the offshore bycatch fishery and population trends in the rivers | Short term | High | This would allow informed decisions on future mitigation measures |
| Improve methods to develop biological benchmarks used in assessment modeling (fecundity-at-age, mean weight-at-age for both sexes, partial recruitment vector/maturity schedules) for river herring stocks | Short term | Moderate | Panel agrees there is a need but other recommendations will have a greater impact |
| Explore use of peer-reviewed stock assessment models for use in additional river systems in the future as more data become available | Long term | Moderate | In addition, further develop existing models to understand coast wide differences in dynamics, etc. |
| **Implementation** | | | |
| Develop better fish culture techniques and supplemental stocking strategies for river herring | Long term | Low | Success rate in other stocking programs (e.g. Atlantic salmon, shad, etc.) has been low |
| Encourage studies to quantify and improve fish passage efficiency and support the implementation of standard practices | Long term | High | Dams and other impediments will continue to impact river herring; improving passage efficiency is critical to sustaining/restoring runs |

Table 3, cont'd.

| Research recommendation | Time period | Priority | Review Panel Comments |
|---|---|---|---|
| **Population dynamics** | | | |
| Investigate contribution of landlocked versus anadromous produced fish. | Long Term | Low | Peripheral to management of coastal population |
| Continue genetic analyses to determine population stock structure along the coast and enable determination of river origin of incidental catch in non-targeted ocean fisheries. | Short term | High | Research underway in combination with otolith chemistry |
| Determine and quantify stocks impacted by mixed stock fisheries (including bycatch fisheries). Methods to be considered could include otolith microchemistry, oxytetracycline otolith marking, genetic analysis, and/or tagging. | Long Term | High | Combined with above. |
| Develop models to predict the potential impacts of climate change on river herring distribution and stock persistence. | Short term | Low | Premature given state of data and model developments; need to link to population dynamics |
| Validate [better estimate] the different values of $M$ for river herring stocks and improve methods for calculating $M$. | Long term | High | Important to understand sources of high $M$ (e.g. predation, habitat, etc) |
| Continue to assess current ageing techniques for river herring, using known-age fish, scales, otoliths, and spawning marks. | Short term | High | Review panel fully supports this recommendation |
| Conduct biannual ageing workshops to maintain consistency and accuracy in ageing fish sampled in state programs. | Long term | High | Important for ageing program quality assurance |
| Summarize existing information on predation by striped bass and other species; quantify consumption through modeling (e.g., MSVPA), diet, and bioenergetics studies. | Long term | Moderate | Important but sort out $M$ issue (above) first |
| Investigate the relation between juvenile river herring production and subsequent year class strength, with emphasis on the validity of juvenile abundance indices, rates and sources of immature mortality, migratory behavior of juveniles, and life history requirements. | Long term | High | Has potential to indicate relative role of production (catch plus growth) and environment in recruitment strength, however, not easily achievable |
| Evaluate the performance of hatchery fish in river herring restoration. | Long term | Low | Due to low current hatchery production |

Table 3, cont'd.

| Research recommendation | Time period | Priority | Review Panel Comments |
|---|---|---|---|
| **Monitoring** | | | |
| Improve reporting of harvest by water body and gear. | Short term | High | The Panel agrees this should be a priority at all levels. |
| Investigate additional sources of historical catch data of the U.S. small pelagic fisheries to better represent or construct earlier harvest of river herring. | Short term | Moderate | Would assist current model formulation but would not facilitate interpretation of current status |
| Develop and implement monitoring protocols and analyses to determine river herring population responses and targets for rivers undergoing restoration (dam removals, fishways, supplemental stocking, etc.). | Short term | High | Also should be assessing success of moratoria |
| Develop comprehensive angler use and harvest survey techniques for use by Atlantic states with open or future fisheries to assess recreational harvest of river herring. | Long term | Low | It is a higher priority to address issues in larger fisheries |
| Expand observer and port sampling coverage to quantify additional sources of mortality for alosine species, including bait fisheries, as well as rates of incidental catch in other fisheries. | Long term | High | However, first undertake statistical study of observer allocation and coverage (see Hanke et al., 2011 for example) |
| Evaluate and ultimately validate large-scale hydroacoustic methods to quantify river herring escapement (spawning run numbers) in major river systems. | Long term | Moderate | Considered an adjunct to current monitoring systems and would have to be implemented in tandem |
| * Explore the sources of and provide better estimates of incidental catch in order to reduce uncertainty in incidental catch estimates. | Short term | High | Explore existing data but also observer coverage analysis as indicated above |
| *Develop bottom and mid-water trawl CPUE indices of offshore biomass. | Short term | Moderate | This is exploratory, data are available and may or may not provide useful indices |
| *Consider the use of GLM to provide better trend estimates and to better characterize uncertainty in trends. | Short term | Moderate | GLM provides a general statistical structure to the description of uncertainty in stock indices |

**8. Recommend timing of the next benchmark assessment and updates, if necessary, relative to the life history and current management of the species.**

The Panel completely agrees with the SASC's recommended time frame and justification for an update of the trend analysis in 5 years followed by a benchmark assessment in 10 years.

> "We recommend an update of trend analyses in 5 years and the next benchmark assessment for river herring be conducted in 10 years (finalized in 2022). Due to the high variability of fisheries independent surveys, a benchmark assessment at a shorter timeframe (e.g. 5 years) will likely not show any significant changes in indices of abundance. Any population changes resulting from closures of fisheries in 2012; improved access to historic spawning grounds; and additional beneficial management measures, such as sustainable fishing plans and action by the federal councils, cannot be expected to result in any population change until at least one cohort of river herring has grown to maturity (assuming age at maturity is 3 – 6 years). A 10 year timeframe for the next benchmark assessment will also allow a longer time series of estimated total incidental catch in non-targeted ocean fisheries to be evaluated." (Sec 3.2 Stock Assessment Report)

In addition, the Panel also believes that the 5 year interval prior to the trend assessment will allow for the results of more recent fishing moratoria to be evaluated.

## Advisory Report

### A. Status of stocks: Current and projected, where applicable

The coast wide meta-complex of river herring is depleted to near historic lows. Analysis of trends in abundance, mean length, and maximum age, as well as estimates of total mortality for 52 in-river stocks of alewife and blueback herring for which data were available indicated that 22 were depleted, 1 stock was increasing, and the status of 28 stocks could not be determined because the time-series of available data was too short (see response to ToR 6 for more on status determination). In addition, stock assessments for 3 rivers (the Monument, Nanticoke, and Chowan), representing a broad geographic range, indicate populations are at very low levels. Total mortality rates in all systems explored were higher than the benchmark $Z_{40\%}$, and most were above the $Z_{20\%}$ benchmark. The Panel felt a benchmark closer to $Z_{40\%}$ was more appropriate, such that mortality is likely too high in all systems where it was estimated. Determining the relative contribution of various factors to this mortality is difficult given the limited data, but it is likely that a number of factors will need to be addressed, including fishing (both in-river and ocean bycatch), water passageways, water quality, predation, and climate change, to allow for the recovery of river herring.

### B. Stock Identification and Distribution

There are no formal reports of stock identification for alewife and blueback herring. An ongoing study, funded by the National Fish and Wildlife Foundation (NFWF), is currently assessing both genetic and otolith biomarkers to associate both species back to specific regions and, where possible, specific watersheds. However, existing data suggest anadromous alewife exchange genes between adjacent watersheds (cf. Palkovacs et al. 2008). This implies genetic markers will not be able to resolve populations to the level of individual rivers, although one goal of the NFWF project is to determine whether there is greater ability to identify stocks in large rivers vs. small, coastal streams.

Alewife and blueback herring have extensive ranges along the North American east coast (Schmidt et al. 2003). Alewife range from Newfoundland to North Carolina; blueback herring are found from New Brunswick, Canada as far south as the St. Johns River in Florida (McBride et al. 2010). Alewife is more common in the northern end of their range overlap, and blueback herring is more common in the southern end.

### C. Management Unit

River herring are managed on a state or watershed level, as coordinated by the ASMFC. Genetic work to verify distinct populations by river is ongoing (see B above; E. Palkovacs, Duke University, personal communication), but as with American shad it appears reasonable. It is also reasonable to consider a regional scale, within which rivers are grouped by geography and physiography, with particular attention to how spawning adults might encounter a river via ingress from the ocean, sounds (e.g., Albemarle, Pamlico, Long Island), or bays (e.g., Chesapeake, Cape Cod).

**D. Landings**

Total coast-wide landings of river herring in the U.S. averaged 18.5 million pounds from 1887 to 1928; although landings information was sparsely reported in many areas, likely under-reported (see ToR 1), and not available in some years. Reported values during this period ranged from 22,000 pounds to a high of 85.5 million pounds. Landings from this period were predominately reported from Maryland, North Carolina, Virginia, and Massachusetts. Overall landings during this period are likely underestimates due to inconsistent reporting.

Coast wide landings increased sharply from lows in the early 1940s to more than 50 million pounds by 1951 and peaked at 74.9 million pounds in 1958. Severe declines in landings began coast wide in the early 1970s and domestic landings are now a fraction of what they were at their peak, having remained at persistently low levels since the mid-1990s. Moratoria have been enacted in Massachusetts (commercial and recreational in 2005), Rhode Island (commercial and recreational in 2006), Connecticut (commercial and recreational in 2002), Virginia (for waters flowing into North Carolina in 2007), and North Carolina (commercial and recreational in 2007). As of January 1, 2012 river herring fisheries in states or jurisdictions without an approved sustainable fisheries management plan, as required under ASMFC Amendment 2 to the Shad and River Herring FMP, were closed. As a result, prohibitions on harvest (commercial or recreational) were extended to the following states: New Jersey, Delaware, Pennsylvania, Maryland, D.C., Virginia (for all waters), Georgia and Florida.

River herring are caught incidentally (termed incidental catch) in a number of different ocean fisheries. Some incidental catch is retained, and the remainder is discarded, but quantifying the total incidental catch and the amount retained versus discarded is problematic. Although estimates of incidental catch are available starting in 1989, the sampling of mid-water trawl (MWT) vessels was sparse prior to 2005. Since MWT vessels collect a large portion of the total incidental catch, estimates of total incidental catch prior to 2005 are deemed unreliable. There are additional factors adding to the uncertainty in the estimation of incidental catch of river herring. First is the error in identifying river herring by species. Second is an unidentified category of incidental catch labeled herring NK (for not known), which also includes Atlantic herring, and the relative proportion of river herring in this category is unknown. Finally, it is unknown how much of the estimated incidental catch also gets reported as landed catch, such that estimates of incidental catch may be biased high in certain years.

Estimation uncertainty notwithstanding, from 2005-2010, the total annual incidental catch of alewife ranged from 19.0-473.3 MT in New England and 8.9-256.2 MT in the Mid-Atlantic. Estimates of precision (coefficients of variation) exhibited substantial interannual variation and ranged from 0.28-3.12 across gears and regions.

Total annual blueback herring incidental catch from 2005-2010 ranged from 13.9–176.5 MT in New England and 1.2-382.6 MT in the Mid-Atlantic. During this period, estimates of total incidental catch are of comparable magnitude to commercial landings. Given the high estimates of incidental catch (and the high degree of uncertainty in these estimates), particularly in relation to total landings, the Review Panel felt that obtaining a better understanding of the incidental catch of river herring is imperative (see Research Recommendations in ToR 7).

Recreational catches of river herring remains largely unknown. The Marine Recreational Information Program (MRIP) estimates the numbers of river herring harvested and released by anglers, but estimates are very imprecise, show little trend, and are deemed not useful for management purposes. MRIP concentrates their sampling strata in coastal waters and does not capture data on recreational fisheries occurring in inland waters. Few states conduct creel surveys or other consistent survey instruments (diary or log books) in inland waters to collect data on recreational catch of river herring. Some data are reported in the state chapters of the current stock assessment, but data are too sparse to conduct systematic comparisons of trends.

## E. Data and Assessment

*Data*

Fishery dependent data were deemed of limited use by the SASC due to problems with documentation of mixed species, data gaps, combined sexes, and variable catchability of gear over time (see ToR 1). The Panel believes that the increasing number of state fishing moratoria will continue to reduce this source of data. Fishery independent data were considered more reliable and used for state and coast wide trend analyses of catch per unit effort. The absence of consistent trends in the fishery-independent data was observed as decreases in regions south of Long Island and increase in northern locations. The reason for this discrepancy may be due to the relatively short duration of the time series available as noted in ToR 1. By the next assessment, time series should provide a more complete indication of state and coast wide trends in both river herring species.

The SASC utilized the biological data (age, length, weight) to its fullest practical extent in their trend analyses as well as mortality estimates. The Panel would like to emphasize the need for caution in the analyses that use age data and believe the need for a standardized and validated ageing method would enhance the use of life history traits in future assessments (see ToR 1).

Overall, the Review Panel believes the SASC made good use of the reliable data that were available.

*Assessment*

Besides examining trends in fishery-dependent and -independent indices of abundance, the SASC pursued three main categories of analyses to estimate population parameters: 1) river-specific total mortality (Z) with associated Z reference points based upon a Spawner per Recruit (SPR) analysis; 2) estimation of both river-specific and coast wide exploitation rates (u), and 3) two sets of population models, one set for specific rivers (Monument, Chowan, and Nanticoke) and a second set for the coast wide stock.

The Z estimates were based on application of the Chapman-Robson (1960) survival analysis to age frequency information available for many of the coast's rivers from a variety of fishery-dependent and -independent sources. The method makes a number of assumptions including representative sampling of the abundance of each year-class, the first age of full recruitment as the age class with the highest frequency of occurrence, and the selectivity for all fully recruited ages being one. In addition, as with all age-based methods, accuracy in the ageing data is assumed. Problems in age reading of river herring scales have been noted and thus the SASC undertook an analysis of repeat spawner data available for each stock component. The Panel was concerned that while this analysis would address the ageing issue, other issues may be present. Specifically, skip spawning would produce biased (high) estimates of Z. If spawning checks and scale rings were annual, both estimates should be highly correlated, which was not the case. On balance, the Panel preferred the age-based Z estimates for use with the Z reference points noted below.

Regarding exploitation rates, river-specific values were estimated for five New England rivers by dividing the in-river harvest by the total run size (escapement plus harvest) for a given year. While useful for these rivers, the approach has limited broader utility due to the lack of data. Relative exploitation rates were estimated for the coast-wide river herring population by dividing the annual estimate of total catch by an index of total biomass. A coast wide rather than regional or river-based estimate was calculated due to the inability to partition incidental catch to region or river. This method can produce adequate trends in relative exploitation as long as its assumptions are not severely violated. Here, the catch comes from both freshwater and marine environments while the biomass index is only from the latter at one time of the year (spring). The age/size composition of the catch and survey index may be very different. There is evidence that the size composition of the freshwater landings and marine incidental catch are different (ToR 2) but no evidence on survey size composition was provided. The Panel considered that while the results were interesting, they require further verification of the approach's assumptions before being used.

Regarding the population models, the set of Statistical Catch at Age (SCAA) models developed for the Monument (MA), Chowan (NC), and Nanticoke (MD) rivers differed significantly in a number of details but overall were innovative implementations. The Monument model was the most advanced while the Nanticoke model was the least developed. Overall, while none of the models are appropriate to inform management decisions at the coast wide scale, the Panel considered the SCAA models innovative and strongly urged further developments. In addition, they provide platforms for the study of alewife and blueback herring population dynamics at both the river and coast wide scale (see ToR 3). Further efforts to expand SCAA models to other rivers as data and resources permit are strongly encouraged.

The depletion-based stock reduction analysis (DB-SRA) developed for the coast-wide river herring population, while also innovative (see ToR for details), was strongly constrained by the input assumption on current depletion (assumed to be on the order of 10% of virgin biomass). The model also produced an estimate of $U_{MSY}$ (0.06) which appears to be unrealistically low. This may be due to a mis-specified production function. A further complication is that the dynamics of two species (alewife and blueback herring) are being jointly modeled. In summary, the DB-SRA model did not adequately model river herring stock conditions and should not be used to assess status. On the other hand, it is a valuable heuristic tool to explore the possible dynamics of the resource and guide future modeling efforts which more explicitly incorporated observational informational as part of an optimization process.

Overall, data were insufficient to allow assessment of the coast wide state of the river herring resource, requiring resort to the description of abundance and mortality trends in the river-specific fishery dependent and independent indices.

**F. Biological Reference Points**

It is only possible to reach consensus on total mortality (Z) reference points associated with the analysis of the annual age-frequency data available by state, river, species, sex and year. The SASC provided three reference points based upon total mortality (Z): $Z_{COLLAPSE}$, the amount of mortality that would cause a stock to collapse; $Z_{20\%}$, the amount that would reduce the biomass per recruit to 20% of the unfished stock; and $Z_{40\%}$, reduced biomass to 40% of unfished biomass. These were all based upon an analysis of spawner per recruit dynamics (see ToR 5 for details).

Values of $Z_{COLLAPSE}$ for alewife across rivers ranged from 2.0-3.0 while those for blueback herring for a more limited number of rivers ranged 1.6-3.2. The Panel considered the $Z_{COLLAPSE}$ reference point as a useful upper limit to total mortality but must be considered with caution given its dependence on uncertain stock-recruit relationships and assumptions on natural mortality.

The $Z_{20\%}$ and $Z_{40\%}$ reference points are analogous to the widely used $F_{20\%}$ and $F_{30\%}$ proxies of $F_{MSY}$ in which the percentage of maximum spawning potential used for the determination of the mortality reference point is based upon the productivity characteristics of the species, with lower percentages (15-20%) sustainable for highly productive species and higher percentages (35-40%) used for less productive species. Based on a meta-analysis of Pacific groundfish stocks (Punt et al, 2008) which examined how optimal harvest rates change with a stock`s production dynamics, the Panel recommends that $Z_{40\%}$, rather than $Z_{20\%}$, be used as the total mortality reference point. The $Z_{40\%}$ reference point is very sensitive to assumptions of $M$. The SASC developed two sets of reference points based on natural mortality ($M$) equal to 0.3 and 0.7. There is good evidence that total mortality (Z) is high and there is evidence from various sources that fishing mortality has likely been declining over a long period. This suggests that $M$ is closer to 0.7 than 0.3. The Panel therefore considered $Z_{40\%}$ for $M = 0.7$, as proposed by the SASC, as a useful reference point against which to measure total mortality.

**G. Fishing Mortality**

Estimation of coast wide exploitation on the river herring meta-complex was not possible. Attempts were made using DB-SRA, but precise estimates from this model were deemed unrealiable by the Review Panel. The DB-SRA model resulted in very low estimates of exploitation, suggesting that only 20% of the population was removed each year during peak exploitation in the late 1960s and early 1970s. Comparisons of temporal $F$ values and estimates of $F_{MSY}$ from the DB-SRA model with estimates from the statistical catch at age (SCAA) models for the Monument, Nanticoke, and Chowan Rivers suggest DB-SRA values are likely very low.

While the magnitude of DB-SRA estimates of exploitation is unreliable, the trends in recent years may not be. Most of the DB-SRA runs showed peak exploitation rates in the late 1960s and early 1970s, followed by a decline in recent years. This declining trend in exploitation rates is supported by the index of relative exploitation calculated using data from the Spring NMFS trawl survey. Also, exploitation rates estimated from the statistical catch-at-age model for blueback herring in the Chowan River showed a slight declining trend from 1999 to 2007 at which time a moratorium was instituted. There appears to be support among various assessment methodologies that exploitation has decreased in recent times. The Review Panel concurred with the notion of a decline in exploitation rates, particularly over the past decade because more restrictive regulations or moratoria have been enacted by states.

**H. Recruitment**

Recruitment trends were examined using Cluster Analysis in the time series of the state-run Young-of-Year (YOY) seine surveys conducted on a number of rivers along the coast. For 1980-2007 and 1993-2007, the analysis identified five groups based upon abundance trends over time. However, these groups were not geographically based (e.g. group 1 consisting of rivers in the northern part of the stock range) but rather, different temporal patterns occurred along the extent of the coast. Overall, of the rivers included in the analysis, for alewife, six exhibited either no change in abundance or a decline with only one exhibiting an increase in abundance. For blueback herring, all eight rivers exhibited either no change or a decline. The extent to which the YOY surveys indicate recruitment to the population is not clear, being indices of the young of the year, a life stage which experiences significant mortality. Thus, trends must be interpreted with caution.

**I. Spawning Stock Biomass**

Coast wide status of the stock biomass in relation to management reference points could not be determined. While coast wide biomass was relatively high prior to the 1960s, after which it declined rapidly, there is considerable uncertainty in more recent trends, with some DB-SRA model formulations suggesting a small increase, while others indicated relative stability. The base DB-SRA model also suggested exploitation was low until the mid-1960s, rapidly rose to a peak in the early 1970s, and then steadily declined until the present. Thus, while biomass is lower than historical levels and fishing mortality has likely declined more recently, the extent of these reductions is highly uncertain.

**J. Bycatch**

See ToR 2 above.

**K. Other Comments –** None.

**L. Sources of Information (Literature Cited)**

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# Section B

## Shad and River Herring Technical Committee Response to Peer Review Report

***Clarification of Incidental Catch Analysis***

The Peer Review Panel mischaracterized the purpose of the incidental catch analysis as it was not designed for comparison to reported annual landings.

The purpose of the analysis was to quantify river herring and shad incidental catch by fleet (i.e. fishing region, gear group and quarter) to identify which fleets comprised the majority of the incidental catch. As stated in section 2.1.6.1 of this stock assessment, the estimates were developed as part of the work for Amendment 14 to the Atlantic Mackerel, Squid and Butterfish (MSB) Fishery Management Plan, which addresses reducing the incidental catch of river herring and shads.

It appears that the Peer Review Panel mistakenly compared the incidental catch estimates to reported commercial landings. We note that commercial landings cannot be compared to the incidental catch estimates because commercial landings represent part of the total incidental catch. However, the proportion of the incidental catch truly represented by commercial landings is unknown, due to a high degree of uncertainty in both estimates.

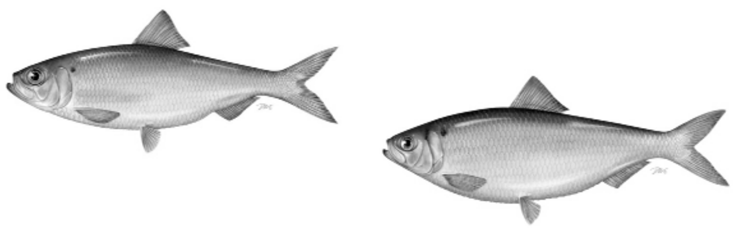
As discussed within the Conclusions Section (3.0) of the Stock Assessment Report for Peer Review, it is unclear what proportion of reported landings is distinct from estimates of total incidental catch. This uncertainty is due to several factors. One factor is a lack of accurate reporting by species. In a limited number of comparisons, some trips that listed river herring as landed on the VTR reports did not list river herring on the corresponding dealer reports.

Furthermore, as recognized by the Peer Review Panel, the "Herring NK [not known]" category is comprised of an unknown proportion of river herring. Another factor is the unknown proportions of total reported landings from state coastal waters, state riverine waters and federal waters. The t/k ratios represent the catches of river herring from federal and state coastal waters because the Northeast Fisheries Observer Program does not sample riverine fisheries. However, state landings reported to NMFS are comprised of an unknown proportion of riverine landings, which are used in the raising factor to quantify total incidental catch from the t/k ratios. Together, these uncertainties can lead to either under- or over-estimations of both river herring incidental catch and commercial landings, making direct comparisons between the two estimates inappropriate.

In addition, within TOR 2 of the advisory report, the Peer Review Panel incorrectly described commercial or reported landings as catch. These estimates represent only landings because they do not incorporate estimates of discards which should be reported as part of the catch.

Section C

# River Herring Stock Assessment for Peer Review



# Coastwide

Prepared by the
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ATLANTIC STATES MARINE FISHERIES COMMISSION

**Atlantic States Marine Fisheries Commission**

*Working towards healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015*

**ACKNOWLEDGEMENTS**

The Atlantic States Marine Fisheries Commission thanks all of the individuals who contributed to the development of the River Herring Stock Assessment.

Shad and River Herring Technical Committee (2008-2012): Larry Miller – Chair (USFWS); Robert Sadzinski, Harry Rickabaugh and Karen Capossela (MD Department of Natural Resources); Russ Allen and Heather Corbett (NJ Division of Fish and Wildlife); Jacqueline Benway (CT Department of Environmental Protection); Phillips Brady and Brad Chase (MA Division of Marine Fisheries); Michael Brown (Department of Marine Resources); Ellen Cosby (Potomac River Fisheries Commission); Mike Dionne (NH Fish and Game); Phillip Edwards (RI Department of Environmental Management); Ruth Haas-Castro (NMFS); Don Harrison (GA Department of Natural Resources); Kathryn Hattala (NY State Department of Environmental Conservation); Mike Hendricks (PA Fish and Boat Commission); Reid Hyle (FL Fish and Wildlife Conservation Commission); Wilson Laney (USFWS); John Olney and Eric Hilton (Virginia Institute of Marine Science); Bill Post (SC Department of Natural Resources); Ray Rhodes (College of Charleston); Michael Stangl (DE Department of Natural Resources and Environmental Control); Joseph Swann (D.C. Fisheries and Wildlife); Kathy Rawls and Sara Winslow (NC Division of Marine Fisheries).

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**DEDICATION**

This document is dedicated to the memory of Dr. John Olney, professor at the Virginia Institute of Marine Science and active member of the ASMFC Shad and River Herring Technical Committee for more than a decade. Throughout his life and in his work, John was committed to the preservation of marine fisheries resources and the science that supports Atlantic coast fisheries management. Professor Olney was a respected teacher and advisor, published author, talented chef, expert mushroom forager and generous friend, husband and father. John will be forever a part of the Commission's legacy of restoring Atlantic coast alosine fisheries.

## TERMS OF REFERENCE

1. Characterize precision and reliability of fishery-dependent and fishery-independent data used in the assessment, including the following but not limited to:
    a. Provide descriptions of each data source (e.g. geographic location, sampling methodology, potential explanation for outlying or anomalous data)
    b. Describe calculation and standardization (if performed) of abundance indices.
    c. Discuss trends and associated estimates of uncertainty (e.g. standard errors)
    d. Justify inclusion or elimination of available data sources.
    e. Discuss the effects of data strengths and weaknesses (e.g. temporal and spatial scale, gear selectivities, aging consistency, and sample size) on model inputs and outputs.

2. If possible, develop models used to estimate population parameters (e.g., *F* or *Z*, biomass, abundance) and biological reference points, and analyze model performance and stability.
    a. Justify choice of CVs, effective sample sizes, or likelihood weighting schemes.
    b. Perform sensitivity analyses for starting parameter values, priors, etc. and conduct other model diagnostics as necessary.
    c. Perform retrospective analyses, assess magnitude and direction of retrospective patterns detected, and discuss implications of any observed retrospective pattern for uncertainty in population parameters (e.g., *F* or *Z*, SSB), reference points, and/or management measures.
    d. Clearly and thoroughly explain model strengths and limitations.
    e. Briefly describe history of model usage, its theory and framework, and document associated peer-reviewed literature. If using a new model, test using simulated data.
    f. If multiple models were considered, justify the choice of preferred model and the explanation of any differences in results among models.

3. State assumptions made for model and for calculations of indices and survival estimates, if used, and explain the likely effects of assumption violations on synthesis of input data and model outputs. Examples of assumptions may include (but are not limited to):
    a. Age and size of full selectivity.
    b. Method of calculation.
    c. Calculation of *M*. Choice to use (or estimate) constant or time-varying *M* and catchability.
    d. Choice of equilibrium reference points or proxies for reference points.
    e. Constant ecosystem (abiotic and trophic) conditions.
    f. Choice of stock-recruitment function.
    g. No error in the catch-at-age or catch-at-length matrix.
    h. Choice of a plus group for age-structured species.

4. Where possible, assess stock status based on biological characteristics, including but not limited to:
    a. Trends in age and size structure
    b. Long-term trends in landings or other historical indicators of abundance

5. Characterize uncertainty of model estimates and biological or empirical reference points.

6. Recommend stock status as related to reference points (if available). For example:
    a. Is the stock below the biomass threshold?
    b. Is mortality above the threshold?
    c. Is the index above or below a reference index value?

7. Other potential scientific issues:
    a. Compare reference points derived in this assessment with what is known about the general life history of the exploited stock. Explain any inconsistencies.

8. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.

9. Recommend timing of next benchmark assessment and intermediate updates, if necessary relative to biology and current management of the species

## TERMS

| | |
|---|---|
| **Stock Assessment:** | An evaluation of a stock, including age and size composition, reproductive capacity, mortality rates, stock size, and recruitment. |
| **Benchmarks:** | A particular value of stock size, catch, fishing effort, and fishing mortality that may be used as a measurement of stock status or management plan effectiveness. Sometimes these may be referred to as biological reference points. |
| **Bycatch:** | The total catch of river herring, regardless of final disposition, that is taken in fishery operations that target other species. |
| **Catch Curve:** | An age-based analysis of the catch in a fishery that is used to estimate total mortality of a fish stock. Total mortality is calculated by taking the negative slope of the logarithm of the number of fish caught at successive ages (or with 0, 1, 2... annual spawning marks). |
| **Catch-Per-Unit-Effort (CPUE):** | The number or weight of fish caught with a given amount of fishing effort. |
| **Cohort:** | See "Year Class." |
| **Discard:** | A portion of what is caught and returned to the sea unused. Discards may be either alive or dead. |
| **Exploitation:** | The annual percentage of the stock removed by fishing either recreationally or commercially. |
| **Fish Passage:** | The movement of fish above or below an river obstruction, usually by fish-lifts or fishways. |
| **Fish Passage Efficiency:** | The percent of the fish stock captured or passed through the anthropogenic obstruction. |
| **Fishing Mortality (F):** | The instantaneous rate at which fish in a stock die because of fishing. |
| **Habitat:** | All of the living and non-living components in a localized area necessary for the survival and reproduction of a particular organism. |
| **Historic Potential:** | Historic population size prior to habitat losses due to dam construction and reductions in habitat quality |
| **Iteroparous:** | Life history strategy characterized by the ability to spawn in multiple seasons. |
| **Incidental catch:** | See bycatch |

| | |
|---|---|
| **Mortality:** | The rate at which fish die. It can be expressed as annual percentages or instantaneous rates (the fraction of the stock that dies within each small amount of time). |
| **Natural Mortality (M):** | The instantaneous rate at which fish die from all causes other than harvest or other anthropogenic cause (i.e., turbine mortality). Some sources of natural mortality include predation, spawning mortality, and senescence. |
| **Oxytetracycline (OTC):** | An antibiotic used to internally mark otoliths of hatchery produced fish. |
| **Recovery:** | Describes the condition of when a once depleted fish stock reaches a self-sustaining or other stated target level of abundances. |
| **Recruitment:** | A measure of the weight or number of fish that enter a defined portion of the stock, such as the fishable stock or spawning stock. |
| **Relative Exploitation:** | An approach used when catch is known or estimated, but no estimates of abundance are available. For example, it may be calculated as the catch divided by a relative index of abundance. Long-term trends in relative exploitation are can be useful in evaluating the impact of fishing versus other sources of mortality. |
| **Restoration:** | In this assessment, this describes the stocking of hatchery produced young-of-year to augment wild cohorts and the transfer of adults to rivers with depleted spawning stocks. Restoration also includes efforts to improve fish passage or remove barriers to migration. |
| **River herring:** | Refers to both alewife and blueback herring. |
| **Run Size:** | The magnitude of the upriver spawning migration of anadromous fish. |
| **Semelparous:** | Life history strategy in which an organism only spawns once before dying. |
| **Senescence:** | The process of ageing. |
| **Spawning Stock Biomass:** | The total weight of mature fish (often females) in a stock. |
| **Stock:** | A part of a fish population usually with a particular migration pattern, specific spawning grounds, and subject to a distinct fishery. |
| **Stock Status:** | The agreed perspective of the SASC of the relative level of fish abundance |

**Sub-adult:** Juvenile river herring which are part of the ocean migratory mixed-stock fish.

**Total Mortality (Z):** The instantaneous rate of removal of fish from a population from both fishing and natural causes.

**Year Class:** Fish of a particular species born during the same year.

**Yield-per-Recruit:** The expected lifetime yield per fish of a specific cohort.

# EXECUTIVE SUMMARY

This document provides a benchmark assessment of river herring (alewife, *Alosa pseudoharengus*, and blueback herring, *Alosa aestivalis*) stocks of the U.S. Atlantic Coast from Maine through Florida. It was prepared by the River Herring Stock Assessment Subcommittee of the Atlantic States Marine Fisheries Commission (ASMFC) Shad and River Herring Technical Committee. The analyses and descriptions stem from data and summary reports provided by U.S. federal and state freshwater and marine resource management agencies, power generating companies, and universities to the ASMFC.

River herring is a collective term that is used to refer to alewives and blueback herring. Both species are anadromous, highly migratory, schooling, pelagic fishes that spend most of the annual cycle at sea, but migrate to fresh water to spawn in the spring. Alewife is distributed from the Gulf of St. Lawrence and northern Nova Scotia south to North Carolina (Berry 1964; Rullifson et al. 1982; Rulifson 1994). Blueback herring are distributed from Nova Scotia to the St. John's River in northern Florida and are most abundant in waters from the Chesapeake Bay south (Bigelow and Schroeder 1953; Hildebrand 1963; Leim and Scott 1966; Scott and Crossman 1973; Williams et al. 1975; Manooch 1988; Scott and Scott 1988). River herring are anadromous, returning to their natal waters to spawn in the spring. However, some individuals have been found to stray to adjacent streams or colonize new areas; others have even reoccupied systems from which they were previously extirpated (Havey 1961; Thunberg 1971; Messieh 1977; Loesch 1987). Alewife and blueback herring are an important forage fish for marine and anadromous predators, such as striped bass, spiny dogfish, bluefish, Atlantic cod, and pollock (Bowman et al. 2000, Smith and Link 2010). River herring utilize a variety of habitat throughout their lifecycle. As adults, river herring reside in marine waters most of the year and move to freshwater rivers to spawn. Nursery areas primarily include freshwater portions of rivers and their associated bays and estuaries.

The first coast-wide ASMFC assessment of Atlantic coastal river herring stocks was conducted by Crecco and Gibson (1990). This assessment evaluated the status of six blueback herring stocks and nine alewife stocks between New Brunswick, Canada and North Carolina, USA using long term commercial catch and effort, age composition, and relative abundance data for juveniles and adults. The authors concluded that the St. John River alewife and blueback herring and the Damariscotta, Potomac, and Chowan River alewife stocks were or had been overfished to the point that recruitment failure was apparent.

The River Herring Stock Assessment Subcommittee assessed Atlantic coastal river herring stocks on an individual river basis for a few systems and also using a coast-wide population approach when sufficient data were available. As an anadromous species, ideally river herring should be assessed and managed by individual river systems. However, the majority of the life history of river herring is spent in the marine environment where factors influencing survival likely have impacts upon multiple river stocks when they mix during marine migrations. The complex life history of anadromous species complicates assessments on a coast-wide scale as it is difficult to partition in-river factors from marine factors governing population dynamics. Also complicating the assessment of river herring is the variability in data quality among rivers along the coast.

The data gaps for river herring can be attributed mostly to the low priority the species receives in some agency monitoring efforts. This understandable prioritization results in there being few long-term fishery-independent indices, except on rivers with fish passage. Fishery-dependent indices provide some long time series but most data contain gaps and are not documented as to stock composition as summaries provided are on a state basis, with few exceptions reported for rivers. Another concern is the changing effectiveness (catchability) of gear over time. Some of the current fishery-independent surveys should be of sufficient length to be useful in assessments five to 10 years from now if monitoring continues.

The earliest commercial river herring data were generally reported in state and town reports or local newspapers. Landings of alewife and blueback herring were collectively classified as "river herring" by most states. During 1880 to 1938, reported commercial landings of river herring along the Atlantic Coast averaged approximately 30.5 million pounds per year. In the 1950s and 1960s, a large proportion of the harvest came from Massachusetts purse seine fisheries that operated offshore on Georges Bank targeting Atlantic herring. Severe declines in landings began coastwide in the early 1970s and domestic landings are now a fraction of what they were at their peak having remained at persistently low levels since the mid-1990s. Moratoria were enacted in Massachusetts (commercial and recreational in 2005), Rhode Island (commercial and recreational in 2006), Connecticut (commercial and recreational in 2005), Virginia (for waters flowing into North Carolina in 2007), and North Carolina (commercial and recreational in 2007). As of January 1, 2012 states or jurisdictions without an approved sustainable fisheries management plan, as required under ASMFC Amendment 2 to the Shad and River Herring FMP, were closed. As a result, prohibitions on harvest (commercial or recreational) were extended to the following states: New Jersey, Delaware, Pennsylvania, Maryland, D.C., Virginia (for all waters), Georgia and Florida.

**Commercial CPUE**

Since the mid 1990s, CPUE indices for alewives showed declining trends in the Potomac River and James River (VA), no trend in the Rappahannock River (VA), and increasing trends in the York River (VA) and Chowan River (NC). CPUE indices available for blueback herring showed a declining trend in the Chowan River and no trend in the Santee River (SC). Combined species CPUE indices showed declining trends in Delaware Bay, and the Nanticoke River, but CPUE has recently increased in the Hudson River.

**Run Counts**

Major declines in run sizes occurred in many rivers during 2001 to 2005. These declines were followed by increasing trends (2006 to 2010) in the Androscoggin River (ME), Damaraiscotta River (ME), Nemasket River (MA), Gilbert-Stuart River (RI), and Nonquit River (RI) for alewife and in the Sebasticook River (ME), Cocheco River (NH), Lamprey River (NH), and Winnicut River (NH) for both species combined. No trends in run sizes were evident following the recent major declines in the Union River (ME), Mattapoisett River (MA), and Monument River (MA) for alewife and in the Exeter River (NH) for both species combined. Run sizes have declined or are still declining following recent and historical major declines in the Oyster River (NH) and Taylor River (NH) for both species, in the Parker River (MA) for alewife, and in the Monument River (MA) and Connecticut River for blueback herring.

**Young-Of-The-Year Seine Surveys**

The young-of-the-year (YOY) seine surveys were quite variable and showed differing patterns of trends among rivers. Maine rivers showed similar trends in alewife and blueback herring YOY indices after 1991 with peacks occurring in 1995 and 2004. YOY indices from North Carolina, and Connecticut showed declines form the 1980s. New York's Hudson River showed peaks in YOY indices in 1999, 2001, 2005, and 2007. New Jersey and Maryland YOY indices showed peaks in 1994, 1996, and 2001. Virginia YOY surveys showed peaks in 1993, 1996, 2001, and 2003.

**Juvenile-Adult Fisheries-Independent Seine, Gillnet and Electrofishing Surveys**

The juvenile-adult indices from fisheries-independent seine, gillnet and electrofishing surveys showed a low and stable or decreasing trend after a major decline in the Rappahannock River (gillnet, alewife and blueback herring), a stable or increasing trends in the James River (alewife and blueback herring), no trend after a major decline in the St. John's River (FL – blueback herring), no trends over the time series in Narragansett Bay (RI – combined species) and coastal ponds (RI – combined species), and opposing trends and then declining trends in the Rappahannock River (electrofishing, alewife and blueback herring).

**Juvenile and Adult Trawl Surveys**

Trend in trawl survey indices varied greatly with some surveys showing an increase in recent years, some showing a decrease, and some remaining stable. Trawl surveys in northern areas tended to show either an increasing or stable trend in alewife indices whereas trawl surveys in southern areas tended to show stable or decreasing trends. Patterns in trends across surveys were less evident for blueback herring. The NMFS surveys showed a consistent increasing trend coastwide and in the northern regions for alewife and the combined river herring species group.

**Mean Length**

Mean sizes for male and female alewife declined in 4 of 10 rivers, and mean sizes for female and male blueback herring declined in 5 of 8 rivers. The common trait among most rivers in which significant declines were detected is that length data were available prior to 1990. Mean lengths started to decline in the mid to late 1980s; therefore, it is likely that declines in other rivers were not detected because of the shortness of the time series. Mean lengths for combined sexes in trawl surveys were quite variable through time for both alewives and blueback herring. Despite this variability, alewife mean length tended to be lowest in more recent surveys. This pattern was less apparent for blueback herring. Trend analysis of mean lengths indicated significant declines in mean lengths over time for alewives coastwide and in the northern region in both seasons, and for blueback coast-wide and in the northern region in fall.

**Maximum Age**

Except for Maine and New Hampshire, maximum age of male and female alewife and blueback herring during 2005-2007 was one or two years lower than historical observations.

**Mean Length-at-Age**

Declines in mean length of at least one age were observed in most rivers examined. The lack of significance in some systems is likely due to the absence of data prior to 1990 when the decline in sizes began, similar to the pattern observed in mean length. Declines in mean lengths-at-age for most ages were observed in the north (New Hampshire) and the south (North Carolina). There is little indication of a general pattern of size changes along the Atlantic coast.

**Repeat Spawner Frequency**

Examination of percentage of repeat spawner in available data revealed significant, declining trends in the Gilbert-Stuart River (RI – combined species), Nonquit River (RI – combined species), and Nanticoke River (blueback herring). There were no trends in the remaining rivers, although scant data suggests that current percentages of repeat spawners are lower than historical percentages in the Monument River (MA) and Hudson River (NY).

**Total Mortality (Z) Estimates**

With the exception of male blueback herring from the Nanticoke River, which showed a slight increase over time, there were no trends in the Z estimates produced using age data.

**Exploitation Rates**

Exploitation of river herring appears to be declining or remaining stable. In-river exploitation estimates have fluctuated, but are lower in recent years. A coastwide index of relative exploitation showed a decline following a peak in the 1980s and has remained fairly stable over the past decade. The majority of depletion-based stock reduction analysis (DB-SRA) model runs showed declining exploitation rates coastwide. Also, exploitation rates estimated from the statistical catch-at-age model for blueback herring in the Chowan River also showed a slight declining trend from 1999 to 2007 at which time a moratorium was instituted. There appears to be a consensus among various assessment methodologies that exploitation has decreased in recent times. The decline in exploitation over the past decade is not surprising because river herring populations are at low levels and more restrictive regulations or moratoria have been enacted by states.

**Summary**

Of the 52 in-river stocks of alewife and blueback herring for which data were available, 22 were depleted, 1 stock was increasing, and the status of 28 stocks could not be determined because the time-series of available data was too short (Table 1). In most recent years, 2 were increasing, 4 were decreasing, and 9 were stable with 38 rivers not having enough data to assess recent trends. The coastwide meta-complex of river herring stocks on the US Atlantic coast is depleted to near historic lows. A depleted status indicates that there was evidence for declines in abundance due to a number of factors, but the relative importance of these factors in reducing river herring stocks could not be determined.

Commercial landings of river herring peaked in the late 1960's, declined rapidly through the 1970's and 1980's and have remained at levels less than 3% of the peak over the past decade. Estimates of run sizes varied among rivers, but in general, declining trends in run size were evident in many rivers over the last decade. Fisheries-independent surveys did not show consistent trends and were quite variable both within and among surveys. Those surveys that showed declines tended to be from areas south of Long Island. A problem with the majority of fisheries-independent surveys was that the length of their time series did not overlap the period of peak commercial landings that occurred prior to 1970. There appears to be a consensus among various assessment methodologies that exploitation has decreased in recent times. The decline in exploitation over the past decade is not surprising because river herring populations are at low levels and more restrictive regulations or moratoria have been enacted by states.

The decline of river herring is not unique as declines in many other diadromous species have been observed in the North Atlantic basin (see Limburg and Waldman 2009 for a review). Multiple factors are likely responsible for river herring decline such as overfishing, inadequate fish passage at dams, predation, pollution, water withdrawals, acidification, changing ocean conditions, and climate change. It is difficult to partition mortality into these possible sources and evaluate importance in the decline of river herring. To sustain the resilience of fish populations in the face of multiple threats, Brander (2007) suggested that age and geographic structure must be preserved rather than relying solely on management of biomass. Thus, the recovery of river herring will need to address multiple factors including anthropogenic habitat alterations, predation by native and non-native predators, and exploitation by fisheries.

The major conclusions drawn from available data and observations during this assessment are:

- River herring populations have greatly declined as evidenced by a 93% decrease in U.S. commercial landings since the 1970s.
- High levels of U.S. commercial landings from the 1950s to 1970s (mean of 22,000 MT/year) compared to the last 10 years (mean of 775 MT/year) suggests that stocks were considerably

larger during this period in order to support this level of harvest. Declining catch per effort suggests that the decline is likely driven by decreasing abundance. However, some of this decline was likely driven by decreased effort.

- Additional declines in run sizes occurred in 10 out of 17 rivers from 1999 – 2010.
- Fisheries-independent surveys often showed contradictory trends in abundance indices. Most surveys began after the majority of the decline in landings occurred and current monitoring programs measure what remains of these greatly reduced stocks.
- The NEFSC trawl survey, which is the only coastwide fisheries-independent survey, showed increasing trends in relative abundance beginning in 2008.
- Observed trends in biological data (e.g., decline in mean length, mean length-at-age, and percent repeat spawners) are characteristic of declining populations undergoing increasing total mortality.
- Conclusions about trends in aged-based *Z* estimates remain uncertain due to issues with aging methodologies and the narrow age distributions that were available to calculate Z estimates.
- There is uncertainty surrounding benchmark Z values, but they likely reflect current productivity levels of the stocks.
- Estimated total incidental catch (retained + discards) of river herring in non-targeted ocean fisheries averaged 459 MT (1.01 million pounds) from 2005 to 2010. The age structure and stock composition of this catch is uncertain, but is known to include both immature and mature fish.
- Incidental catch of “Herring NK [not known]” in non-targeted ocean fisheries ranged from seven to 328 MT (15,400 – 723,108 pounds) between 2005 and 2010. The proportion of river herring in this species category is unknown.
- Lack of accurate detailed reporting makes determination of the amount of retained incidental catch that is reported as landings uncertain, thereby making comparisons between reported landings and total incidental catch difficult.
- Exploitation rates have declined in the last decade likely due to the lower abundance of river herring and enactment of stricter harvest regulations and moratoria.
- At low levels, stocks are sensitive to both biotic and abiotic perturbations that truncate age structure thereby reducing population resilience.
- Recovery of river herring stocks will need to address multiple factors (e.g., fish passage, predation, water quality, climate change, etc.) in addition to harvest.

Table 1. Summary of river herring trends from select rivers along the Atlantic Coast.

| State | River** | Commercial CPUE | | Run Counts | | YOY survey | | Z | | Trawl Survey† | | Mean Length | Max Age | Percent Repeat Spawners | Status Relative to Historic Levels / Recent Trends* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 5-year Trend | Time-series | 5-year Trend | Time-series | 5-year Trend | Time-series | 5-year Trend | Time-series | 5-year Trend | Time-series | | | | |
| ME | Androscoggin | | | $\leftrightarrow^{A}$ | $\uparrow^{A}$ | | | $\leftrightarrow^{A}$ | $\leftrightarrow^{A}$ | | | n.s | $\leftrightarrow^{A}$ | | Unknown$^{A}$, Unknown$^{A}$ |
| | Kennebeck | | | $\uparrow^{RH}$ | $\uparrow^{RH}$ | | | | | | | | | | Unknown$^{RH}$, Unknown$^{RH}$ |
| | Sebasticook | | | $\uparrow^{RH}$ | $\uparrow^{RH}$ | $\leftrightarrow^{A}$, $\downarrow^{B}$ | $\leftrightarrow^{A}$, $\nearrow\searrow^{B}$ | $\leftrightarrow^{A}$ | $\leftrightarrow^{A}$ | | | | | | Unknown$^{A}$, Unknown$^{A}$ |
| | Damariscotta | | | $\uparrow^{A}$ | $\downarrow^{A}$ | | | | | | | | | | Depleted$^{A}$, Stable$^{A}$ |
| | Union | | | $\uparrow^{A}$ | $\leftrightarrow^{A}$ | | | | | | | | | | Increasing$^{A}$ , Stable$^{A}$ |
| NH | Cocheco | | | $\uparrow^{RH}$ | $\nearrow\searrow^{RH}$ | | | $\leftrightarrow^{A,B}$ | $\downarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | $\uparrow^{A}$, $\downarrow^{B}$ | n.s | $\uparrow^{A}$, $\leftrightarrow^{B}$ | n.s | Unknown$^{A,B}$, Stable$^{A,B}$ |
| | Exeter | | | $\leftrightarrow^{RH}$ | $\nearrow\searrow^{RH}$ | | | | | | | n.s | $\leftrightarrow^{A}$ | n.s. | Depleted$^{A}$, Increasing$^{A}$ |
| | Lamprey | | | $\leftrightarrow^{RH}$ | $\nearrow\searrow^{RH}$ | | | $\leftrightarrow^{A}$ | $\downarrow^{A}$ | | | n.s | $\uparrow^{A}$ | n.s. | Depleted$^{A}$, Unknown$^{A}$ |
| | Oyster | | | $\leftrightarrow^{RH}$ | $\nearrow\searrow^{RH}$ | | | $\leftrightarrow^{B}$ | $\leftrightarrow^{B}$ | | | | $\uparrow^{B}$ | n.s. | Depleted$^{B}$, Stable$^{B}$ |
| | Taylor | | | $\leftrightarrow^{RH}$ | $\downarrow^{RH}$ | | | | | | | | | n.s. | Depleted$^{B}$, Decreasing$^{B}$ |
| | Winnicut | | | $\leftrightarrow^{RH}$ | $\leftrightarrow^{RH}$ | | | $\leftrightarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | | | n.s | $\uparrow^{A}$, $\leftrightarrow^{B}$ | n.s. | Depleted$^{A,B}$, Unknown$^{A,B}$ |
| MA | Mattapoisett | | | $\uparrow^{A}$ | $\nearrow\searrow^{A}$ | | | | | | | | | | Depleted$^{A}$, Unknown$^{A}$ |
| | Monument | | | $\uparrow^{A}$ | $\nearrow\searrow^{A}$ | | | $\leftrightarrow^{A,B}$ | $\uparrow^{A}$, $\leftrightarrow^{B}$ | | | $\downarrow^{A,B}$ | $\downarrow^{A,B}$ | $\downarrow^{A,B}$ | Depleted$^{A}$, Unknown$^{A}$ |
| | Nemasket | | | $\uparrow^{A}$ | $\leftrightarrow^{A}$ | | | $\leftrightarrow^{A}$ | $\leftrightarrow^{A}$ | | | | | n.s. | Unknown$^{A}$, Unknown$^{A}$ |
| | Parker | | | $\uparrow^{A}$ | $\downarrow^{A}$ | | | $\leftrightarrow^{A}$ | $\leftrightarrow^{A}$ | | | | | | Depleted$^{A}$, Unknown$^{A}$ |
| | Stony Brook | | | | | | | | | | | $\downarrow^{A}$ | | | Depleted$^{A}$, Unknown$^{A}$ |
| RI | Buckeye | | | $\leftrightarrow^{A}$ | $\leftrightarrow^{A}$ | | | | | | | | | | Depleted$^{A}$, Unknown$^{A}$ |
| | Gilbert | | | $\uparrow^{A}$ | $\nearrow\searrow^{A}$ | $\leftrightarrow^{RH}$ | $\nearrow\searrow^{RH}$ | $\leftrightarrow^{A}$ | $\uparrow^{A}$ | $\leftrightarrow^{A}$, $\downarrow^{B}$ | $\uparrow^{A}$, $\nearrow\searrow^{B}$ | $\downarrow^{A}$ | $\downarrow^{A}$ | $\downarrow^{RH}$ | Depleted$^{A}$, Decreasing$^{A}$ |
| | Nonquit | | | $\downarrow^{A}$ | $\downarrow^{A}$ | | | $\leftrightarrow^{A}$ | | | | $\downarrow^{A}$ | | n.s. | Depleted$^{A}$, Decreasing$^{A}$ |
| CT | Bride Brook | | | $\leftrightarrow^{A}$ | $\leftrightarrow^{A}$ | | | | | | | | | | Unknown$^{A}$, Unknown$^{A}$ |
| | Connecticut | | | $\leftrightarrow^{B}$ | $\nearrow\searrow^{B}$ | $\uparrow^{B}$ | $\downarrow^{B}$ | | | | | | | | XXX |
| | Farmington | | | $\leftrightarrow^{A,B}$ | $\downarrow^{A,B}$ | | | | | $\leftrightarrow^{A,B\ (Fall)}$<br>$\leftrightarrow^{A\ (Spring)}$<br>$\uparrow^{B\ (Spring)}$ | $\leftrightarrow^{A,B\ (Fall)}$<br>$\uparrow^{A,B\ (Spring)}$ | | | | Unknown$^{A,B}$, Unknown$^{A,B}$ |
| | Mianus | | | $\leftrightarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | | | | | | | | | | Unknown$^{A,B}$, Unknown$^{A,B}$ |
| | Mill Brook | | | $\leftrightarrow^{A}$ | $\downarrow^{A}$ | | | | | | | | | | Unknown$^{A}$, Unknown$^{A}$ |
| | Naugatuck | | | $\leftrightarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | | | | | | | | | | Unknown$^{A,B}$, Unknown$^{A,B}$ |
| | Shetucket | | | $\leftrightarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | | | | | | | | | | Unknown$^{A,B}$, Unknown$^{A,B}$ |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NY | Hudson | $\uparrow^{RH}$ | $\searrow\nearrow^{RH}$ | | | $\leftrightarrow^{A,B}$ | $\uparrow^{A}$, $\leftrightarrow^{B}$ | | | | | $\downarrow^{A,B}$ | | | Depleted$^{A,B}$, Stable$^{A,B}$ |
| NJ, DE,PA | Delaware | $\leftrightarrow^{RH}$ | $\downarrow^{RH}$ | | | $\leftrightarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | | | $\leftrightarrow^{A}$, $\uparrow^{B}$ | $\leftrightarrow^{A,B}$ | | | | Unknown$^{A,B}$, Unknown$^{A,B}$ |
| MD, DE | Nanticoke | $\downarrow^{RH}$ | $\downarrow^{RH}$ | | | $\uparrow^{A,B}$ | $\leftrightarrow^{A,B}$ | $\leftrightarrow^{A}$, $\uparrow^{B}$ | $\leftrightarrow^{A}$, $\uparrow^{B}$ | | | $\downarrow^{B}$ | $\leftrightarrow^{A}$, $\downarrow^{B}$ | $\downarrow^{B}$ | Depleted$^{A,B}$, Decreasing$^{A,B}$ |
| VA, MD, DC | Potomac | $\leftrightarrow^{A}$ | $\downarrow^{A}$ | | | $\leftrightarrow^{A}$ | $\leftrightarrow^{A}$ | | | | | | | | Depleted$^{A,B}$, Unknown$^{A,B}$ |
| VA | James | $\leftrightarrow^{A}$ | $\leftrightarrow^{A}$ | | | $\leftrightarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | | | | | | | | Unknown$^{A,B}$, Unknown$^{A,B}$ |
| | Rappahannock | $\leftrightarrow^{A}$ | $\nearrow\searrow^{A}$ | | | $\leftrightarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | | | | | n.s. | | | Unknown$^{A,B}$, Unknown$^{A,B}$ |
| | York | $\uparrow^{A}$ | $\rightarrow\nearrow^{A}$ | | | $\leftrightarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | | | | | | | | Unknown$^{A,B}$, Unknown$^{A,B}$ |
| NC | Alligator | | | | | | | $\leftrightarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | | | | | n.s | Unknown$^{A,B}$, Unknown$^{A,B}$ |
| | Chowan | $\leftrightarrow^{A,B}$ | $\downarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | $\downarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | $\downarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | $\downarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | $\downarrow^{A,B}$ | $\downarrow^{A,B}$ | n.s. | Depleted$^{A,B}$, Stable$^{A,B}$ |
| | Scuppernog | | | | | | | $\leftrightarrow^{A,B}$ | $\leftrightarrow^{A,B}$ | | | | | n.s. | Unknown$^{A,B}$, Unknown$^{A,B}$ |
| SC | Santee-Cooper | $\uparrow^{B}$ | $\searrow\nearrow^{B}$ | | $\uparrow^{B}$ | | | | $\downarrow^{B}$ | | | n.s | | | Depleted$^{B}$, Increasing$^{B}$ |

†: Adult or all age fish only; trawl surveys take place in bay or inshore state ocean waters

n.s. Trend was not statistically significant

Supers Data available for

A Alewife only

B Blueback herring only

A,B Alewife and blueback herring by species

RH Alewife and blueback herring combined (river herring)

↔ No trend (flat or high inter-annual variability)

XXX Consensus not reached

No data

*Status relative to historic levels (pre-1970). Recent trends reflects last ten years of data.

**Table reflects rivers that had data in addition to landings. Refer to the state chapter and/or coastwide summary for a complete list of rivers assessed and trends.

Table 2. 2008 – 2010 average Z estimates by river with associated $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

| | |
|---|---|
| Z (red) | 3 year average of Z is above both the Z-20% and Z-40% benchmarks |
| Z (orange) | 3 year average of Z is between the Z-20% and Z-40% benchmarks |
| Z (green) | 3 year average of Z is below both the Z-20% and Z-40% benchmarks |
| | No current estimates of Z are available |

| State | River | Species | $Z_{40\% (M=0.7)}$ | $Z_{20\% (M=0.7)}$ | $Z_{3yr\text{-}Avg}$ |
|---|---|---|---|---|---|
| ME | Androscoggin | Alewife | 0.93 | 1.12 | 1.35 |
| | Kennebeck | River herring | | | |
| | Sebasticook | Alewife | 0.93 | 1.12 | 1.67 |
| | Damariscotta | Alewife | | | |
| | Union | Alewife | | | |
| NH | Cocheco | Alewife | 0.92 | 1.11 | 1.03 |
| | Cocheco | Blueback | 0.95 | 1.15 | 1.14 |
| | Exeter | Alewife | | | |
| | Lamprey | Alewife | 0.92 | 1.11 | 1.18 |
| | Oyster | Blueback | 0.95 | 1.15 | 1.02 |
| | Taylor | Blueback | | | |
| | Winnicut | Alewife | 0.92 | 1.11 | 1.12 |
| | Winnicut | Blueback | 0.95 | 1.15 | 1.53 |
| MA | Mattapoisett | Alewife | | | |
| | Monument | Alewife | 0.92 | 1.11 | 1.19 |
| | Monument | Blueback | | | |
| | Mystic | Alewife | 0.92 | 1.11 | 1.14 |
| | Nemasket | Alewife | 0.92 | 1.11 | 1.23 |
| | Parker | Alewife | | | |
| | Stony Brook | Alewife | | | |
| | Town | Alewife | 0.92 | 1.11 | 1.06 |
| RI | Buckeye | Alewife | | | |
| | Gilbert | Alewife | 0.94 | 1.14 | 1.80 |
| | Nonquit | Alewife | 0.94 | 1.14 | 1.81 |
| CT | Bride Brook | Alewife | | | |
| | Connecticut | Blueback | | | |
| | Farmington | Alewife | | | |
| | Farmington | Blueback | | | |
| | Mianus | Alewife | | | |
| | Mianus | Blueback | | | |
| | Mill Brook | Alewife | | | |
| | Naugatuck | Alewife | | | |
| | Naugatuck | Blueback | | | |
| | Shetucket | Alewife | | | |
| | Shetucket | Blueback | | | |
| NY | Hudson | Alewife | | | |
| | Hudson | Blueback | | | |
| NJ, DE, PA | Delaware | Alewife | | | |
| | Delaware | Blueback | | | |
| MD | Nanticoke | Alewife | 0.93 | 1.13 | 1.08 |
| | Nanticoke | Blueback | 0.92 | 1.11 | 1.34 |
| VA-MD-DC | Potomac | Alewife | | | |
| | Potomac | Blueback | | | |
| VA | James | Alewife | | | |
| | James | Blueback | | | |
| | Rappahannock | Alewife | | | |
| | Rappahannock | Blueback | | | |
| | York | Alewife | | | |
| | York | Blueback | | | |
| NC | Alligator | Alewife | | | |
| | Alligator | Blueback | | | |
| | Chowan | Alewife | 0.93 | 1.12 | 1.60 |
| | Chowan | Blueback | 0.92 | 1.11 | 1.06 |
| | Scuppernog | Alewife | | | |
| | Scuppernog | Blueback | | | |
| SC | Santee-Cooper | Blueback | | | |

# Status of River Herring Stocks in Maine

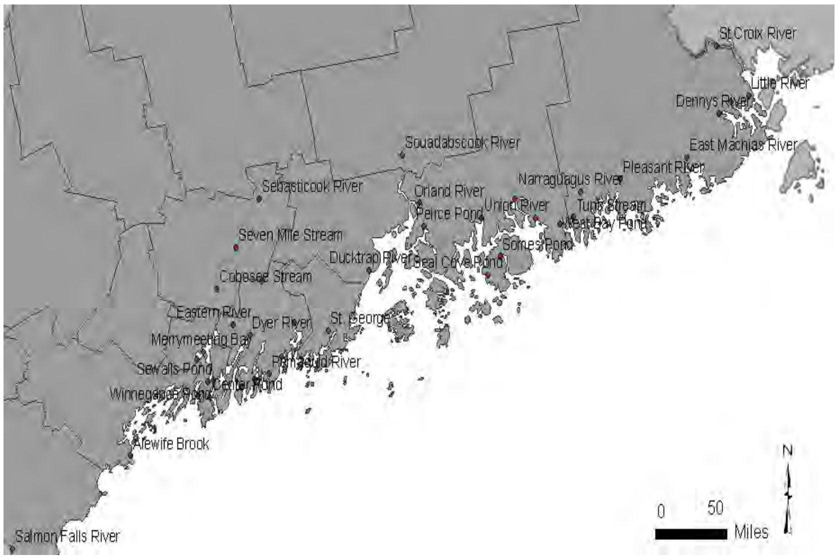



Figure 1. Map of Maine rivers with river herring runs.

## Distribution

Both alewife and blueback herring are present in Maine rivers and streams. Alewives (Alosa pseudoharengus) are present at all locations that support populations of blueback herring (*Alosa aestivalis*). Large populations of blueback herring are most common in the large rivers located in mid-coast Maine including the Kennebec, Sebasticook, Sheepscot, and Orland rivers. The riverine sections of these watersheds provide spawning and nursery habitat to support large populations of blueback herring.

Alewives returning to Maine to spawn, home to the natal waters where they were born. These are lake and ponded habitats in the lower sections of the larger watersheds and coastal ponds. Watersheds with access to large areas of spawning habitat are best suited to support large alewife populations. The Sebasticook, St. George and Orland rivers support large commercial fisheries that target alewives which return each spring to spawn.

## Commercial Fisheries

There are 40 municipalities with exclusive river herring harvest rights. These municipalities, in conjunction with the State of Maine Department of Marine Resources (Maine DMR) manage each municipal fishery as a separate stock. These fisheries are limited to one participant who is permitted to fish at only one location on the stream, river, or lake. The harvest rights are often leased to the highest bidder by the municipality which holds the harvest rights. The season begins when the fish first arrive and ends by law on June 5th of each year.

Commercial catches declined after the 1970s and have not recovered to those levels since. Up until 1988 a twenty-four hour closed period was required to allow spawning fish to escape the fishery and reach spawning habitat. An additional day was added to the escapement period in 1988 to increase spawning escapement and reverse the declining trend in landings. Starting in

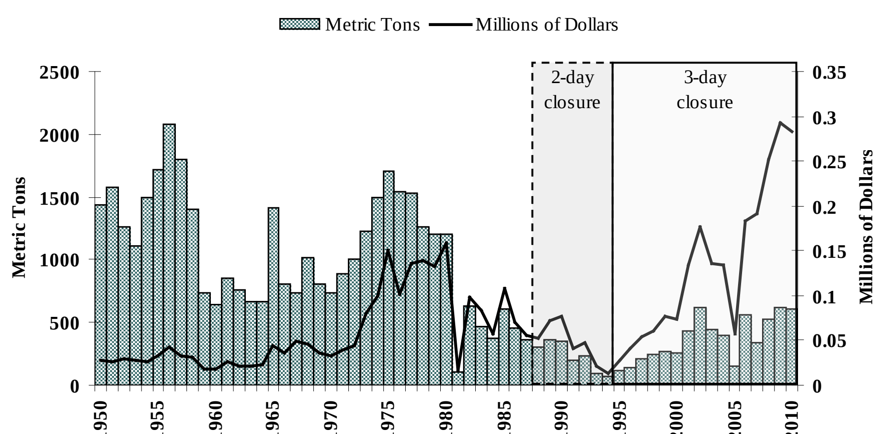



Figure 2. Commercial catch (in MT) and value (in millions of dollars) of river herring catch from Maine.

1995 a third closed day was required by the Maine Department of Marine Resources. This appeared to have stabilized the decline in commercial catches for the period 2001 – 2010.

Directed river herring harvest in waters not managed under a municipal management plan or in the coastal waters of Maine continued through 2011. These fisheries were regulated by requiring three closed days in the fishery per week, gear restrictions, and area closures. A coast wide moratorium in 2012 closed all directed river herring fisheries in Maine except 19 municipal fisheries that are permitted to continue with approved sustainable fisheries management plans. Bycatch of river herring still occurs in the coastal waters. The impact these fisheries have on native and migratory population of river herring is unknown.

**Population Trends**

River specific trends in population size very among rivers. Most rivers in Maine experienced population declines in the late 1980 through the mid 1990s. Since that time many population have rebounded as result of restoration efforts, improvements in upstream passage, and increased escapement from commercial fisheries. The five largest river herring populations in Maine have populations that are trending up or are stable during the past twenty year period. Populations of river herring where there is poor upstream and downstream passage or other limiting factors tend to have high annual variability. These populations tend to peak one year and crash the following year. Environmental conditions often play a significant role in return rates and juvenile production in these populations.

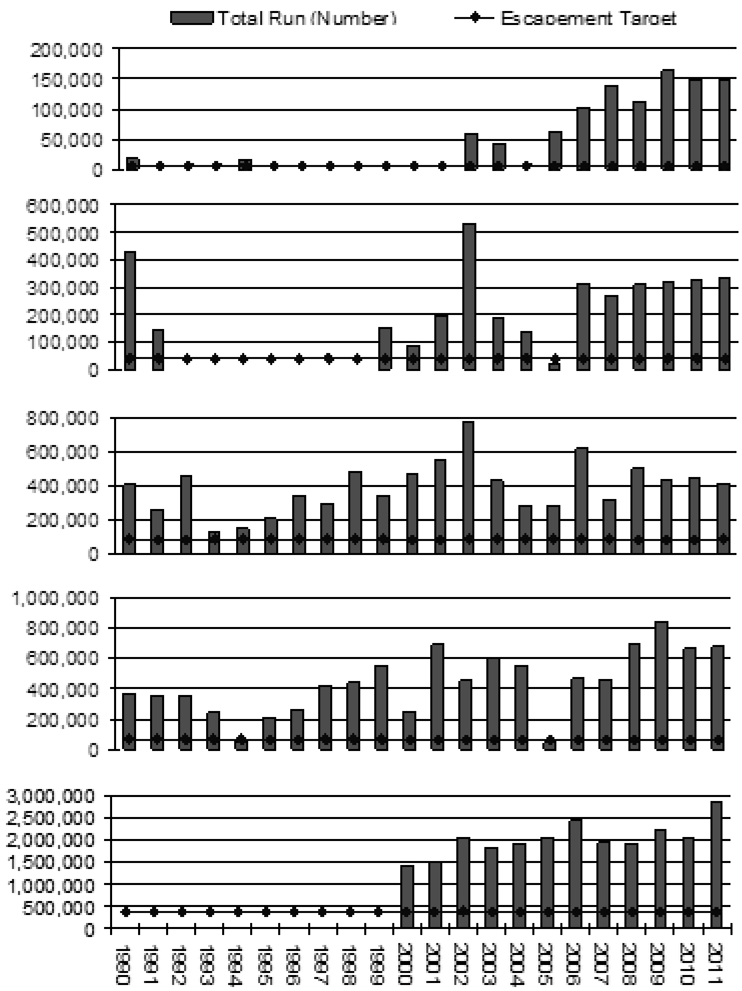


Figure 3. Run count estimates from select Maine rivers. Top to bottom: Dresden, Orland, Ellsworth, Warren and Benton Fishways.

The Maine DMR monitors river herring populations at all commercial river herring fishing locations. Non-commercial or commercial fisheries that are closed for conservation are not monitored annually by the Maine DMR, though a number of these runs are monitored by conservation groups, town official, universities, and dam owners. Populations under active restoration are closed to all commercial and recreational fishing. These populations are a priority for population assessment and annual restoration if necessary.

**Assessments and Bench Marks**

There has not been a formal coast-wide assessment of individual river herring populations conducted for Maine rivers. The Damariscotta River population was assessed in 1990 by Crecco and Gibson (ASMFC report) which estimated exploitation, spawning stock size, and fishing pressure to develop biological benchmarks for this population. Assessment of biological data (length at age, maximum age) indicates that these indices have not changed significantly during the past 20 years. Heavy exploitation of river herring at most commercial fishing locations began prior to any collection of biological data to develop historic reference point for any of these populations. Historical accounts of maximum age indicate that alewife lived to age 13. The maximum age of alewives in commercial and non-commercial runs today range from 5-8 years old. Length at age of individual runs remains stable at locations where historic data are available for comparison. The collection of biological data (age, length, weight, sex) for most commercial fisheries began in 2008.

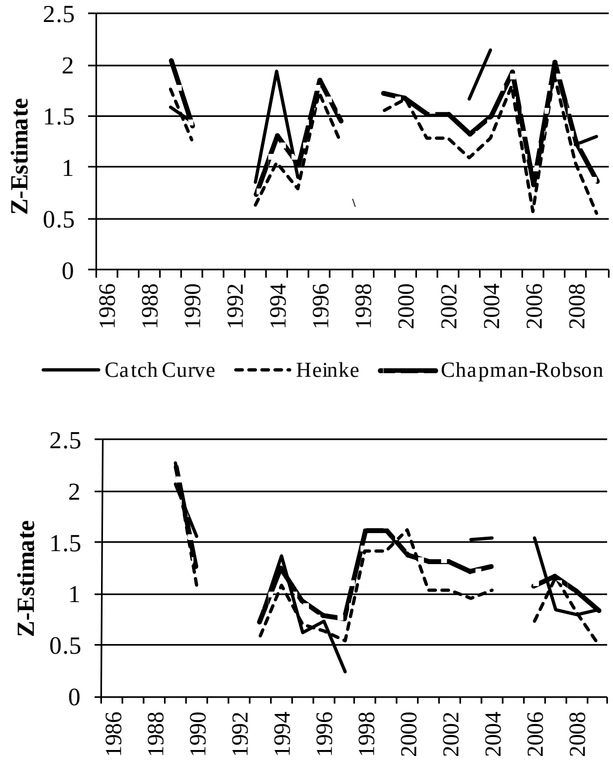


Figure 4. Age based Z estimates for males (top) and females (bottom) in the Androscoggin River

Estimates of biological reference points for three Maine rivers (Androscoggin, Damariscotta, Union) were established using Gibson and Myers spawning stock biomass per recruit model and the Crecco and Gibson model used for Damariscotta River in 1990 (Gary Nelson Massachusetts Division of Marine fisheries). Z-collapse values changed dependent on time series used, life history value inputs, and model selection. Total instantaneous mortality estimates using length, age, or repeat spawning data often exhibit the same trends though the values vary depending on the method used. Catch-curve, Heinke, and Chapman-Robson methods were used to estimate the Z-estimates for the Androscoggin River dataset starting in 1988. During some years the age based mortality estimates for male alewives are close to the z-collapse values calculated by Nelson. Age based z-values for females appear to be below those experienced by male alewives which return to the Androscoggin River. The Androscoggin River has a non-commercial population of river herring. The Androscoggin River dataset is the largest continuous dataset of anadromous fish data in Maine. Data collection for most commercial mortality estimates began in 2008.

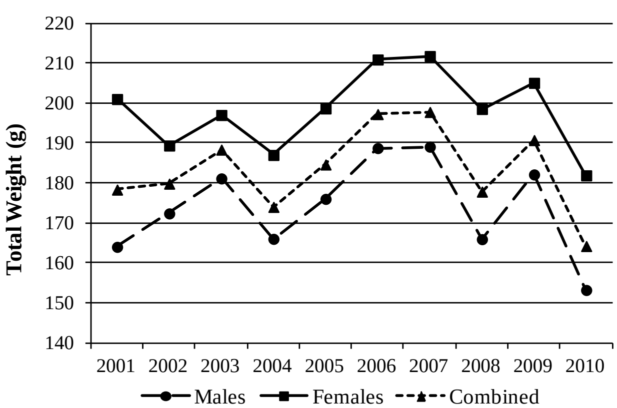


Figure 5. Total weight (g) of alewives sampled at the Brunswick Fishway from 2001 through 2010.

**Summary**

Maine continues to have sustainable populations of river herring in many river systems. These populations do not reflect the abundance or biological characteristics that are found in historical accounts of these species in Maine. Populations of river herring declined from the mid 1970s through the mid 1990s. Populations in some rivers have rebounded to provide new commercial fishing opportunities while others have not experienced the same success.

Both commercial and non-commercial populations appear to experience high mortality from the time they leave the nursery areas to the time the return to spawn four years later. Non-commercial populations at some locations experience higher mortality than commercial runs. At some locations mortality rates are different between males and females and between species (alewives vs. blueback herring).

| | Z-collapse values |
|---|---|
| Androscoggin River | 1.97-2.46 |
| Damariscotta River | 1.74-3.17 |
| Union River | 1.71-2.59 |

Table 1. Z collapse values for select Maine Rivers.

Environmental conditions during periods of upstream and downstream migration at times have profound affects on spawning success, juvenile survival, and survival of post spawn adult returns to the ocean. Effective upstream and downstream passage can mitigate some of these environmental effects. Poor water quality, loss of spawning habitat, and at-sea bycatch are more difficult to assess in terms of impacts to these populations coast wide.

The State of Maine will continue to monitor commercially exploited river specific populations in Maine to track trends in population size, composition, mortality, and age structure. Habitat restoration will continue where existing river herring populations are in decline or require improved passage. The current trap and transfer program will continue to provide additional broodstock to historic habitats that do not produce enough annual returns to maintain the population.

# Status of River Herring Stocks in New Hampshire

## Distribution, Biology and Management

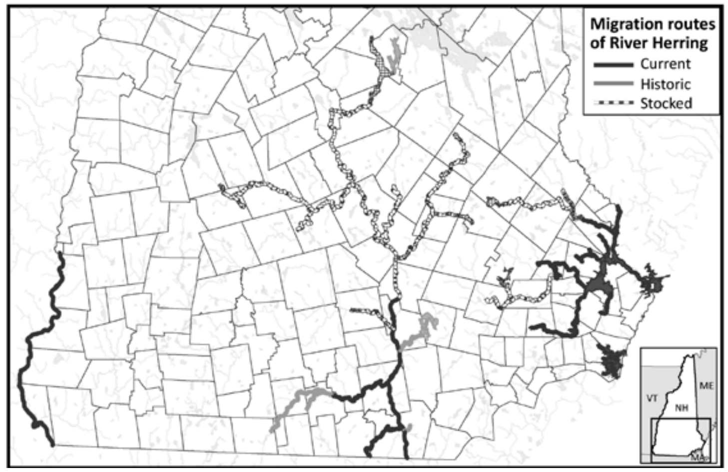



Figure 1. Map of New Hampshire's river herring migration routes (historic, current and stocked fish).

Both alewives and blueback herring are found in the coastal rivers and streams of New Hampshire. Alewives spawn from late-April to late-May, while blueback herring typically spawn from early-May until the end of June. Individual river herring spawning runs in the Exeter (Squamscott), Lamprey, Winnicut, Oyster, Cocheco, and Taylor Rivers were evaluated independently in this report as units of the State's river herring stock.

New Hampshire Fish and Game Department manages river herring populations within state waters. In 1987, the taking of river herring in state waters on Wednesdays by any method was prohibited. New regulations were instituted in 2005 closing a large section of tidal waters in the Taylor River and restricting harvest days in the Squamscott River in Exeter. The new regulations were intended to allow more river herring returns to the Exeter and Taylor river fishways.

## The Fisheries

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

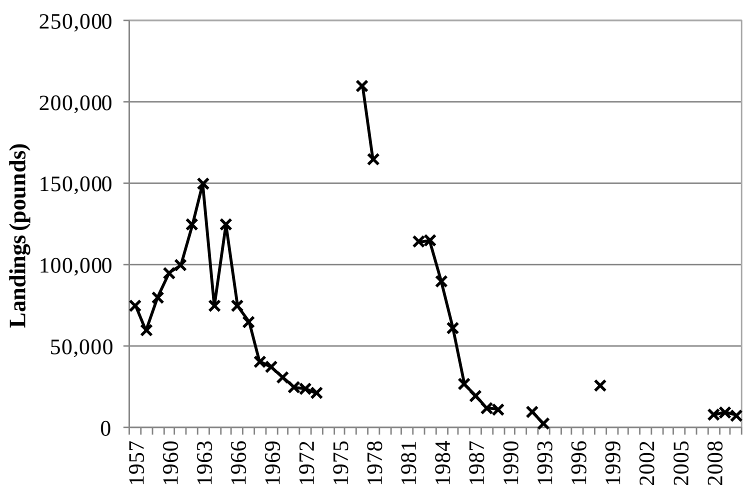



Figure 2. Commercial landings (in pounds) of river herring in NH.

Most of the current New Hampshire commercial landings of river herring are from vessels fishing in the EEZ. Landings peaked in 1977 at 210,000 pounds and have dropped ever since. The river herring caught in ocean waters were most likely of mixed stock origin. There is a very limited recreational fishery for river herring at head-of-tide dams on some of New Hampshire's coastal rivers. This recreational fishery mainly occurs on the Squamscott, Cocheco, and Lamprey Rivers.

**Indices**

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

The Cocheco and Lamprey Rivers generally have the highest number of returning river herring each spring. Returns to these rivers have exceeded 40,000 fish on several occasions. The Oyster River spawning population has been declining since the early 1990s. The Exeter and Taylor Rivers have declining river runs as well. The Winnicut River monitored spawning run has been generally increasing since 1998. Several factors may be contributing to the overall decline in river herring return numbers including high flows before and during the runs, the efficiency of fishways, poor water quality, water withdrawals by the local municipalities, and drought conditions in some years.

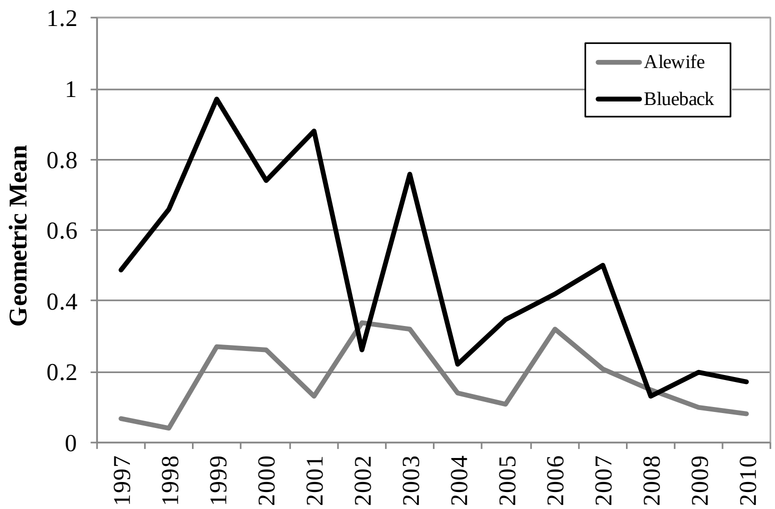


Figure 3. Annual juvenile abundance index of river herring seined in Great Bay Estuary, New Hampshire, 1997-2010.

A beach seine survey is conducted annually on a monthly basis from June to November at 15 fixed stations in New Hampshire's estuaries. This relative annual index can be used to determine successful occurrence of river herring spawning activity between years. However, due to the estuary-wide design and limited sampling rate in close proximity to monitored rivers during times of peak juvenile river herring emigration in the late summer/fall months these indices should be used conservatively. The highest relative abundance for juvenile blueback herring occurred in 1999 when nearly 12,000 were captured. Peaks in relative abundance for alewives occurred in 2002, 2003, and in 2006. The indices, in general, are very low for juvenile alewives. In contrast, blueback herring are one of the more commonly captured species at some stations in certain years.

**Assessment Results**

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

**Benchmarks**

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

**Summary**

New Hampshire rivers were severely impacted over the past several centuries, negatively affecting anadromous species. Dams, fishing, and poor water quality are among the many obstacles that river herring have faced. Restoration efforts should continue with focus on the following strategies for New Hampshire coastal rivers targeted for restoration: 1) Continue efforts to monitor and improve water quality; 2) Continue transfers of spawning adult river herring from donor rivers to increase available spawning habitat and augment declining runs in other rivers; 3) Continue work to install upstream and downstream fish passage or remove dams in coastal rivers; 4) Continue to monitor returns of spawning adult river herring to fish ladders and 5) Efforts should be made to identify and reduce all sources of mortality whether during ocean residency or in-river.

# Status of River Herring Stocks in Massachusetts

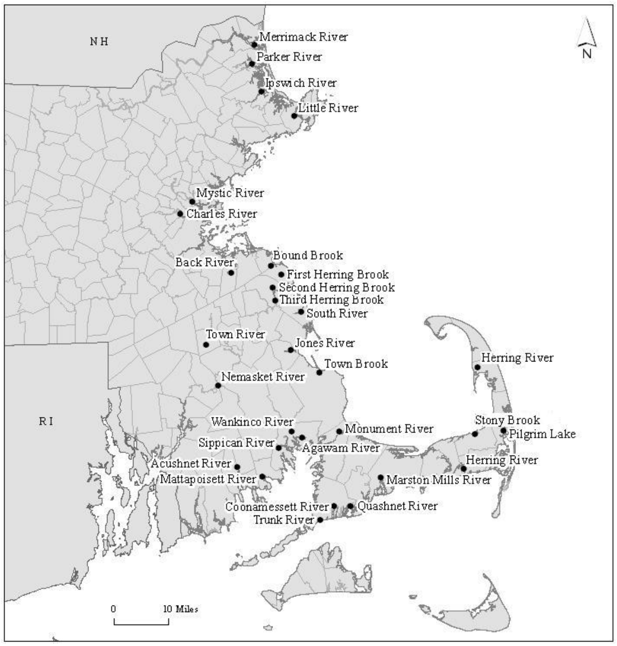



Figure 1. Location of river herring runs in Massachusetts

## Distribution, Biology and Management

In Massachusetts, more than 100 coastal rivers and streams are home to the anadromous alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), known colloquially as "river herring". River herring was a staple food source for Native Americans prior to colonial settlement. Early colonial records refer to river herring as providing food for the first European settlers of New England. By the 1920s, Massachusetts lost an estimated 90% of the river herring runs that had existed in colonial times due to dam installations, water quality, and overfishing. Herring runs in Massachusetts are managed directly by the Massachusetts Division of Marine Fisheries (DMF) or directly by local town governments with DMF oversight.

Both blueback herring and alewife are found in many coastal stream systems in Massachusetts. Bluebacks spawn in more riverine areas, while alewives tend to spawn in more lacustrine (ponds and lakes) areas. In general, alewives begin to spawn in late March to mid-May when water temperature reach about 10.5$^{o}$C, while blueback herring begin to spawn later in the spring (late April through June) when water temperatures reach about 13.9$^{o}$C. Juvenile herring begin their migration to the ocean in July with peak migration occurring in September on Cape Cod. In the marine environment, river herring feed on zooplankton such as microcrustaceans, fish eggs and fish larvae. Both species mature between 3 and 5 years of age.

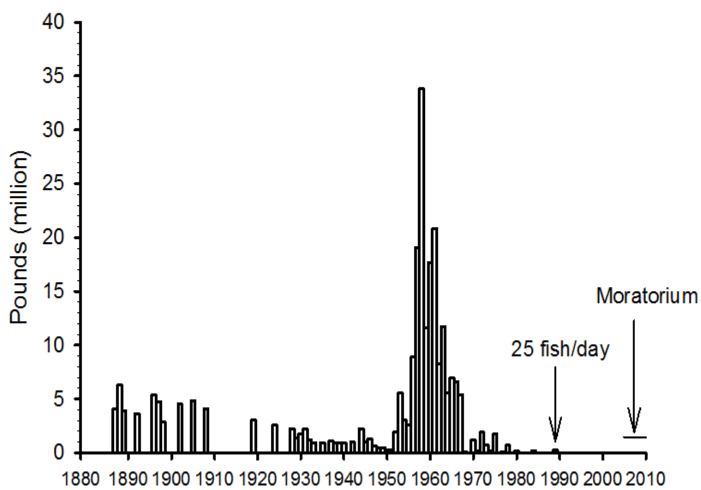



Figure 2. Commercial river herring landings in Massachusetts.

## The Fisheries

Historically, river herring were one of the most valuable anadromous fishes harvested commercially in Massachusetts and sold as food or commercial bait. Prior to the 1950s, annual landings were 2.3 million kilograms or less. Landings increased dramatically during the late 50s-early 60s to 15 million kilograms in 1958 as foreign fleets, using purse seines, exploited herring on Georges Bank. 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. The landings data reported by NMFS are underestimated because of poor or no record-keeping of harvest by towns with herring runs. DMF collects harvest data from towns of Middleboro, Bournedale, and Mattapoisett. Bycatch of river herring does occur in ocean commercial fisheries that are targeting other species. River herring have been taken by recreational anglers for bait. Since 2005, there has been a moratorium on the possession and sale of river herring in Massachusetts.

**Indices**

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. Passage counts and run size used in this assessment came from the Monument River, Mattapoisett River, Nemasket River, Parker River and Town River. Count data for three (Parker, Monument and Mattapoisett Rivers) of the five rivers indicated a precipitous decline in alewife abundance after 2000. Such a decline was not observed in the Nemasket River, but average passage count after 2004 (587,000 fish) was about half of the average run size prior to 2004 (1.04 million fish). The passage counts for alewife and blueback herring in the Town River have fluctuated without trend since 2000. A decline in the Monument River run size of blueback herring was not observed until after 2004 and total run size remains low.

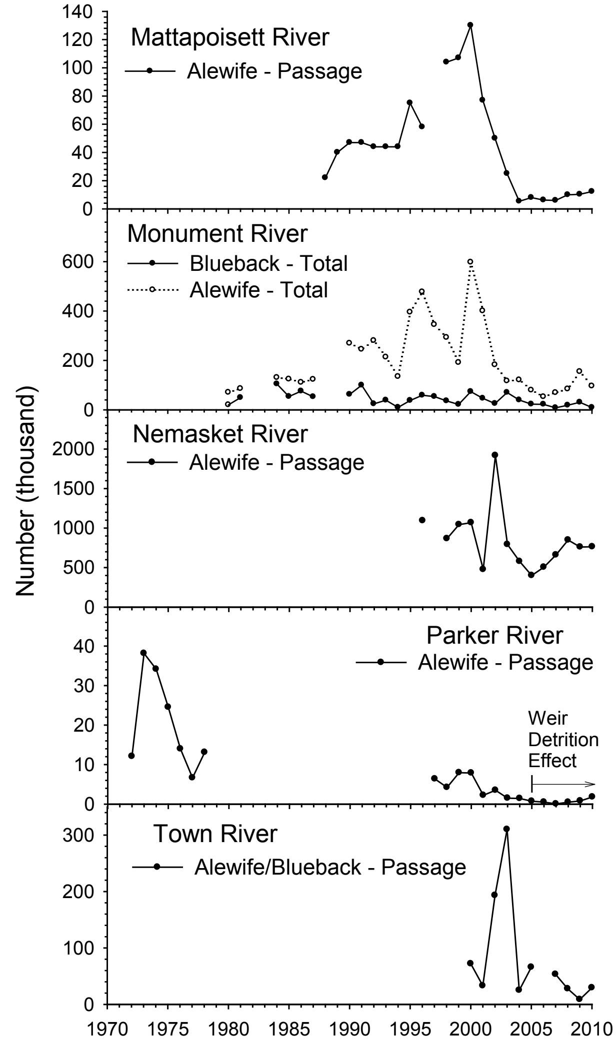
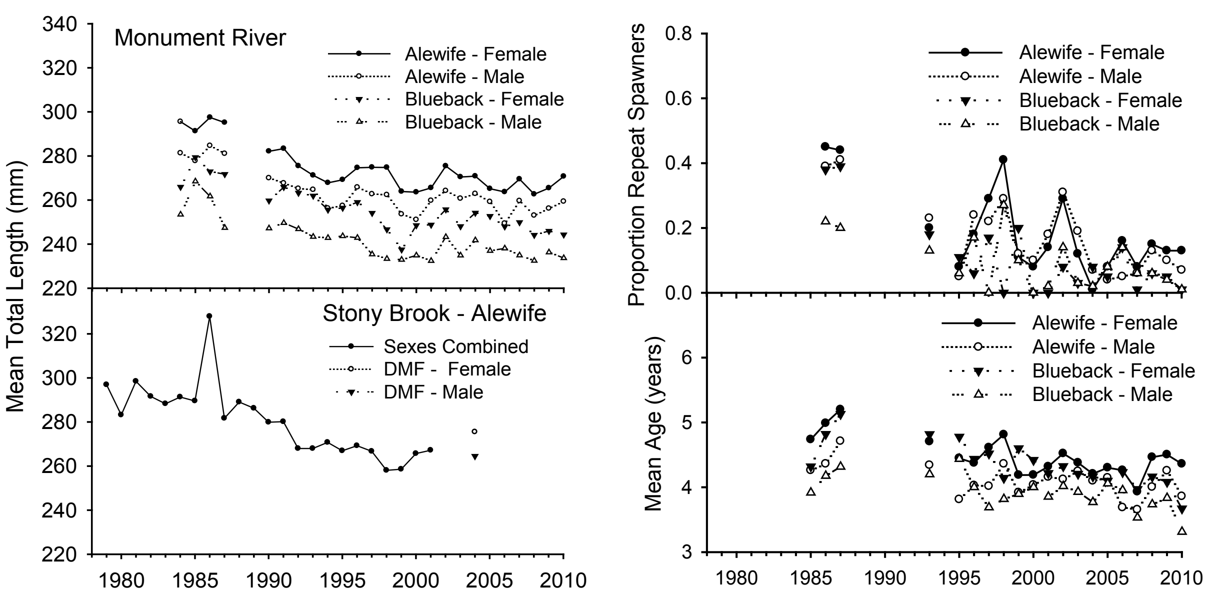
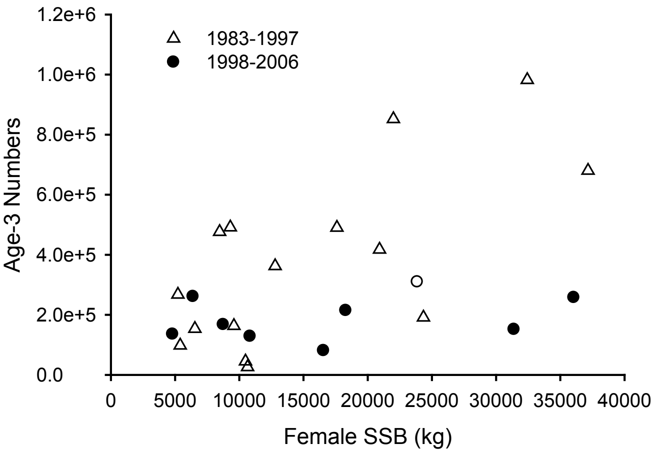
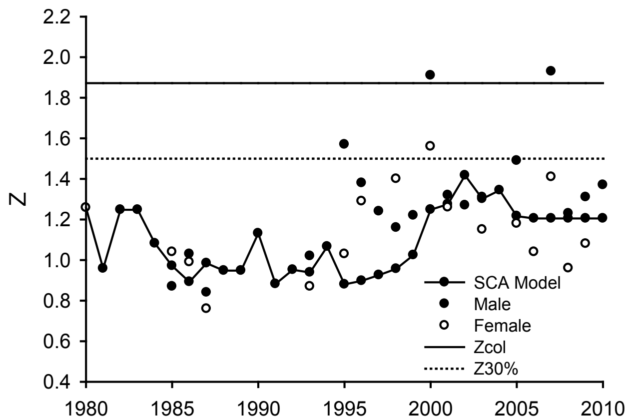



Figure 3. River herring passage counts at select Massachusetts Rivers




Figures 4 – 6. River herring mean total length (left), proportion of repeat spawners (top, right) and mean age (bottom, right) from select Massachusetts rivers.




Figures 7 and 8. Plot of S-R data for Monument River alewife with year-classes symbolized by time periods (1983-1997 and 1998-2006) (top) and 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%).

Mean total length of both species and sexes from the Monument River declined from 1984 through the mid-1990s. A similar decline was observed in Stony Brook for alewife (sexes combined). Mean age and proportion of repeat spawners of alewife and blueback herring in the Monument River, although variable, showed declining trends over time.

**Assessment Results**

All indices described above indicate declining trends in abundance and population characteristics of several river herring stocks in the early 1990s (size) and through the mid-2000s (abundance, mean age, and repeat spawners). Recruitment (age-3 numbers) to the Monument River alewife stock has been poor since 1998.

Total instantaneous mortality estimates calculated from age data and a statistical catch-at-age model show that Z for the Monument River alewife stock averaged about 1.0 $yr^{-1}$ prior to 1996, but increased to an average of 1.3 $yr^{-1}$ after 2000.

**Benchmarks**

We calculated biological reference points ($Z_{30}$ and $Z_{collapse}$) from the spawning stock biomass-per-recruit model of Gibson and Myers using Monument River inputs for weight- and maturity-at-age (vulnerability-at-age is assumed embedded in maturity-at-age), and an estimate of M (0.74) from the catch-at-age model. $Z_{30}$ was 1.50 $yr^{-1}$and $Z_{collapse}$ was 1.87 $yr^{-1}$. Current Z values are close but below $Z_{30}$ and are well below $Z_{collapse}$.

**Summary**

River herring stocks in Massachusetts have experienced major declines in size, age, and repeat spawners since the early 1990s. Abundances of several alewife stocks showed precipitous declines after 2000, but appear now to be slowly recovering. Total mortality of alewife in the Monument River began to rise before the decline in abundance. Recruitment of age-3 alewife to the Monument River stock has been low since 1998. Potential causes of changes in abundance and population characteristics include: 1) decreases in autumn rainfall during the last decade potentially causing shifts in the carrying capacity of nursery grounds or affecting the migration success of juveniles, 2) increased selective predation by striped bass (*Morone saxatilis*), cormorants (*Phalacrocorax auritus*), spiny dogfish *(Squalus acanthias*), and seals (*Phoca vitulina*), since the mid-1990s, 3) increases in bycatch mortality in several fisheries off Massachusetts since the late 1990s, and 4) continued degradation of many rivers by water withdrawals, transport of wastewater out of the watershed, and loss of water inputs due to development within the watershed.

# Status of River Herring Stocks in Rhode Island

## Distribution, Biology and Management

Gilbert Stuart and Nonquit river herring stocks are iteroparous and predominately alewives. The Rhode Island Department of Environmental Management (RIDEM) Division of Fish and Wildlife has management authority over river herring (alewives and bluebacks) occurring in the state's fresh and marine waters. The DFW currently manages 21 river herring runs and operates and maintains 18 fishways on 11 of the systems. These systems include small brooks and streams to large rivers and impoundments. Currently there is a moratorium on harvest of river herring (alewives and bluebacks) in Rhode Island's fresh and marine waters

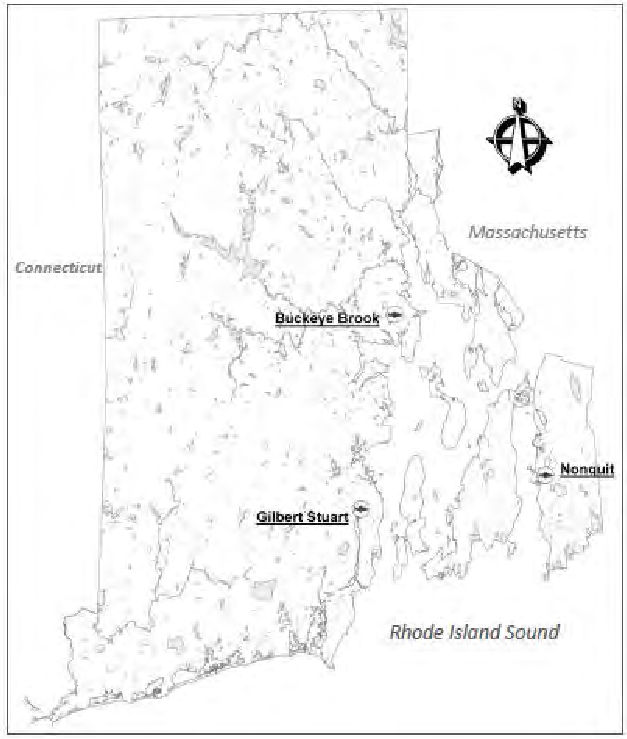



Figure 1. Location of select river herring runs in Rhode Island.

## The Fisheries

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

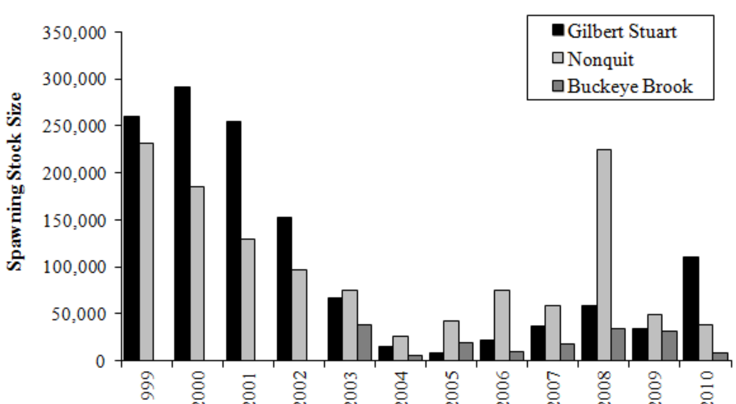



Figure 2. Spawning stock size estimate (in numbers of fish) from the Gilbert Stuart River, Nonquit River and Buckeye Brook.

## Indices

Each spring river herring spawning stock size is estimated using electronic fish counters or direct count methods on several Rhode Island river systems. The anadromous life history of river herring allows for a unique sampling and monitoring opportunity when they return to their native freshwater systems to spawn. In addition to estimating run sizes, a representative sample of river herring from Gilbert Stuart and Nonquit were sampled for biological data. The Marine Division of Rhode Island Fish and Wildlife conducts a trawl survey, a

Narragansett Bay seine survey, and coastal pond seine survey. The marine surveys are conducted in Narragansett Bay, Block Island Sound and surrounding coastal ponds. All three surveys collect river herring numbers and length frequency data.

Between 1988 and 1996 a trapnet was installed at the Gilbert Stuart River during the fall to capture juveniles exiting the freshwater impoundment. Due to high juvenile mortality the JAI was discontinued in 1996. During the 2007 season a different style trapnet, which prevents juvenile mortality, was utilized. Juvenile surveys are also conducted in the Nonquit and Pawcatuck Rivers.

**Assessment Results**

Rhode Island river herring spawning stock sizes drastically decreased from 2000 to 2004. Since the statewide closure in 2006, the run sizes have increased but are still well below the run sizes estimated between 1999 and 2002. River herring from Gilbert Stuart and Nonquit have displayed a decrease in length at age over time. Since 2000, the mean length at ages recorded for Gilbert Stuart, were consistently lower for all age classes than reported in 1992. Percent repeat spawning at Gilbert Stuart and Nonquit has decreased since 2000.

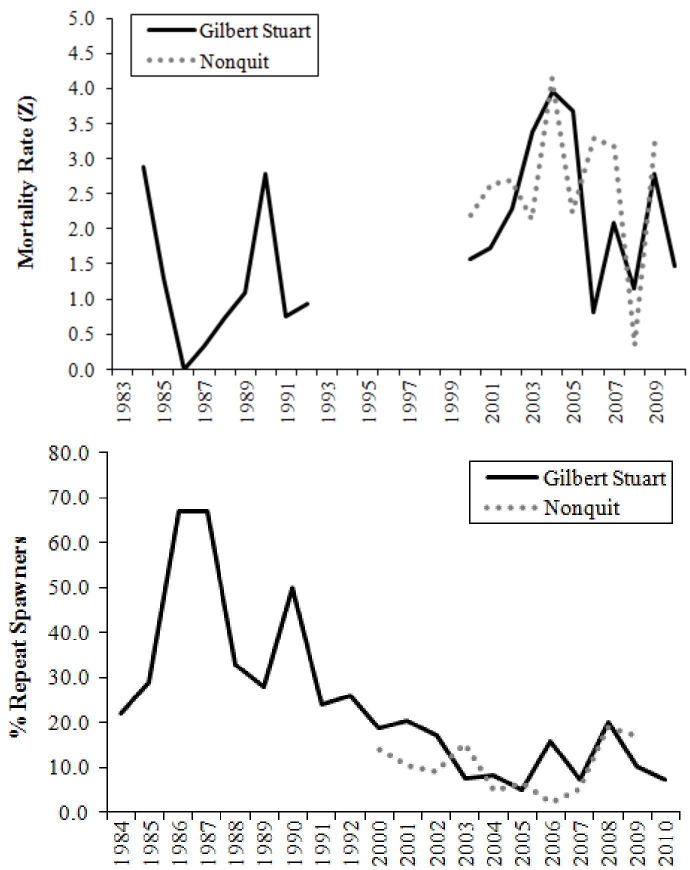


Figure 3. Mortality rates (top) and repeat spawner percentage (bottom) for the Gilbert Stuart and Nonquit Rivers.

**Benchmarks**

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

**Summary**

Since 2001, Rhode Island river herring stocks experienced sharp declines in spawning stock size, causing Rhode Island to impose a statewide closure in 2006 to the harvest of river herring in fresh and marine waters. In addition to decreases in spawning stock size, Rhode Island river herring stocks displayed increases in mortality rates (Z), decreases in percentage of repeat spawners, and truncated age structures. Reasons for the drastic declines in Rhode Island river herring run sizes may be related to a combination of factors which may have affected river herring stocks prior to the closure. Some theories include degradation of spawning and nursery habitat, an increase in predator populations, and overfishing. Degradation of spawning habitat could be the result of changes in water quality in the freshwater systems affecting egg development or juvenile mortality. Predator population increases in certain sportfish and bird species, may have been affecting river herring stocks. Overfishing may have been a result of an increase in the in-river fishery, an unregulated marine fishery in Rhode Island marine waters prior to 2006, or an ocean by-catch fishery intercepting Rhode Island river herring stocks during seasonal migrations.

Recent results show there has been some improvement since the closure, but current run sizes are still well below the estimated run sizes (1999-2001) recorded prior to the decline. Towards a river herring restoration goal and stock recovery, the Rhode Island Division of Fish and Wildlife will continue to monitor runs throughout the state, transplant adult broodstock into extirpated or restored systems, work with partners on numerous fish passage projects, and represent the state at regional meetings.

# Status of River Herring Stocks in Connecticut

## Distribution, Biology, Management

Historically river herring could be found in all three of Connecticut's major watersheds (the Connecticut, Housatonic, and Thames Rivers) as well as most of the coastal rivers and streams across the State.

Alewife spawning migrations in Connecticut start as early as the beginning of March and continue in some rivers until mid-June, while blueback herring spawn from late April to mid- to late-June. Blueback herring are more abundant in the larger rivers of the state and have been known to ascend the Connecticut River nearly 200 miles (Gephard and McMenemy 2004). Blueback herring also enter the smaller coastal streams in the state, but less often than alewives and typically are thought to be more common in the western end of the state.

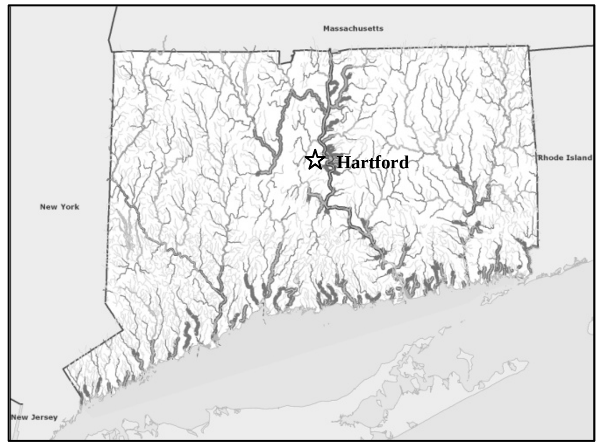



Figure 1. Location of existing alewife runs.

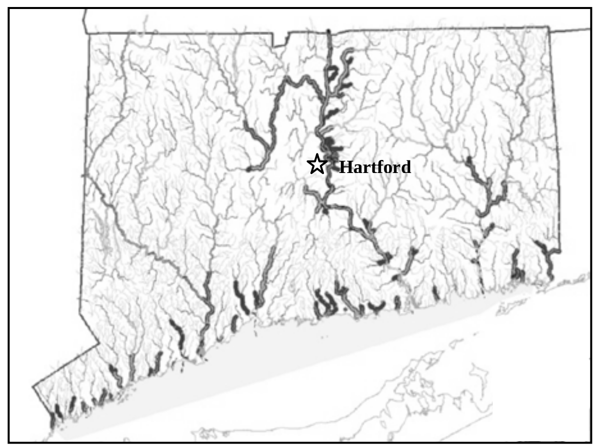



Figure 2. Location of existing blueback herring runs.

Connecticut's river herring runs during the late 18th and early 19th century were greatly impacted by settlement and industrialization which included deforestation, dam construction and water pollution. River herring populations have benefitted from water quality improvement, declines in commercial fishing effort, as well as ongoing restoration of access to spawning habitat through fish passage projects. Connecticut Department of Energy and Environmental Protection's Inland Fisheries Division (IFD) restoration efforts have focused on increasing fish passage and transplanting river herring. Barrier dams are identified as one of the greatest threats to river herring populations in the freshwater environment. There are over 500 dams within the historic range of river herring in Connecticut. Access to habitat previously blocked has been restored through construction of fishways and dam removal, providing more spawning habitat to increase production. Since 1990, 11 dams have been removed and 53 fishways have been constructed throughout the state with more projects being completed each year. Transplantation of river herring from streams with healthy stocks to systems with depressed or extirpated stocks is also being used to enhance production and increase the rate of re-colonization.

River herring runs appeared to be abundant and stable during the 1970s and 1980s (Crecco and Gibson 1990). A large decrease in numbers of blueback herring lifted over the Holyoke Dam (rkm 139) in the 1990s was well documented and widely reported. A similar decline in American shad also took place in the Connecticut River. Several hypotheses were examined and strong statistical and empirical evidence was shown to support striped bass predation as the best explanation of alosine declines in the Connecticut River (Savoy and Crecco 2004). Further, in striped bass predation studies in the river, Davis et al.(2009) estimated striped bass consumed 200,000 river herring and 100,000 American shad during May 2008 between Hartford, CT (Rkm 80) and the CT/MA border.

## The Fisheries

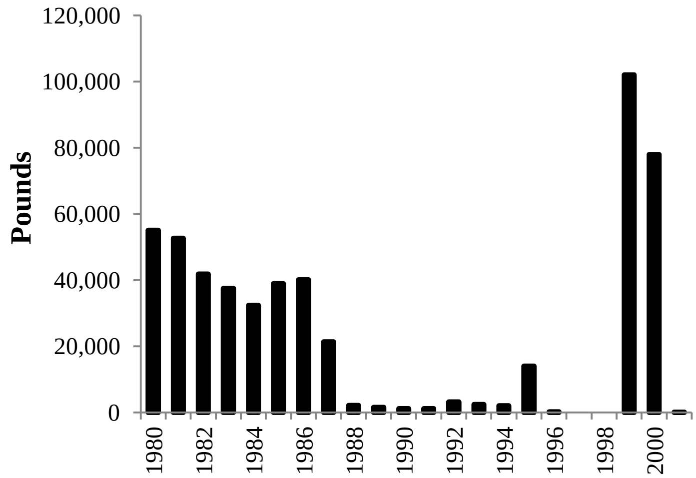


Figure 3. Connecticut commercial river herring landings (in pounds), 1980-2001.Moretorium implemented in 2002.

Declines in abundance in the late 1980s were followed by increasingly restrictive regulations (bag limit decrease, area closures). Currently there are no directed commercial or recreational fisheries in Connecticut. Losses through poaching are thought to be minimal. Connecticut commercial harvest during the 1980s and 1990s was primarily by haul seine in the Connecticut River. These fisheries phased out during the late 1980s. Since 1980, Connecticut commercial landings have remained below 60,000 lbs with two exceptions. During most of the 1990s the small amount of landings in Connecticut are attributed to gillnets, with the exception of trawl landings in 1999 and 2000. These two years of high landings can be attributed to catches outside of Long Island Sound (Block Island Sound and EEZ) that were landed in Connecticut.

The observed decline in river herring abundance in the Connecticut River in the late 1980s and early 1990s through reports from the public and conservation law enforcement, lead to CT DEEP to close key spawning tributaries to harvest in the late 1990s. In 2002, a complete statewide harvest moratorium was implemented for both the commercial and recreational fisheries through emergency declaration by the CT DEEP Commissioner. This moratorium has been extended through 2012.

Prior to the river herring stock declines documented in the 1990s, commercial effort had already decreased and harvest was minimal. River herring were harvested recreationally in many of the coastal rivers and streams across Connecticut for bait (lobster, striper) and, to a lesser degree, human consumption. Harvested primarily by scoop/dip netting, pressure on river herring was likely higher in rivers with the strongest runs i.e. Sasco Creek, Brides Brook, Poquetanuck Brook.

Since river herring make extensive annual coastal migrations, this potentially makes these stocks susceptible to incidental catch in various fishing fleets in New England and Mid-Atlantic waters. Species-specific river herring incidental catch estimates by gear type and region collected through the Northeast Fisheries Observer Program, are presented in section 2.1.6.1 of the Coastwide Assessment section within this document.

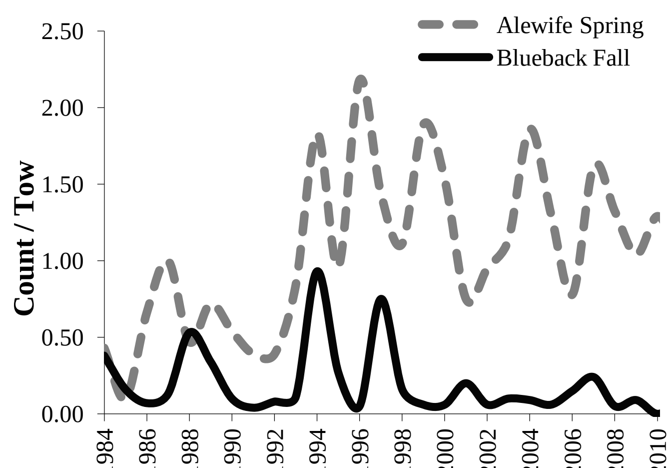


Figure 4. Long Island Sound Trawl Survey for age 1+ index alewife (Spring Survey) and blueback (Fall Survey) 1984-2010

## Indices

*Long Island Sound Trawl Survey (LISTS)* – The LISTS has been conducted annually throughout Long Island Sound since 1984. The survey has documented age 1+ alosines since 1984. Alosines collected in the survey have emigrated from their natal rivers. There are small numbers of adults collected as well as alosines that remain in Long Island Sound for 1 or 2 years before they join the coastal migratory stocks (Savoy 1993). Relative abundance is expressed as the annual geometric mean catch per tow (Gottschall et al. 2011).

*Seine Survey* - Seven stations in the Connecticut River from Holyoke, MA to Essex, CT are sampled from July through October. The annual juvenile index is calculated on as both an arithmetic and geometric mean catch per seine haul. The 2010 blueback seine survey also produced the second highest annual catch in the time series of over 32,000 fish.

*Holyoke Lift Counts* - Counts of blueback herring lifted at the Holyoke dam on the Connecticut River (rkm 139) are collected annually by Massachusetts Division of Fisheries and Wildlife. The Holyoke lift counts were used as a proxy of adult blueback herring abundance during the 1980s and early 1990s. When the lift numbers rapidly declined and fell below 100,000 Holyoke lift counts became non-informative as an indicator of adult blueback abundance for the Connecticut River system.

*Fishway counts* - Counts of alewife at six fishways are available to monitor population trends, particularly when the amount of habitat available above the dam has been constant for several fish generations. Additionally, Bride Brook (East Lyme, CT), lacks a fishway, but has a counting weir which allows enumeration of the run prior to the fish entering the lake.

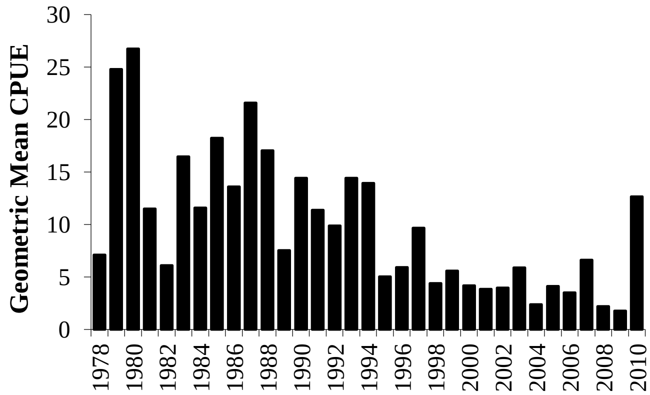



Figure 5. Connecticut River juvenile blueback herring seine survey index, 1979-2010.

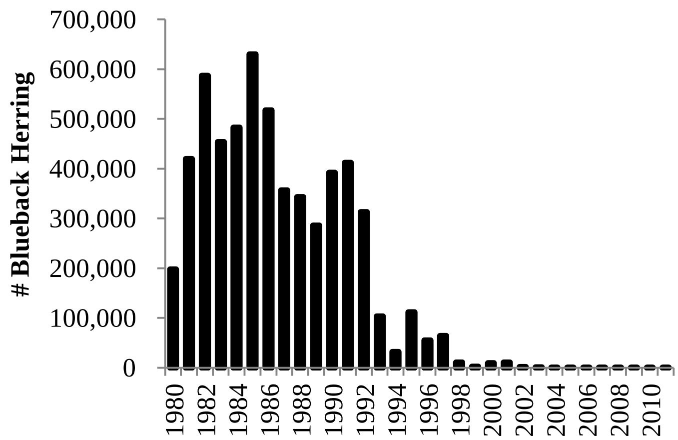



Figure 6. Blueback herring lifted at the Holyoke Dam (Rkm 139), 1980-2010. Counts after 1998 are uninformative as to total CT River run size.

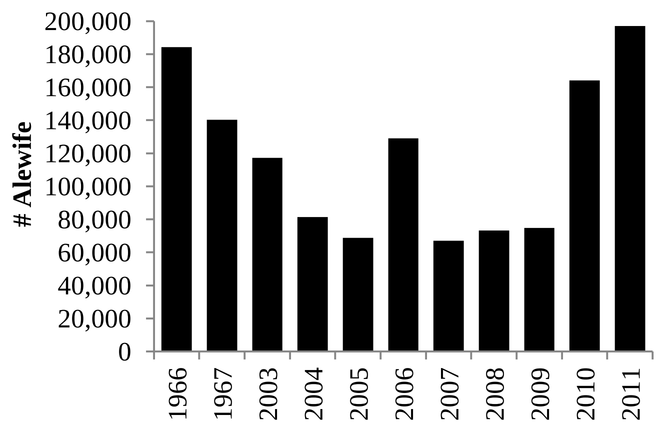



Figure 7. Number of adult alewife counted at Bride Lake, 1966, 1967, and 2003-2011.

**Assessment Results**

Fishing mortality rates for river herring in Connecticut waters were not calculated as Connecticut has had a moratorium on harvest since 2002. Adult pre-spawning blueback herring returning to the Connecticut River have experienced large decline despite high and stable juvenile production in recent years. The documented decrease in blueback herring adults cannot be attributed to directed fisheries in Connecticut. Incidental ocean catches of river herring have been quantified in recent years but cannot be apportioned out by individual stocks so their effect on Connecticut River herring stocks is unknown. Blueback herring stock collapse in the Connecticut River has been linked to striped bass predation through statistical and empirical evidence (Savoy and Crecco 2004). Successful rebuilding of the striped bass population resulted in a rise in abundance coincident with the decline of blueback herring in the Connecticut River.

Trawl Survey indices for blueback herring in Connecticut are low and do not correlate with juvenile production so it is unknown if trawl indices provide much of a signal of stock status in Connecticut waters. Alewives appear to be more available to the trawl. Mixed age alewife indices from LISTS shows a fluctuating but increasing trend since 1984.

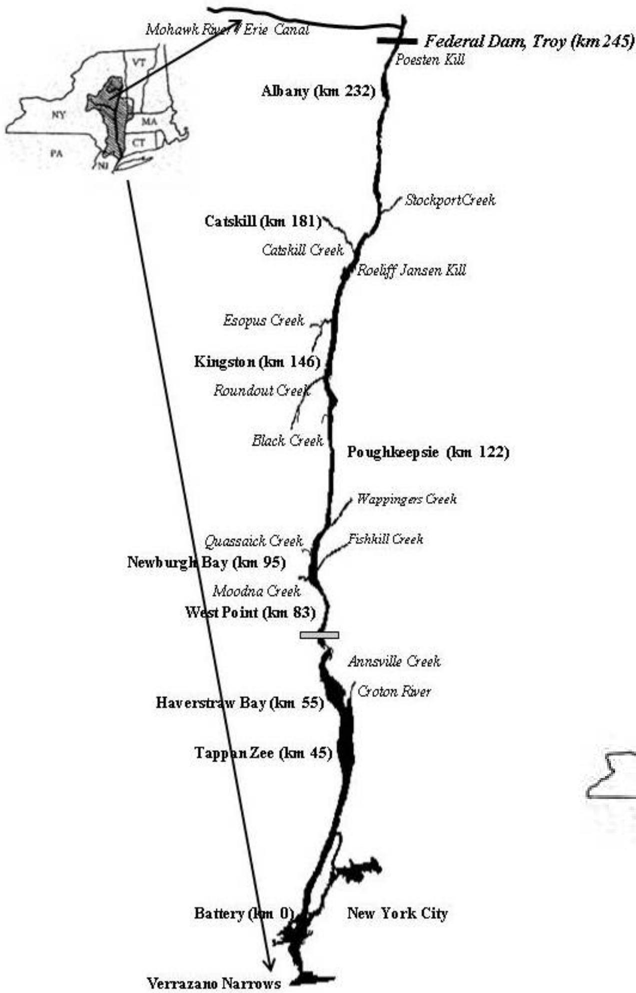
The CT River seine survey index for juvenile blueback herring shows a fluctuating trend with decreases seen after the decline in adult bluebacks passed above Holyoke. However, the index continues to show moderate to strong year classes that include one of the highest in the time series during 2010. Few juvenile alewives are taken in the Connecticut River seine survey.

Index stream EPUEs for blueback herring have fluctuated from their respective means slightly over the series but the trend has been generally downward except in 2011, when there was a slight increase. The IFD Presence Index data through the time series tends to mirror the EPUE data with fluctuations through the series and recent data showing an upward trend line. Fishway and fish counter data generated over the past ten years vary by river system. Large inland fishways on the Connecticut, Shetucket and Farmington Rivers have low counts of river herring. The Shetucket River Fishlift has varied from 13 to 800 bluebacks and 129 to 2,422 alewives. The Farmington River counts have fluctuated between 1 to 1,254 bluebacks and 1 to 71 alewives. Bride Brook is one of the more consistently monitored coastal systems. There, at Bride Lake a stable trend of alewife returns has been seen since 2002, with increased counts of 164,149 and 196,996 in 2010 and 2011, respectively.

## Summary

Examination of Connecticut indices indicate that the Statewide alewife stocks appear more stable since 1996 during which time blueback herring stock abundance in the Connecticut River had fallen by more than 90%. Enhanced predation by striped bass provides the best explanation for the recent collapse of blueback herring in the upper Connecticut River. The emergence of the very strong 2010 blueback year class, when only 92 adults were passed at the Holyoke Fishlift, suggest a differential build-up of blueback production in the lower 80 km of the river that is not reflected in the Holyoke lift count. Statistical evidence consists of a significant inverse relationship between several relative indices of striped bass abundance from the Connecticut River and Long Island Sound from 1981 to 2010 and adult bluebacks in the Connecticut River. In addition, estimated consumption rates of bluebacks by striped bass based on model runs show nearly a five-fold increase from 1981 to the late 1990s which is also coincident with the systematic decline of blueback herring (Crecco and Benway 2010). These assessments are supported by striped bass food habits studies within the river which document significant predation on bluebacks is occurring (Davis et al. 2009). The divergent trend between the large decline in adult blueback herring documented in the Connecticut River at the Holyoke Dam and alewife abundance in a coastal system demonstrating stable or increasing numbers in a coastal lake is understandable. Connecticut fisheries staff believe that alewives are suffering less predation and migratory disruption from striped bass since alewife spawning migration takes place earlier when water temperatures are lower, striped bass are less densely aggregated in coastal Connecticut waters, and in colder temperatures the striped bass metabolism is lower so less feeding is occurring. The size of the coastal streams and head water lakes in comparison to the main stem Connecticut River also is telling in that less habitat is available; therefore fewer predators can physically fit into these smaller systems. In addition to direct predation losses it is believed that the simple presence of large numbers of striped bass, particularly at river herring migratory delay points, including the Holyoke lift itself, greatly reduces the number of river herring able to enter the lift and be counted. Thus, while there remains evidence of a serious decline in blueback herring abundance, the Holyoke lift counts grossly overstate the magnitude of stock decline in the Connecticut River.

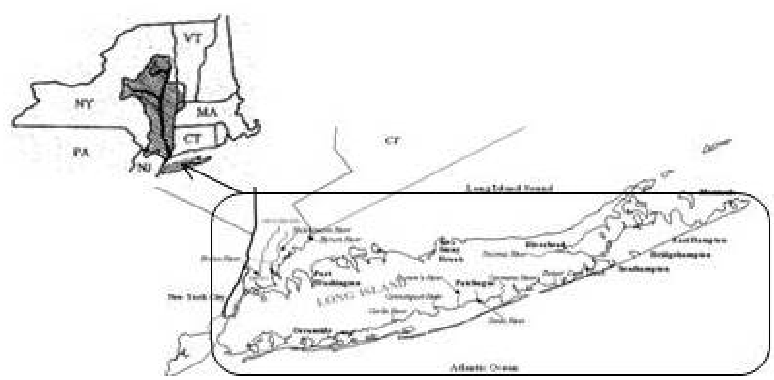
# Status of New York River Herring Stocks




## Distribution, Biology and Management

Hudson River: Anadromous fish have been harvested from the Hudson River since the 1600s when the Dutch first colonized the valley. Fisheries for river herring, comprised of both alewife (*Alosa pseudoharengus*), and blueback herring (*Alosa aestivalis*), were over-shadowed by the American shad fishery in the Hudson, however they undoubtedly were harvested along with shad. Gear restrictions and an escapement period put in place in 1868 to protect shad most likely provided some protection for the smaller herring.

The Hudson is an incredibly productive system. It is tidal for 254 km to the first barrier at Troy NY. Herring spawn in fresh water in the mid and upper portion of the estuary above Newburgh NY and nearly all of the Hudson's tributaries (>60 streams). Of the two species, blueback herring move beyond the estuary and utilize the Mohawk River via the Erie Canal as far as Rome (439 km inland from the Atlantic Ocean).




Figures 1 and 2. Hudson River Estuary, New York, with major river herring spawning tributaries (left) and Major streams on Long Island, Bronx and Westchester County; some with identified river herring spawning runs (right).

Long Island (LI), Bronx and southern Westchester Counties: Nearly all runs in Long Island streams are made up of alewife. Most streams are relatively short runs to the ocean from either head ponds or deeper kettle hole lakes. Either can be fed by a combination of groundwater, run-off or area springs. Passage for spawning adults into the head ponds or kettle lakes occurs on just a few streams. Little is known about river herring in stream in the Bronx and south shore of Westchester County.

In ocean waters, the coastal migratory range extends from the Bay of Fundy, Nova Scotia south to coastal waters of Virginia. Current management is through a cooperative inter-state fishery management plan coordinated through the Atlantic States Marine Fisheries Commission.

## The Fishery

New York's commercial harvest records for river herring began in the 1900s. The highest peak of 1.9 million kg occurred in 1960 (not shown in graph). During the period just prior to, and during World War

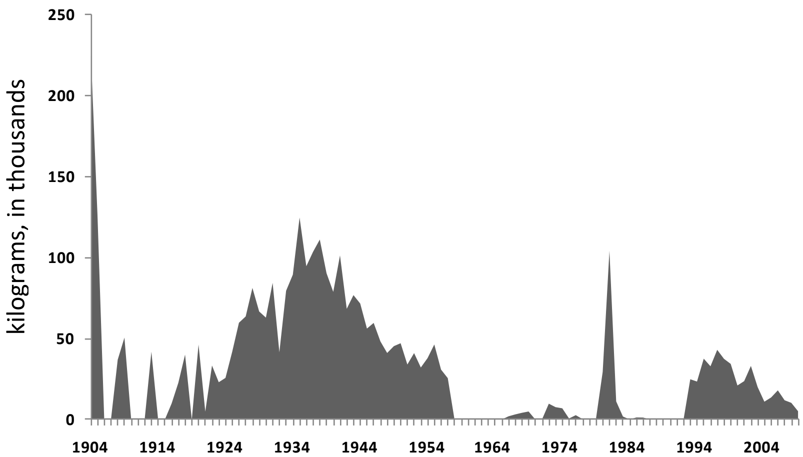



Figure 2. Historic commercial fishery landings of New York river herring (1904-2010).

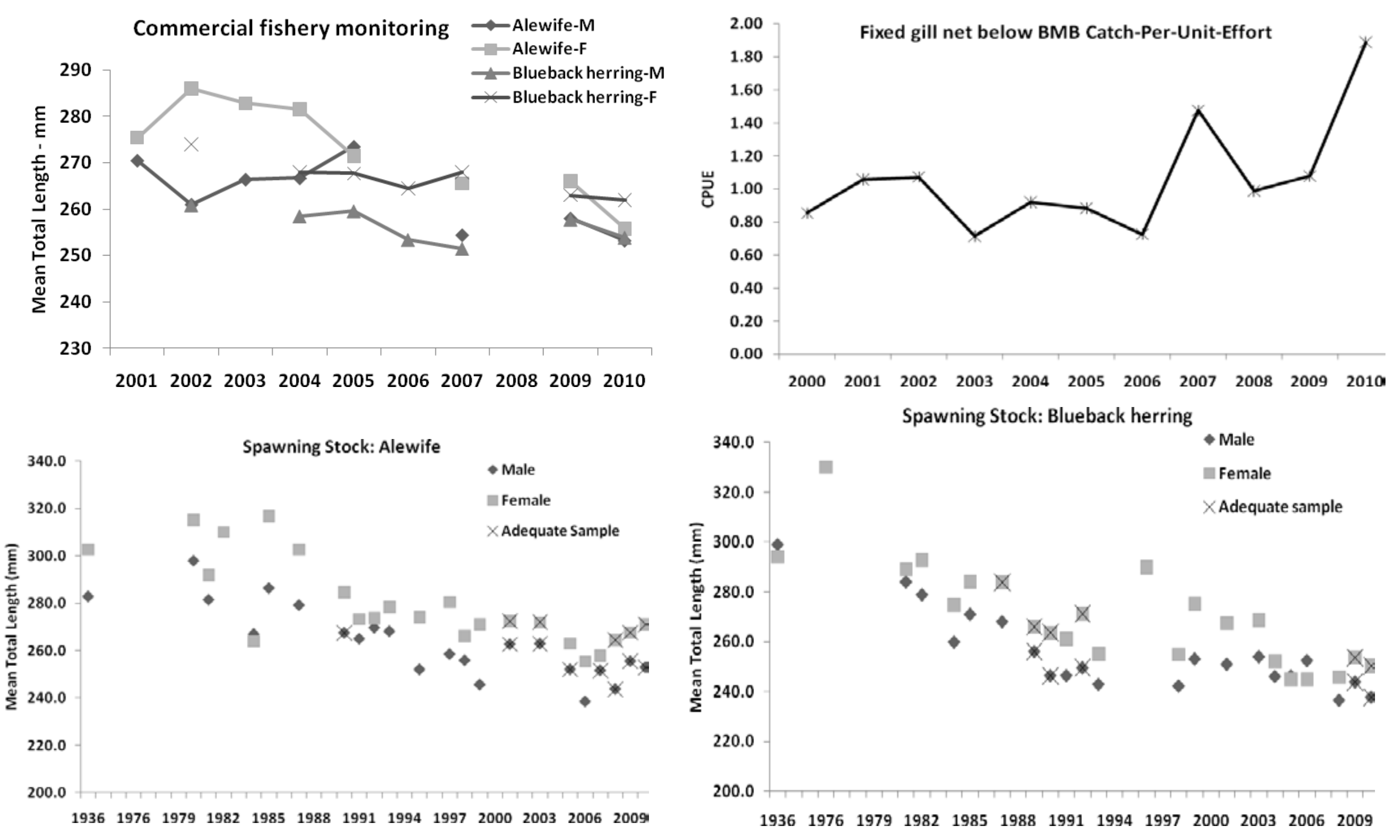
Two, herring harvest was high, followed by a decline through the 1950s. Landings were low through the mid 1960s through 1989, with the one exception noted above. Reported harvest increased beginning in 1994, peaked in 1998 and has slowly declined since then.

## Hudson River Indices

### *Spawning Stock*

We use the data from the passive fixed gear gill net fishery in the lower Hudson below the Bear Mountain Bridge (rkm 76) as a relative abundance indicator. This Catch-per-unit-effort (CPUE) series indexes adult herring as they migrate through the lower river to upriver spawning areas. Data are usable after 2000 when reporting became mandatory.

A decline in fish size occurred from 2001 to the present in samples from the commercial fishery. Longer term data from fishery independent sampling also show a decline in fish size.. Larger older fish disappeared through the late 1980s and mid 1990s. Size of fish has only leveled off over the past few years.




Figures 3 – 6. Mean total length of male and female alewife and blueback herring from fisheries dependant monitoring (top, left), CPUE for fixed gill nets below the Bear Mountain Bridge (top, right), mean total length of adult (>170mm) alewife (bottom, left) and blueback herring (bottom, right) collected in electrofishing, beach seine, and herring seine gears in the Hudson River Estuary.

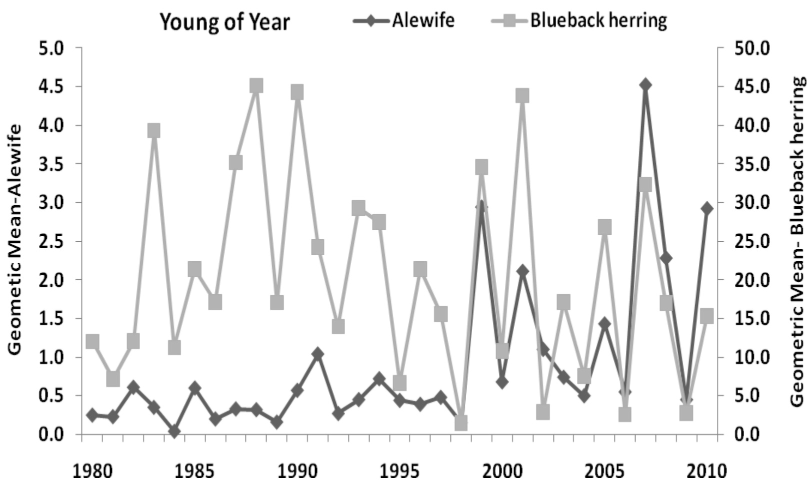



Figure 7. YOY indices for alewife and blueback herring collected in the Hudson River Estuary.

***Young-of- the-Year (YOY):*** The YOY abundance index for alewife was low until 1998 after which it began to increase. The YOY index for blueback herring were higher in the late 1980s, declined until 1998 then have been extremely variable to the present. The similar erratic trend in these two species may indicate a change in overall stability in the river ecosystem.

**Long Island (LI), Bronx and southern Westchester Counties:** Few sampling programs exist for the river herring runs in these areas. Stock status is currently unknown.

**Assessment Results**

The Hudson River indices present an inconsistent picture of stock status. The adult relative abundance CPUE from the commercial fishery reports is increasing, while mean total length of the spawning fish is in decline. The alewife YOY index is increasing, although in an erratic pattern; the blueback herring YOY index declined since the mid 1980s and has since become erratic.

**Summary**

Current data on stock status are inconclusive. However, However, we should emphasize that mortality on stocks must have been high in the last 30 years to have so consistently reduced mean size and presumably mean age. The recent erratic pattern in recruitment indices is of concern; it may indicate some instability in the system. River herring are vulnerable to a host of fisheries on the Atlantic coast during the entire duration of their ocean residency. Total ocean bycatch estimates remain unknown for the New York stocks.

| **Source Data** | **Year Range** | **Trend** |
|---|---|---|
| *Fishery Dependent Data* | | |
| Adult CPUE fixed gear below BMB | 2000-2010 | Increasing; Not significant |
| Mean size- Alewife | 2001-2010 | Decreasing**; Significant** |
| Mean size- Blueback herring | 2001-2010 | Decreasing; Not significant |
| *Fishery Independent Data* | | |
| Mean size- Alewife | 1990-2010<br>2001-2010 | Male: Decreasing**; Significant**<br>Female: Decreasing; Not significant |
| Mean size- Blueback herring | 1989-2010<br>1987-2010 | Male: Decreasing; Not Significant<br>Female: Decreasing; **Significant** |
| YOY index-Alewife | 1980-2010 | Increasing; **Significant** |
| YOY index-Blueback herring | 1980-2010 | Decreasing; Not Significant |

Table 1. Trends from river herring fisheries dependant and fisheries independent surveys in New York.

# Status of River Herring Stocks in Coastal New Jersey

## Distribution, Biology and Management

River herring refers collectively to alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*). The river herring data presented within this summary focuses on the coastal waters off of New Jersey. Adult alewife and blueback herring will typical enter New Jersey streams to spawn beginning in early February. Peak spawning activity occurs during mid-April through May. Post-spawned adults will return to the ocean by mid-June. Larvae will hatch and juvenile will maintain freshwater residence through mid-November, although juvenile emigration can occur as early as July. Mature adults will return to their natal streams to spawn. New Jersey Division of Fish and Wildlife manages river herring populations occurring within New Jersey's sections of the Basin and the coastal waters from Cape May Point to Sandy Hook including Raritan Bay and River.

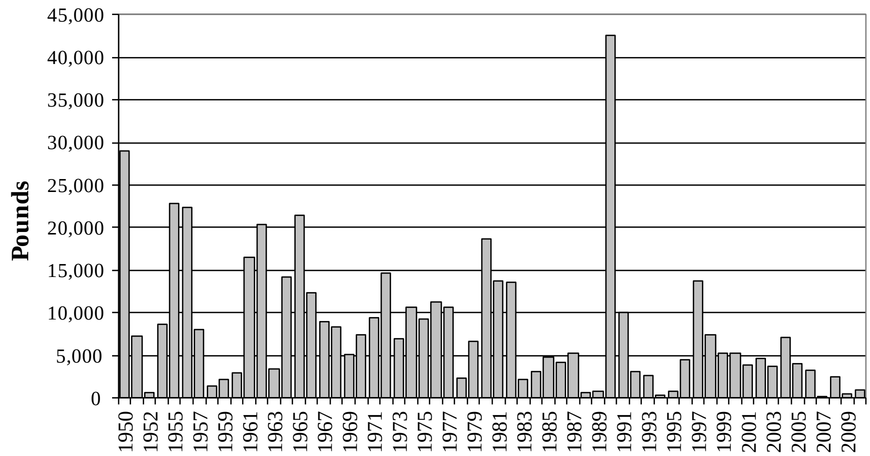



Figure 1. New Jersey commercial fishery landings from 1950 – 2010. (Note: landings reported from entire state)

## The Fisheries

Historically, no specific regulations have been adopted to reduce or restrict commercial landings of river herring in New Jersey, however there have been regulations which have limited commercial fishing effort and have a direct impact on catch. As of January 1, 2012 landings of river herring in New Jersey is prohibited. The recreational fishery for river herring was very small with few participants and low retention rates. Those herring that were landed were typically frozen for bait, pickled, harvested for their roe, and other traditional uses. As of January 1, 2012 the recreational fishery will be closed.

## Indices

The New Jersey Ocean Trawl Survey is a multispecies survey that started in August 1988 and samples the near shore waters from the entrance of New York Harbor south, to the entrance of the Delaware Bay five times a year. The Raritan River, which empties into

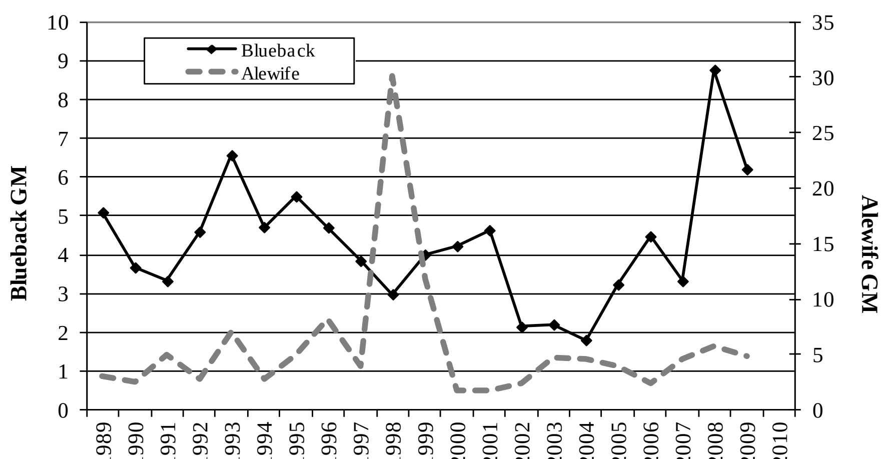



Figure 2. Alewife and blueback herring geometric mean per tow from the NJ Ocean Trawl Survey from 1989 - 2010

Raritan/Sandy Hook Bay, historically supported a spawning run of American shad. A second survey occurred sporadically from 1996 to 2005 at a fish ladder on the Raritan River, located at the Island Farm weir just downriver of the Millstone-Raritan river confluence.

**Assessment Results**

The trawl index for blueback herring showed a declining trend from 1993 to 2004 but has shown an increasing trend ever since. This included the highest index of the time series in 2008. The alewife index has varied without much of a trend since the beginning, although there has been a slight increase since 2000. The Raritan fish ladder data is a very short term data set that was discontinued in 2005. Regardless the data showed a decreasing trend from 1997 to 2005.

**Benchmarks**

No benchmarks have been developed for New Jersey's coastal streams and rivers.

**Summary**

Data for stock assessment of New Jersey's coastal rivers and streams is virtually non-existent. There are only two sources of river herring data from New Jersey's coastal waters, only one of which is currently ongoing. The Ocean Trawl survey, which collects fishery independent data of mixed coastal stocks, showed an increase in blueback herring in recent years and a slight increasing trend for alewife since 2002. In contrast, the short data set from the Raritan fish ladder showed an overall decreasing trend. With so little data available, it is not possible to determine an accurate state of river herring stocks in New Jersey's coastal waters. It would be beneficial to undertake a more rigorous investigation of the population dynamics of these species within and outside the New Jersey coast.

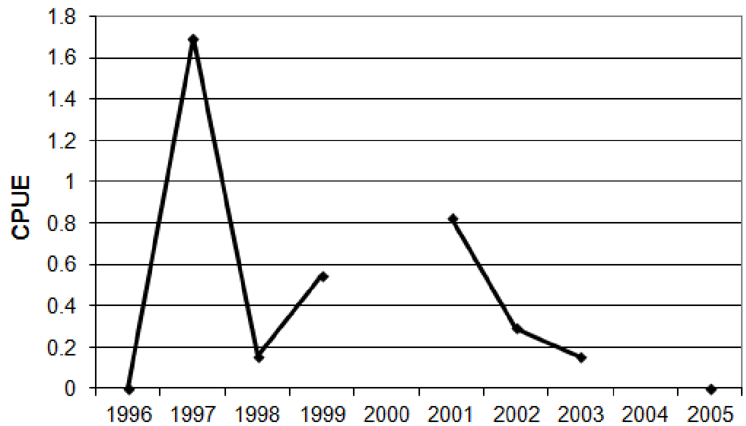


Figure 3. Raritan River Island Farm Weir fish ladder viewing CPUE (1996 – 2005).

Recommendations for the New Jersey coast would include:

- Additional information collected on commercial and recreational landings
- Improved assessment of river herring adults at all fish ladder installations
- Improved assessment of river herring production in targeted tributaries
- Investigations on predator-prey relationships especially with striped bass, bluefish and white perch for YOY and striped bass, weakfish, bluefish, spiny dogfish for adults
- Evaluation of habitat
- Development of age-length keys from samples collected during the Ocean Trawl Survey
- Revisit Raritan Bay fish ladder survey data

## Status of River Herring Stocks in Delaware Bay and River

### Distribution, Biology and Management

River herring (alewife and the blueback herring) occur throughout the Delaware River and Bay (Basin). The Basin consists of the Delaware River, including the East and West branches above Hancock, New York, and its tributaries to the mouth of Delaware Bay, encompassing some 13,539 square miles and 216 tributaries. The Basin includes the states of Delaware, New Jersey, New York, and Pennsylvania.

Many of the Basin tributaries contained spawning runs of river herring until pollution, overfishing and dams restricted the population and destroyed spawning habitat. On the Delaware side of the Basin all of the major tributaries contained spawning runs of river herring as recently as 1990. On the New Jersey side of the Basin, field investigations during the early to mid-1970s confirmed 132 river herring spawning runs in rivers and streams that were contiguous with the marine environment although nine herring runs had already become extinct.

Adult alewife and blueback herring typically enter the Basin to spawn beginning in early February. Peak activity for alewife occurs during April and the beginning of May, while blueback herring peak activity occurs during April through May. The adults emigrate downstream soon after spawning although a limited number of fish that spawned in ponds may remain in the ponds throughout the summer.

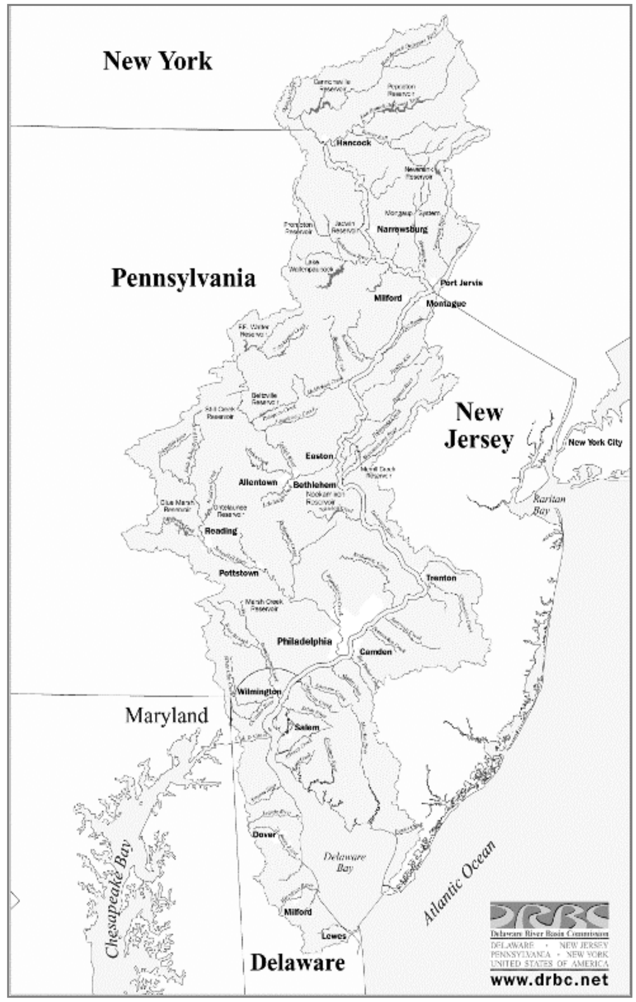



Figure 1. Map of the Delaware River/Bay Watershed.

Management authority lies with the New York Department of Environmental Conservation (NYDEC), Pennsylvania Fish and Boat Commission (PFBC), New Jersey Division of Fish and Wildlife (NJFFW) and Delaware Division of Fish and Wildlife (DFW). The Delaware River north of Port Jervis, NY is a shared water body between the states of New York and Pennsylvania. River herring have not been documented to occur in this section of the Delaware River and will not be discussed in this chapter.

### The Fisheries

The commercial fishery for river herring is relatively small but highly variable in Delaware, ranging from 500 lbs to 36,000 lbs annually since 1985. Commercial landings occur from February through May with peak landings in March and April.Total landings are estimated at $248 of dockside cash value, compared to Delaware’s total estimated dockside value of $0.9 million for all species combined in 2010.

The average reported NMFS landings from New Jersey from 1950 to 2010 is estimated at 8,180 pounds. There are no estimates of underreporting, however it is assumed that the current data for river herring is underreported since some landings may be categorized as bait. Commercial logbooks should only be used for potential trends and not absolute numbers. Harvest was only categorized as herring and could include some Atlantic herring landings. A CPUE developed for this data shows a declining trend since 2000.

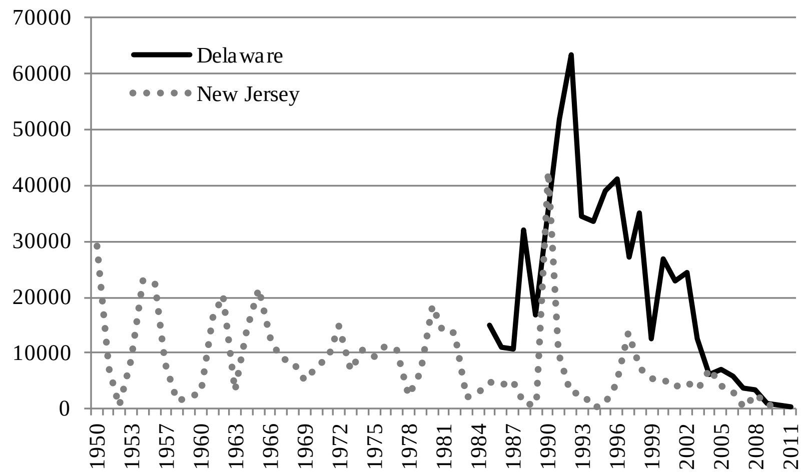



Figure 2. Commercial landings (in pounds) from New Jersey (1950 – 2010) and Delaware (1986 – 2011). (Note: landings reported are from entire state.)

Adult river herring commercial landings are typically the result of bycatch from other fisheries like the white perch fishery. Overall landings data in both New Jersey and Delaware show that landings have declined in recent years. The best indicator of the commercial fishery seems to be the CPUE from mandatory commercial catch reports. In Delaware, the commercial CPUE for the Delaware Estuary has been in decline since the mid-1990's and the lowest CPUE in the time series for the Delaware River occurred in 2010. The New Jersey commercial CPUE, except for 2000, has decreased since 1997. The recreational gill net CPUE for Delaware peaked in 1998 with no data between 2004- 2006, then a slight incline with data collected in 2007. The declines seen in the commercial and recreational data could be a result of declining stocks, declining effort, or regulatory changes.

Recreational catches in Delaware ranged from 4,400 fish in 1996 to 297 in 2002 from the recreational gillnet fishery from 1996 through 2003.. The number of river herring harvested per trip declined steadily from 1998 through 2004. A total of 7,553 river herring were estimated to be caught and 4,916 were harvested by recreational anglers in the Delaware River from New Jersey for 2002, which was the last year a recreational study was conducted. Angler catch rate was estimated 0.0189 per angler hour and the harvest rate was estimated at 0.0123 per angler hour.

**Indices**

The DFW bottom trawl survey documents the relative abundance and distribution of adult finfish species in the Delaware Estuary from March through December. Adult densities were calculated for blueback herring and alewife by dividing the number of individuals for a species by the distance towed (N/NM) at each station sampled, then calculating arithmetic means and standard errors in the typical fashion. Length frequencies have been determined for blueback herring and alewife.

Public Service Electric and Gas (PSEG) constructed and maintains twelve fish ladders on Delaware River Estuary tributaries for spawning run restoration of alewife and blueback herring. Adult passage monitoring typically occurred from March to early June. PSEG also conducted electrofishing twice a month from September through November to gauge juvenile river herring presence and relative abundance at the impoundments discussed earlier in this document. The survey was discontinued in 2005.

The Delaware Estuary is monitored annually by DFW to document the relative abundance and distribution of juvenile finfish species in the Delaware Bay and River from April through October. JAIs were determined for YOY and age 1 blueback herring and alewife resulting from collections during this survey, and length frequencies have also been determined.

New Jersey has conducted a juvenile abundance survey for striped bass in the Delaware River from Trenton to Artificial Island since 1980 during the months of August, September, and October at representative stations. A juvenile abundance index is calculated for alewife and blueback herring using a geometric mean. Length frequencies of juvenile blueback herring and alewife have been determined from collections since 2002. No trends were discernible from this short time series of data.

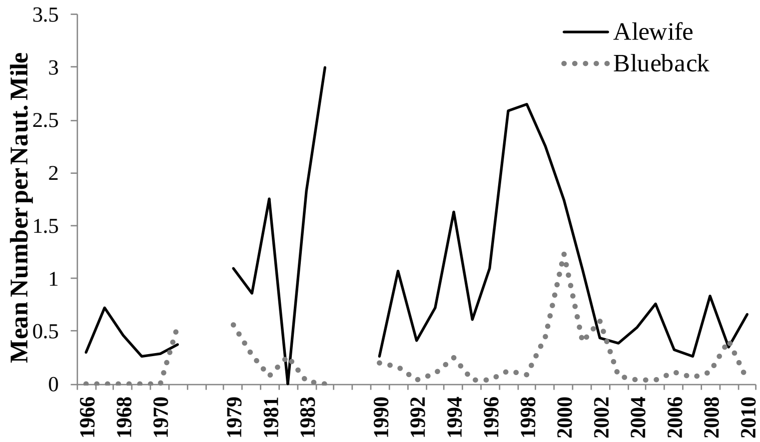



Figure 3. Adult River Herring indices for the Delaware Bay 30 foot trawl: 1966 – 2010. There is no data for 1972-1978 and 1985-1989.

### Assessment Results

*Spawning Stock Abundance*

Adult data from Delaware's finfish trawl survey show the greatest recent increase in alewife abundance occurred from 1996-1998. After 1998 alewife relative abundance decreased and has remained at substantially depressed levels since 2002. Blueback herring varied without trend throughout the 1990's prior to good year classes in 1999 and 2000. Blueback herring abundance has trended downward from 2001-2003 and has remained at depressed levels without trend since 2003.

The aggregate PSEG fish ladder passage CPUE (#/Hr) has trended downward since 1996 in Delaware and New Jersey ponds. This index has declined throughout the time series from the highest value of 0.5 in 1996 to the lowest value of 0.01 in 2010. Blueback herring have been the primary users of the fish ladders and river herring runs in the Basin are dominated by blueback herring overall. Alewife use of the ladders increases slightly in the northern part of the Basin. These numbers need to be considered with certain caveats however. For blueback herring, ladders that had high usage are no longer sampled every year. Likewise, newer ladders have yet to see any significant usage but are monitored 24 hours per day. The increase in alewife usage comes mainly from the Sunset Lake (NJ) fish ladder where restoration seems to be going well for alewife, while all other fish ladders have yet to see the same results.

*Juvenile Abundance*

The annual abundance (geometric mean catch per tow) from 16-foot otter trawl sampling for YOY alewife in the Delaware River and Bay varied without trend throughout the time series with peak years in 1996, 2000, 2003 and 2007. The Age 1 alewife index declined since the highest value was reached in 1997. The YOY index for blueback herring increased slightly from 1990 through 2003, but substantial declines were noted since then. The age 1 blueback herring index has varied substantially since 1991 with no discernible trend. It is unknown if these changes in the trawl index are actual trends or more a function of gear inefficiency. Environmental conditions may have also played a factor in the number of river herring captured.

The PSEG electrofishing survey for YOY alewife fluctuates wildly but shows an increasing trend. The blueback herring index shows an increasing trend from 1996 to 2001 before declining through 2005 when sampling was discontinued.

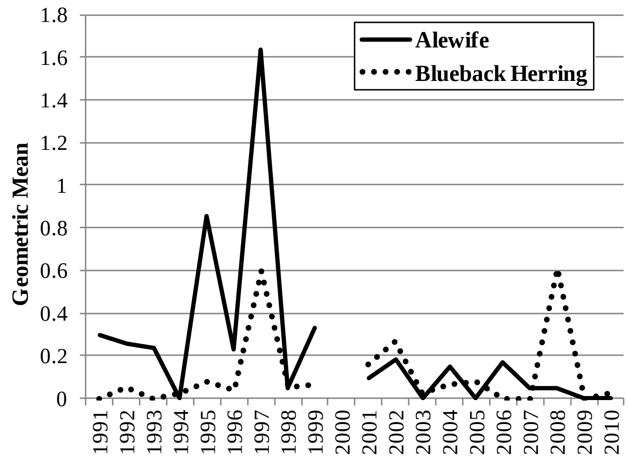



Figure 4 Annual Age 1 alewife and blueback herring relative abundance index (geometric mean catch per tow) for the Delaware Estuary. The 2000 age 1 annual abundance estimate was not available due to sampling missed in April of that year.

Juvenile production was very low for both species in the early years of the NJDFW striped bass survey. Since that time, the blueback herring index has varied with a fairly steady increase in blueback herring production from 1980 through the first real high year class in 1993. From 1993 through 2001, the survey included two additional large year classes (1996 and 2001) with some production years below average. Since 2001 the production of blueback herring has decreased with five straight years of below average recruitment. Abundance of YOY alewife has fluctuated without trend with years of high abundance (1988, 1996, 2001 and 2005) mixed with years of low abundance (1992, 1998, 2002, and 2006). More recent alewife trends are similar to blueback herring, although 2007 was considered a good year. It should be noted that environmental conditions in 2002 (drought) and 2006 (floods) were not conducive for good spawning or survival of either species.

**Benchmarks**

No benchmarks were developed at this time for river herring fisheries in the Basin.

**Summary**

Overall river herring landings in the Delaware Basin have declined since 1992. Although fish passage may have been considered fair to good in some years, reproduction in these freshwater impoundments has been poor overall. The installation of fish ladders in Delaware ponds have resulted in little success and it appears that to date, this effort has been ineffective in restoring river herring populations. However, alewives in New Jersey have increased in recent years due to an increase in passage at the Sunset lake fish ladder.

The overall assessment of data from these stocks indicates stocks have declined. The reason for this is unknown. There are no estimates of mortality for the Delaware Basin stocks of river herring so it is not possible to determine the cause or causes of this decline.

## Status of River Herring Stocks in Upper Chesapeake Bay

### Distribution, Biology and Management

Alewife and blueback herring are synonymous with the term river herring. Both species historically occur in significant numbers in the Chesapeake Bay with pre-spawn alewife herring appearing in the tributaries during late February followed by blueback herring in April. Some fish may return to spawn for four consecutive years. Young-of-the-year begin leaving the Chesapeake Bay in late fall. Juveniles remain in the ocean until sexual maturity, most returning to their natal rivers to spawn. There appears to be annual overwintering of both species of herring in the Chesapeake.

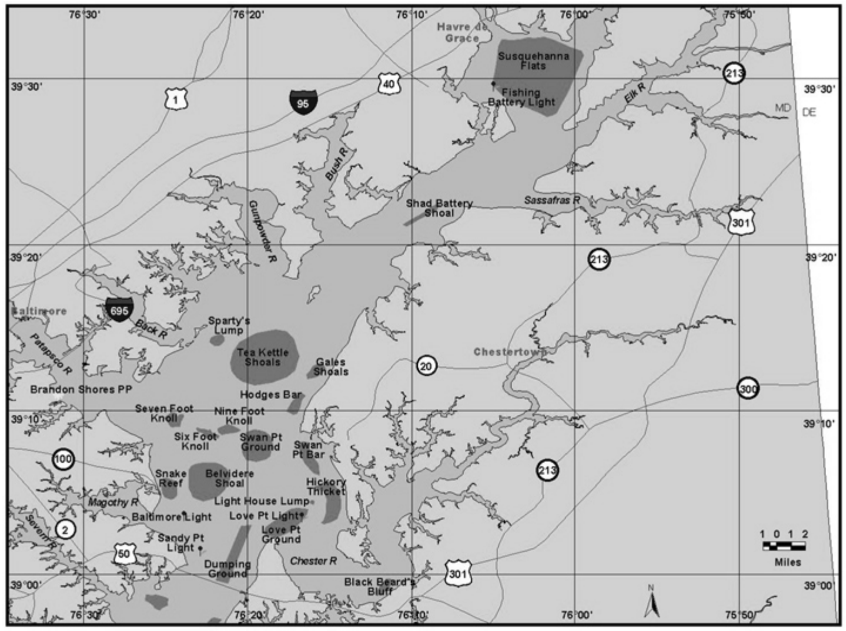



Figure 1. Map of Upper Chesapeake area *(MD Division of Natural Resources).*

Each river is considered a separate stock because most river herring in the Chesapeake Bay will return to their natal rivers to spawn. The Maryland portion of the Chesapeake Bay begins at the Virginia line on Maryland's eastern shore, just south of the mouth of the Pocomoke River, and continues north ending at the Susquehanna Flats. The two major tributaries in the Upper Chesapeake Bay are the Susquehanna and Nanticoke Rivers. The Susquehanna River watershed is located in Maryland, Pennsylvania and New York; however river herring cannot access the New York portion. The Nanticoke River watershed originates in southwest Delaware and flows through Maryland before emptying into the Chesapeake Bay. In addition to the mainstem of the Nanticoke River, river herring runs primarily occur in two main tributaries to the Nanticoke River in Delaware, Deep Creek and Broad Creek.

The management authorities in the Upper Chesapeake Bay include the Maryland Department of Natural Resources (MD DNR), the Delaware Division of Fish and Wildlife (DFW) and the Pennsylvania Fish and Boat Commission (PFBC).

### The Fisheries

Maryland's commercial river herring fishery historically has been seasonally restricted. Since most fish have returned to the ocean by June, this law has little, if any, management consequences. Up until 2005, it was primarily a directed fishery using drift gill nets. A limited pound and fyke net bycatch fishery also exists. As of January 1, 2012 possession of river herring are prohibited in Maryland and Delaware, and landings of river herring are prohibited in Pennsylvania waters of the Susquehanna River. . No specific regulations were ever adopted to reduce or restrict commercial landings of river herring in Delaware, however there are regulations that apply to the commercial fishery that limited commercial fishing effort and have a direct impact on catch and effort. As of January 1, 2012 landings of river herring are prohibited in Delaware and in Pennsylvania waters of the Susquehanna River.

Maryland has no recreational landings data but limited data indicated that catches are minimal although there may be small incidental catches of river herring for striped bass bait that is not documented. Historically, the recreational fishery for river herring in Delaware was very small with few participants and low harvest rates. Those herring landed were typically frozen for bait, pickled, kept for their roe and other traditional uses. The fishery often occurred on the mainstem and below the two low-head dams that form Records and Concord Ponds where herring concentrated during the spring spawning season.

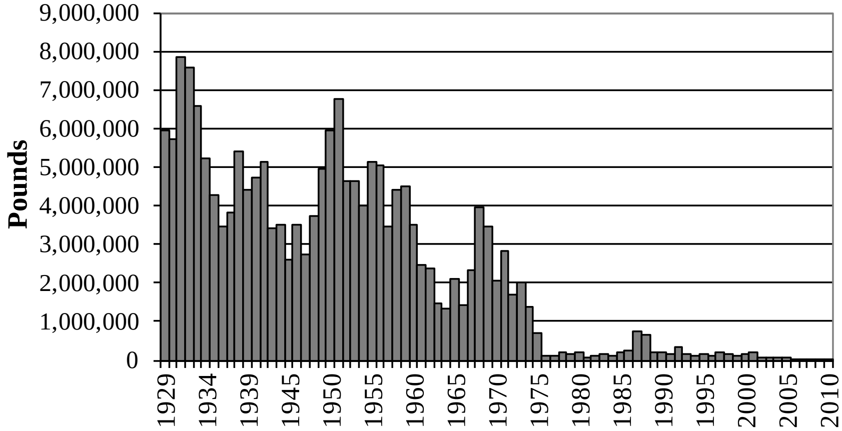


Figure 2. Commercial river herring landings from Maryland state waters, 1929-2010.

Relative abundance, measured as annual CPUE for alewife and blueback herring collected from pound and fyke nets in the Maryland portion of the Nanticoke River were calculated as the geometric mean (based on a loge-transformation) of fish caught per net day. Nanticoke River pound net CPUEs and commercial landings of alewife and blueback herring (species combined) were analyzed for trends using linear regression. The combined geometric mean CPUE for alewife and blueback herring have shown no trend overtime (1989-2010; $r^2$=0.15 $P$=0.08). Alewife geometric mean CPUE has varied without trend (1989-2010, Figure 13.11), while for blueback herring geometric mean CPUE has significantly decreased (1989-2010). In Delaware's portion of the Nanticoke River the commercial gill net CPUE declined since the mid 1990's with the lowest CPUE in the time series occurring in 2010. The Delaware effort data reflects days that fishermen actually landed river herring and does not account for days when the species was not landed.

## Indices

The only source of fishery-independent data for river herring comes from the fish lifts at Conowingo Dam in the Susquehanna River. There are two lifts (West and East) operating at the lowest dam on the Susquehanna River. The lifts are operated to give priority to American shad passage and therefore flows have been increased.

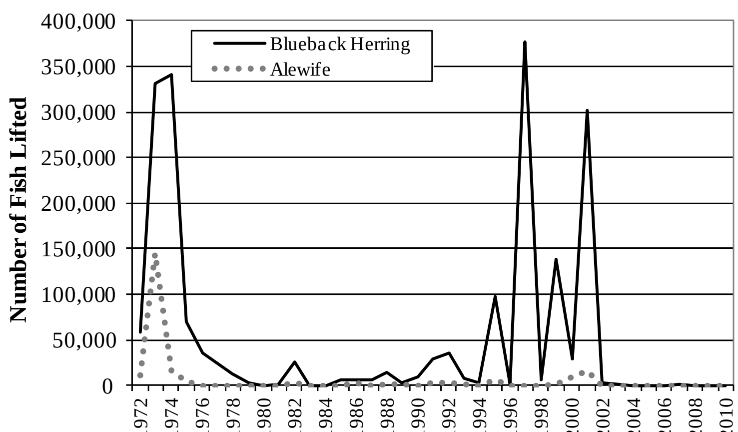


Figure 3. Annual combined east and west lift spring catches of adult alewife and blueback herring from Conowingo Dam on the Susquehanna River, 1972-2010.

Maryland's river herring juvenile indices are derived annually from seine sampling designed to sample striped bass at 22 fixed stations within the upper Chesapeake Bay area. Additionally, a haul seine survey is used to generate a juvenile abundance index for the upper Nanticoke River in Delaware. Haul seine sampling was initiated in 1999 and is conducted annually to assess reproduction and recruitment of all alosines.

## Assessment Results

*Spawning Stock Abundance*

Alewife geometric mean CPUEs for the lower Nanticoke River s varied without trend, while those for blueback herring have significantly decreased. River herring lift catches at Conowingo Dam were erratic for the time series. Flows have been manipulated in recent years to encourage American shad to use the lift which can preclude river herring usage of the lifts. This is one factor that may have influenced the wide range of annual values.

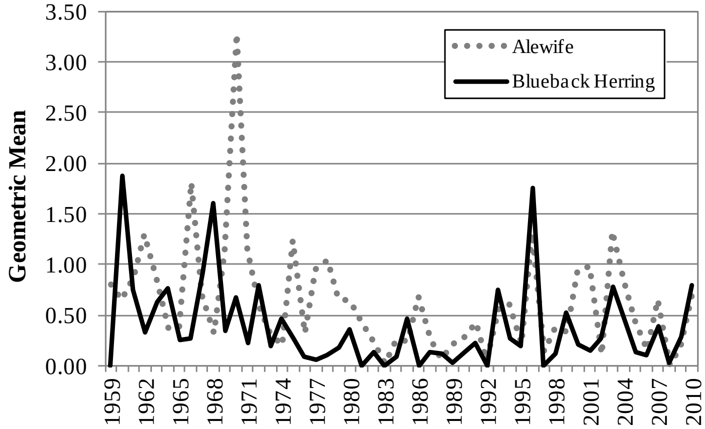



Figure 4. Nanticoke River juvenile alewife and blueback herring geometric mean CPUEs from MD haul seine survey, 1959-2010.

*Juvenile Sampling*

Haul seine sampling conducted by MD DNR since 1959 in the lower Nanticoke has fluctuated without much trend for both alewife and blueback herring. The highest index value in a decade was recorded for blueback herring in 2011 (0.98) although this was still below the series average (1.16).

Haul seine sampling conducted in the Upper Nanticoke River by DFW has seen no long-term trend from 1999-2010 in juvenile blueback herring relative abundance. However, juvenile blueback herring relative abundance increased to the third highest value in 2009 and to the highest value in the 12-year time series in 2010. Anecdotal information from Delaware electrofishing surveys indicated the majority of river herring in the upper Nanticoke system consisted of blueback herring.As a result, alewife relative abundance has been calculated from small sample sizes, Alewife relative abundance hastrended down since 1999. butthe 2010 alewife geometric mean CPUE increased to the highest index value over the past eight years.

*Trends in Mean age and length at age*

The river herring data for Maryland is based on the commercial fishery in the lower Nanticoke River. Data indicates that in the last few years, older fish are no longer present and mean length-at-age is decreasing. In general, ages four and five were the most prevalent fish in the samples but river herring were generally not fully recruited to the spawning population until age five, as determined by the lack of a freshwater spawning mark on some five year-old fish.

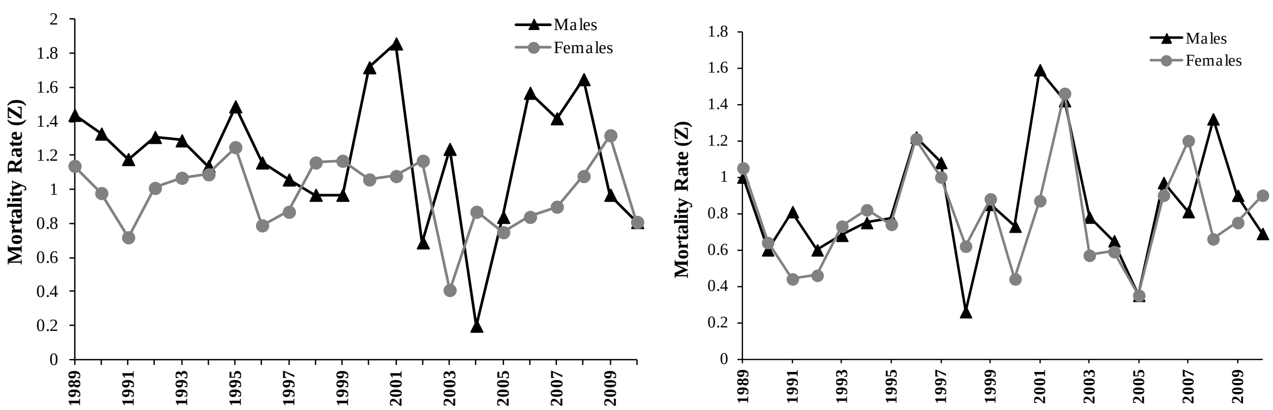



Figure 5. Total instantaneous mortality estimates for blueback herring (right) and alewife (left)

*Total instantaneous mortality*

Total instantaneous mortality (Z) was estimated for alewife and blueback herring by the $\log_e$-transformed spawning group frequency plotted against the corresponding number of times spawned, assuming that consecutive spawning occurred (Figure 5). Z was relatively constant for male and female alewife herring through the 1990s, declined after 2001 and generally increased again after 2005. In contrast, Z for both male and female blueback herring is variable over time.

**Benchmarks**

No benchmarks have been developed for Maryland at this time.

**Summary**

Commercial landings in Maryland and Delaware have shown a decline. The declines seen in the commercial and recreational data could be a result of declining stocks, declining effort, or regulatory changes. All recreational and commercial river herring landings were prohibited in Maryland and Delaware beginning January 1, 2012. This regulatory change will help protect the remaining spawning populations and aid in reversing the declining trend in river herring abundance.

Maryland's best estimate of adult relative abundance comes from the Nanticoke River Both alewife and blueback herring populations have remained low for the time series, and blueback herring continue to decline. Data from the Conowingo Dam fish lifts on the Susquehanna River are highly influenced by flow and likely do not reflect the abundance of river herring in the system. Juvenile alewife abundance shows a decreasing trend in the upper Nanticoke, but high values were seen during sampling efforts in 2010 in both the upper and lower portions of the river. Blueback herring juvenile relative abundance increased to the third highest value in 2009 and to the highest value in 2010 during the 12-year time series.

# Status of River Herring Stocks in the Potomac River

## Distribution, Biology and Management

Figure 1. Map of the Potomac River Watershed

River herring (*Alosa psuedoharengus* and *Alosa aestivalus*) are important anadromous species that frequent the waters of the Potomac River. There was a significant abundance of herring caught in the Potomac River from the Colonial Period through the 19th Century. Sexually mature river herring return each spring to spawn in the Potomac River. Adult herring are normally present in the Potomac River for about three months each year from March through May. In addition to the annual run of adult river herring, the juveniles that were spawned use the region as a nursery to grow and develop. Each year clouds of juvenile river herring consume tiny plankton during the summer months before migrating out of our region by autumn.

The Potomac River Fisheries Commission (PRFC) regulates only the mainstem of the river, while the tributaries on either side are under Maryland and Virginia jurisdiction, while the DDOE (District Department of the Environment) monitors the waters under the District's jurisdiction. The PRFC has never had any specific regulations regarding river herring. However, gear specific mesh size restrictions (which generally would not impact the herring catch), and prohibitions against certain gears such as purse nets, trawls, trammel nets, troll nets, or drag nets have been in place. River herring are monitored by DDOE and the PRFC each year to assess the status of the local populations and determine how that may affect the overall coastal stock. Because of the two distinct life stages (adult and juvenile) that are represented in the Potomac River, sampling efforts are designed to target each group specifically. Data is analyzed annually and compared by year to determine significant trends in population structure and size. In 1964, licenses were required to commercially harvest fish in the Potomac River. After Maryland and Virginia established limited entry fisheries in the 1990's, the PRFC responded to industry's request and, in 1995, capped the Potomac River pound net fishery at 100 licenses. As of January 1, 2010 harvest of river herring was prohibited in the Potomac River, with a minimal bycatch provision of 50 pounds per licensee per day for pound nets.

## The Fisheries

The PRFC regulates all the commercial harvest of river herring in the Potomac River. Since the mid-1960's, the river herring harvest has declined from just over 11 million pounds to the current low level. From 1966 to 1976 there was a dramatic and consistent decline. From 1976 through

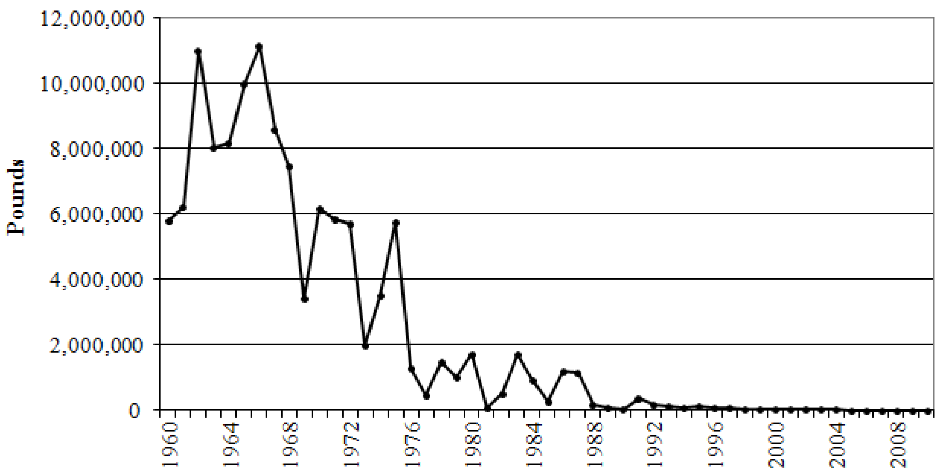


Figure 2. Commercial landings of river herring from the Potomac River waters under the jurisdiction of the Potomac River Fisheries Commission.

1987 harvest was relatively stable, but at very low levels. After 1988 the fishery has been all but non-existent. Today, the river herring harvest in the Potomac is almost exclusively taken by pound nets. With the moratorium in place in 2010, preliminary data for the bycatch allowance resulted in a commercial pound net harvest of 898 pounds harvested by five pound net fishermen and approximately 820 pounds were reported as discards.

There is no information on the recreational fishery occurring in the Potomac River below the District and in the tributaries of Maryland and Virginia. Within the District, recreational fishing may have occurred, but it is believed to have been minimal. As of January 1, 2010 recreational landings were prohibited in the mainstem of the Potomac River under the jurisdiction of PRFC. As of January 1, 2012 recreational landings are prohibited in the Potomac River water's under the jurisdiction of the DDOE.

**Indices**

The DDOE Fisheries Research Branch conducts three main surveys in which river herring are regularly encountered. These surveys include boat electrofishing, seining, and push net. Additionally, Maryland Department of Natural Resources conducts a juvenile survey in the Potomac River.

A standardized electrofishing survey is conducted throughout the District of Columbia's waters from March–November. This survey is conducted on a monthly basis at eight standard sites and four alternative sites located throughout the District's jurisdiction from May–November. The data collected from the adult river herring include species identification, length and sex of each fish netted.

A beach seining survey was initiated by DDOE in 1990 targeting all YOY finfish occurring within the District of Columbia. During June through October, a single haul is made at each of six fixed locations. Data that are recorded includes species and length.

The push net survey to capture YOY alosine species is conducted in the District of Columbia's Potomac River waters from July to September since 2005. When samples are examined all fish are identified to species and counted; lengths are taken from a subset of 50 individuals.

MDNR has been annually sampling for juvenile/YOY river herring within the Chesapeake Bay since 1959. Sampling is monthly, with rounds occurring during July, August, and September. The river herring juvenile indices for the Potomac River are derived from the MDNR juvenile survey.

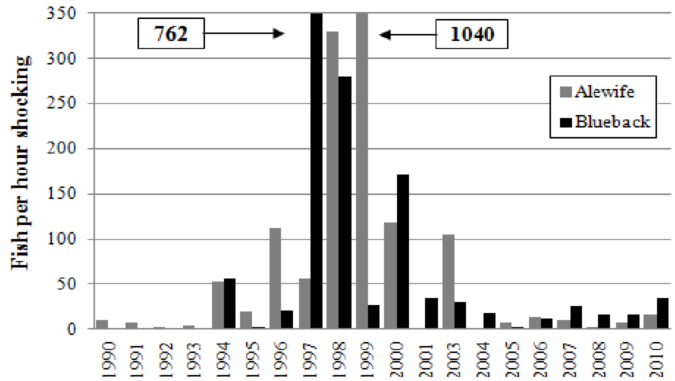


Figure 3. CPUE (fish per hour of shocking) of adult alewife and blueback herring during boat electrofishing survey, 1990-2010

## Assessment Results

*DDOE Electrofishing Survey* – CPUE (fish captured per hour of shock time) indices derived from this survey show a drastic decline for both alewife and blueback herring from the late 1990s to early 2000s.

*DDOE Beach seining / push net surveys* – Geometric means (average number of fish per haul) derived from the beach seining survey show a dramatic decline in alewife numbers from the early 1990's until present day while blueback herring appear to have followed a cyclical pattern since 1994. The push net survey shows an increasing trend for blueback herring.

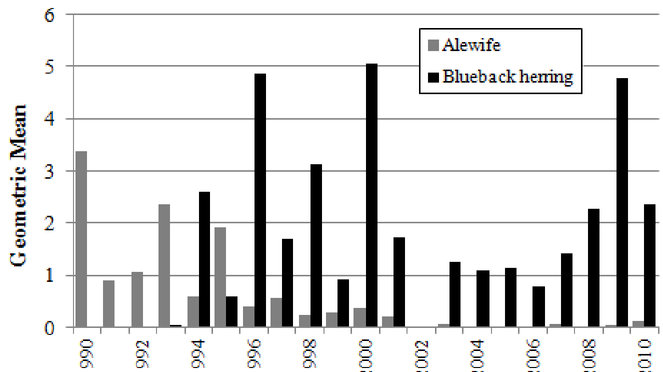


Figure 4. Geometric mean (average number of fish per haul) of YOY alewife and blueback herring caught during 100ft beach seining survey, 1990-2010 (no data available for 2002).

*MDNR juvenile/YOY survey* - Catches blueback herring occur in higher proportions. There are no apparent trends in the YOY indices.

## Benchmarks

There are no benchmarks established for river herring fisheries in the Potomac River. The YOY indices have fluctuated widely without trend. The 2010 MDNR YOY survey geometric mean CPUE for alewife was 0.47, which was very close to the average, indicating that spawning is

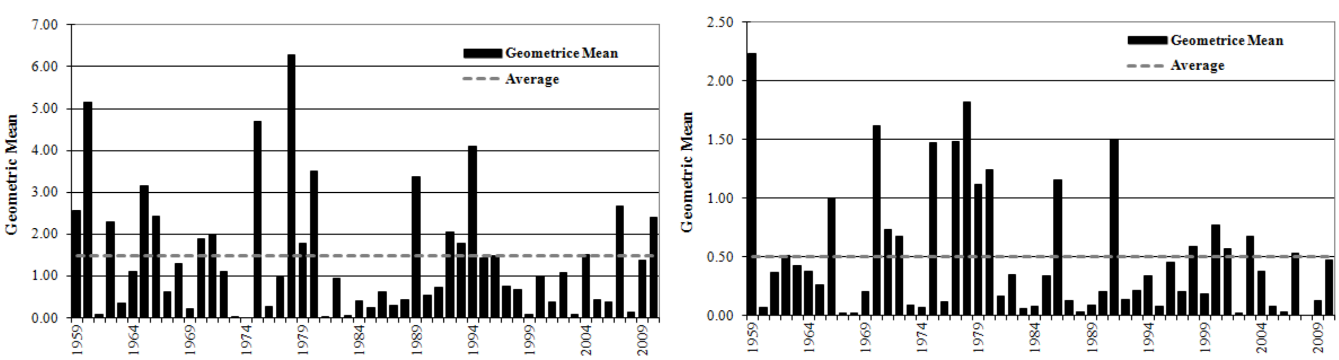


Figure 5. Juvenile alewife (right) and blueback herring (left) geometric mean (catch per haul) in the Potomac River (1959 – 2010). Source: Maryland Department of Natural Resources.

occurring and for blueback herring was 1.41 which exceeded the average. The population of blueback herring appears to be more abundant in the Potomac River than alewife herring.

**Summary**

The adult stock of river herring in the Potomac River, based on the landing data, is at an extremely low level. Harvest has been on a declining trend since the 1960's. The pound net CPUE is also low, but relatively stable. PRFC and DDOE recognize that invasive species such as blue catfish potentially pose a threat to the river herring populations within the Potomac River. The PRFC and DDOE will continue to use the bycatch landings data, CPUE, and YOY indices to track relative health of the river herring stock. PRFC and DDOE will continue to communicate with the other management authorities on the Potomac River for additional data that may become available for the assessment of river herring.

# Status of River Herring Stocks in Virginia

## Distribution, Biology and Management

River herring (alewife, *Alosa pseudoharengus* and blueback herring, *A. aestivalis*) are anadromous, highly migratory, schooling, pelagic fishes that spend most of the annual cycle at sea but enter Virginia's rivers and streams to spawn during late winter and spring. Alewives migrate earlier than other alosine fishes (blueback herring, American shad, hickory shad) and spawn at lower temperatures (Schmidt et al. 2003), thereby being the first anadromous species available for harvest each year in Virginia. Assessment of alewife and blueback herring stocks is performed on a river-specific basis; each natal river is considered a unit stock.

Virginia's Department of Game and Inland Fisheries (VDGIF) is responsible for the management of fishery resources in the state's inland waters, while the Virginia Marine Resources Commission (VMRC) oversees the management of resources in the state's marine waters. As of January 1, 2008, possession of alewives and blueback herring was prohibited on rivers draining into North Carolina. On June 28, 2011, the VMRC voted to implement a ban on the possession of alewives and blueback herring in state waters. The ban will become effective as of January 1, 2012 and was enacted due to the collapse of the fishery over the last four decades and in order to comply with Amendment 2 to the Shad and River Herring (ASMFC 2009).

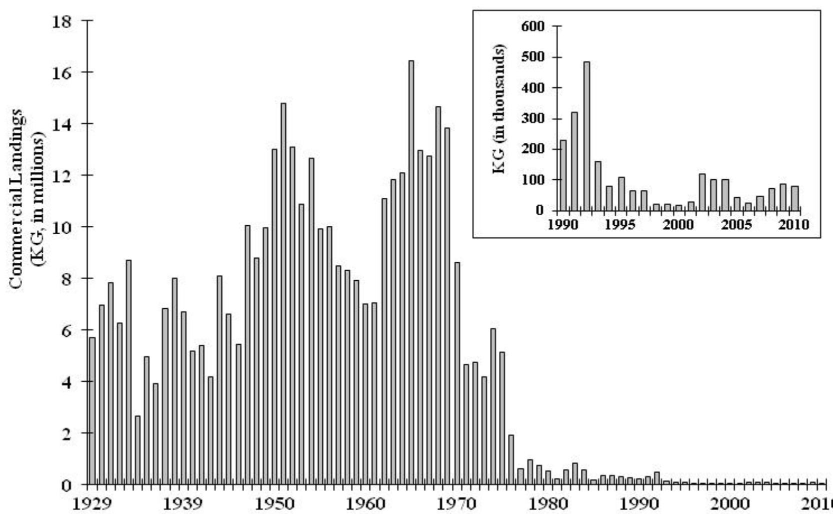


Figure 1. Commercial landings, in kilograms, of river herring from Virginia, 1929 – 2010.

## The Fisheries

Since 2003, commercial fishing for river herring in Virginia takes place primarily in marine and estuarine waters. The major gears are gill nets and pound nets, with some ancillary use of haul seines, fyke nets, and other gears. The other category includes common dip nets, hand lines, and pots, based on VMRC reporting records. Recreational anglers fish for river herring primarily in upstream areas using hook and line, recreational gill nets, and dip nets. A brief history of Virgnia's *Alosa* fisheries can be found in Loesch and Atran (1994).Data obtained from the VMRC's mandatory reporting program suggest alewives continue to make up the majority (~98%) of Virginia's commercial river herring landings. However, it is likely that at least a portion of the blueback herring landings continue to be reported as alewives. There is also concern that some commercial landings reported as alewives are, in fact, Atlantic menhaden. Annual commercial landings were available for intermittent years from 1880 through 1925 and were available for all years beginning in 1929. Available historical commercial landings data for river herring in Virginia depict an active and productive fishery in the period 1950–1970 with total landings exceeding 14 million kilograms in some years. The time series of commercial landings suggest several periods of declining landings (during the 1930s; during the mid-1950s to early 1960s) followed by periods of increased landings. A steep decline in Virginia's landings in the late 1970s was followed by an apparent collapse of the fishery.

## Indices

*VDGIF Electrofishing Surveys:* In the Rappahannock River, peak catch rates of blueback herring occurred in 2001 although in some year's blueback herring were not collected in the survey. Peak catch rates of alewives occurred in 2004 and 2005. In the James River, blueback herring have dominated the catch and 2010 being the highest in the time series. The catch rates show a low relative abundance of alewives in the James River relative to the Rappahannock.

*VIMS Experimental Anchor Gill-Net Survey:* The index for alewives has maintained relatively low levels with no obvious trend over the time series. The blueback herring index declined from the beginning of the time series through 1994 and increased to the time series peak in 1995. The index then decreased and has remained at relatively low levels through the present.

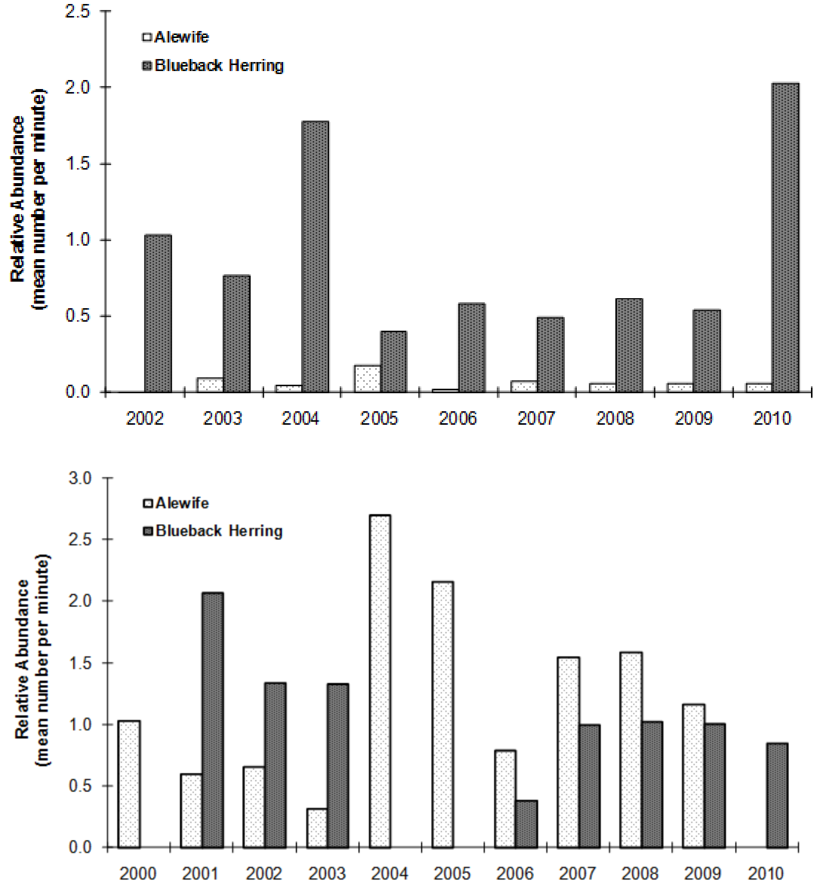



Figure 2. Catch rates (arithmetic average number of fish per minute) of alewives and blueback herring collected by the VDGIF's electrofishing survey of the James (bottom) and Rappahannock Rivers (top).

*VIMS Juvenile Striped Bass Seine Survey:* The juvenile abundance index (JAI) for alewife has been consistently lower than the blueback herring JAI in the James, York, and Rappahannock rivers. There are no obvious trends in the JAI time series for either of the species, and variability about the annual estimates has been fairly high.

*VIMS Juvenile Shad-River Herring Push-Net Survey:* Juvenile indices were calculated for alewife and blueback herring in the Mattaponi and Pamunkey rivers. The JAI values for alewives have been lower

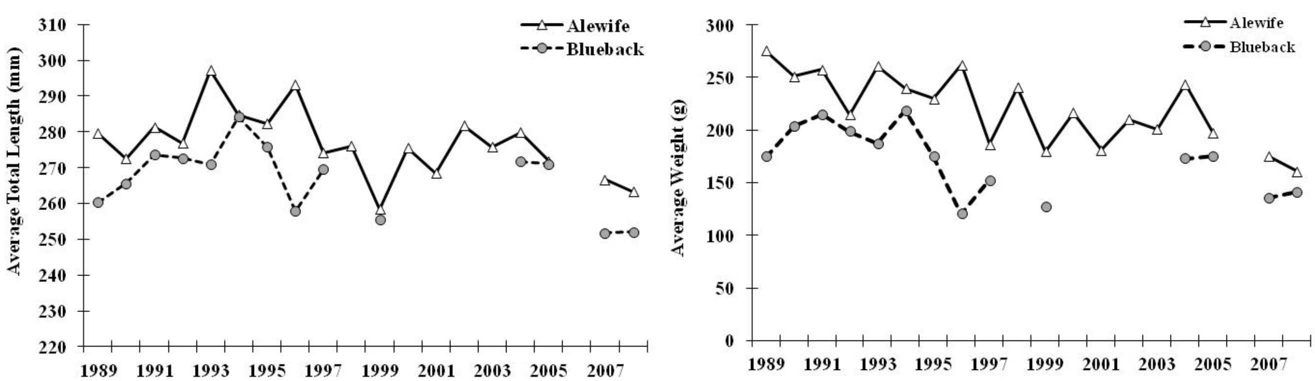



Figure 3. Average length (mm, top) and weight (g, bottom) of alewives and blueback herring sampled from Virginia's commercial landings, 1989–2008.

than that for blueback herring in both tributaries throughout the time series; however catchability of alewives and blueback herring may differ.

**Assessment Results**

Trends in Relative Abundance: The indices of relative abundance of adult alewives and adult blueback herring in the Rappahannock River derived from the VIMS Experimental Anchor Gill-Net Survey were found to have significantly decreasing trends over the time series.

Temporal Trends in Size: There was a statistically significant decreasing trends over time for the average length and weight of both male and female alewives sampled from the Rappahannock River commercial pound net fishery. Additionally, despite the limited data from recent years, the annual average lengths of male and female blueback herring show a statistically significant declining trend over time.

Mortality: Estimates of annual *Z*s for alewives ranged from a low of 0.44 to a high of 1.8 among all computed estimates. Annual *Z*s were highest in the Rappahannock River for most years. Alewife samples from the James River yielded the lowest estimates of *Z*. Blueback herring total mortality estimates ranged between 0.32 and 2.0. Estimates of blueback herring *Z*s were generally similar among the three rivers.

**Benchmarks**

The available data for alewives and blueback herring in the James, York, and Rappahannock rivers were considered insufficient to perform a reliable assessment of the status of these stocks. The data were also considered inadequate for developing benchmarks.

**Summary**

The available data reported here are insufficient to quantitatively assess the current status of alewives and blueback herring in the James, York, and Rappahannock rivers. Based on the results of fishery-independent sampling there is strong evidence that commercial harvest data since 1994 are not an accurate depiction of the species composition of the catch in Virginia. The species are likely misidentified in Virginia reported harvest and landings and this fact significantly diminishes our understanding of their exploitation. Abundance indices of juveniles depict considerable annual variability and show little trend over the available time series. However, there are no data on juvenile abundance during the 1950s to 1970s when landings were higher and spawning runs were presumably stronger. The collapse of Virginia's commercial river herring fishery in the late 1970s reflects the same trend that has been observed for river herring landings along the U.S. east coast (Schmidt et al. 2003). This pattern has also been reported for Virginia's stocks of American shad during the same time period (ASMFC 2007). In the case of American shad, the VMRC imposed a ban on fishing in the Chesapeake Bay and its tributaries in 1994 in response to declining harvest. At the time, fisheries-independent data were insufficient to assess the stocks and there were no existing monitoring programs to evaluate stock status. Subsequent research and the recent ASMFC stock assessment have confirmed that the 1994 ban on fishing was an appropriate action that has led to some recovery in the York River system (ASMFC 2007).

## Status of River Herring Stocks in North Carolina

### Distribution, Biology and Management

River herring have historically been found in all N.C. coastal rivers and streams, with the main populations found in the Albemarle Sound and its tributaries. Smaller runs historically occurred in the Tar, Pamlico, Neuse and Cape Fear River systems. The management of river herring in North Carolina is conducted in joint and coastal waters by the NCDMF and in inland waters by the NCWRC. The management units established in the 2000 Albemarle Sound River Herring Fishery Management Plan (ASFHRMP) include the two species of river herring (blueback and alewife) and their fisheries throughout coastal North Carolina (Figure 1).

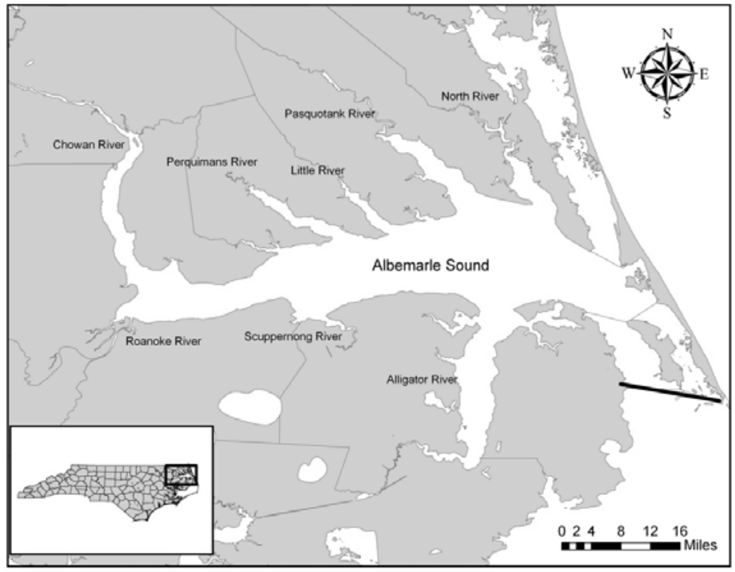



Figure 1. Map of North Carolina and the Albermarle Sound region

### The Fisheries

River herring once supported commercial and recreational fisheries in most of North Carolina's coastal rivers. Due to overfishing, habitat loss and water quality degradation, river herring landings in North Carolina began to decline in the mid to late 1980's (Figure 2). The Albemarle Sound area has always been the center of the North Carolina fishery, accounting for 66-100% of the state's river herring harvest from 1889 to 1994. Currently, the commercial fishery is restricted to a 7,500 pound research set aside, with 4,000 pounds allocated to be harvested over a 4 day period during the Easter holiday weekend in the Chowan River. Participation is limited to permitted fishermen.

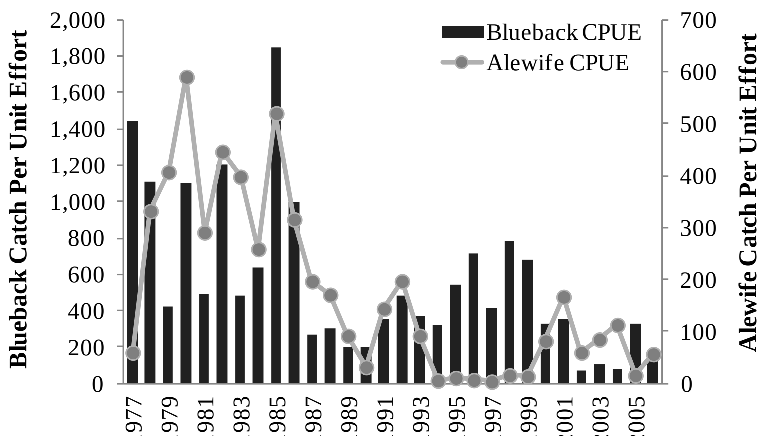



Figure 2. Catch per unit effort for blueback herring and alewife from the Chowan River commercial pound net fishery 1977-2006.

### Indices

The DMF began nursery area sampling for juvenile blueback herring and alewife in the Albemarle Sound area in 1972. This survey was designed to index annual relative abundance of juvenile blueback herring and alewife (Figure 3).

Since 1990, NCDMF has been conducting an independent gill net survey throughout the Albemarle Sound area (Figure 3). The survey was designed for striped bass data collection. However, river herring are captured during the survey and size, age, and sex data are collected.

**Assessment Results**

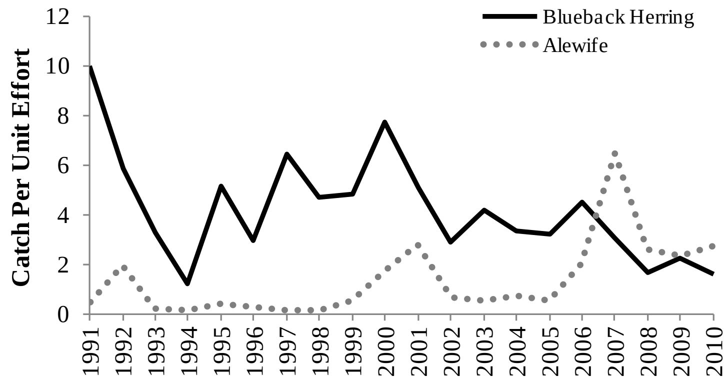


Figure 3. Catch per unit effort for alewife and blueback herring from the Albemarle Sound Independent Gill Net Survey, 1991-2010.

Exploitation rates for blueback herring in the Chowan River before the 2007 moratorium ranged as low as 0.14 in 1979 to as high as 0.87 in 1986. Exploitation averaged about 0.28 prior to 1985, increased to an average of 0.70 during 1985–1988, and averaged about 0.40 between 1989 and 2006. Since the moratorium, exploitation rates have been close to zero. Fishing mortality averaged about 0.34 prior to 1985, increased to an average of 1.3 during 1985–1988, and averaged about 0.56 between 1989 and 2006. Since the moratorium, fishing mortality has been close to zero.

Blueback herring total abundance (3+) declined steadily from 133 million fish in 1976 to 31 million fish in 1979. Total abundance increased through 1983 to 62 million fish but then declined precipitously to its lowest value of 0.74 million fish in 2002. Since 2007, total abundance has averaged 1.40 million fish. Age-3 abundance peaked at 97 million fish in 1975, declined to 28.0 million fish in 1980, increased to 62 million through 1983, and then declined precipitously to its lowest value of 0.7 million fish in 2002. Since 2007, total abundance of age-3 fish has averaged 2.3 million fish.

Female SSB fluctuated but declined steadily from the peak of 5.2 million kilograms in 1972 to a low of 0.14 million kilograms in 1986. Female SSB increased slightly to 0.45 million through 1990, but then it declined slowly to its lowest level of 15 thousand kilograms in 2003. Since 2004, female SSB has averaged about 81 thousand kilograms.

For exploitation rates and female SSB, the retrospective patterns were over- and under-estimation of the value, respectively. For the total population abundance, the terminal year value was consistently under-estimated.

**Benchmarks**

From the spawner-recruit data and production model, $F_{\mathrm{MED}}$ was estimated to be 0.59. The fishing mortality rate that produces maximum sustainable yield, $F_{\mathrm{MSY}}$, was 0.39 and corresponding spawning stock bass, $SSB_{\mathrm{MSY}}$, was 1,955,333 kilograms. $SSB_{\mathrm{MSY}}$ was higher than the 20% of the equilibrium spawner biomass, $SSB_{20\%}$ (1,195,873 kilograms). Current female spawning stock biomass is only 5% of $SSB_{\mathrm{MSY}}$. The fishing mortality rate that drives the population to extinction, $F_{\mathrm{COL}}$, was 0.91. The estimates of $F_{\mathrm{MSY}}$ and $F_{\mathrm{COL}}$ are considerably lower than those estimated for alewife ($F_{\mathrm{MSY}} > 1.0$; $F_{\mathrm{COL}} > 1.82$) in three Canadian rivers by Gibson and Myers (2003b). When comparing fishing mortality rate estimates to the derived reference points the fishing mortality exceeded all reference points several times over the time series, particularly after 1985.

**Summary**

The previous North Carolina River Herring Fishery Management Plan (2007) concluded that the ASMA river herring stock was undergoing overfishing and was overfished, despite the low TAC. No model used in the assessment (Grist, 2005) was estimated to rebuild the stock within the legal time frame of 10 years. Based on these results, the 2007 FMP recommended a fishing moratorium, coupled with gear restrictions (no use of gill nets <3 ¼-inch stretched mesh and limiting 3 ¼-inch gill nets to 800 yards, eliminate use of drift gill nets and limiting pound net participants). A limited harvest (7,500 lbs) was set aside for research purposes. The 2007FMP identified four stock recovery indicators for the Chowan River blueback herring stock:

1. A three-year running average juvenile abundance index of greater than 60 fish per haul
2. A spawning population comprised of greater than 10% repeat spawners
3. A spawning stock biomass of greater than 4 million pounds (1.8 million kg)
4. And a three-year running average of greater than 8 million age three fish.

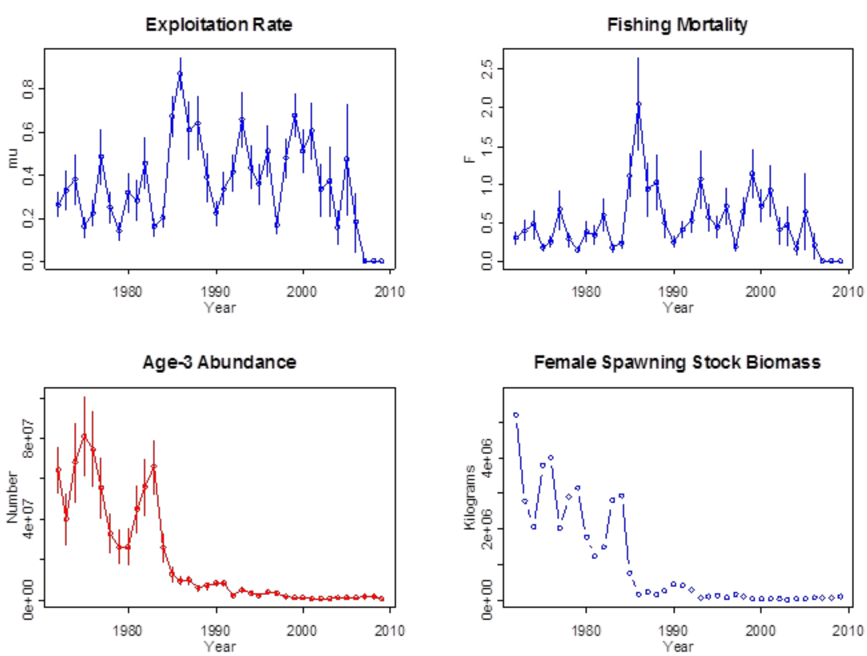



Figure 4. Estimates of exploitation rates, derived fishing mortality rates, recruitment (age-3 numbers), and estimates of female spawning stock biomass (in kilograms) for Chowan River blueback herring. Vertical lines, where present, represent 95% confidence intervals.

The factors leading to this recommendation remain largely unchanged since 2007, despite a fishing pressure that is almost negligibly low. Therefore, although the stock is not currently experiencing overfishing, it remains overfished since the spawning stock biomass remains less than 5% of the amount necessary to replace itself in the complete absence of fishing.

While current research programs are recommended to continue, assessing progress towards recovery goals would be improved with additional research and surveys. Data collected through the Chowan River Pound Net Survey and the juvenile abundance surveys are essential in determining stock status of Chowan River blueback herring. Although the Chowan River is the dominant system for river herring in North Carolina, the 2007 FMP identified a research need to expand data collection to all areas of the Albemarle Sound as well as other systems in the state.

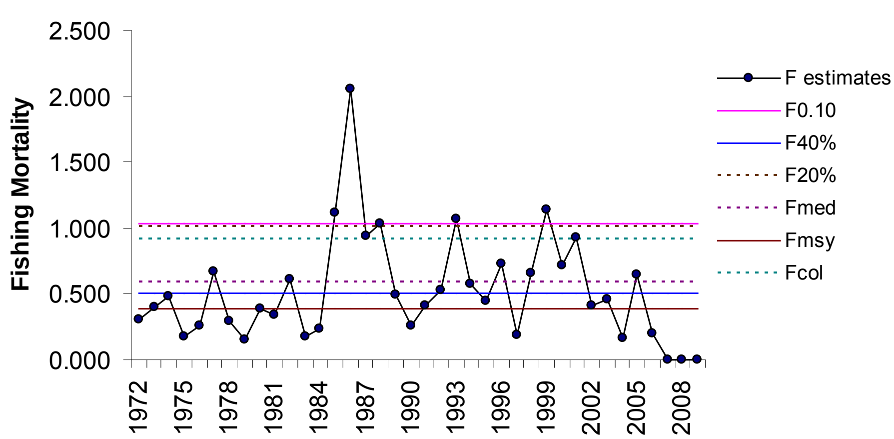



Figure 5. Comparison of fishing mortality rates to reference points.

## Status of River Herring Stocks in South Carolina

### Distribution, Biology and Management

Historically, river herring (blueback herring *Alosa aestivalis* and alewife *Alosa pseudoharengus*) occurred in most of South Carolina's major rivers. In recent years, there has been no evidence of alewife in South Carolina and we believe that North Carolina has become the southernmost extent of their range. Blueback herring of South Carolina spawn in the spring in freshwater portions of coastal rivers and streams. Blueback herring in the Santee River are iteroparous and have been observed to spawn up to four times over their lifetime. Mature fish leave the spawning reaches shortly after spawning. Once in the ocean, blueback herring from the Santee River migrate widely along the Atlantic Coast. Tag returns from fish tagged in spring in the Santee River have been recaptured from as far north as the Bay of Fundy (Christie and Cooke 1987)

Management of blueback herring in South Carolina is shared between the Marine Resources and Freshwater Divisions of the Department of Natural Resources (SCDNR). Management units are defined by stock and the complex of river(s) utilized.

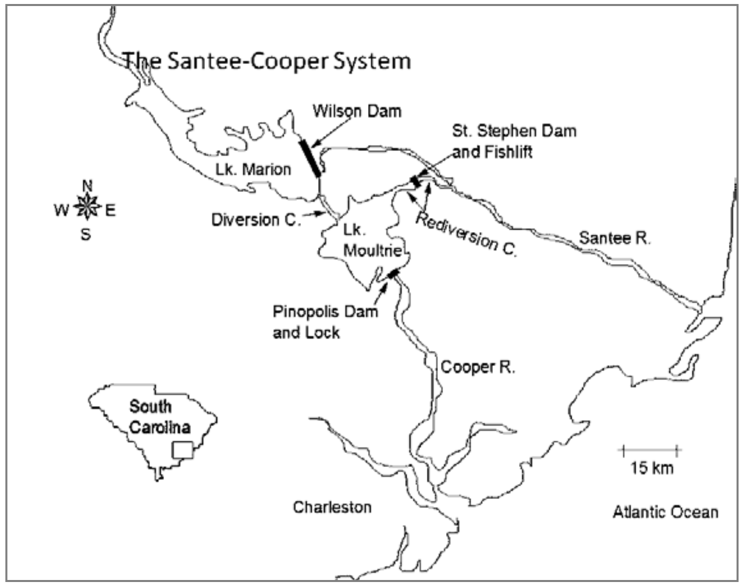



Figure 1. Map of Santee-Cooper River, SC

### The Fisheries

Commercial fisheries for blueback herring in South Carolina occur to a limited extent in open rivers such as Winyah Bay tributaries, but most fishing activity occurs in hydro-electric tailraces of the Santee-Cooper River system. The SCDNR manages commercial herring fisheries using a combination of seasons, gear restrictions, and catch limits. Today, the commercial fishery for blueback herring has a 10 bushel daily limit (227 kg) per boat in the Cooper and Santee Rivers and the Santee-Cooper Rediversion Canal and a 250 lb (113.4 kg) per boat limit in the Santee-Cooper lakes. Seasons generally span the spawning season. All licensed fishermen have been required to report their daily catch and effort to the SCDNR since 1998. Annual variation in reported landings since the early 1970s may have been influenced by changes in allowable catch over the years. Landings in the Santee Cooper system were also affected by changes in discharge from the three dams and concurrent changes in fish migration and gear effectiveness.


Figure 2. Commercial landings of river herring, in kilograms, in South Carolina (1969 – 2010).

Recreational fisheries for blueback herring exist, but only as a bycatch to the American shad fishery. The recreational fishery has a 1 bushel (22.7 kg) fish aggregate daily creel for blueback herring in all rivers; however very few recreational anglers target blueback herring. Catch per unit effort of blueback herring in the recreational fishery varied without trend from 2003 through 2007.

**Indices**

Data are available to assess trends in fishery and stock status of blueback herring for the following river systems and life stages in South Carolina: Cooper River, Santee River, and the Rediversion Canal for adult herring and Winyah Bay, Waccamaw River, Santee River, Cooper River, Edisto River, and Combahee River for juveniles.

**Assessment Results**

Mark recapture population estimates of blueback herring were conducted in the Santee River from 1977 through 1990. Resulting population estimates varied substantially among years and had wide confidence limits. Estimates declined from 1980 to 1982, then increased through 1990 with the exception of a one-year decline in 1987 one year after completion of the Rediversion Canal The increase in Santee River population estimates after completion of the canal occurred concurrently with the decline in CPUE in the commercial fishery on the Cooper River. It is interesting to note that estimates began to increase in the Santee River in 1984 which was the second year of a harvest ban in the Santee Fishery, but one year before the rediversion was completed. The population estimates did not correlate with passage numbers at the St. Stephen Fish Lift in 1986-1990.

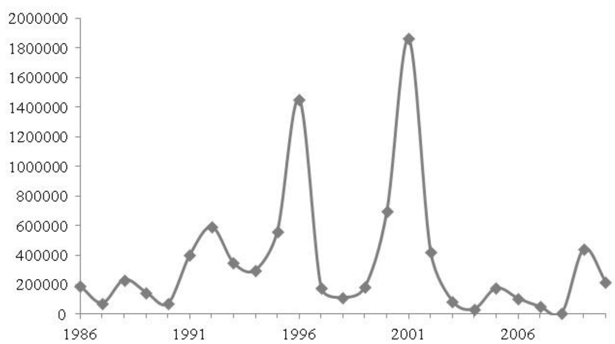


Figure 3. Number of blueback herring lifted over the St. Stephens Dam on the Santee-Cooper Rediversion Canal, SC

Fish released upriver of the St. Stephen Dam are counted as they pass through the exit channel of the fish lift. Numbers were interpreted from hydro-acoustic sampling in 1986 and1987, real-time observer counts in 1988-1994, and from time-lapse video recording from 1994 through 2007. With the exception of 1996 and 2001 annual counts were below 700,000 animals. Lowest counts occurred in 2004 with 35,545 animals and in 2007 with 49,343 animals. Since efficiency of the lift operation is poorly known and probably varied among years with changes in operational characteristics and river flow, we did not consider passage numbers to be good indices of numbers of blueback herring in the Santee-Cooper system.

Mean size (fork length-mm) of blueback herring in the St. Stephen's Fish Lift on the Rediversion Canal declined between 1991 and 2007. Decreased length could result from declining recruitment to the fished population or from increased mortality. Mean age of blueback herring in both rivers increased prior to rediversion as the age structure broadened to include older fish. This increase was most dramatic in the Cooper River where the increase encompassed a time period prior to and during rapid population increase.

Limited juvenile abundance data for blueback herring in South Carolina have been obtained by electrofishing. Catches of blueback herring in this sampling have been too low to detect annual trends.

**Benchmarks**

Biological reference points were not calculated for any South Carolina river herring stock**.**

**Summary**

All available data show that river herring landings have declined from historic levels in South Carolina.

Abundance of blueback herring in the Santee and Cooper Rivers has varied widely between rivers and among years. Changes in abundance appear to have resulted from a combination of habitat alteration from flow regulation and drought, and from fishing.

Abundance of blueback herring in the Cooper River was reduced in the early 1970s from apparent over fishing. It rebounded a bit in the early 1980s after imposition of harvest regulations, but declined again following the rediversion of water from the Cooper back to the Santee River in 1985. Abundance has remained low in the Cooper River since that time.

Blueback herring abundance in the Santee River increased following rediversion and remained at relatively high levels through the 1990s. Abundance declined abruptly in the early 2000s after several years of drought. Rates of mortality from commercial harvest of this stock from 1990 through the present have been low and it is unlikely that fishing has affected stock abundance or age structure. We do not know if current abundance indices (CPUE, minimum population size) reflect low stock level resulting from poor recruitment following the drought or are just low index values caused by decreased effectiveness of fishing and passage.

We recommend that:

- Age data be obtained from blueback herring of the Santee River, the Santee-Cooper Rediversion Canal, and the Cooper River and that the commercial creel survey of tailrace fisheries in the system be continued. Age and harvest data are important to understanding current stock dynamics and factors affecting recent river herring abundance.
- Estimates be made of blueback herring absolute abundance in the Santee system to verify abundance changes suggested indices. Estimates should be made for three or more contiguous years.
- A sample program be developed or existing programs be improved to track annual production of young. Numbers of blueback herring collected in current sample programs for juvenile fish are too low for meaningful evaluations.
- Commercial harvest regulations should not be relaxed for the Santee-Cooper system.
- Harvest in the Cooper River and Rediversion Canal recreational fisheries appear to be minor since herring are not target species. However, we advise continuing the creel survey to monitor this fishery.
- Bycatch of river herring in near-shore-ocean fisheries should be evaluated, in concert with other states.

# Status of River Herring Stocks in Georgia and Florida

**Distribution, Biology and Management**

The St. Johns River, Florida harbors the southernmost spawning run of blueback herring *Alosa aestivalis* on the Atlantic coast of the United States. Blueback herring in Florida are iteroparous and spawn in the St. Johns River from January to late March and occasionally early April. There is no active management of blueback herring in Florida. Blueback herring are known to occur in the St. Johns and St. Mary's rivers which would presumptively be two independent management units. The St. Mary's River on the Georgia/Florida border is known to have historically contained a blueback herring run but no data are available for an assessment of the St. Mary's. Additional populations of blueback herring have been reported in Georgia include the Altamaha and Ogeechee Rivers, as well as the Savannah River on the Georgia/South Carolina Border.

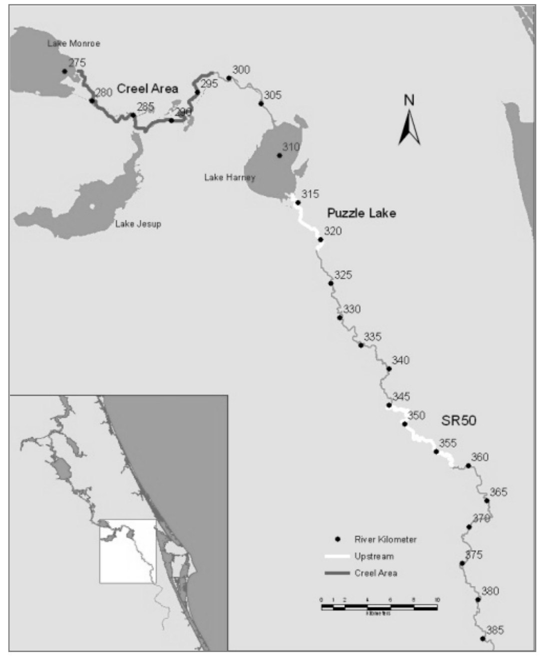



Figure 1. Map of St. Johns River, FL.

**The Fisheries**

The St. John's River run is currently not harvested by either commercial or recreational anglers and no harvest has been recorded since the 1960s. Limited landings data and anecdotes suggest that the blueback herring run in the St. Johns River was large in the past. There is no directed fishery. Gear restriction preclude there being any fisheries operating where bycatch is likely. Various gear restrictions have effectively eliminated all commercial harvest of blueback herring in Florida waters and there is no known recreational fishing for them.

No fisheries target blueback herring in Florida and no fisheries are operating in the river that are likely to encounter blueback herring as by-catch. Any additional source of fishing mortality of sub-adults or adults is probably remote to the St. Johns River such as those in the Atlantic mackerel and Atlantic herring fisheries in the northeast (Harrington et al. 2005).

**Indices**

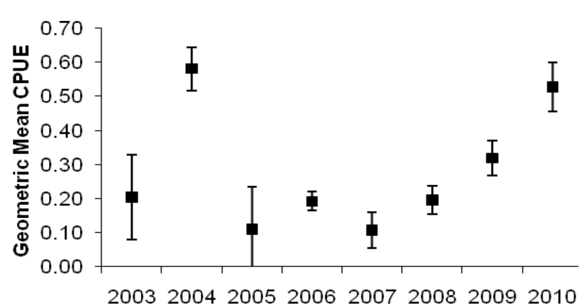



Figure 2. Average catch of adult blueback herring per 10 minute electrofishing transect during February and March in the St. John's River.

River herring had been largely ignored in the St. Johns River until Florida began to implement monitoring for American shad (*Alosa sapidissima*) in accordance with Amendment 1 of the Shad and River Herring Fishery Management Plan. Monitoring efforts are directed at American shad since there is an active, though small, recreational American shad fishery in Florida There are no long time series of either fishery dependent or fishery independent data for this stock. Modern abundance indices are not directly comparable to the limited historical data because gears used and sampling methods differ. Available data, though limited in scope, suggest that modern blueback herring abundance is low in the St. Johns River, Florida. Spawning adults are smaller than those collected by researchers in 1972 and 1973. Blueback herring were much more abundant than American shad *Alosa sapidissima* in fishery independent samples in 1972 and 1973 and are now the less abundant in contemporary sampling within the St. Johns River even with shad abundance also historically low.

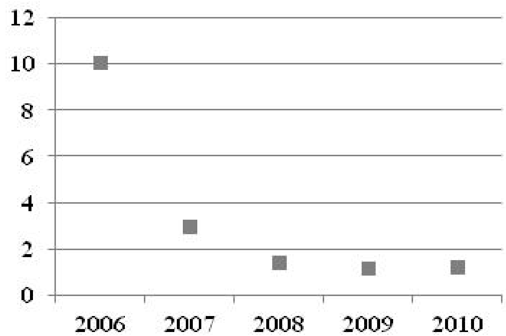


Figure 3. Geometric mean catch per 5-minute sample in the push trawl survey for juvenile blueback herring in the St. Johns River, FL.

In-migrating adult Alosa species were collected by seine in 1972 and 1973. Williams et al. 1975 reported 355.3 and 268.3 blueback herring per seine haul during January – March in 1972 and 1973 respectively. Juveniles were collected by seine and towed surface trawl throughout the year in 1972 and 1973. Subsequent juvenile sampling in those years yielded 1983 blueback herring and 273 American shad in 1972 and 4050 blueback herring and 655 American shad in 1973.

Adult Alosa species were collected on the spawning grounds in the St. Johns River by electrofishing beginning in 2001. The sampling protocol was standardized beginning in 2003. Sex, total length (TL) (mm), and weight (g) were recorded for all *Alosa spp.* collected. From 2003 to 2005 scales and otoliths were retained but aging has not been attempted. Electrofishing CPUE has been low and without trend since 2003.

A bow mounted pushnet was constructed in 2006 to begin developing a juvenile abundance index for Alosa species in the St. Johns River, Florida. The average catch rate of juvenile blueback herring was greatest in 2006 during testing of the new gear. Since then, catches have been lower under the standard protocol with catches of juvenile American shad being similar to or exceeding the catch of blueback herring. No trend analysis is feasible on this short time series.

**Assessment Results**

*Trends in Size:* Blueback herring collected in 1972 and 1973 were larger than those collected in modern sampling (McBride et al. 2010). Although the gears are different and were fishing different sections of the river there isn't reason to believe that either gear was size selective. The reduced mean length of adult blueback herring during 2001-2010 as compared to the runs in 1972 and 1973 could point to a demographic shift. The mean size of blueback herring spawning in the St. Johns River in 2001-2010 corresponds to age 3-4 fish in the 1972 and 1973 runs during which 2.9% and 17% of males and 0.6% and 9.6%. of females were age 4 in those years. The majority of spawning herring in 1972 and 1973 were older than age 4. Such a shift in demographics can be the result of increased mortality. We have no modern age data so we cannot confirm that the change in size is reflective of reduced growth or age truncation in the St. Johns River population.

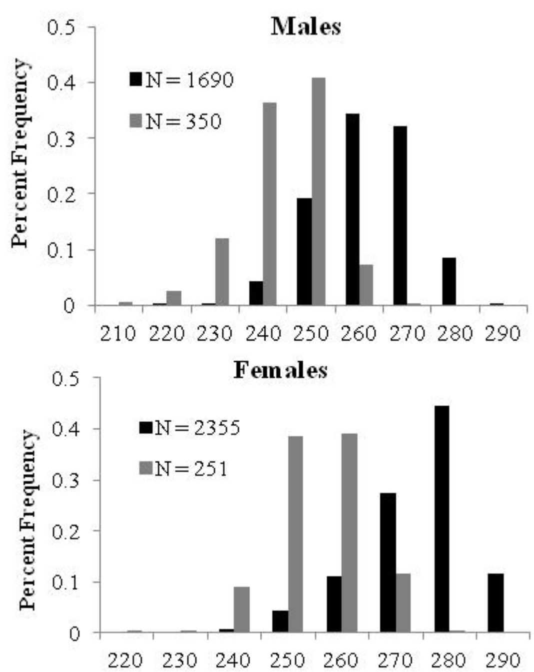


Figure 4. Percent frequency of males (top) and females (bottom) by length by length (in mm) in the St. John's River, FL.

*Relative Abundance:* Adult herring were far more abundant, 9.7 and 7.4 times, than American shad in seine samples in 1972 and 1973 but shad were more numerous in modern electrofishing samples, often by greater than a factor of 10 even though the American shad population is at low abundance (McBride and Holder 2008). However, we do not know whether or not electrofishing is selective for American shad relative to blueback herring or whether by focusing on the primary river channels sampling is missing areas where herring aggregate in this system. Electrofishing in small tributaries and along the littoral zones of larger lakes for other monitoring has not detected blueback herring. To date they are primarily encountered in the main stem of the river when electrofishing for American shad.

Juvenile herring were six to seven times more abundant that American shad in 1972 and 1973 samples. Juvenile American shad were as or more abundant than juvenile blueback herring in four out of five years of modern (2006-2010) sampling with a pushed trawl. The geographic and temporal coverage was similar between the 1972-73 sampling and modern sampling. There is no reason to believe that the pushed trawl is more selective for American shad relative to herring than the surface trawls and seines used in 1972 and 1973. Catch rates are not comparable between the different gears but the proportion of each species present has changed.

Neither measure of relative abundance is conclusive and it may be a stretch to base the assessment of blueback herring abundance on the relative abundance of blueback herring as compared to the relative abundance of American shad in common samples. However, the low adult relative abundance of blueback herring in electrofishing samples corresponds to what appears to be low relative abundance of juveniles in trawl gear. Blueback herring were the most abundant alosine in the St. Johns River, Florida in past decades (Hale et al. 1985, Moody 1961, Williams et al. 1975). Taken in aggregate these indices do point to low blueback herring abundance relative to historic levels in the St. Johns River.

**Benchmarks**

Data are insufficient to establish a benchmark for the St. John's River or Savannah River.

**Summary**

The reduced size of adults might indicate increased mortality remote to the St. Johns. The age structure of the returning adults needs to be determined in order to establish whether the reduced size is a result of a change in growth or age structure of returning adults.

Water quantity and quality are potential threats to both spawning success and juvenile growth and survival to out-migration. As noted in the habitat section, alosines spawn during the dry season in the St. Johns River when water levels are typically low. This may make them particularly sensitive to withdrawals. Data are needed on habitat selection by adults for spawning in order to assess how habitat might be affected by proposed water withdrawals and changes in average stage.

Juvenile monitoring should continue to assess whether any changes in water quality or habitat impact annual juvenile abundance.

There is no blueback herring fishery in Florida therefore there are no possible fishery interventions that would improve the population of blueback herring in the St. Johns River, Florida. The source of at sea mortality needs to be determined and reduced and water quality problems within the St. Johns River should be addressed if blueback herring population of the St. Johns River is to increase.

## Trends in Alewife and Blueback Herring from the Northeast Fisheries Science Center Bottom Trawl Surveys

**Description of NEFSC Bottom Trawl Survey**

The Northeast Fisheries Science Center (NEFSC) bottom trawl surveys are conducted in both the spring and fall and sample from Maine through North Carolina (Azarovitz et al 1997). These surveys were used to investigate trends in alewife, blueback herring and river herring (combined alewife and blueback herring) relative abundance and biomass, mean length, and growth. The surveys follow a stratified random sampling design with strata defined primarily by depth and stations allocated approximately in proportion to stratum area (Azarovitz 1981; Figure 1). Strata have been most consistently sampled by the research vessels *Albatross IV* and *Delaware II* since the fall of 1975 and spring of 1976. Prior to these time periods, either only a portion of the survey area was sampled or a different vessel and gear were used to sample the inshore strata. In 2009, the survey changed primary research vessels from the *Albatross IV* to the *Henry B. Bigelow*.

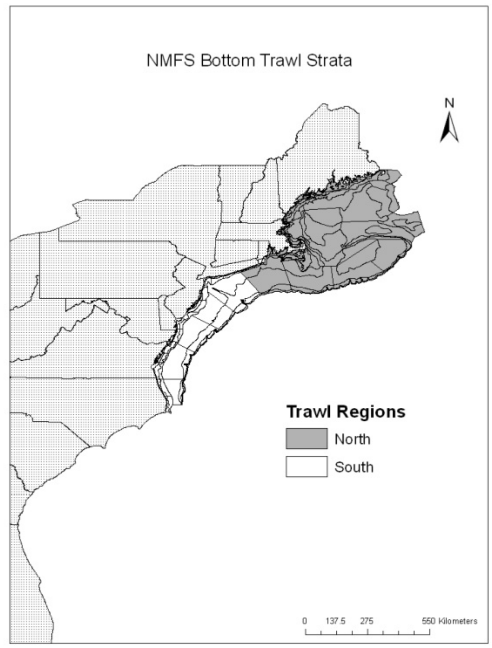



Figure 1. NEFSC bottom trawl survey strata comprising the northern and southern regions.

**Data Analysis**

Relative abundance (stratified mean number-per-tow) and biomass (stratified mean kilogram-per-tow) indices were calculated for alewife and blueback herring using data from NEFSC spring (1976-2011) and autumn (1975-2011) bottom trawl surveys. Survey indices were developed for each species separately as well as for both species combined (i.e., river herring). For both seasons, survey indices were computed for the entire northwest Atlantic coast. For the spring survey, indices were also calculated separately for a northern set and a southern set of survey strata (Figure 1). Bottom trawl catches of the subject alosid species tend to be higher during the daytime due to diel migration patterns. Accordingly, only daytime tows were used to compute relative abundance and biomass indices. Calibration factors used to convert *Bigelow* and *Delaware II* catches to *Albatross IV* equivalents (Byrne and Forrester 1991; Miller et al. 2010).

To assess trends in relative abundance indices, autoregressive integrated moving average models (ARIMA, Box and Jenkins 1976) were fit to log-transformed stratified mean catches. The terminal year of the survey was compared to an index based reference point (the 25$^{th}$ percentile of the fitted index values) and the probability of being less than the reference point in the terminal year was estimated [P(<0.25)].

Trends in mean length (fork length, cm) of alewife and blueback herring were assessed using a non-parametric Mann-Kendall test for a monotonic trend. Age data for river herring were available for a limited time period from 1973 – 1987. Non-linear regression was used to fit season-specific von Bertalanffy growth models to both the coastwide and regional data.

**Results**

Predicted values from ARIMA models for alewife showed an increasing trend coastwide during both seasons and in the northern region during the spring. These indices exhibited a 0.0 probability that the relative abundance in the final year was below the 25$^{th}$ percentile reference point (Figure 2). However, the spring survey index for the southern region showed a decreasing trend with a 0.446 probability that the 2011 relative abundance was below the 25$^{th}$ percentile reference point.

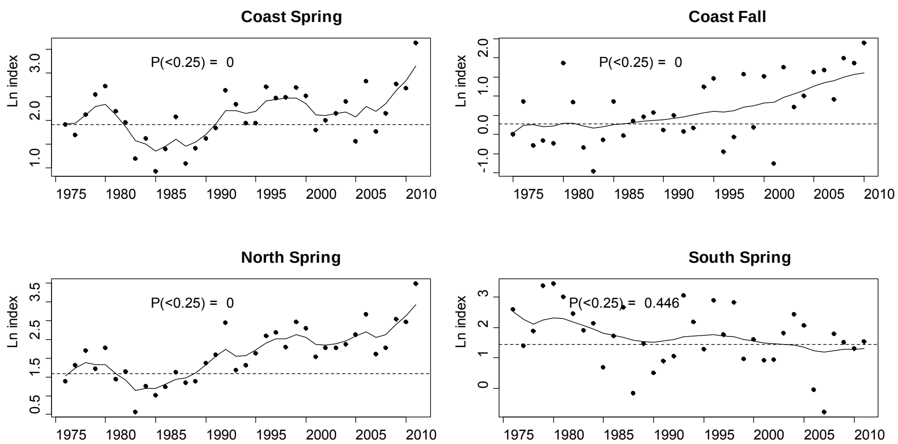



Figure 2: Autoregressive integrated moving average (ARIMA) model fits to alewife stratified mean number-per-tow from the NEFSC bottom trawl survey. The dotted horizontal line represents the 25th percentile of the fitted values and the probability represents the probability that the fitted value in the terminal year is less than the 25th percentile index based reference point with 80% confidence.

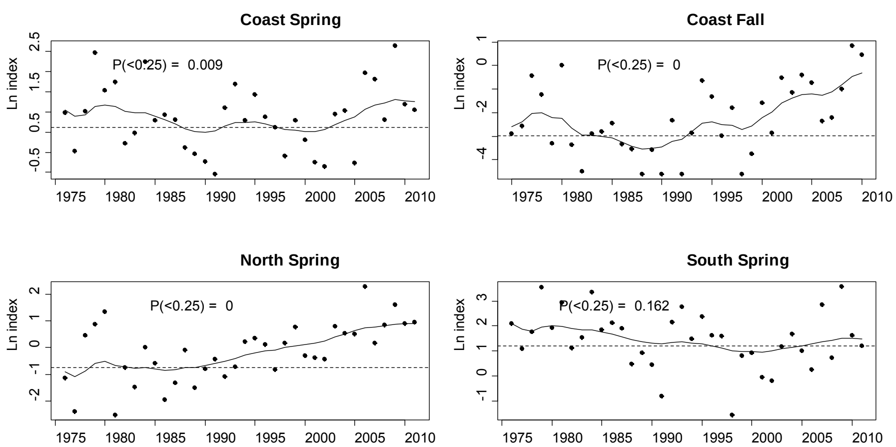



Figure 3: Autoregressive integrated moving average (ARIMA) model fits to blueback herring stratified mean number-per-tow from the NEFSC bottom trawl survey. The dotted horizontal line represents the 25th percentile of the fitted values and the probability represents the probability that the fitted value in the terminal year is less than the 25th percentile index based reference point with 80% confidence.

Blueback herring and also showed similar patterns to alewife, with increasing abundance trends coastwide during the fall and in the northern region during the spring. In the spring, the southern region appeared to decline in the beginning of the time series, but appeared to vary without trend after approximately 1990. For this region and season, the probabilities of being below the 25th percentile reference point in 2011 was 0.162 for blueback herring.

Alewife mean length significantly decreased in all seasons and regions (Table 1). Blueback herring mean length significantly decreased for the coastwide index in the fall. However, blueback herring mean length significantly increased in the southern region in the spring (Table 1). For the coastwide and northern spring indices, blueback herring mean length did not exhibit a significant monotonic trend.

Alewife lengths ranged from 6 to 30 cm and ages ranged from 1 to 14 years. Blueback herring lengths ranged from 6 to 28 cm and ages ranged from 1 to 12 years. Approximate 95% confidence limits were compared to infer differences in growth parameters among regions and seasons. Alewife $L_\infty$ and K were not significantly different between seasons in coastwide growth models. During spring surveys, $L_\infty$ was slightly greater in the northern region compared to the southern region, but K was greater in the southern than in the northern region. Blueback herring growth parameters did not differ significantly among seasons or regions, potentially due to low sample sizes.

## Discussion

Catches of river herring in the NEFSC bottom trawl surveys varied spatially and temporally. River herring catches generally appeared to increase in northern areas during spring surveys. However in the southern region, river herring catches appear to either decrease or vary without trend. These trends are more evident for alewife than for blueback herring. Differences in relative abundance trends among regions could be a consequence of true regional differences in population trends or a distributional shift of the species. Nye et al. (2009) observed a northward shift in the distribution of alewife, and found that changes in the distribution of multiple species in the NEFSC trawl surveys were correlated with large-scale warming and climactic conditions such as the Atlantic Multidecadal Oscillation.

Table 1: Results of the Mann-Kendall test for a monotonic trend in mean length of river herring from NEFSC spring and fall bottom trawl survey data. Negative *S* statistics indicate a declining trend and positive *S* statistics indicate an increasing trend.

| Species | Region | Season | Years of data | Mann-Kendall *S* statistic | p-value |
|---|---|---|---|---|---|
| Alewife | Coast | Fall | 36 | -162 | 0.03 |
| | | Spring | 36 | -292 | <0.01 |
| | North | Spring | 36 | -228 | <0.01 |
| | South | Spring | 36 | -144 | 0.05 |
| Blueback | Coast | Fall | 36 | -203 | 0.01 |
| | | Spring | 36 | -56 | 0.45 |
| | North | Spring | 36 | -71 | 0.34 |
| | South | Spring | 36 | 184 | 0.01 |

Mean lengths tended to decrease for river herring from the NEFSC bottom trawl surveys, which could be indicative of increasing mortality (Beverton and Holt 1957). However, indications of increasing mortality are contradictory to the observed increasing trends in relative abundance, especially in the northern region during the latter part of the time series.

Table 2: Von Bertalanfy growth parameters for river herring from NMFS bottom trawl survey (1973 - 1987). CL is the approximate 95% confidence limits on parameter estimates.

| Species | Region | Season | n | $L_\infty$ | CL($L_\infty$) | K | CL(K) | $t_0$ | CL($t_0$) |
|---|---|---|---|---|---|---|---|---|---|
| Alewife | Coast | Spring | 7,165 | 29.44 | 29.24 - 29.64 | 0.40 | 0.39 - 0.41 | -0.22 | -0.26 - -0.19 |
| | | Fall | 1,203 | 29.45 | 28.88 - 30.01 | 0.36 | 0.33 - 0.39 | -1.33 | -1.50 - -1.16 |
| | North | Spring | 4,224 | 30.33 | 30.02 - 30.65 | 0.35 | 0.34 - 0.37 | -0.30 | -0.35 - -0.25 |
| | South | Spring | 2,941 | 28.26 | 28.05 - 28.48 | 0.49 | 0.47 - 0.51 | -0.09 | -0.13 - -0.04 |
| Blueback | Coast | Spring | 128 | 27.15 | 26.23 - 28.08 | 0.50 | 0.42 - 0.57 | 0.20 | 0.07 - 0.33 |
| | | Fall | 16 | 27.73 | 26.01 - 29.45 | 0.35 | 0.23 - 0.47 | -1.74 | -2.63 - -0.85 |
| | North | Spring | 31 | 28.13 | 23.93 - 32.33 | 0.38 | 0.21 - 0.54 | -0.03 | -0.43 - 0.38 |
| | South | Spring | 85 | 26.70 | 25.96 - 27.45 | 0.58 | 0.50 - 0.67 | 0.31 | 0.19 - 0.42 |

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# 1.0 INTRODUCTION

This document provides a benchmark assessment of river herring (alewife, *Alosa pseudoharengus*, and blueback herring, *Alosa aestivalis* ) stocks of the U.S. Atlantic Coast from Maine through Florida. It was prepared by the River Herring Stock Assessment Subcommittee of the Atlantic States Marine Fisheries Commission (ASMFC) Shad and River Herring Technical Committee. The analyses and descriptions stem from data and summary reports provided by U.S. Federal and State freshwater and marine resource management agencies, power generating companies, and universities to the ASMFC.

## 1.1 GENERAL BIOLOGY

### 1.1.1 Life History

*Compiled by: Laura M. Lee, Virginia Marine Resource Commission*

River herring is a collective term that is used to refer to alewives and blueback herring. Both species are anadromous, highly migratory, schooling, pelagic fishes that spend most of the annual cycle at sea, but migrate to fresh water to spawn in the spring. Alewives are distributed from the Gulf of St. Lawrence and northern Nova Scotia south to North Carolina (Berry 1964; Rullifson et al. 1982; Rulifson 1994). Blueback herring are distributed from Nova Scotia to the St. John's River in northern Florida and are most abundant in waters from the Chesapeake Bay south (Bigelow and Schroeder 1953; Hildebrand 1963; Leim and Scott 1966; Scott and Crossman 1973; Williams et al. 1975; Manooch 1988; Scott and Scott 1988). Landlocked stocks for both species occur (Klauda et al. 1991; Waldman and Limburg 2003), but this occurrence is much rarer for blueback herring (Schmidt et al. 2003).

River herring are anadromous, returning to their natal waters to spawn in the spring. However, some individuals have been found to stray to adjacent streams or colonize new areas; others have even reoccupied systems from which they were previously extirpated (Havey 1961; Thunberg 1971; Messieh 1977; Loesch 1987). Most river herring reach sexual maturity between 3 and 6 years of age. The onset of spring spawning is related to temperature and varies with latitude. Alewives spawn at lower temperatures than other alosine fishes and typically migrate earlier (Schmidt et al. 2003). At the southern end of their range, alewives spawn from late February to June (Marcy 1976b; Neves 1981; Loesch 1987). Further north, alewives typically spawn from June through August. Blueback herring begin spawning as early as December or January at the extreme southern end of their range (McLane 1955; Marcy 1976a). At the northern end of the range, blueback herring may not spawn until June and spawning can continue through August (Leim and Scott 1966; Marcy 1976b). Both species are broadcast spawners, releasing their eggs over a variety of substrates. Adults leave the spawning grounds immediately after spawning, reaching deep water by fall.

Eggs hatch between 50 and 360 hours (2 to 15 days) after spawning, depending on water temperature (Fay et al. 1983), but most often hatch within 80 to 95 hours (3 to 4 days; Edsall 1970). Larvae begin to feed externally three to five days after hatching and transform gradually into the juvenile stage. Juvenile alewives and blueback herring begin migrating from their nursery areas as water temperatures decline in the fall. Other factors that trigger downstream migration include changes in water flow, water levels, precipitation, and light intensity. There is some evidence that a high abundance of juveniles may trigger a very early (e.g., summer) emigration of large numbers of small juveniles from the nursery area (Richkus 1975). Little information is available concerning the life history of sub-adult and adult river herring once they migrate to the sea.

The species are distinct and can be distinguished by cutting the abdomen and examining the pigmentation of the peritoneum, the membrane that lines the abdominal cavity. In alewife, the peritoneum is pale or white; in blueback herring, the peritoneum is sooty dark or black. This dissection is not a routine procedure in most commercial fisheries. When fresh specimens of both species are in hand, the alewife has a much larger eye and is deeper bodied than blueback herring. Despite these clear differences, the species are often misidentified and mixed in fishery statistics. To further complicate assessments of abundance and stock status, river herrings can be confused with young American shad, hickory shad, Atlantic menhaden, Atlantic herring, and other similar species. Scientists suspect that these species are often misidentified and mixed in reports of harvest and landings.

Because alewives migrate earlier than other alosine fishes (blueback herring, American shad, hickory shad), they are usually the first anadromous species available for harvest each year in most Atlantic Coast rivers. The flesh of river herrings is consumed usually as a smoked, salted, or fresh product. The ripe ovaries (roes) of females are highly prized. The annual spring spawning runs of river herring stocks and American shad are an important cultural and culinary event in many states and their traditional fisheries have cultural significance. In addition to human consumption, river herrings are the prey of striped bass, blue catfish, longnose gar, and other predators encountered along the migratory route. A comprehensive review of river herring biology and their ecological services is presented by Munroe (2002).

### 1.1.2 Predation

*Compiled by: Dr. Katie Drew, Atlantic States Marine Fisheries Commission*

Alewife and blueback herring are an important forage fish for marine and anadromous predators, such as striped bass, spiny dogfish, bluefish, Atlantic cod, and pollock (Bowman et al. 2000, Smith and Link 2010). Historically, river herring and striped bass landings have tracked each other quite well, with highs in the 1960s, followed by declines through the 1970s and 1980s (Figure 1.1). Although populations of Atlantic cod and pollock are currently low, the populations of striped bass and spiny dogfish have increased in recent years (since the early 1980s for striped bass and since 2005 for spiny dogfish) while the landings and run counts of river herring remain at historical lows. This has led to speculation that increased predation may be contributing to the decline of river herring and American shad (e.g., Hartman 2003, Crecco et al. 2007, Heimbuch 2008).

Quantifying the impacts of predation on alewife and blueback herring is difficult. The diet of striped bass has been studied extensively, and the prevalence of alosines varies greatly depending on location, season, and predator size (Walter et al. 2003). Studies from the northeast US continental shelf show low rates of consumption by striped bass (alewife and blueback herring each make up less than 5% of striped bass diet by weight) (e.g., Smith and Link 2010), while studies that sampled striped bass in rivers and estuaries during the spring spawning runs found much higher rates of consumption (greater than 60% of striped bass diet by weight in some months and size classes) (e.g., Walter and Austin 2003, Rudershausen, et al. 2005). Translating these snapshots of diet composition into estimates of total removals requires additional data on both annual per capita consumption rates and estimates of annual abundance for predator species.

The diets of other predators, such as bluefish and spiny dogfish, along with marine mammals and birds, have not been quantified nearly as extensively, making it more difficult to assess the importance of river herring in the freshwater and marine food webs. As a result, some models predict a large effect of predation (e.g., Hartman 2003, Heimbuch 2008), while other studies did not find an effect (e.g., Tuomikoski et al. 2008, Dalton et al. 2009).

In addition to predators native to the Atlantic coast, river herring are also vulnerable to invasive species such as the blue catfish (*Ictalurus furcatus*) and the flathead catfish (*Pylodictis olivaris*). These catfish are large, opportunistic predators native to the Mississippi River drainage that were introduced into rivers on the Atlantic coast. They've been observed to consume a wide range of species, including alosines, and ecological modeling on flathead catfish suggests they may have a large impact on their prey species (Pine 2003, Schloesser et al. 2011). In August 2011, ASMFC approved a resolution calling for efforts to reduce the population size and ecological impacts of invasive species and named blue and flathead catfish specifically as species of concern due to their increasing abundance and potential impacts on native anadromous species. Non-native species are a particular concern because of the lack of native predators, parasites, and competitors to keep their populations in check.

Predation and multispecies models, such as the MS-VPA (NEFSC 2006), have tremendous data needs and more research needs to be addressed before they can be applied to river herring. However, given the potential magnitude of predatory interactions it is an area of research worth pursuing.

## 1.2 HABITAT DESCRIPTION

*Compiled by: Laura M. Lee, North Carolina Division of Marine Fisheries*

River herring utilize a variety of habitat throughout their lifecycle. As adults, river herring reside in marine waters most of the year and move to freshwater rivers to spawn. Nursery areas primarily include freshwater portions of rivers and their associated bays and estuaries. Both alewives and blueback herring can tolerate a wide range of salinities. Alewives may prefer cooler water and northern populations may be more cold tolerant than other migratory anadromous fish (Stone and Jessop 1992).

Alewives spawn over a range of substrates such as sand, gravel, organic detritus, and submerged aquatic vegetation in a diversity of physical habitats that includes rivers, small streams, lakes, and ponds. Blueback herring usually spawn over sand or gravel in swift-flowing areas of freshwater tributaries, channel sections of fresh and brackish tidal rivers, and Atlantic coastal ponds over gravel and clean sand substrates, especially in northeastern rivers where alewives and blueback herring coexist. In southeastern rivers where alewives are few, blueback herring exhibit more of a variety in their spawning sites including shallow areas covered with vegetation, rice fields, swampy areas, and small tributaries upstream of the tidal zone. Substrates with 75% silt or other soft material containing detritus and vegetation are suggested as optimal for spawning, egg, and larval habitat for river herring.

Nursery habitats for alewives and blueback herring occur in non-tidal and tidal freshwater and semi-brackish areas during spring and early summer, moving upstream during periods of decreased flows and encroachment of saline waters. In the lower Chesapeake Bay, juvenile river herring can be found among submerged aquatic vegetation beds, which have been linked to improved water quality.

Along the U.S. continental shelf, Neves (1981) found that catches of river herring were most common at depths less than 92 meters. The National Marine Fisheries Service (NMFS) observed alewives in water depths from 56 to 110 meters in offshore areas. Blueback herring were found at depths of 27 to 55 meters throughout their offshore range. Stone and Jessop (1992) looked at the seasonal distribution and relative abundance of river herring offshore of Nova Scotia. They found that catches shifted from mid-depths in the spring (101–183 meters) to shallower, near shore waters (46–82 meters) in the summer and finally to deeper offshore waters (119–192 meters) in the fall.

## 1.3 STATE REGULATIONS

*Compiled by: Dr. Gary Nelson, Massachusetts Division of Marine Fisheries and Kate Taylor, Atlantic States Marine Fisheries Commission*

**Maine**

The Department of Marine Resources (DMR), along with municipalities granted the rights to harvest river herring resources, cooperatively manage these municipal fisheries. Each town must submit an annual harvesting plan to DMR for approval that includes a three-day per week escapement period or biological equivalent to insure conservation of the resource. In some instances, an escapement number is calculated and the harvester passes a specific number upstream to meet escapement goals. River herring runs not controlled by a municipality and not approved as sustainable by the ASMFC River Herring and American Shad Management Board, as required under Amendment 2, are closed.

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

The state permitted twenty-two municipalities to fish for river herring in 2011. The river specific management plans require the remaining municipalities to close their runs for conservation and not harvest. There are several reasons for these state/municipal imposed restrictions on the fishery. Many municipalities voluntarily restrict harvest to increase the numbers of fish that return in subsequent years. Some of these runs are large, but have the potential to become even larger. The commercial fishery does not exploit the estimated 1.5 – 2.0 million river herring that return to the East Machias River annually.

Recreational fishermen are allowed to fish for river herring year-round. The limit is 25 fish per day and gear is restricted to dip net and hook-and-line. Recreational fishermen may not fish in waters, or in waters upstream, of a municipality that owns fishing rights. Recreational fishermen are not required to report their catch. The MRFSS and MRIP programs do sample some of these fishermen based on results queried from the database. Recreational fishing for river herring in Maine is limited and landings are low.

**New Hampshire**

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

The current general regulations are: 1) no person shall take river herring, alewives and blueback herring from the waters of the state, by any method, between sunrise Wednesday and sunrise Thursday of any week, 2) any trap or weir used during the period specified in paragraph (a) above, shall be constructed so as to allow total escapement of all river herring, and 3) any river herring taken by any method during the period specified in paragraph (a) shall be immediately released back into the waters from which it was taken. Specific river regulations are:

<u>Taylor River</u>: From the railroad bridge to the head of tide dam in Hampton shall be closed to the taking river herring by netting of any method.

<u>Squamscott River</u>: During April, May and June the taking of river herring in the Squamscott River and its tributaries from the Rt. 108 Bridge to the Great Dam in Exeter is open to the taking of river herring by netting of any method only on Saturdays and Mondays, the daily limit shall be one tote per person (“tote”

means a fish box or container measuring 31.5"x 18" x 11.5") and the tote shall have the harvester's coastal harvest permit number plainly visible on the outside of the tote.

These regulations have been approved through a sustainable fisheries management plan, as required under ASMFC Amendment 2 to the Shad and River Herring FMP.

**Massachusetts**

In response to drastic declines of many river herring spawning runs the Massachusetts Marine Fisheries Advisory Commission approved in November of 2005 a three year moratorium regulation on the harvest, possession and sale of river herring in the Commonwealth. The moratorium was extended in 2008 through 2011. As of January 1, 2012, public hearings are scheduled to consider extending the moratorium through 2015.

**Rhode Island**

Currently there is a moratorium on harvest of river herring (alewives and blueback herring) in Rhode Island's fresh and marine waters (RIDFW Reg. Part II; RIMF Reg. Part 7.20). Due to drastic declines in spawning stock size beginning in 2001, Rhode Island passed regulations in March 2006 for the complete closure. Prior to 1998, the freshwater daily river herring limit was 12 fish per day and closed Sunday, Monday, and Tuesday. There were no regulations for marine waters. In 1998 the daily freshwater limit was increased to 24 with the same closed days, and then decreased to 12 in 2005. The 2006 closure marked the first time there were reciprocal regulations for Rhode Island marine and fresh waters. The marine and freshwater closure continued through 2012.

**Connecticut**

River herring were harvested primarily by haul seine, dip net, gill net and otter trawl. Trawling is prohibited in Connecticut estuaries and is not allowed inland of a statutory line that is generally not more than ¼ mile from shore. The gill net and haul seine fisheries were primarily directed toward collecting fish for bait. The fishermen involved were commercial as well as personal use lobstermen and recreational anglers. The drift gill net fishery operated in Long Island Sound and the Connecticut and the lower Thames River. Since 2002, there has been a prohibition on the commercial or recreational taking of migratory alewives and blueback herring from all marine waters and most inland waters. This action was initially taken in April of 2002, and has been extended through 2012.

**New York**

During the 19$^{th}$ century, regulating fisheries within New York waters was the sole responsibility of the state. In 1868, in response to an apparent decline in American shad, the New York State legislature implemented fishing net restrictions, an escapement period and a season to control fishing on the Hudson. It is likely that these restrictions (season and net use) also affected the take of river herring, as all three Alosines (American shad, alewife and blueback herring) occurred in the river at the same time. Some variant of these 19$^{th}$ century rules still exist to the present. Current regulations allow for a restricted river herring commercial and recreational fishery in the Hudson River and tributaries, while all other state waters prohibit river herring fisheries. These regulations have been approved through a sustainable fisheries management plan, as required under ASMFC Amendment 2 to the Shad and River Herring FMP.

**New Jersey/Delaware**

No specific regulations had historically been adopted to reduce or restrict commercial landings of river herring, however there were regulations that apply to the commercial fishery which limited commercial fishing effort and have a direct impact on catch. In Delaware, these restrictions included a limited entry license system, limitations on the amount of gear allowed to be fished, and season and area closures. New Jersey also has general regulations that applied to the commercial fishery such as limited entry, limitations on the amount of gear, time /area restrictions and gear restrictions in defined areas. Pennsylvania and New York do not permit the commercial harvest of river herring within the Delaware River Basin. As of January 1, 2012 commercial harvest of river herring was prohibited in New Jersey and Delaware, as required by ASMFC Amendment 2 to the Shad and River Herring FMP.

Historically, the recreational fishery for river herring was very small with few participants and low retention rates. Those herring that were landed were typically frozen for bait, pickled, kept for their roe and other traditional uses. In Delaware, the recreational fishery took place at the various low-head dams that form mill ponds on the majority of Delaware's tidal rivers where herring concentrated during the spring spawning season. Prior to 2005, no limits for river herring existed for the State of Delaware. In an effort to prevent over exploitation of these small herring runs, a 25 fish limit was adopted in 2005. The popularity of this fishery continued to increase and consequently a 10 fish possession limit was adopted in the spring of 2008 to help conserve remaining spawning stocks and to prevent "stock-piling" in net pens or live cars. New Jersey historically had a 35 fish creel limit, in aggregate of alewife and blueback herring, with recreational gear such as hook and line, dip net, bait seine, and cast net. As of January 1, 2012 recreational harvest of river herring was prohibited in New Jersey and Delaware, as required by ASMFC Amendment 2 to the Shad and River Herring FMP.

**Maryland**

Maryland's commercial river herring fishery was historically seasonally restricted, running from 1 January to 5 June, but since most fish returned to the ocean by June, this law had little, if any, management consequences. Up until 2005, it was primarily a directed fishery using drift gill nets with meshes ranging from $3^{1/8}$ to $3^{1/4}$ inches. A limited pound and fyke net bycatch fishery also existed. After 2005, the directed fishery reported few fish and little effort, and many commercial gill netters no longer targeted river herring. A directed commercial river herring fishery developed after 2006 in a select Chesapeake Bay tributary, based on landing records, and was the result of new spring regulations that allowed the use of river herring as live bait to target striped bass in the upper Chesapeake Bay. As of January 1, 2012 commercial harvest of river herring was prohibited in Maryland, as required by ASMFC Amendment 2 to the Shad and River Herring FMP.

Maryland's recreational river herring fishery was also seasonally restricted, running from 1 January to 5 June, with no size or creel limits on river herring, but with gear and area restrictions on harvest. Historically, anglers used dip nets to catch river herring and very few herring were caught by hook and line, usually when fishing for other species. Maryland has no recreational landings data but limited data from other sources indicates that catches are minimal but there may be small incidental catches of river herring for striped bass bait that is not documented. As of January 1, 2012 recreational harvest of river herring was prohibited in Maryland, as required by ASMFC Amendment 2 to the Shad and River Herring FMP.

**Potomac River Fisheries Commission / District of Columbia**

Since the first meeting of the Potomac River Fisheries Commission (PRFC) in 1963, the Commission has never had any specific regulations regarding river herring. However, gear specific mesh size restrictions (which generally would not impact the herring catch), and prohibitions against certain gears such as purse nets, trawls, trammel nets, troll nets, or drag nets have been in place. The PRFC regulates only the mainstem of the river, while the tributaries on either side are under Maryland and Virginia jurisdiction. The District Department of the Environment (DDOE) has authority for the Potomac River to the Virginia shore and other waters within D.C. Today, the river herring harvest in the Potomac is almost exclusively taken by pound nets. In 1964, licenses were required to commercially harvest fish in the Potomac River. After Maryland and Virginia established limited entry fisheries in the 1990's, the PRFC responded to industry's request and, in 1995, capped the Potomac River pound net fishery at 100 licenses. As of January 1, 2010 harvest of river herring was prohibited in the Potomac River, with a minimal bycatch provision of 50 pounds per licensee per day for pound nets. These regulations have been approved through a sustainable fisheries management plan, as required under ASMFC Amendment 2 to the Shad and River Herring FMP.

**Virginia**

Virginia's Department of Game and Inland Fisheries (VDGIF) is responsible for the management of fishery resources in the state's inland waters. As of January 1, 2008, possession of alewives and blueback herring was prohibited on rivers draining into North Carolina. (4 VAC 15-320-25). The Virginia Marine Resources Commission (VMRC) is responsible for management of fishery resources within the state's marine waters. There were creel and length limits for anadromous (coastal) alewives and blueback herring above and below the fall line in all coastal rivers of the Chesapeake Bay, but there were no creel or size limits in place for alewives or blueback herring taken from Virginia's tidal waters. The VMRC's gill net regulations allowed a smaller minimum mesh size for the harvest of river herring during late winter/spring in designated areas of the James, Mattaponi, Pamunkey, and Rappahannock rivers (4 VAC 20-430 et seq.). As of January 1, 2012 commercial and recreational harvest of river herring was prohibited in all waters of Virginia, as required by ASMFC Amendment 2 to the Shad and River Herring FMP.

**North Carolina**

From 1915-1965 various regulations including season and area closures as well as gear restrictions were implemented in the North Carolina river herring fisheries. Beginning in 1995 various restrictions including season closures and total allowable catch limits were implemented. In 2000, two management areas were established with an annual quota of 300,000 pounds divided between the management areas by gear. Additionally a 25 fish per person per day aggregate alewife and blueback herring recreational creel limit was established. The commercial annual quota was further reduced in 2006. A no harvest provision for river herring, commercial and recreational, within North Carolina was approved in 2007. A limited research set aside of 7,500 pounds was established to collect data necessary for stock analysis, and to provide availability of local product for local festivals. To implement this harvest of this discretionary amount, a Discretionary Herring Fishing Permit (DHFP) was created. Individuals interested in participating had to meet the following requirements: (1) obtain a DHFP, (2) harvest only from the Joint Fishing Waters of Chowan River during the harvest period, (3) must hold a valid North Carolina Standard Commercial Fishing License (SCFL) or a Retired SCFL, and (4) participate in statistical information and data collection programs. Sale of harvested river herring must be to a licensed and permitted River Herring Dealer. Each permit holder was allocated 125-250 pounds for the four day season during Easter weekend. These regulations have been approved through a sustainable fisheries management plan, as required under ASMFC Amendment 2 to the Shad and River Herring FMP.

The North Carolina Wildlife Resources Commission (NCWRC) has authority over the Inland Waters of the state. Since July 1, 2006, harvest of river herring, greater than 6 inches has been prohibited in the inland waters of North Carolina's coastal systems.

**South Carolina**

The South Carolina Division of Natural Resources (SCDNR) manages commercial herring fisheries using a combination of seasons, gear restrictions, and catch limits. In 1964, commercial blueback herring fishing in Cooper River was restricted to daylight hours with a dip net not more than three feet in diameter and a limit of 100 pounds per fisher per day. By 1969, regulations had been liberalized to allow nets with six foot diameters, fishing until ten o'clock p.m., and no limit on the harvest. Between 1966 and 1969, herring were abundant and the fishery expanded. Fishing success declined in the early 1970s and a limit of 100 pounds of herring per fisher day was re-imposed in 1975. Today, the commercial fishery for blueback herring has a 10 bushel daily limit (500 pounds) per boat in the Cooper and Santee Rivers and the Santee-Cooper Rediversion Canal and a 250 pounds per boat limit in the Santee-Cooper lakes. Seasons generally span the spawning season. All licensed fishermen have been required to report their daily catch and effort to the SCDNR since 1998. The recreational fishery has a 1 bushel (22.7 kg) fish aggregate daily creel for blueback herring in all rivers; however very few recreational anglers target blueback herring. These regulations have been approved through a sustainable fisheries management plan, as required under ASMFC Amendment 2 to the Shad and River Herring FMP.

**Georgia**

The take of blueback herring is illegal in freshwater. Historically, blueback herring could be taken for bait by using dip nets and cast nets. Harvest of blueback herring for any other purpose other than as bait was prohibited. As of January 1, 2012, harvest of river herring was prohibited in Georgia, as required by ASMFC Amendment 2 to the Shad and River Herring FMP.

**Florida**

The St. Johns River, Florida harbors the southernmost spawning run of blueback herring. There is currently no active management of blueback herring in Florida. Historically, regulations concerning river herring and shad prohibited the harvest or attempted harvest of any shad or river herring, by or with the use of any gear other than hook and line gear. As of January 1, 2012, harvest of river herring was prohibited, as required by ASMFC Amendment 2 to the Shad and River Herring FMP.

## 1.4 PAST ASSESSMENTS

*Authored by: Andrew W. Kahnle, New York State Department of Environmental Conservation*

The first coast-wide ASMFC assessment of Atlantic coastal river herring stocks was conducted by Crecco and Gibson (1990). This assessment evaluated the status of six blueback herring stocks and nine alewife stocks between New Brunswick, Canada and North Carolina, USA using long term commercial catch and effort, age composition, and relative abundance data for juveniles and adults. The assessment developed benchmark estimates of maximum sustained yield (MSY) and of fishing rates ($u$) at MSY ($u_{msy}$) and at stock collapse ($u_{coll}$). Benchmark fishing rates were then compared to recent estimates of u. Stocks were considered overfished if the observed $u$ exceeded $u_{msy}$ and severely overfished if $u$ exceeded $u_{coll}$. Stocks were considered fully exploited if $u$ was within 75% of $u_{msy}$ and partially exploited if $u$ was less than 75% of $u_{msy}$. Models were modified to include both inriver and ocean fishing to allow predictions of effects of change in ocean fishing on benchmark estimates for in-river fisheries in two blueback herring stocks.

To obtain benchmark estimates of MSY and $u$, the assessment combined biomass per recruit (B/R) and yield per recruit (Y/R) from species specific (stocks combined) Thompson-Bell yield per recruit models with species and stock specific Shepherd stock recruitment relationships to generate equilibrium spawning stock biomass, recruitment, and yield at a range of instantaneous fishing rates ($F$). Resulting curves were then used to identify MSY, $F$ at MSY, and $F$ at stock collapse. Instantaneous fishing mortality rates were then converted to estimates of $u_{msy}$ and $u_{coll}$ assuming a type I fishery. Thompson-Bell models were run for fishing rates from $F = 0.1$, to $F = 2.1$ by 0.1 increments. The model used a natural mortality of $M = 1.0$, a composite maturity schedule (species and stocks combined), weight at age based on species specific von Bertalanffy growth parameters (stocks combined), and full recruitment to fishing for ages three through eight. The stock recruitment (S-R) curve was fit to recruitment in numbers and spawning stock biomass for four alewife stocks and three blueback herring stocks. The slope of the S-R curve at the origin or alpha ($\alpha$) and the spawning stock biomass at which density – dependent effects become dominant (*K)*, were determined by least squared regressions. The slope of the S-R curve ($\beta$) was constrained to values between 0.7 and 2.0 during model fitting. The assessment explored alternate estimates of alpha using: life history based models and observed intrinsic rate of increase in 10 alewife stocks and 1 blueback herring stock in New England that had colonized previously inaccessible habitat. Mean alpha estimates from the S-R curves, the life history models, and the observed population increase were similar suggesting that those used in the S-R analyses were adequate.

Estimates of recent instantaneous total mortality (Z) were developed for five alewife and six blueback herring populations using the catch curve method applied to age data or spawning frequencies. Estimates of *u* were then developed by subtracting *M* from Z and converting *F* to *u*. Estimates of in-river *u* were also obtained directly for three populations of alewife and two populations of blueback herring by dividing total in-river catch by spawning escapement plus catch.

Shepherd stock recruitment relationships were developed for alewives from the St John River, New Bruswick (1968-1982); Damariscotta River, Maine (1949-1989); the Lamprey River, New Hampshire (1972-1985), the Annaquatucket River, Rhode Island (1945-1989) and for blueback herring in the St. John River (1968-1982); the Connecticut River (1971-1989), and the Chowan River, North Carolina (1972-1988). There was no latitudinal gradient in the degree of fit to observed data or to the alpha or K parameters. The shapes of the S-R curves varied among stocks and included power functions, asymptotic curves and dome shaped curves. Sustainable annual fishing rates ($u_{msy}$) for alewife ranged from 0.59 for the St. John River and Annaquatucket Rivers to 0.70 for the Damariscotta and Lamprey Rivers. The K parameter was positively correlated to river area. Sustainable fishing rates for blueback herring ranged from 0.67 in the Chowan River to 0.75 in the St John and Connecticut Rivers. Fishing rates at collapse followed a similar trend among rivers. Mean estimates of *u* at MSY and collapse for the three blueback herring stocks were $u_{msy} = 0.73$ and $u_{coll} = 0.86$. Mean estimates for the four alewife stocks were $u_{msy} = 0.65$ and $u_{coll} = 0.79$.

Estimates of MSY for alewives ranged from 95 x $10^3$ pounds for the Lamprey River to 756 x $10^3$ for the St. John River. MSY for blueback herring ranged from 288 x $10^3$ pounds in the St. John River to 7072 x $10^3$ pounds in the Chowan River. MSY was positively correlated to river area.

There were positive relationships between alpha (a) and F at MSY and collapse among the seven stocks for which a stock recruitment curve was generated. These relationships (species combined) were used to predict *F* and then *u* at MSY and collapse for five additional alewife stocks and four additional blueback herring stocks for which alpha estimates had been obtained from either life history or stock growth approaches. The mean $u_{msy}$ across all river systems was significantly greater for blueback herring stocks ($u_{msy} = 0.68$) than the mean $u_{msy}$ for alewives ($u_{msy} = 0.64$). The mean annual fishing rate at stock collapse was also significantly greater for blueback herring stocks ($u_{coll} = 0.83$) than for alewife stocks ($u_{coll} = 0.78$). The overall $u_{coll}$ (both species) was only about a 20% greater than $u_{msy}$ (both species) suggesting a narrow margin of error for these stocks between safe harvest levels and those that would cause stock collapse.

Recent estimates of fishing mortality rates tended to be higher at the northern and southern extremes of the geographic range where inriver fisheries occurred. Stocks in mid-Atlantic states had lower fishing mortality rates and generally did not experience inriver fisheries. Fishing rates for alewife stocks in the St.

John, Damariscotta, and Potomac Rivers exceeded $u_{coll}$, and these stocks were considered severely overfished. Fishing rates for Chowan River alewives and St. John River blueback herring exceeded $u_{msy}$ and the stocks were considered overfished. All of the alewife stocks had declined, while the blueback herring stock had not. Fishing rates for Nanticoke River alewives and blueback herring of the Chowan and Potomac Rivers were within 75% of $u_{msy}$ and the stocks were considered fully exploited. All of these stocks had also declined. Lamprey, Herring, Annaquatucket, and Rappahannock River alewife stocks and the Connecticut, Rappahannock, and Nanticoke River blueback herring stocks were considered to be partially exploited. Only blueback herring of the Nanticoke River exhibited a decline.

The authors concluded that the St. John River alewives and blueback herring and the Damariscotta, Potomac, and Chowan River alewife stocks were or had been overfished to the point that recruitment failure was apparent. The authors recommended that restrictions should be placed on these stocks to bring fishing mortality rates below $u_{msy}$ levels.

When ocean fishing mortality was added to the S-R models for blueback herring of the Chowan and Connecticut Rivers, MSY, $u_{msy}$, and $u_{coll}$ decreased for inriver fisheries. Since ocean losses to a given stock are often not known, the authors recommended that inriver fishing rates should be kept 20 - 30% below $u_{msy}$ levels for all stocks.

## 1.5 ASSESSMENT OVERVIEW

As an anadromous species, ideally river herring should be assessed and managed by individual river systems. However, the majority of the life history of river herring is spent in the marine environment where factors influencing survival likely have impacts upon multiple river stocks when they mix during marine migrations. The complex life history of anadromous species complicates assessments on a coast-wide scale as it is difficult to partition in-river factors from marine factors governing population dynamics. Also complicating the assessment of river herring is the variability in data quality among rivers along the coast.

The River Herring Stock Assessment Subcommittee assessed Atlantic coastal river herring stocks on an individual river basis where the data were available and also using a coast-wide population approach. The following sections include (1) summary of available data and usefulness; (2) a trend analysis overview that provides summaries of the most meaningful data from state and major river systems; (3) a coast-wide mixed stock population perspective exploring trend analyses, relative exploitation of a coastal analysis of the mixed stock assemblage in ocean waters, and a depletion-based stock reduction model using the mixed stock assemblage data.

We used coast wide approaches in addition to river specific approaches for several reasons. First- river herring stocks have been exploited in oceanic and estuarine mixed-stock fisheries as well as river-specific fisheries. Few of the mixed-stock fisheries are adequately monitored. There is no information about how to allocate the mixed-stock harvest among stocks. In-river data vary widely. Harvest is monitored for most in-river commercial fisheries but recreational harvest is monitored less often or non-existent. Little information is available on bycatch (discard and/or incidental catch) and so an analysis is provided.

The data gaps for river herring can be attributed mostly to the low priority the species receives in some agency monitoring efforts. This understandable prioritization results in there being few long-term fishery-independent indices, except on rivers with fish passage.

Fishery-dependent indices provide some long time series but most data contain gaps and are not documented as to stock composition as summaries provided are on a state basis, with few exceptions reported for rivers. Other concerns are on changes in effectiveness (catchability) of gear over time. Some of the current fishery-independent surveys should be of sufficient length to be useful in assessments five to 10 years from now if monitoring continues.

### 1.5.1 Summary of Available State / Jurisdiction Data

River specific data used in this assessment are summarized in Appendix 1 and the quality and quantity of available data varied greatly among river systems. The data used represents a mix of fisheries dependent and independent data sources. Time series ranged in lengths up to as many as 67 years, but most time series were of shorter duration and often were not continuous. Some rivers had a full suite of data (e.g. harvest, age, length, weight, repeat spawner, and fisheries independent surveys) while others were limited in the types of data available or had data that was not reliable for assessment purposes.

In addition to river specific data, several coastal trawl surveys were available for this assessment. Again, the length of time series of these data varied from 3 to 36 years of data.

### 1.5.2 Assessment Approaches

Given the data gaps and issues described above, we were not able to apply analyses requiring catch-at-age data to most stocks. This assessment was largely confined to analyses of trends, comparisons of trends among rivers or survey gears, and methods designed for data poor stocks, with the exception of the Monument River in Massachusetts, the Chowan River in North Carolina, and the Nanticoke River in Maryland, which had sufficient data to support statistical catch-at-age models.

### 1.5.3 Trends in available state data

As data quality varies widely along the coast we chose a simplistic trend approach. Data examined includes some fishery dependent (catch per unit effort) data, but primarily focuses on fishery-independent survey data (e.g. estimated run sizes, relative abundance indices, mean length or mean length at age, estimates of total instantaneous mortality, and in-river exploitation rates) . We chose to do this to provide some perspective of current status and to examine if patterns in trends were consistent across systems and regions. Analyses of trends included simple non-parametric Mann-Kendall tests for monotonic trends and correlation analyses to compare trends among rivers.

### 1.5.4 Trends in coastal composite data

Some data were only available as composite coastal populations stocks. There are currently no methods to allow for discrimination of individual stocks from coastal fisheries surveys. This includes several state trawl surveys conducted in near shore ocean waters (ME-NH survey, the Long Island trawl survey conducted by CT, the NJ coastal survey) and coastwide bottom trawl survey conducted by the NEFSC. Autoregressive integrated moving average (ARIMA) models were used to evaluate trends in trawl surveys and correlation analyses were used to compare trawl survey indices to run sizes of river herring.

### 1.5.5 Total mortality estimates and benchmarks

Although there are issues identified with ageing techniques, we developed benchmark estimates of total mortality to provide a perspective of the trends evident in current available mortality estimates. We used simple spawning stock biomass-per-recruit models using data inputs at the stock level where possible, although ancillary data from mixed stock sources were occasionally used as supporting information.

### 1.5.6 Relative exploitation

An index of relative exploitation was calculated from minimum swept area estimates of total biomass from the Northeast Fisheries Science Center (NEFSC) bottom trawl survey and estimates of total catch (reported U.S. landings plus incidental catch). Although this approach did not yield absolute estimates of exploitation rates that could be compared to benchmarks, it did provide a means to observe relative trends in exploitation through time.

### 1.5.7 Depletion Based Stock Reduction

A depletion-based stock reduction analysis (DBSRA) is an assessment approach for data poor stocks and was employed in this assessment to generate sustainable yield reference points and to examine trends in exploitation. This model was applied to the coastwide meta-population of river herring, rather than individual stocks.

### 1.5.8 Assessment overview summary

This assessment may not provide definitive answers to all the questions plaguing management of Atlantic coastal river herring (fishing, predation, other sources of natural mortality, fish passage), but it gives insight to managers on the complexity of the issues to assist them in decision-making. It also illustrates areas of uncertainty and lays the foundation for future assessments in terms of data sources and methods needed for data sets that may support the use of more complex assessment models.

## 1.6 DATA UNCERTAINTIES

### 1.6.1 Age and mortality uncertainty

River herring are aged using scales, using protocols first developed by Cating (1953) for American shad and Marcy (1969) for river herring. Although used extensively, these protocols have not been validated with known-age fish, and there have not been many efforts to standardize river herring ageing across states. As with any ageing method, there is the potential for bias both between labs and within labs over time as personnel change and methods are not consistently standardized.

Total mortality rates reflect the combined impact of intensive fisheries, spawning mortality, predation, and mortality associated with downstream passage at hydroelectric dams in some systems. Almost no stocks have sufficient information to separate mortality into these sources. Uncertainty about natural mortality is perhaps the biggest limiting factor in drawing strong conclusions about the status of river herring. There are no empirical estimates of natural mortality associated with spawning. Inferences about its magnitude are based almost entirely on total mortality rates and spawning marks on scales. Although interpretation of spawning marks on scales needs a validation study, spawning marks may help in establishing the magnitude of spawning mortality. Unfortunately, a lack of spawning marks may simply be a reflection of intensive fishing; for example, if a high percentage of migrants are harvested fewer will return to spawn. Considerable uncertainty also exists about the magnitude of predation. A brief description appears in the previous section. This predation could occur in rivers, estuaries, and in the ocean, and may be an important source of mortality for juvenile or adults. Recent concern has focused on predation by striped bass, whose population has increased coastwide. There is much diet information available for striped bass, but the magnitude of predation mortality is difficult to assess because of uncertainty about the proportion of the striped bass population within different bodies of water.

Length-based estimates of mortality (e.g. Beverton and Holt 1957; Gedamke and Hoenig 2006) were not considered in this assessment because of those method’s underlying assumptions of constant mortality, as well as uncertainty about the length at full recruitment to respective gears. Also, conversion of length frequency data to age frequency data by use of age-length keys from other river systems is questionable because of potential stock differences in growth patterns.

### 1.6.2 Total harvest uncertainty

Reporting requirements for anadromous fish have been strengthened across all states, and the reported landings from the directed in river commercial fisheries are considered fairly reliable in recent years. However, there are other directed and incidental fisheries that harvest river herring that are not well monitored.

River herring are caught by recreational anglers in-river, either as a target species or as bait for other gamefish. We explored, but did not use data from the National Marine Fisheries Service (NMFS) Marine Recreational Fisheries Statistics Survey (MRFSS) for several reasons. Recreational fishermen rarely catch river herring in marine waters, and MRFSS does not adequately sample the freshwater recreational fishery. As a result, MRFSS estimates of recreational catch, where they exist, have extremely high proportional standard errors (PSEs).

There is also considerable concern about potential species misidentification. Anecdotal evidence from state biologists indicates that hickory shad, which are growing in abundance, have been misidentified as river herring or young American shad, especially by anglers. Data are presented in the Fishery Dependent section, but not used due to the identified issues.

River herring are also caught incidentally at sea in fisheries targeting other species such as Atlantic herring, squid, and mackerel. The magnitude of this ocean catch is highly uncertain because of the short time series of bycatch data due to underreporting and a lack of observer coverage. In addition, there are no data on the stock composition of the incidentally caught fish and thus no way to partition estimates of bycatch among river systems. With no estimates of coastwide stock size, it is also difficult to assess the significance of these removals on the total population.

## 2.0 COASTWIDE TRENDS

## 2.1 FISHERY DESCRIPTIONS

### 2.1.1 Historical Landings Data

Anadromous species have been fished in the U.S. since human civilizations were present. Their observed spawning runs signaled the end of winter and the beginning of spring and it not only allowed sustenance for early settlers but a source of income as it was commercialized. Characteristics of these early fisheries are difficult to quantify because of the lack of quantifiable data.

The earliest commercial river herring data were generally reported in state and town reports or local newspapers. In 1871, the U.S. Fish Commission was founded, and its name has evolved through the years including the “U.S. Fish and Fisheries Commission” in 1881. This organization collected fisheries statistics to characterize the biological and economic aspects of commercial fisheries. Data describing historical river herring fisheries were available from two of this organization’s publications—the Bulletin of the U.S. Fish Commission (renamed Fishery Bulletin in 1971; Collins and Smith 1890; Smith 1891) and the U.S. Fish Commission Annual Report (USFC 1888–1940). River herring data were transcribed from these reports and entered into Microsoft Excel. When available, dollar values were converted to 2010 dollar values using conversion factors based on the annual average consumer price index (CPI) values, which were obtained from the U.S. Bureau of Labor Statistics (pers. comm.). Note that CPI values are not available for years prior to 1913 so conversion factors could not be calculated for years earlier than 1913.

There are several caveats to using the historical fisheries data. There is an apparent bias in the area sampled. In most cases there was no systematic sampling of all fisheries; instead, sampling appeared to be opportunistic, concentrating on the mid-Atlantic states. It is also difficult to assess the accuracy and precision of these data. In some instances, the pounds were reported at a fine level of detail (e.g., at the state/county/gear level), but details regarding the specific source of the data were often not described. The level of detail provided in the reports varied among states and years. Additionally, not all states and fisheries were canvassed in all years so absence of landings data does not necessarily indicate the fishery was not active; it is very possible that a canvass was not conducted. For these reasons, these historical river herring landings should not be considered even minimum values because of the variation in detail and coverage over the time series. No attempt was made to estimate missing river herring data since no benchmark or data characteristics could be found, we also did not attempt to estimate missing data in a time series at a particular location because of the biased associated with these estimates.

During 1880 to 1938, reported commercial landings of river herring along the Atlantic Coast averaged approximately 30.5 million pounds per year (Figure 2.1.). The majority of river herring landed by commercial fisheries in these early years are attributed to the mid-Atlantic region (NY–VA; Figure 2.1). The dominance of the mid-Atlantic region is, in part, due to the apparent bias in the spatial coverage of the canvass (see previous section describing methods). From 1920 to 1938, the average weight of reported commercial river herring landings was about 22.8 million pounds (Table 2.1; Figure 2.2.). The value of the commercial river herring landings during this same time period was approximately 2.87 million dollars (2010 USD; Figure 2.2 ).

### 2.1.2 Coastwide Commercial Landings

*Compiled and authored by: Christine Jensen, North Carolina Division of Marine Fisheries and Katie Drew, Atlantic States Marine Fisheries Commission*

Domestic commercial landings of river herring were presented by state (Table 2.2; Figures 2.3, 2.4 and 2.3) and by gear (Table 2.3; Figure 2.5) from 1887 to 2010 where available. Landings of alewife and blueback herring were collectively classified as "river herring" by most states. Only a few states had species-specific information recorded for a limited range of years. Commercial landings records were available for each state since 1887 except for Florida, which began in 1929, and the Potomac River Fisheries Commission (PRFC), which began in 1960 (Table 2.2). It is important to note that historic landings presented here do not include all landings for all states over the entire time period and are likely underestimated, particularly for the first third of the time series, since not all river landings were reported.

Total domestic coastwide landings averaged 18.5 million pounds from 1887 to 1928; however, landings information was sparse and only available intermittently during that time and ranged from a low of 22,000 pounds to a high of 85.5 million pounds (Table 2.2). During this early time period, landings were predominately from Maryland, North Carolina, Virginia, and Massachusetts (overall harvest is likely underestimated because landings were not recorded consistently during this time). Virginia made up approximately half of the commercial landings from 1929 until the 1970s, and the majority of Virginia's landings came from the Chesapeake Bay, Potomac River, York River, and offshore harvest. Coastwide landings increased sharply from lows in the early 1940s during World War II to more than 50 million pounds by 1951 and peaked at 74.9 million pounds in 1958. In the 1950s and 1960s, a large proportion of the harvest came from Massachusetts purse seine fisheries that operated offshore on Georges Bank targeting Atlantic herring (G. Nelson, Massachusetts Division of Marine Fisheries, personal communication) (Figure 2.5). Landings from North Carolina were also at their highest during this time and originated primarily from the Chowan River pound net fishery. Severe declines in landings began coastwide in the early 1970s and domestic landings are now a fraction of what they were at their peak having remained at persistently low levels since the mid 1990s (Figure 2.3). Moratoria were enacted in Massachusetts (commercial and recreational in 2005), Rhode Island (commercial and recreational in 2006), Connecticut (commercial and recreational in 2002), Virginia (for waters flowing into North Carolina in 2007), and North Carolina (commercial and recreational in 2007). As of January 1, 2012 river herring fisheries in states or jurisdictions without an approved sustainable fisheries management plan, as required under ASMFC Amendment 2 to the Shad and River Herring FMP, were closed. As a result, prohibitions on harvest (commercial or recreational) were extended to the following states: New Jersey, Delaware, Pennsylvania, Maryland, D.C., Virginia (for all waters), Georgia and Florida.

Pound nets were identified as the dominant gear type used to harvest river herring throughout the 1887-2010 time period (Table 2.3; Figure 2.5). Seine use was more prevalent prior to the 1960s, but by the 1980s, they were rarely used. Purse seines were only used for herring landed in Massachusetts, but made up a large proportion of the landings in the 1950s and 1960s. Historically, gill nets made up a small percentage of the overall harvest. However, even though the actual pounds landed continued to decline, the proportion of gill nets that contributed to the overall harvest has increased in recent years.

Foreign fleet landings of river herring (reported as alewife and blueback shad) are available through the Northwest Atlantic Fisheries Organization (NAFO) and are summarized in Table 2.3.

Offshore exploitation of river herring and shad (generally $\leq$190 mm in length) by foreign fleets began in the late 1960s and landings peaked at about 80 million pounds in 1969 (Table 2.3).

Total U.S. and foreign fleet harvest of river herring from the waters off the coast of the US (NAFO areas 5 and 6; Figure 2.6) peaked at about 140 million pounds during 1969 (Figure 2.7). Landings declined dramatically thereafter. After 1977 and the formation of the Fishery Conservation Zone, foreign allocation of river herring (to both foreign vessels and joint venture vessels) between 1977 and 1980 was 1.1 million pounds. The foreign allocation was reduced to 220,000 pounds in 1981 due to the condition of the river herring resource. In 1985, a bycatch cap of no more than 0.25% by catch was enacted. The cap was exceeded once in 1987 and this shut down the foreign mackerel fishery. In 1991 area restrictions were passed to exclude foreign vessels from within 20 miles of shore for two reasons: 1) in response to the increased occurrence of river herring bycatch closer to shore and 2) to promote increased fishing opportunities for the domestic mackerel fleet.

### 2.1.3 Coastwide Commercial CPUE

*Analyzed by: Gary A. Nelson, Massachusetts Division of Marine Fisheries*

All indices were normalized and graphed for comparative purposes. Linear and loess smoothers (Maindonald and Braun, 2003) were applied to all time series for a given state and species to elucidate trends in the annual estimates. Although offered as indices of relative abundance, the catch-per-unit-effort indices discussed below need to be validated in the future.

**New York**

Relative abundance of river herring is tracked through catch per unit effort (CPUE) statistics of fish taken from the targeted river herring commercial fishery in the lower Hudson River Estuary. All commercial fishers annually fill out mandatory reports. Data reported include catch, discards, gear, effort, and fishing location for each trip. Data within week is summarized as total catch divided by total effort, separately by gear type (fixed gill nets, drift gill nets, and scap nets). CPUE is calculated as the number of river herring caught per unit effort (square yards of net x hours fished). CPUE of the fixed gear fishery is used as an estimate of relative abundance as the fishery is located downriver of the spawning reach and it captures river herring moving through the reach to upriver spawning locations. Only data since 2000 was used as this is when mandatory reporting was enforced. CPUE for this gear declined slightly from 2000 to about 2006 then has slowly increased since (Figure 2.8).

**New Jersey**

New Jersey landing estimates for river herring were obtained from the NMFS for 1950 to 1999. These estimates are for the entire state and not solely from the Delaware Bay. River herring estimates for 2000 to 2010 were obtained from mandatory logbooks of the small mesh gill net fishery in Delaware Bay. The average reported landings for the time period is estimated at 8,263 pounds. There are no estimates of underreporting, however it is assumed that the current data for river herring are grossly underreported since the majority of landings are categorized as bait. New Jersey has voluntary effort data from reliable commercial fishermen in Delaware Bay. The fishery is directed towards white perch with river herring being a harvestable bycatch. The gear is not standardized and therefore the data should only be used for potential trends and not absolute numbers. CPUE has declined since 1997 (Figure 2.8).

**Maryland**

River herring commercial landings and effort data from pound nets are available from the Nanticoke River. In general, CPUE has declined over time (Figure 2.8).

**Potomac River Fisheries Commission**

River herring harvest in the Potomac River is almost exclusively taken by pound nets. In 1964, licenses were required to commercially harvest fish. After Maryland and Virginia established limited entry fisheries in the 1990’s, the PRFC responded to industry’s request and, in 1995, capped the Potomac River pound net fishery at 100 licenses. Catch-per-unit effort indices (kilograms of herring per pound net days-fished) are available from 1976-1980 and 1988-2010. CPUE indices from 1998-2008 for alewives are much lower than CPUE indices from 1976-1980 and values have declined since 1988 (Figure 2.8).

**Virginia**

Annual commercial fishery harvest rates for alewives are available from 1994 to 2010 for selected Virginia waters. The harvest rates are computed as a ratio by dividing commercial harvest (kilograms) by the number of fishing trips for each area and gear. Only fishing trips with positive harvest of alewife were included in the calculations because only positive harvest is reported. Gill net harvest rates for alewife have been variable among Virginia water bodies from 1994 to 2007 (Figure 2.9). Harvest rates in the James River have been variable, but the data suggest a general decline through 2009 and an increase in 2010.

In the Rappahannock River, there was no obvious trend in harvest rates over time, though a small peak is evident in 2000. A three-year period of relatively higher rates occurred from 2002 to 2004 and an increase in 2010. Gill net harvest rates in the York River were highest after 2002 and showed an increasing trend through 2010.

**North Carolina**

Harvest and effort data from the pound net fishery are available for alewife and blueback herring form the Chowan River from 1977 – 2006. CPUE (harvest divided by pound net weeks fished) for alewife declined from 1977 through the late 1990s, while CPUE for blueback herring declined from 1977 through the late 1980s (Figure 2.10). A slight increase in CPUE for alewife was observed through 2006. Blueback CPUE increased through the late 1990s but declined thereafter.

**South Carolina**

Annual estimates of CPUE (kg catch/man day) are available since 1969 from surveys of the Santee River and Cooper River blueback herring fisheries. Estimates of CPUE fluctuated widely over the time series. Estimates of CPUE were highest early in the time series in the Cooper River and declined dramatically soon after to a low that lasted through the late 1970s (Figure 2.10). Estimates increased again through the early 1980s and then declined as the Rediversion Canal was completed and flows shifted to the Rediversion Canal and the Santee River. CPUE increased in the Rediversion Canal and the Santee River but then began to decline in the late 1990s through 2006 and have since increased.

### Comparison of Trends in CPUE

Historical CPUE indices were compared to identify common trends among rivers and species. Common trends were identified via hierarchical cluster analysis using correlations among all rivers as the measures of similarity. Normalized CPUE indices were then plotted together based on major grouping identified in the cluster dendrogram. Trends among rivers were examined for 2000-2010. Only data from New York, Maryland, PRFC, and Virginia could be used due to missing values in the time series of other states, or the index was not considered an index of abundance.

Cluster analysis grouped the similarities of trends in CPUE into four main groups (Figure 2.11). Groups 1 and 2 represent rivers in which CPUE had opposing trends after 2007 (York and Nanticoke Rivers). Group 3 represents rivers in which CPUE increased in 2007, declined in 2008 and increased through 2010 (James and Hudson Rivers). Group 4 represents rivers in which CPUE was varied without trend from 2005-2010 (Rappahannock and Potomac Rivers).

### 2.1.4 Recreational Landings and Releases

*Compiled and authored by: Gary A. Nelson, Massachusetts Division of Marine Fisheries*

The Marine Recreational Statistics Survey (MRFSS) provides estimate of numbers of fish harvested and released by recreational fisheries along the Atlantic coast. State harvest and releases estimates for alewives (NODC code=8747010105) and blueback herring (NODC code=8747010102) were extracted from the MRFSS catch and effort estimates files available on the web. Historically, there have been few reports of river herring being taken by recreational anglers for food. Most often, river herring were taken for bait. Very few estimates were available for alewife and blueback herring (Table 2.5.). MRFSS estimates of the numbers of river herring harvested and released by anglers are very imprecise and show little trend. These data are not useful for management purposes.

MRFSS concentrates their sampling strata in coastal water areas and do not capture any data on recreational fisheries that occur in inland waters. Few states conduct creel surveys or other consistent survey instruments (diary or log books) in their inland waters to collect data on recreational catch of river herring. Some data are reported in the state chapters; but data are too sparse to conduct any systematic comparison of trends.

### 2.1.5 Ocean Bycatch of River Herring

The Magnuson-Stevens Act defines bycatch as “fish which are harvested in a fishery but are not sold or kept for personal use […]” – i.e., discards. However, the term “bycatch” is often used to refer to both discarded fish and fish which are not targeted by a fishery but caught incidentally and landed. In this assessment, we do not use the stricter Magnuson-Stevens definition and instead use the terms “bycatch” and “incidental catch” interchangeably to refer to the total catch of river herring, regardless of final disposition, that is taken in fishery operations that target other species. We use the term “discards” to refer to the portion of the incidental catch that is discarded at sea.

### 2.1.6 Previous estimates of river herring discards and incidental catch

Three recent studies have estimated river herring discards and incidental catch. These studies have used different ratio estimators based on data from the Northeast Fishery Observer Program (NEFOP), as well as different raising factors to obtain total estimates. As such, the discard and incidental catch estimates are not directly comparable among studies. Cieri et al. 2008 estimated the kept (i.e. landed) portion of river herring incidental catch in the Atlantic herring fishery. In contrast, Wigley et al. (2009) quantified river herring discards across fishing fleets that had sufficient observer coverage from July 2007 – August 2008.

Finally, Lessard and Bryan (2011) estimated the total incidental catch of alewives, blueback herring, and American shad across seven gear categories from 2000 – 2008.

Cieri et al. (2008) quantified the kept portion of river herring incidental catch in directed Atlantic herring trips using a ratio estimator as:

$$R = \frac{k_{RH}}{K_{AtlH}}$$

where $k_{\mathrm{RH}}$ represents kept (landed) river herring and $K_{AtlH}$ represents Atlantic herring landings, as reported in the vessel trip report (VTR) database. Directed trips were defined as those trips landing greater than 2,000 lbs of Atlantic herring, and total Atlantic herring landings were used as the raising factor to expand the above ratio to total kept catch. Incidental catch estimates were stratified by year, quarter, region and gear. Regions were defined as Western Gulf of Maine (GOM), Eastern GOM, Georges Bank/Cape Cod and Southern New England (SNE). Investigated gears included single midwater trawls, paired midwater trawls, purse seines and bottom trawls.

Cieri et al. (2008.) estimated an average annual landed river herring catch of approximately 324 MT in the Atlantic herring fishery for 2005 – 2007, and the corresponding coefficient of variation (CV) was 0.56. Cournane et al. (2010) extended this analysis with additional years of data. Further work is needed to elucidate how the landed catch of river herring in the directed Atlantic herring fishery compares to total incidental catch across all fisheries. Since this analysis only quantified kept river herring in the Atlantic herring fishery, it underestimates the total catch of (kept+discarded) of river herring across all fishing fleets.

Wigley et al. (2009) employed a combined ratio estimator to quantify river herring discards from July 2007 – August 2008 for 22 fishing fleets as:

$$R = \frac{d_{RH}}{K_{All}}$$

where $d_{RH}$represents discarded pounds of river herring and $K_{All}$ represents the kept pounds of all species. Fleet landings from the VTR database were used as the raising factor to expand the estimated discard rate to total river herring discards. Discard estimates were stratified by quarter, region, gear type, mesh, access area and trip category.

Wigley et al. (2009) estimated that approximately 48 MT were discarded during the 12 months, and the estimated precision was low (149% CV). This analysis only estimated river herring discards (in contrast to total incidental catch), and noted that midwater trawl fleets generally retained river herring while otter trawls typically discarded river herring.

Lessard and Bryan (2011) estimated the total incidental catch of alewives, blueback herring and American shad from 2000-2008 across seven gears: scallop dredges, gillnets, long lines, bottom trawls, single midwater trawls, paired midwater trawls and purse seines. The incidental catch rate for each species was quantified as:

$$R = \frac{C_{obs}}{E_{obs}}$$

where $C_{obs}$ represents the total observed catch of each species and $E_{obs}$ represents the total observed effort (number of tows). Total number of tows from the VTR database was used as the raising factor to calculate total incidental catch from the estimated rate. Lessard and Bryan (2011) reported total incidental catch estimates stratified by gear and region (GOM, Georges Bank, SNE and Mid-Atlantic) for the period 2000 – 2008. In addition, annual estimates of incidental catch were presented based on the CPUE from all years combined and annual estimates of effort.

Lessard and Bryan (2011) estimated an average incidental catch of river herring and American shad of 1,512 mt/yr from 2000-2008. The methodology used in this study differed from that of the Standardized Bycatch Reporting Methodology (SBRM), the standard method used to quantify bycatch in stock assessments conducted at the NOAA Northeast Fisheries Science Center (NEFSC) (Wigley et al. 2007). Data from the Northeast Fishery Observer Program (NEFOP) were analyzed at the haul level; however, the sampling unit for the NEFOP database is at the trip level. Within each gear and region, all data, including those from high volume fisheries, appeared to be aggregated across years from 2000 through 2008. However, substantial changes in NEFOP sampling methodology for high volume fisheries were implemented in 2005, limiting the interpretability of estimates from these fleets in prior years. Total number of tows from the VTR database was used as the raising factor to estimate total incidental catch. The use of effort without standardization makes the implicit assumption that effort is constant across all tows within a gear, potentially resulting in a biased effort metric. In contrast, the total kept weight of all species is used as the raising factor in SBRM. When quantifying incidental catch across multiple fleets, total kept weight of all species is an appropriate surrogate for effective fishing power because it is likely that all trips will not exhibit the same attributes. Lessard and Bryan (2011) also did not provide precision estimates, which are imperative for estimation of incidental catch.

#### 2.1.6.1 River herring incidental catch estimates

*Compiled by: Kiersten Curti, National Marine Fisheries Service*

**Methods**

The total incidental catch of river herring was estimated as part of the work for Amendment 14 to the Atlantic Mackerel, Squid and Butterfish (MSB) Fishery Management Plan, which addresses reducing the incidental catch of river herring and shads. The full working paper resulting from these efforts is included in Appendix 3.

The total (retained + discarded) incidental catch of river herring (alewives and blueback herring) was quantified by fleet. Fleets included in the analyses were those sampled by the NEFOP and were stratified by region fished (Mid-Atlantic versus New England), time (year and quarter), gear group, and mesh size. Gear groups included in the analyses were: bottom trawls, paired midwater trawls, single midwater trawls, gillnets, dredges, handlines, haul seines, longlines, pots/traps, purse seines, scallop trawl/dredge, seines and shrimp trawls. Bottom trawls and gillnets were further stratified into three mesh-size categories (see Appendix 3).

The combined ratio method (Wigley et al. 2007) is the standard discard estimation method implemented in Northeast Fisheries Science Center (NEFSC) stock assessments. We used this method to quantify and estimate the precision (CV) of river herring total incidental catch for 1989 – 2010 across all fleets. Incidental catch estimates for the midwater trawl (MWT) fleets are only provided for 2005-2010 because marked improvements to NEFOP sampling methodologies occurred in the high-volume MWT fisheries beginning in 2005, limiting the interpretability of estimates from these fleets in prior years.

For each trip, NEFOP data were used to calculate a total catch to kept (t/k) ratio, where t represents the total (retained + discarded) catch of an individual species (e.g., alewife) and k is the kept weight of all species. Annual estimates of total incidental catch were derived by quarter. Imputations were used for quarters with one or zero observed trips.

The t/k ratios were expanded using a raising factor to quantify total incidental catch. With the exception of the midwater trawl fleets, total landed weight of all species (from the dealer database) was used as the raising factor. Total landings from the dealer database are considered to be more accurate than those of the VTR database because VTR landings represent a captain’s hail estimate. However, for the MWT fleets, we were unable to use the dealer data to estimate the kept weight of all species when stratifying by fishing area. When the area allocation (AA) tables were developed, MWT was not included in effort calculations because of difficulties determining effort for paired MWTs. Only those gears with effort information could be assigned to a statistical area. Consequently, VTR data were used as the expansion factor for the MWT fleets.

**Results**

From 2005-2010, the total annual incidental catch of alewife ranged from 19.0-473.3 MT in New England and 8.9-256.2 MT in the Mid-Atlantic. The dominant gear varied across years between paired midwater trawls and bottom trawls (Figure 2.12). Corresponding estimates of precision (coefficients of variation) exhibited substantial interannual variation and ranged from 0.28-3.12 across gears and regions.

Total annual blueback herring incidental catch from 2005-2010 ranged from 13.9–176.5 MT in New England and 1.2-382.6 MT in the Mid-Atlantic. Across years paired and single midwater trawls exhibited the greatest blueback herring catches, with the exception of 2010 in the mid-Atlantic where bottom trawl was the most dominant gear (Figure 2.13). Corresponding estimates of precision ranged from 0.27 – 3.65.

The temporal distribution of incidental catches was summarized by quarter and fishing region for the most recent six-year period (2005-2010) (Table 2.6). River herring catches occurred primarily in midwater trawls (76%, of which 56% were from paired midwater trawls and the rest from single midwater trawls), followed by small mesh bottom trawls (24%). Catches of river herring in gillnets were negligible. Across gear types, catches of river herring were greater in New England (56%) than in the Mid-Atlantic (44%). The percentages of midwater trawl catches of river herring were similar between New England (37%) and the Mid-Atlantic (38%). However, catches in New England small mesh bottom trawls were three times higher (18%) than those from the Mid-Atlantic (6%). Overall, the highest quarterly catches of river herring occurred in midwater trawls during Q1 in the Mid-Atlantic (35%), followed by catches in New England during Q4 (16%) and Q3 (11%). Quarterly catches in small mesh bottom trawls were highest in New England during Q1 (7%) and totaled 3-4% during each of the other three quarters.

Species-specific annual incidental catch estimates and the associated coefficients of variation are presented in Table 2.7.

#### 2.1.6.2 Incidental Catch Biological Information

*Compiled by: Dr. Katie Drew, Atlantic States Marine Fisheries Commission*

In addition to counts of species, observers will collect information on the length composition of sampled fish (Figures 2.14 and 2.15). Sample size is small to non-existent in some years, but has increased in recent years, and provides valuable insight into the biological characteristics of the river herring caught in these fisheries.

The Kolmogorov-Smirnov goodness-of-fit test was used to compare the length frequencies from the bottom-trawls and the mid-water trawls for each species and found a significant difference for both alewife and blueback herring ($p<0.001$). Fish caught by mid-water trawls had a slightly smaller mean length and a lower variance than fish caught by bottom trawls.

The distributions of fish caught in bottom trawls and mid-water trawls overlapped with the distributions of fish caught in in-river fisheries (Figures 2.16 and.2.17). However, both the mid-water and bottom trawls caught size classes of small fish that were not observed in the river samples. Although no histological data were collected, these small fish were most likely immature, since they were not represented in the spawning adults returning to the rivers.

## 2.2 TRENDS IN FISHERIES-INDEPENDENT SURVEYS

Fisheries-independent data on alewives and blueback herring come from mostly historical reports and/or current work conducted by state, federal, and academic agencies as well as local citizen groups interested in protecting river herring resources. The data used in the summaries below were selected by state biologists as reflecting trends in each state's alewife and blueback herring populations. Some data were not used because lack of statistical design, non-reflectance of natural abundance trends, and shortness of time series (see state reports for details).

### 2.2.1 Run Size Estimates

*Compiled and Analyzed by: Gary A. Nelson, Massachusetts Division of Marine Fisheries*

Run sizes (total or escapement counts), proxies (number of fish lifted), or population sizes estimates of alewives and blueback herring (or both species combined) were available from six states, primarily from New England. Run sizes for Maine, New Hampshire, Massachusetts and Rhode Island were estimated using electronic counters or visual methods. Connecticut used the number of fish lifted at the Holyoke Dam and run counts made in 11 fishways using a variety of counting methods. North Carolina provided estimates of population sizes of blueback herring and alewives in the Chowan River from a stock assessment conducted in 2010 and 2005, respectively. South Carolina provided population abundance estimates from mark-recapture experiments for blueback herring in the Santee River. See state reports for full details. All time series were normalized ($Z$ transformed) prior to analysis to eliminate scale and to make comparison of trends easier.

**Maine**

Run size estimates are available for the Androscoggin River (alewife), Damariscotta River (alewife), Kennebec River (combined species), Sebasticook River (combined species), and Union River (alewife) from 1977-2010 (Figure 2.18).

<u>Androscoggin River</u> - Since 1983 the DMR has operated the vertical slot fishway in the Brunswick dam located at the head-of-tide on the Androscoggin River. The construction of fish lifts at the next two up-stream dams, Pejepscot and Worumbo, allows passage of anadromous fish to Lewiston Falls. The majority of alewife habitat is located in the lakes and ponds in the Sabattus and Little Androscoggin rivers. These ponds are not currently accessible due to FERC licensed hydropower dams without upstream fish passage. The DMR has transported alewives to ponds in these two drainages annually since 1983. The number stocked fluctuates widely over the years and relates to the amount and location of habitat stocked in previous years. The highest number of stocked fish was 113,686 in 2004.

<u>Damariscotta River</u> - The Damariscotta fishery is one of the most studied fisheries in Maine. A 150-meter stone pool and chute fishway passes river herring into spawning habitat. The elevation of the 1,781-hectare lake is 16 meters above mean high tide. The efficiency of this fishway varies and its ability to pass larger female river herring was studied by Libby (1981). He concluded the male to female ratio of the commercial catch at the base of the fishway, compared to the ratio of alewives entering the lake favored males and directly relates to the efficiency of the fishway and its length. The ratios of males to females entering the lake were as high a 4:1 during the run. Unobstructed upstream passage is available to migrating fish throughout the run. Harvesters trap fish in a side channel that provides supplemental attraction water at the base of the fishway. The commercial fishery operates four days a week throughout the run. The number of fish entering the lake are counted during a ten minute period each hour and expanded to the hours of operation. The highest number of fish observed was 1,305,380 in 1977.

<u>Kennebec and Sebasticook Rivers</u> - The DMR implemented a restoration plan for alewives in the Kennebec River watershed above Augusta in 1986 because of an agreement with the majority of hydroelectric dam owners in the watershed. The plan called for the stocking of alewives in the program's initial years to build up the population size, with eventual fish passage later. This agreement was modified in 1998 and incorporated into the Kennebec River Settlement Accord, which resulted in the removal of

the Edwards Dam in 1999, continued funding for the anadromous fish restoration program, and established new dates for fish passage. The alewife restoration program in the Kennebec River focuses on stocking lakes and ponds in the Sebasticook River watershed and Seven Mile Stream drainage. DMR has mainly stocked warm water lakes due to concerns of Maine Department of Inland Fisheries and Wildlife (IF&W) biologists that the restoration of alewives to cold water lakes might result in competition with smelt, an important forage species for landlocked salmon and brown trout. Results of a ten-year cooperative study in Lake George from 1987 through 1996, involving IF&W, DMR, and the Department of Environmental Protection (DEP),showed that the stocking of six alewives per surface acre of lake habitat had no negative impact on inland fisheries or water quality (Kircheis et al, 2002). Based on these findings, DMR and IF&W staffs recommended the initiation of the restoration of alewives in additional lakes in the Sebasticook drainage. The highest numbers of stocked fish was 2,211,658 in 2009 in the Sebasticook River and 93,775 in 2008 in the Kennebec River.

<u>Union River</u> - The Town of Ellsworth maintains the Union River fishery by stocking adult alewives above the hydropower dam at head-of-tide. There is no free passage or upstream fish passage facility required at this hydropower station. The FERC license requires transporting river herring around the dam by Pennsylvania Power and Light, the dam owners. Two lakes support this commercial fishery. The annual stocking rate (from 2011 forward) is 150,000 fish from the commercial run, during the harvest. The Union River is one of three commercially harvested resources with known escapement numbers. The highest number of stocked fish was 1,238,790 in 1986.

Common trends in run sizes were observed among rivers. Run sizes peaked during the 1980s in the Androscoggin River, Damariscotta River, and Union River. Run size declined in most rivers during the early 1990s, but it increased gradually and peaked again around 2004. In 2005, run counts dropped dramatically as a result of near-record high spring precipitation impeding upriver passage. Since 2005, increases and small declines in run size have been evident in all rivers (Figure 2.18). Fluctuations in run size for the Androscoggin, Kennebec, Sebasticook and Union rivers are likely influenced by DMR lifting and stocking activities.

**New Hampshire**

Run size estimates are available for the Cocheco River, Exeter River, Lamprey River, Oyster River, Taylor River and Winnicut River from 1972-2010 (Figure 2.19). Counts represent combined species totals or escapement numbers.

<u>Cocheco River</u> – The Cocheco River flows 48 km southeast through southern New Hampshire to Dover where it joins the Salmon Falls River to form the Piscataqua River. The lowermost dam (4.6 m high, built on a natural ledge for a total height of 8-10 m) on the Cocheco River is within the City of Dover at the head-of-tide, at rkm 6.1. A Denil fish ladder was constructed at the dam in 1969 to 1970 for anadromous fish by NHFGD, funded in part by the USFWS. The next barrier is a set of natural falls located at rkm 10.6. The City of Dover currently owns the dam and leases the attached hydroelectric facility to Southern New Hampshire Hydroelectric Development Corporation (SNHHDC). The FERC requires SNHHDC to provide downstream fish passage and utilize a grating system to prevent small fish from passing through the turbines. The downstream passage system is a PVC tube emptying in a plunge pool below the dam. This system successfully passes emigrating diadromous species when operating efficiently. Emigrating juvenile and adult river herring must either pass over the dam if flows allow, travel through the downstream migration tube, or move through the turbines at the hydroelectric facility if they can pass through the grating system. The highest number of river herring (combined species) passed upstream was 79,835 in 1995.

Exeter River - The Exeter River drains an area of 326 square km in southern New Hampshire. The River flows east and north from the Town of Chester to the Town of Exeter. It empties into Great Bay northeast of Exeter. The head-of-tide occurs at the Town of Exeter and the saltwater portion of the river is called the Squamscott River. The two lowermost dams on the main stem Exeter River are the Great Dam in Exeter at river kilometer (rkm) 13.5 and the Pickpocket Dam at rkm 26.9 (each 4.6 km high). The next barrier above Pickpocket Dam is a set of natural falls at rkm 38.1. NHFGD constructed upstream fish passage facilities (Denil fishways) on both dams from 1969 to 1971 for anadromous fish, funded in part by the USFWS. Fish ladder improvements occurred in 1994 and 1999 and a fish trap was constructed at the upriver end of the Great Dam fish ladder. There are no downstream fish passage facilities on either dam so emigrating adults and juveniles pass over the spillway when river flows allow. There are approximately one hundred meters of fresh water that occurs between head-of-tide and the Great Dam caused by an elevated ledge that prevents saltwater incursion. River herring have been observed below the Great Dam and have the ability to spawn in this area. Most spawning and rearing habitat occurs above the dam. Despite regulations introduced in 2005 to reduce harvest in the Exeter/Squamscott River it continues to account for between 40-89% of the total river herring harvested in New Hampshire between 2004 and 2010. Exeter/Squamscott River harvest in 2010 accounted for approximately 79% of all the river herring harvested in NH. However, the regulations introduced in 2005 implemented a daily limit of 1 tote per person and limited the fishery to only Saturdays and Mondays allowing for five days of escapement for migrating river herring. The highest number of river herring observed was 15,626 in 1981.

Lamprey River - The Lamprey River flows 97 km through southern New Hampshire to the Town of Newmarket where it becomes tidal and enters the Great Bay estuary just north of the mouth of the Squamscott River. The Macallen Dam, located at rkm 3.8 in Newmarket, is the lowermost head-of-tide dam (8.2 m high) on the Lamprey River. Fish passage on this river is a Denil fish ladder constructed from 1969 to 1970 for anadromous fish by NHFGD, funded in part by the USFWS. The Wiswall Dam is located 4.8 km above the Macallen Dam and currently does not have fish passage. It has a 3.4 m spillway and is an effective barrier to upstream movement of river herring and other diadromous species. A fish passage system is being designed and construction is anticipated to occur within the next five years. There are no downstream passage facilities at the Macallen Dam and emigrating juveniles and adults must pass over the spillway. Fish kills have not been observed below the first dam suggesting that adults and juveniles emigrate with limited mortality. The highest number of river herring observed was 66,333 in 2004.

Oyster River - The Oyster River drains a watershed of 27.5 km through southeast New Hampshire. It begins in Barrington and flows southeast to Lee, then flows east-southeast through Durham where it empties into Little Bay. The first dam exists at the head of tide just west of NH Route 108 at approximately rkm 5. The spillway length is 42.7 m and a height of 3 m. A Denil fish ladder was constructed at this dam around 1975. The next barrier to fish passage is a dam at about rkm 7.6. As with the other rivers, high flows in 2005, 2006, and 2007 might have contributed to lower juvenile production resulting in low returns for this and future years. Unpublished data acquired by the University of New Hampshire in the fall of 2005 showed hypoxic conditions in the impounded reaches of the Oyster River (Brian Smith, personal communication). The highest number of fish observed was 157,024 in 1992.

Taylor River - The Taylor River is located in southeastern New Hampshire and is about 17.1 km long. The river begins on the border between Hampton Falls and Kensington, New Hampshire. It flows north, east, then southeast through Hampton Falls where it meets tide water at Interstate 95. The lowermost 6.4 km of the river forms the boundary between Hampton and Hampton Falls. The first dam is located at rkm 3.2. There is a Denil fish ladder at this head-of-tide dam that was constructed in the late 1960s. The next dam is a barrier to further fish passage and is located at rkm 5.1. In 2009 the fish ladder was operated only as a swim through due to staff constraints. Due to low return numbers and lack of a trap for fish collection, no biological sampling was conducted in 2010. The Taylor River has had very low return numbers for the past ten years. Eutrophication of the Taylor River impoundment compounded by high flow years in 2005, 2006, and 2007 are believed to be the main reasons for the decline. The highest number of river herring observed was 450,000 in 1976.

Winnicut River - The Winnicut River drains a watershed of 36.8 square km in southeast New Hampshire. It originates in the town of North Hampton and flows north through Greenland where it empties into Great Bay. The only barrier to fish passage is a dam that occurs at the head-of-tide at approximately 1.6 rkm. The dam was built in 1957 by NHFGD to create waterfowl habitat and is located in the Town of Greenland. It has a height of 4 m and a spillway length of 23.2 m. The dam incorporates a Canadian Step Weir fishway. This type of fishway is not efficient for the passage of river herring; however with modifications, limited numbers of river herring do utilize this fishway. Plans for removal of this dam are scheduled for 2009-2010. The Winnicut River head-of-tide dam and associated fish ladder were removed during the summer of 2009. A fish ladder will be constructed approximately 100 meters upstream from the former dam site during the summer 2011. The ladder will be placed in a river constriction under the NH Route 33 bridge. The river under the bridge contains many large boulders that are thought to be a possible impediment to emigrating juvenile river herring. Also, under certain flow conditions this constriction could be a possible velocity barrier to upstream migrating adult river herring as well. The highest number of river herring observed was 8,359 in 2008.

Common trends in run sizes were observed among rivers. Run sizes peaked either during the late 1970s-early 1980s (Lamprey River, Taylor River, and Exeter River) or the late 1980s (Cocheco River and Oyster River) (Figure 2.19). Declines in run size from peak abundance were observed through the mid-1990s in the Lamprey River and Taylor River, or briefly during the mid-1990s in the Cocheco River and Oyster River. Run sizes increased gradually and peaked around 2003-2004 in the Cocheco River, Exeter River, Lamprey River and Winnicut River but they continued to decline in the Oyster River and Taylor River. In 2005, run counts may have dropped as a result of near-record high spring precipitation impeding upriver passage. Run counts dropped dramatically in 2005-2006 in most rivers, but appear to have rebounded or increased during 2007 in the Cocheco River, Lamprey River, and Winnicut River. Run size in the Cocheco River and Lamprey River remain high, while those in the Exeter River, Oyster River and Taylor River remain low. In 2009 and 2010, run size in the Winnicut River declined.

**Massachusetts**

Run size estimates are available for the Mattapoisett River, Monument River, Nemasket River and Parker River from 1972-2010 (Figure 2.20).

Mattapoisett River – Since 1988, a local watershed group, Alewives Anonymous, has provided total and escapement abundance estimates of alewives by using an electronic fish counter at the fish ladder located at the outlet of Snipatuit Pond in Rochester (River mile: 11.1). This counter is used to estimate the number of alewives reaching the final and primary spawning impoundment (710 acres). The highest number of alewife observed was 132,500 in 2000.

Monument River - DMF has been scientifically monitoring the abundance, sex composition, length structure, age composition and removals of alewives and blueback herring populations in the Monument River, Bournedale, Massachusetts since the early 1980s. Prior to 1985, abundance was estimated by using visual counts following the statistical design of Rideout et al. (1979). Since 1985, run size has been estimated by using a Smith-Root electronic fish counter that is calibrated daily. The counter is situated just upstream of the river mouth at the top weir of the fish ladder at Benoit's Pond Dam in Bourne (River Mile: 0.2). The highest numbers of alewives and blueback herring observed were 597,937 in 2000 and 104,645 in1984, respectively.

Nemasket River - Since 1996, members of the Middleborough/Lakeville Herring Fishery Commission has provided abundance estimates of alewife escapement using visual counts and the Rideout et al. (1979) design. Counting takes place at the upstream exit of the Wareham Street Dam and fishway (River mile: 7.5). The highest number of alewives observed was 1,919,000 in 2002.

Parker River - The Parker River is a small stream arising in the town of Boxford and flowing 25.8 km north and east into Plum Island Sound. The freshwater portion drops 20 m during its 12.5 km length and flow is impeded by six low head dams. A pool and weir fish ladder was built at each dam. In 1974, the pool-and-weir fishway at dam 6 was replaced by a Denil type ladder. Students and researchers at the University of Massachusetts, Amherst conducted several studies that provide information on juvenile and adult population characteristics, abundance and migration of alewives during the. Since 1997, the Parker River Clean Water Association has been estimating run size at the first dam using visual counts and the statistical design of Rideout et al. (1979). Due to heavy rains in 2005, the weir at dam 1 was damaged and continues to run at lower efficiency. The highest number of alewives observed was 38,102 in 1973.

Total run sizes of alewives in the Mattapoisett River and Monument River increased from lows in the later 1980s and peaked in 2000 (Figure 2.20). After 2000, alewife run sizes declined precipitously in the Mattapoisett River, Monument River and Parker River. Run size in the Nemasket River peaked in 2002 and declined thereafter. For blueback herring, total run size was highest in the Monument River during 1980-1991, but it dropped to lower levels during 1992-2002. In 2005, run counts may have dropped dramatically as a result of near-record high spring precipitation impeding upriver passage. Since the run lows, river herring abundance has been increasing slowly.

**Rhode Island**

Run size estimates of alewives are available for Buckeye Brook, Gilbert-Stuart River and Nonquit River from 1980-2010 (Figure 2.21).

Buckeye Brook - The Buckeye Brook Coalition and RI DFW partnered in 2003 to initiate a direct count program utilizing volunteers. The highest number of fish observed was 38,949 in 2003.

Gilbert-Stuart River - Gilbert Stuart has an Alaskan steeppass fishway which provides access to 68 acres of nursery and spawning habitat. Gilbert Stuart Pond empties into the Narrow River and discharges into the Atlantic Ocean. RI DFW has estimated spawning stock size since 1981 by electronic fish counter or direct count methods. The highest number of alewife observed was 290,814 in 2000.

Nonquit River - Nonquit has a Denil fishway which provides access to 202 acres of nursery and spawning habitat. Nonquit Pond spills into Almy Brook which joins the Sakonnet River and empties into the Atlantic Ocean. The Division has estimated spawning stock size at Nonquit since 1999 by a solar powered electronic fish counter. The only known data prior to 1999 included run size estimates (80,000) from 1976. The highest number of alewife observed was 230,853 in 1999.

Total run size of alewife in the Gilbert-Stuart River increased from the early 1990s through 2000 (Figure 2.21). Dramatic drops in run size were observed after 1999-2000 in the Gilbert-Stuart River and Nonquit River, and after 2003 in Buckeye Brook. Run sizes in all rivers have increased slightly through 2008, but have since declined in the Buckeye Brook and Nonquit River through 2010.

**Connecticut**

A proxy of blueback herring run size (number of fish lifted) was available for the Connecticut River from 1966 to 2010. Shorter time series (2002-2010) were available for alewives and blueback herring in Bride

Brook, Maianus River, Mill Brook, Naugatuck River, Shetucket River, Naugatuck River and Farmington River (Figure 2.22).

Bride Brook – The number of alewives passing has varied considerably over the short time series (Figure 2.22). The highest number observed in the time series (164,149) occurred in 2010.

Connecticut River – The number of blueback herring lifted at the Holyoke Dam increased dramatically from the late 1970s and peaked around 1985 (Figure 2.22). After 1985, the number of fish lifted began to decline and it dropped precipitously after 1991. The number of fish lifted has remained close to pre-1977 levels since 2002. The highest number of fish observed was 630,000 in 1985

Farmington River – Trends in alewife and blueback counts were nearly identical (Figure 2.22). Counts of both species declined from the peak in 2002, remained low through 2009, and increased slightly in 2010. The highest numbers of alewives and blueback herring observed were 54 and 63, respectively, in 2003.

Mianus River - Trends in alewife and blueback counts were nearly identical (Figure 2.22). Counts of both species increased beginning in 2006, peaked in 2007-2008, and declined in 2009. Alewife counts increased in 2010 but blueback counts declined. The highest numbers of alewives and blueback herring observed were 93,077 in 2010 and 13,309 in 2008, respectively.

Mill Brook - The number of alewives passing has varied considerably over the short time series (Figure 2.22). Numbers declined in 2008 and have remained low. The highest number of fish observed was 10,048 in 2002.

Naugatuck River - The numbers of alewives and blueback herring passing have varied considerably without trend over the short time series (Figure 2.22). The highest numbers of alewives and blueback herring observed were 4 in 2004 and 2 in 2005, respectively.

Shetucket River - The numbers of alewives and blueback herring passing have varied considerably without trend over the short time series (Figure 2.22). The highest numbers of alewife and blueback herring observed were 2,422 in 2007 and 216 in 2003, respectively.

**North Carolina**

Population size estimates of alewives and blueback herring from age-structured assessment models are available for the Chowan River from 1972-2003and 1972-2010, respectively.

Chowan River - Alewife abundance in the Chowan River fluctuated widely without trend prior to 1985, declined dramatically through 1989, increased slightly in 1990, but it continued to decline through 2003 (Figure 2.23). Blueback herring abundance declined in the late 1970s, increased during the early 1980s and peaked in 1983, and has steadily declined since 1992. The highest numbers of alewife and blueback herring estimated in the model were 19,348,550 fish in 1984 and 133,738,077 fish in 1976, respectively.

**South Carolina**

Population abundance estimates of blueback herring are available for the Santee River from 1980-1990.

Santee River - Abundance increased from a low of 664,000 fish in 1982 to a high of 9,000,000 fish in 1986 (Figure 2.23). Blueback population size declined briefly in 1987 but then increased to the highest estimated level of 9,353,000 in 1990.

**Comparison of Trends**

Historical river counts were compared to identify common trends among rivers. It should be noted that trends may not reflect natural variation in some rivers due to events like anthropogenic changes to river access (see state reports for more detail). All data were normalized prior to analysis. Common trends were identified via hierarchical, agglomerative cluster analysis with the group average linking method using linear (Pearson) correlations among all rivers as the measures of similarity. Normalized river counts were then plotted together based on major grouping identified in the cluster dendrogram. Trends among rivers were examined for three time periods: 1984-2010, 1999-2010, and 2003-2010. The first period was selected to include as many rivers as possible with long time series, and the latter periods were selected to examine recent changes in river counts from as many rivers as possible. Rivers in the analysis of years 1984-2010 included the Union River, Androscoggin River, and Damariscotta River in Maine, the Lamprey River, Taylor River, Cocheco River and Oyster River in New Hampshire, the Monument River in Massachusetts, the Gilbert-Stuart River in Rhode Island, and the Connecticut River in Connecticut. The 1999-2007 period included the aforementioned rivers plus the Winnicut River and Exeter River in New Hampshire, the Nonquit River in Rhode Island, and the Mattapoisett River, Nemasket River, and Parker River in Massachusetts. The 2003-2010 period included the aforementioned rivers plus the Sebasticook River in Maine, the Buckeye River in Rhode Island, and the Farmington River and Bride Brook in Connecticut.

*1984-2010* - Cluster analysis grouped the similarities of trends in river counts into four main groups (Figure 2.24). Group 1 represents rivers (Monument River alewife and Gilbert-Stuart alewife) in which run sizes increased from 1984, peaked in 2000 and declined thereafter. Since the run lows in 2006 and 2005, respectively, run size increased, albeit slowly (Figure 2.24). Group 2 represents rivers (Oyster River and Cocheco River) in which run sizes increased from 1984, peaked in the early to mid 1990s, and slowly declined or dropped in size after 2003. Since the run lows in 2006, run sizes have increased slowly (Oyster River) or rapidly (Cocheco River) through 2010. Group 3 represents rivers (Lamprey River, Damariscotta River, Androscoggin River) in which run sizes slowly declined from 1984 or peaked in the mid-1980s, declined through the mid-1990s, steadily increased and peaked again in the mid-2000s, and then dropped precipitously through 2005 or 2006. Run sizes increased in all rivers following the run lows in 2005 or 2006. Run size has remained high in the Damariscotta River, has declined in the Androscoggin River after 2008, and has remained stable in the Lamprey River. Group 4 represents rivers (Taylor River, Connecticut River, Monument River blueback herring and Union River alewife) in which run sizes have steadily declined since 1984 or dropped precipitously after 1990-1991. River locations for each cluster group are shown in Figure 2.25 and show that the rivers in Group 1 are located in southeastern New England, those in Group 2 are located in New Hampshire, those in Group 3 are located from New Hampshire through northern New England, and those in Group 4 are scattered throughout New England.

*1999-2010* - Cluster analysis grouped the similarities of trends in river counts into three main groups (Figure 2.26). Group 1 represents rivers (Gilbert-Stuart River, Mattapoisett River, Parker River, Taylor River, Oyster River, Connecticut River, Monument River, Nonquit River, and Exeter River) in which run sizes declined starting in the early 2000s (Figure 2.27). Since the decline, run sizes have remained low (Oyster River, Connecticut River, Exeter River and Taylor River) or have increased over time (Gilbert-Stuart River, Monument River alewife, Mattapoisett River, Parker River, and Nonquit River) , albeit slowly in some cases. Group 2 represents rivers (Union River and Nemasket River) in which run sizes increased through 2002, declined through 2004 or 2005, and increased following run lows to the early levels (Union River) or to moderate levels (Nemasket River). Group 3 represents rivers (Androscoggin River, Winnicut River, Lamprey River, Cocheco River, and Damariscotta River) in which run sizes increased from 1999, peaked in 2003-2004, dropped precipitously in 2004-2005, increased through 2007-2009 and declined or remained stable thereafter. River locations for each cluster group are shown in

Figure 2.28 and show that the rivers in Groups 1 and 3 are located from New Hampshire through north New England and from New Hampshire through southern New England, respectively.

*2003-2010* **-** Cluster analysis grouped the similarities of trends in river counts into three main groups (Figure 2.29). Group 1 represents rivers (Androscoggin River, Winnciut River, Buckeye River and Nonquit River) in which run sizes either increased through 2004, declined through 2005 or 2006, increased through 2008 and declined thereafter (Androscoggin River and Winnicut River) or declined through 2004, increased rapidly through 2008 and declined thereafter (Buckeye River and Nonquit River) (Figure 2.30). Group 2 represents rivers (Damariscotta River, Monument River (alewife), Exeter River, Sebasticook River, Union River, Nemasket River, and Gilbert-Stuart River) in which run sizes declined through 2005-2006, increased through 2009, and either increased or decreased in 2010. Group 3 represents rivers (Farmington River, Oyster River, Cocheco River, Taylor River, Monument River (blueback), Connecticut River, Mattapoisett River, Lamprey River, Bride Brook, and Parker River) in which run sizes declined through 2006-2007 and increased or remain low since the run lows. River locations for each cluster group are shown in Figure 2.31 and show that the rivers in Group 1 and 2 are scattered throughout New England, while those from Group 3 are primarily located from New Hampshire through southern New England.

### 2.2.2 Young-of-the-Year Seine Surveys

*Analyzed and authored by: Gary A. Nelson, Massachusetts Division of Marine Fisheries and Katie Drew, Atlantic States Marine Fisheries Commission*

States of Maine, Rhode Island, Connecticut, New York, New Jersey, Maryland, District of Columbia, Virginia, and North Carolina conduct fixed seine surveys that capture young-of-the-year alewives and blueback herring generally during summer and early fall. Detailed descriptions for each survey are found in state reports; a brief description and comparisons of trends are given below.

Maine – The State of Maine conducts an annual YOY alosine survey for six Maine rivers including Merrymeeting Bay. The survey began in 1979 and expanded to include 17 fixed stations and includes data from a separate juvenile striped bass survey designed to assess the numbers of juvenile striped bass in the lower Kennebec River. Geometric mean indices for blueback herring and alewives are used as relative indices of abundance. Indices for alewives fluctuated without trend over the time series, although large peaks in relative abundance occurred in 1979, 1983, 1995, and 2000 (Figure 2.32). For blueback herring, relative abundance was near zero from 1979 through 1991 but it increased gradually through 2004 before declining in recent years (Figure 2.33).

Rhode Island –The YOY survey is conducted weekly each fall at five stations in the Pawcatuck River estuary. It began in 1988 and the geometric mean index represents relative abundance for combined species. Relative abundance in the Pawcatuck River estuary fluctuated widely but generally increased through 2002 and it declined thereafter (Figure 2.32).

Connecticut – The YOY survey is conducted weekly during the months of July through October at stations located between Essex, CT (river km 10) and Holyoke, MA (river km 4 140). It began in 1978 and the geometric mean catch per seine haul is used as the relative index of blueback herring abundance. Relative abundance of YOY blueback herring fluctuated widely prior to 1989, but it declined gradually over time with a large increase in 2010 (Figure 2.33).

New York – The YOY survey was designed to index alosines and occurs in the upper half of the estuary (RM 60-140) which is generally fresh water and is the nursery reach for alosines. It began in 1980 and the geometric mean number of fish per haul is used as the relative abundance indices for alewives and blueback herring. Relative abundance of YOY alewives was low prior to 1999, but has increased since then, with large year-to-year fluctuations (Figure 2.32). For blueback herring, indices fluctuated widely throughout the time series, but appeared to decline during the late 1990s and then remained stable but variable through the present (Figure 2.33).

New Jersey – The YOY survey is conducted biweekly from August to October at fixed stations in the Delaware River. The survey began in 1980 and the geometric mean catch per haul is used as a relative indices of abundance for alewives and blueback herring. The YOY index for alewives fluctuated without trend over the time series, although peaks in relative abundance occurred in 1988 and 1996 (Figure 2.32). Relative abundance of blueback herring fluctuated widely to high peaks through 2000, and then dropped to lower levels with less variability during 2001-2010 (Figure 2.33).

Maryland – The YOY survey is conducted monthly at fixed stations in the Maryland portion of Chesapeake Bay from summer through late fall. The survey began in 1959 and the geometric mean per haul is used as relative abundance indices for alewives and blueback herring. Relative abundance of alewives fluctuated widely without trend between 1959 and 1977 (peak abundance occurred in 1970) and it declined to lower levels and was less variable during the mid-1980s and early-1990s (Figure 2.32). A slight increase in average relative abundance occurred following 1992. Relative abundance indices for blueback herring also fluctuated without trend prior to 1970, it declined to low levels (except for increase in 1978) and was less variable during the mid-1980s and early-1990s (Figure 2.33). After 1992, the average magnitude and variation in relative abundance increased.

District of Columbia – The YOY survey is conducted annually in the Potomac River and Anacostia River. Sampling occurs monthly from May through August. The survey began in 1990 and the log of the mean number of fish per haul+1 is used as relative abundance indices for blueback herring and alewives. Relative abundance of alewives has declined since the series started in 1990 through 2003, and has remained low since then (Figure 2.32). Relative abundance of blueback herring increased from near zero levels during 1990-1994, and has shown large year-to-year variability since then (Figure 2.33).

Virginia – Indices of YOY relative abundance for alewife and blueback herring come from the VIMS Juvenile Striped Bass Seine Survey which tracks trends in the annual year-class strength of striped bass in the spawning and nursery areas of the lower Chesapeake Bay. The survey began in 1967 with a gap from 1974-1979, and the geometric average number of fish per seine set for all rivers combined (James, York, and Rappahannock rivers) is used as the relative abundance index. VIMS provided data from 1990 onward, when the current sampling stratification was implemented. Relative abundance of alewives and blueback herring fluctuated at low levels without trend (Figures 2.32 and 2.33).

North Carolina – The seine survey began nursery area sampling for YOY blueback herring and alewives in the Albemarle Sound area in 1972. Sampling occurs at 11 fixed stations during June-October and an additional 13 fixed stations are sampled in September of each year. The geometric mean number of fish per haul is used as the measure of the relative abundance. Relative abundance of alewives peaked during 1977-1980, it dropped to low levels during 1981-1994, and it increased slightly through 2004, but has dropped again in recent years (Figure 2.32). For blueback herring, relative abundance peaked in 1973 and declined through 2010 (Figure 2.33).

Comparison of Trends in YOY Seine Surveys - Indices of relative abundance were compared to identify common trends among river systems. Common trends were identified via hierarchical agglomerative cluster analysis with group average linking (Clarke, 1993) using linear (Pearson) correlations among all rivers as the measures of similarity. All data were normalized ((obs-mean)/sd) prior to analysis. Cluster groupings were identified based primarily on the largest distances shown in the cluster dendrogram; however, secondary groups were identified to aid in comparison of trends. Normalized indices were plotted together based on major grouping identified in the cluster dendrogram. Trends among systems were examined for two time periods: 1980-2007 and 1993-2007. The former period was selected to include as many surveys as possible with long time series, and the latter period was selected to examine recent changes in indices from as many systems as possible. The 1980-2007 period included surveys from Maine, Connecticut, New York, New Jersey, Maryland, Virginia and North Carolina. The 1993-2007 period included surveys from Maine, Rhode Island, Connecticut, New York, New Jersey, Maryland, District of Columbia, Virginia and North Carolina.

*1980-2007* - Cluster analysis grouped the similarities of trends in YOY indices into five main groups (Figure 2.34). Group 1 represents YOY indices for blueback herring and alewife from Maine which shows similar fluctuations in relative abundance after 1991 with peaks occurring in 1995 and 2004. Group 2 represents river systems in which YOY indices were high in the early 1980s but relative abundance declined over time (North Carolina alewife and blueback herring, and Connecticut blueback herring). Group 3 represents YOY indices from New York's Hudson River which showed similar fluctuations in relative abundance particularly after 2000 when peaks occurred during 1999, 2001, 2005, and 2007. Group 4 represents YOY indices for blueback and alewives from New Jersey and Maryland which showed similar peaks in relative abundance in 1994, 1996, and 2001. Group 5 represents YOY indices for alewives and blueback herring from Virginia which showed similar peaks in relative abundance during 1993, 1996, 2001, and 2003.

*1993-2007* - Cluster analysis grouped the YOY indices into four main groups, but five groups were selected to explore in more detail the similarity among YOY indices (Figure 2.35). Group 1 represents YOY indices from New York's Hudson River which showed similar peaks in relative abundance in 1999, 2001, 2004, and 2007. Group 2 represents YOY indices for blueback herring in Maryland, North Carolina and the District of Columbia that showed similar peaks in relative abundance in 1996-1997, 2000, and 2004 and have declined over time. Group 3 represents YOY indices for alewives and blueback herring from New Jersey, Maryland, Virginia, and North Carolina that showed similar peaks in relative abundance in 1996, 2000-2001, and 2003, and increased in 2007. Group 4 represents YOY indices from Rhode Island and Maine that showed similar peaks in relative abundance in 1995, 2000, and 2004. Group 5 represents YOY indices for Connecticut blueback herring and District of Columbia alewives that have declined over time.

### 2.2.3 Juvenile-Adult Seine, Gillnet and Electrofishing Surveys

*Analyzed and authored by: Gary A. Nelson, Massachusetts Division of Marine Fisheries*

Rhode Island has conducted large seine fixed station surveys for juvenile and adult river herring in coastal ponds and Narragansett Bay since 1988. Virginia has conducted a multi-panel gillnet surveys for adult river herring in the Rappahannock River since 1991. In addition, Virginia has conducted an electroshocking survey in the Rappahannock and James Rivers since 2000. Similarly, Florida has conducted an electroshocking survey in the St. John's River since 2001 (see state reports for details). Fish biologists from respective states believe that the estimates of catch-per-unit-effort from each watershed reflect changes in river herring abundance.

**Rhode Island**

Seine CPUE for combined species in Narragansett Bay fluctuated without trend from 1988-1997, increased through 2000, declined and then remained stable from 2001-2004, increased again in 2005, and declined in 2006 (Figure 2.36). The pond survey CPUE increased during 1993-1996, declined through 1998, increased in 1999, declined through 2002, peaked in 2003, and then declined and fluctuated without trend thereafter. A significant correlation (rho=0.71, $p \leq 0.01$) between CPUEs from the pond survey (lagged forward two years) and the Narragansett Bay survey was found, suggesting that the pond survey captures year-class strength and it is identified in the estuarine survey two years later.

**Virginia**

Gillnet CPUE for both species in the Rappahannock River declined during 1991 to 1994, increased in 1995, declined rapidly after 1995 and has remained low since 2000 (except for a rise in alewife CPUE during 2008)(Figure 2.37). The electrofishing CPUE indices for alewives and blueback herring in the Rappahannock River showed opposing trends where blueback CPUE was highest during 2001-2003 and alewife CPUE was lowest during the same time period (Figure 2.38). In 2004, blueback CPUE declined to the lowest levels (and remained low through 2005), whereas alewife CPUE increased dramatically to the highest level observed. Blueback CPUE increased from 2006 to 2007 and has remained stable through 2010. Alewife CPUE declined through 2006, increased in 2007, and declined through 2010. The electrofishing CPUEs for alewife and blueback herring in the James River also showed opposing trends over the time series. When blueback CPUE declined, alewife CPUE increased and vice versa. Peak CPUE for blueback herring occurred in 2004, whereas it occurred in 2005 for alewife. Alewife and blueback CPUEs have remained stable since 2007 except for an increase for the latter species during 2010.

**Florida**

The electrofishing CPUE indices for blueback herring in the St. John's River declined precipitously from 2001 to 2002 and has fluctuated without trends since 2003 (Figure 2.38).

**Comparison of Electrofishing CPUE Trends**

Simple correlation analysis was used to compare trends in electrofishing CPUE from 2001-2010. The correlation coefficient between Rappahannock alewife and blueback herring indices indicated a significant ($p \leq 0.05$), negative correlation between species. For the James River blueback and Florida blueback comparison, a significant ($p \leq 0.01$), positive correlation between the two time series was evident. The common trend among the Virginia and Florida electrofishing survey occurred in 2004 when the Rappahannock River alewife index, James River blueback herring index, and St. John's River blueback herring index increased (Figure 2.38).

### 2.2.4 Juvenile and Adult Trawl Surveys

*Analyzed and authored by: Dr. John A. Sweka, US Fish and Wildlife Service, Northeast Fishery Center*

The purpose of this analysis was to summarize trends in river herring relative abundance data from fisheries independent trawl surveys. The trawl surveys used in this analysis are shown in Table 2.8. Details of each survey are provided in individual state summaries. The majority of surveys grouped juvenile and adult fish together (Table 2.8) and no effort was made to develop separate juvenile and adult indices from combined data.

Trawl surveys for river herring can be quite variable, making inferences about population trends uncertain. Observed time series of relative abundance indices represents true changes in abundance, within survey sampling error, and varying catchability over time. One approach to minimize measurement error in the survey estimates is by using autoregressive integrated moving average models (ARIMA, Box and Jenkins 1976).

The ARIMA approach derives fitted estimates of abundance over the entire time series whose variance is less than the variance of the observed series (Pennington 1986). Helser and Hayes (1995) extended Pennington's (1986) application of ARIMA models to fisheries survey data to infer population status relative to an index-based reference point. This methodology yields a probability of the fitted index value of a particular year being less than the reference point [P(indext<reference)]. Helser et al. (2002) suggested using a two-tiered approach when evaluating reference points whereby not only is the probability of being below (or above) the reference point is estimated, the statistical level of confidence is also specified. The confidence level can be thought of as a one-tailed *a*-probability from typical statistical

hypothesis testing. For example, if the P(indext<reference) = 0.90 at an 80% confidence level, there is strong evidence that the index of the year in question is less than the reference point. This methodology characterizes both the uncertainty in the index of abundance and in the chosen reference point. Helser and Hayes (1995) suggested the lower quartile ($25^{th}$ percentile) of the fitted abundance index as the reference point in an analysis of Atlantic wolfish (*Anarhichas lupus*) data. The use of the lower quartile as a reference point is arbitrary, but does provide a reasonable reference point for comparison for data with relatively high and low abundance over a range of years.

Autoregressive integrated moving average models (ARIMA, Box and Jenkins 1976) were fit to log transformed trawl survey indices. In cases where a survey contained "0" values for one or more years, a small number (0.01) was added to the index prior to log transformation. In this analysis, the final year of a given trawl survey was compared to the $25^{th}$ percentile of the fitted index values and a confidence level of 80% was used to assess the probability of the final year of the survey being less than the $25^{th}$ percentile reference point [P(<0.25)]. ARIMA models were fit in R version 2.12.2 and functions in the R package Fish Methods (Gary Nelson, MA DMF author) were used for the ARIMA model fit and comparison to reference points. Values of P(<0.25) were summarized by location of the trawl surveys – northern vs. southern surveys with a general separation occurring at Long Island. Trawl surveys with 10 or more years of data were included in this analysis.

Trends in trawl survey indices varied greatly with some surveys showing an increase in recent years, some showing a decrease, and some remaining stable. Trawl surveys in northern areas tended to show either an increasing or stable trend in alewife indices (Figures 2.39 and 2.41) whereas trawl surveys in southern areas tended to show stable or decreasing trends (Figures 2.40 and 2.41). Patterns in trends across surveys were less evident for blueback herring (Figures 2.42, 2.43 and 2.44). The Northeast Fisheries Science Center (NEFSC) surveys showed a consistent increasing trend coastwide and in the northern regions. The probability of the final year of the survey being less than the $25^{th}$ percentile reference point [P(<0.25)] ranged from 0 to 0.824 for alewives (Table 2.9) and 0 to 0.723 for blueback herring (Table 2.10). These probabilities tended to be less in northern regions compared to southern areas for alewife (Table 2.11). However, the differences in P(<0.25) were not as pronounced between northern and southern regions for blueback herring (Table 2.11)

It appears that there was a greater likelihood of trawl surveys showing a decrease for those surveys in the southern areas. These observations are consistent with hypotheses concerning the effects of climate change on fish species distributions. Nye et al. (2009) showed the center of biomass for many stocks surveyed with the NEFSC bottom trawl survey has moved northward through time and changes in distribution were correlated with large-scale warming and climactic conditions such as the Atlantic Multidecadal Oscillation. In addition to the NMFS data used in this analysis, data from other sources also show similar patterns.

### 2.2.5 Comparison of Trawl Indices and Run Sizes

*Analyzed and authored by: Dr. John A. Sweka, US Fish and Wildlife Service, Northeast Fishery Center*

Spearman rank correlation coefficients were used to evaluate the relationship between river herring run counts and trawl survey indices of river herring relative abundance. Significant correlations would indicate that a trawl survey could be a predictor of future run counts or trawl surveys could be an index of production from a particular run of river herring (if the trawl survey indexes juveniles).Because trawl surveys can occur at different times of the year and catch different ages of river herring, these factors needed to be accounted for when matching run counts with trawl survey data. Trawl surveys or run counts were lagged by the following "rules" prior to correlation analysis.

- If the trawl survey season was spring or all seasons, and ages in the trawl survey were adult or all ages, then the run count year equaled the trawl survey year (spring trawl surveys as predictors of run counts in the same year).
- If the trawl survey season was fall or all seasons, and ages in the trawl survey were adult or all ages, then the run count year equaled the trawl survey year +1 (fall trawl survey as a predictor of run counts the following calendar year).
- If the trawl survey season was fall or spring, and the trawl survey collected age-1 fish, then the run count year equaled the trawl survey year – 1(run counts as a predictor of age-1 production indexed by trawls the following calendar year).
- If the trawl survey season was summer/fall, and the trawl survey collected young-of-the-year, then the run count year equaled the trawl survey year (run counts as a predictor of YOY production indexed by trawls in the same calendar year).

Spearman rank correlations were only run on paired run count and trawl survey time series where there were at least ten overlapping years of data.

A total of 572 correlations between river herring run counts and trawl surveys were possible. Of these, only nine showed significant ($p \leq 0.05$) positive Spearman rank correlation coefficients (Table 2.12). Massachusetts rivers (Mattapoisett, Parker, and Monument) run counts were correlated with trawl surveys located in more southerly regions such as the Delaware River and Bay Juvenile and Adult Finfish Surveys and the North Carolina DMF Western Sound Survey (Table 2.12 ; Figure 2.45). Likewise, run counts for both species in the Taylor River (NH) were correlated with the NEFSC Bottom Trawl Survey conducted in the southern Atlantic region (Table 2.12; Figure 2.47). It is likely that significant positive correlations between run counts and trawl surveys that occurred between rivers and trawl surveys that are highly separated geographically are spurious. Run counts from three rivers (Androscoggin, Cocheco, and Chowan Rivers) were correlated with trawl surveys that were conducted nearer the vicinity of these rivers (Figures 2.46,2.47 and 2.48).

The paucity of significant correlations between river herring run counts and trawl survey indices suggests that trawl surveys may not provide a reliable index of river herring abundance. This may be due to low capture efficiency of bottom trawls for pelagic species such as river herring or a mismatch between the timing of trawl surveys and the location of river herring during ocean migration. Trawl surveys tend to show a high degree of temporal variation with several trawl surveys showing no definitive trends (see Section 2.2.4).

## 2.3 TRENDS IN MEAN LENGTH

*Analyzed by: Dr. Gary A. Nelson, Massachusetts Division of Marine Fisheries*

Length data come from Maine, New Hampshire, Massachusetts, New York, Maryland, North Carolina, South Carolina, and Florida. Length data were converted to total length when applicable. Mean length was calculated for each year by species and sex and the time series were examined to determine if changes have occurred over time. The Mann-Kendall test for trends in data was used to test if negative or positive trends occurred in the mean length data. A significance level of 0.05 ($p = 0.05$) was used to determine whether a statistically significant trend was present.

**Maine**

Plot of the mean total length for female and male alewife from the Androscoggin River versus year indicated that average sizes were slightly larger in the late 1980s than average sizes in the remaining years (Figure 2.49). However, the Mann-Kendall test did not detect a significant trend (Table 2.13).

**New Hampshire**

Plots of mean total lengths from fisheries-independent monitoring versus year for the Cocheco River, Exeter River, Lamprey River, Oyster River and Winnicut River showed variable trends depending on river and species. For alewives, mean total lengths varied without trend in the Cocheco River, Lamprey River and Winnicut River, but slight declines were observed for females and males in the Exeter River (Figure 2.49). No significant trends were detected by the Mann-Kendall test (Table 2.13). For blueback herring, mean total lengths of female and males varied without trend in the Cocheco River and Winnicut River, but notable declines were observed for females and males in the Oyster River (Figure 2.50). Significant trends in average size were detected only for the Oyster River blueback herring (Table 2.13).

**Massachusetts**

Plots of the mean total length from fisheries-independent monitoring versus year for the Monument River and Stony Brook show apparent declines in the average sizes of male and female alewives (Figure 2.40) and blueback herring (Figure 2.49) from 1979 through the mid-1990s. Female and male alewife and blueback herring sampled during 2004-2010 were about 20-27 mm smaller, on average, than alewife and blueback herring of the same sex sampled during the 1984-1987. Trend analyses of mean lengths indicated significant decreases in mean length for males and females of both species in the Monument River and for alewife (sexes combined) in Stony Brook (Table 2.13).

**New York**

Mean length represent spawning stock length from the Hudson River Estuary. NY used only the least size-biased gears from the NYSDEC surveys: electro-fishing gear, the beach seine (61m) and the herring haul seine (91m). As sample size varied among years, all data were combined to characterize size. Mean total length are showed for adult alewives and blueback by sex ($\geq$170mm TL) in Figure 2.49 and Figure 2.50. Female and male alewives and blueback herring sampled during 2004-2010 were about 25-45 mm smaller, on average, than alewives and blueback herring of the same sex sampled prior to 1986. Trend analyses of mean lengths indicated significant decreases in mean lengths for males and females of both species (Table 2.13).

**Maryland**

Alewives and blueback herring in the Nanticoke River were collected from commercial pound nets and fyke nets and a minimum of ten alewives and ten blueback herring were selected at random from unculled commercial catches. Samples were counted, sexed, length measured and scales removed for age analysis. Mean lengths of male and female alewives did not appear to decline over the time series available (Figure 2.49). Female and male blueback herring sampled during 2004-2010 were about 13 mm smaller, on average, than blueback herring of the same sex sampled during 1989-1993 (Figure 2.50). Trend analyses of mean lengths indicated significant decreases in mean length for males and females of blueback herring, but not for males and females of alewives (Table 2.13).

**North Carolina**

The State of North Carolina conducts biological sampling of alewife and blueback herring from fishery-dependent pound net collections in the Chowan River. Length are available from 1972-2009. Declines in mean sizes of male and female alewife (Figure 2.49) and blueback herring (Figure 2.50) were apparent. Female and male alewife and blueback herring sampled during 2004-2010 were about 15-20 mm smaller, on average, than alewife and blueback herring of the same sex sampled during the 1972-1978. Trend analyses of mean lengths indicated significant decreases in mean length for males and females of both species (Table 2.13).

**South Carolina**

Mean length of blueback herring taken in the commercial fisheries in the Santee Rediversion Canal varied widely among years (Figure 2.50). Mean length of males showed a slight declining trend over the time series, while mean length of females showed a slight increasing trend. Mean length of females has exceeded that of males since 2001. Mean lengths of both sexes have declined since 2003. Blueback herring in the commercial catch tended to be smaller than those that survived the fishery and were lifted over the St Stevens Dam (Figure 2.50). Trend analysis of mean lengths indicated no decline in mean lengths over time except for the female blueback herring from the fishlift (Table 2.13).

**Florida**

An anadromous fish study in 1972 and 1973 used a commercial herring seine to capture blueback herring and other Alosines The seine was 306 m long, 131 meshes deep, 6.03 - 6.35 cm stretched mesh, bag with 5.08 cm stretched mesh. Modern length samples are collected by electrofishing. Mean lengths are lower in the 2001-2007sampling period than they were in the 1972 and 1973 samples (Figure 2.50). Trend analysis was not conducted due to the wide gap in data between time periods.

The general results of these analyses were that mean sizes for male and female alewife declined in 4 of 10 rivers, and mean sizes for female and male blueback herring declined in 5 of 8 rivers. The common trait among most rivers in which significant declines were detected is that length data were available prior to 1990. Mean lengths started to decline in the mid to late 1980s; therefore, it is likely that declines in other rivers were not detected because of the shortness of the time series.

**National Marine Fisheries Service Trawl Survey**

NEFSC bottom trawl survey data was analyzed by geographical region and season. Because of the large number of strata (376) and high variability in catches of river herring per tow, strata were aggregated into three regions for spring surveys (March – June): coast-wide, north of Long Island and south of Long Island. Fall surveys (September – December) were only aggregated coastwide because of low catches in southern survey strata.

Mean lengths for sexes combined in trawl surveys were quite variable through time for both alewife and blueback herring (Figure 2.51). Despite this variability, alewife mean length tended to be lowest in more recent surveys (Figure 2.51). This pattern was less apparent for blueback herring. Trend analysis of mean lengths indicated significant declines in mean lengths over time for alewife coastwide in both season and in the northern region during the spring, and for blueback coastwide (Table 2.14).

## 2.4 TRENDS IN AGE DATA

*Analyzed and authored by: Dr. Gary A. Nelson, Massachusetts Division of Marine Fisheries*

Age data comes from commercial and fisheries-independent sampling programs, although lengths of the time series differ greatly (see state reports for more details). Scales are used to age river herring following criteria established by Marcy (1969). In general, female alewife and blueback herring are larger and heavier, and grow slightly faster than males of the same species and age, although blueback herring are smaller than alewife.

### 2.4.1 Trends in Maximum Age

Age data of fish from rivers in Maine, New Hampshire, Massachusetts, Rhode Island, Maryland, and North Carolina were included in the analysis.

**Maine**

The maximum age of both male and female alewife from the Androscoggin River was generally ≥age 6 during the 1990s, but it decreased by about one age during the late 1990s and early 2000s (Figure 2.52). Maximum age has since increased to early 1990s levels.

**New Hampshire**

For alewife, the general trend in maximum age of females and males was river dependent. In the Cocheco River, Lamprey River and Winnicut River, maximum age increased from age 6 to ages 7 – 8 in the early 2000s (Figure 2.52). In the Exeter River, maximum age increased in the early 1990s, but it has been relatively stable at age 6 since that time except for a slight decline in 2010 (Figure 2.52). For blueback herring, the general trend in maximum age of females and males was river dependent. In the Cocheco River, maximum age fluctuated widely, although increases were observed in the latter part of the time series (Figure 2.53). In the Oyster River, maximum age increased by one age beginning in 2001. In the Winnicut River, maximum age fluctuated widely without trend (Figure 2.53).

**Massachusetts**

Maximum age of male and female alewife (Figure 2.52) and female blueback herring (Figure 2.53) in the Monument River declined from ages 7 – 8 in the mid-1980s to ages 5 – 6 during the mid-2000s.

**Rhode Island**

Maximum age of male and female alewife (Figure 2.52) in the Gilbert-Stuart River declined from ages 6 – 7 in the mid-1980s to ages 5 – 6 during the 2000s.

**Maryland**

Maximum age of male and female alewife from the Nanticoke River has fluctuated without trends, although age 9 female have not been observed since the mid-1990s (Figure 2.52). Maximum age of male and female blueback herring from the Nanticoke River declined from ages >9 during the early 1990s to ages5 – 6 and 6 – 7, respectively, during 2005 – 2010 (Figure 2.53).

**North Carolina**

The maximum age observed for male and female alewife ranged from ages 6 to 9 prior to 1983, but it declined thereafter to ages 6 – 7 through 2005. The lowest maximum age observed was age 5 for male alewife in 2006 (Figure 2.52). Maximum age of male and female blueback herring from the Chowan River was generally ≥age 7 prior to 1984 but it declined thereafter to ages 6 – 7 through 2003 (Figure 2.53). After 2003, maximum age declined to ages 5 – 6.

## 2.5 TRENDS IN MEAN LENGTH-AT-AGE

*Analyzed and authored by: Dr. Gary A. Nelson, Massachusetts Division of Marine Fisheries*

Mean lengths-at-age of alewife and blueback herring from state data were examined to determine if changes have occurred over time. The Mann-Kendall test for trends in data was used to test if negative or positive trends occurred in the mean length data for each age. A significance level of 0.05 ($p = 0.05$) was used to determine whether a statistically significant trend was present. Due to low sample sizes, only time series of ages 3-6 mean lengths were tested for trends.

**Maine**

Maine DNR conducts biological sampling of alewives at fish ladders in the Androscoggin River. Length and age data are available from 1993-2010 (Figure 2.54). For alewives, ages observed on the run ranged from 3 to 7 but most fish were ages 4-6. Trend analysis indicated a significant decline in mean length at-age for age-3 female alewives only (Table 2.15).

**New Hampshire**

Length and age data for alewives and blueback herring from the Cocheco River, Exeter River, Lamprey River, Oyster River and Winnicut River have been collected by New Hampshire since 1990. For alewife, ages 3-9 fish were collected on the runs. Plots of mean lengths-at-age showed sizes varied among age, river and sex, but in some rivers, mean lengths-at-age showed some decrease in recent years (Figure 2.54). Trends analyses indicated significant declines in mean lengths-at-age for ages 4-6 female and male alewife from the Cocheco River, for ages 4-6 females and ages 3,5, and 6 males from the Exeter River, for ages 3-5 females and ages 3 and 4 males from the Lamprey River, and for ages 4-5 females from the Winnicut River (Table 2.15). For blueback herring, ages 3-8 fish were collected on the runs. Plots of mean lengths-at-age showed sizes among age, river and sex, but in some rivers, mean lengths-at-age showed some declines over times (Figure 2.55). Trends analyses indicated significant declines in mean lengths-at-age for ages 4-5 male blueback herring from the Cocheco River, and for ages 3-6 females and males from the Oyster River (Table 2.15).

**Massachusetts**

Length and age data for alewives and blueback herring from the Monument River have been collected since 1984, although age data were only intermittently collected prior to 1993. Mean lengths-at-age were plotted by sex and year to determine if changes in growth have occurred over time. Unfortunately, data from 1984-1987 were not available for historical comparison. For alewives, ages 3-8 fish were collected on the run. Although variable, mean length-at-age of alewives for ages 3-5 of both sexes appeared to decline in the mid-1990s and increased near the latter part of time series (Figure 2.54). There were no significant changes in size-at-age detected in the trend analyses (Table 2.15.). For blueback herring, ages 3-7 fish were collected on the run. Mean lengths-at-age of both sexes varied without trend (Figure 2.55). There were no significant changes in size detected in the trend analysis (Table 2.15).

**Rhode Island**

The State of Rhode Island conducts biological sampling of alewife at fish ladders in the Nonquit River and Gilbert Stuart River. Length and age data are available from 2000-2009 in the Nonquit River and from 1984-2010 in the Gilbert Stuart River; however no samples were collected during the mid-late 1990s (Figure 2.54). Ages 2-8 alewives were found in both rivers, although the runs were comprised mostly of ages 3-6. No significant changes in mean lengths-at-age for alewife in the Nonquit River were detected by trend analysis. Mean lengths-at-age from 2000-2010 only in the Gilbert-Stuart River were tested because of the data gap in the 1990s. Significant decreases in mean length at-age were detected for age 4 and 5 females and only age 4 males (Table 2.15.).

**Maryland**

Maryland DNR collects biological samples of alewife and blueback herring from fishery-dependent pound nets in the Nanticoke River. Length and age data are available from 1989-2010. For blueback herring, individuals of ages 3-9 have occurred on the run, but most fish are ages 3-6 (Figure 2.55). Few fish of ages 7-8 have been observed in catches since the late 1990s. Mean lengths for most ages have shown little trend over time except for slight declines in the latter part of time series. A significant decline in mean length was detected only for age-5 male blueback herring (Table 2.15). For alewife, individuals of ages 3-9 have occurred on the run, but most fish are ages 3-6 (Figure 2.56). Fish of age 9 have been rare in catches since the early 1990s. Mean lengths for most ages have shown little trend over time. Significant declines in mean length were detected only for age-5 female and male alewife (Table 2.15).

**North Carolina**

The North Carolina DMF collects biological samples of alewife and blueback herring from fishery-dependent pound nets in the Chowan River. Length and age data are available from 1972-2009. For alewife, fish of age 2 (rare) through age 8 occur on the run but most fish are ages 3-6 (Figure 2.57). Plots of mean lengths-at-age for female and male alewife show that the sizes of most ages have declined over time (Figure 2.57). Trends analyses detected significant declines in sizes for all ages and sexes tested (Table 2.15.). For blueback herring, fish of age 2 (rare) through age 9 occur on the run but most fish are ages 3-7 (Figure 2.57). Plots of mean lengths-at-age for female and male blueback herring show that the sizes of most ages have declined over time (Figure 2.57). Trends analyses detected significant declines in size for all ages and sexes tested (Table 2.15).

**Comparison of Trends**

Declines in mean length of at least one age were observed in most rivers examined. The lack of significance in some systems is likely due to the absence of data prior to 1990 when the decline in sizes began, similar to the pattern observed in mean length (see Section 2.3). Declines in mean lengths-at-age for most ages were observed in the north (New Hampshire) and the south (North Carolina). There is little indication of a general pattern of size changes along the Atlantic coast.

## 2.6 TRENDS IN REPEAT SPAWNING FREQUENCY DATA

### 2.6.1 Description of Spawning Marks and Repeat Spawning Frequency Data

*Authored by: Kathy Hattala and Andrew Kahnle, New York State Department of Environmental Conservation*

Cating (1953) provided a detailed description of American shad scales, which applied to all the alosines, including river herring. Several important components of scales used during the aging process include: 1. annuli or winter rings; 2. false annuli, also called accessory rings, similar in appearance to true annuli; 3. the fresh-water zone, an important false annuli laid down when young-of-year fish pass from fresh to saltwater at the end of their first summer; and 4. spawning marks, scar-like rings extending around the scale, much like an annuli, but caused by absorption, or erosion, of the scale during the spawning migration into fresh water where little or no food is eaten by adult fish. Spawning marks are counted as annuli as they erode back from each year’s outer most annulus. They usually occur annually after fish are mature and begin to spawn each year.

There are several uses of spawning marks. The first and most common use is to calculate total instantaneous mortality (Z). Crecco and Gibson (1988) used the catch curve method of number at each mark (zero to maximum N-marks observed) on spawning marks. Spawning marks are considered to produce better estimates of Z by the catch curve method because they are easier to recognize and count than annuli and they eliminate the issue of defining the age of full recruitment to the catch curve.

Spawning marks also allow the calculation of frequency of repeat spawn. Repeat spawn at age can be used to estimate a simplified maturity schedule. Changes in repeat spawn at age and total repeat spawn can indicate changes in mortality. A decline in frequency of repeat spawn usually indicates an increase in mortality of mature fish and vice versa.

### 2.6.2 Trends in Coastwide Repeat Spawner Rates

*Analyzed and authored by: Laura M. Lee, North Carolina Division of Marine Fisheries and Katie Drew, Atlantic States Marine Fisheries Commission*

Rates characterizing the percentage of repeat spawners were calculated and evaluated for alewife and blueback herring populations along the U.S. East Coast where data were available. Repeat spawner data for these species have been collected from various fisheries-independent (Table 2.16 ) and fisheries-dependent (Table 2.17) monitoring programs. Detailed information on the individual surveys of state water bodies can be found in the individual state summary reports. Repeat spawner rates were calculated by dividing the number of sampled fish with one or more spawning marks by the total number of fish sampled and multiplying the resulting quotient by 100. Rates were calculated by sex, year, water body, gear, and species (when possible) for each state.

Comparisons among the repeat spawner rates from different states were not made due to the large variability in sampling gears and time series available. For data series that had at least five continuous years of data, the Mann-Kendall test for trend in data collected over time. A significance level of 0.05 (α= 0.05) was used to determine whether a statistically significant trend was present.

#### 2.6.2.1 Fisheries Independent Repeat Spawner Rates

A summary of the available repeat spawner data for river herring collected by fisheries-independent surveys is presented in Table 2.16). Annual estimates of repeat spawner rates based on data from these surveys are presented in Tables 2.18 – 2.27.

**Maine**

Androscoggin River: Repeat spawner data collected from the Brunswick Fishway on the Androscoggin River were available from 2005 through 2007. Species-specific data on repeat spawners were not available and so rates represent alewives and blueback herring combined. Also, detailed information on the number of spawning marks at age was not available. Male and female river herring that previously spawned ranged in age from 4 to 7 years. Repeat spawner rates for males exceeded 50% in all three years (Table 2.18). Female repeat spawner rates were similar to rates for males in 2006 and 2007, but were lower than male rates in 2005.

**New Hampshire**

New Hampshire has been collected repeat spawning data from river herring sampled from fishways on the Cocheco, Exeter, Lamprey, Oyster, and Winnicut Rivers. Because of low sample size by species, the data were not analyzed by sex (Tables 2.19 and 2.20; Figure 2.58).

Cocheco River: Alewife in the Cocheco River had up to four spawning marks; repeat spawners ranged from age 3 – 9. The proportion of repeat spawners ranged from 30.4 – 69.6% and showed no statistically significant trends (Tables 2.19 and 2.18 ).

Blueback herring in the Cocheco River had up to four spawning marks; repeat spawners ranged from age 3 – 8 (Table 2.20). Sample sizes were low in several years. The proportion of repeat spawners ranged from 12.5 – 44% and showed no statistically significant trends.

Exeter River: Alewife in the Exeter River had up to three spawning marks; repeat spawners ranged from age 4 – 8 (Table 2.19). The proportion of repeat spawners ranged from 9.0 – 39.0% and showed no statistically significant trends. Blueback herring sample sizes from the Exeter River were too small (0-12 fish in most years) to be analyzed.

Lamprey River: Alewife in the Lamprey River had up to four spawning marks; repeat spawners ranged from age 3 – 9 (Table 2.19). The proportion of repeat spawners ranged from 33 – 63% and showed no statistically significant trends. Blueback herring sample sizes from the Lamprey River were too small (0-12 fish in most years) to be analyzed.

Oyster River: Alewife sample sizes from the Oyster River were too small (0-16 fish in most years) to be analyzed. Blueback herring in the Cocheco River had up to four spawning marks; repeat spawners ranged from age 3 – 8 (Table 2.20). The proportion of repeat spawners ranged from 27.6 – 64.6% and showed no statistically significant trends.

Winnicut River: Alewife in the Winnicut River had up to four spawning marks; repeat spawners ranged from age 4 – 9 (Table 2.19). The proportion of repeat spawners ranged from 32.9 – 63.3% and showed no statistically significant trends. Blueback herring sample sizes from the Oyster River were too small (0-12 fish in most years) to be analyzed.

**Massachusetts**

Information on repeat spawner percentage of river herring species in Massachusetts was available from fisheries-independent dip net surveys of several rivers. Repeat spawner data from the Mattapoisett River, the Quashnet River, and Stoney Brook were limited and so not summarized here, but calculated repeat spawner rates can be found in Tables 2.21 and 2.2.2.

Monument River: Repeat spawner data for alewives sampled during fisheries-independent surveys of the Monument River were available from 1986 through 1987 and from 2004 through 2010. Age-specific data were not available for 1986 and 1987. Of alewife that had spawned previously in recent years, most had only one spawning mark. Repeat spawner rates for male and female alewives were much higher in 1986 and 1987 (41–45%) compared to the most recent years available (1–15%; Tables 2.21and 2.22).

Repeat spawner data for blueback herring collected by dip net during fisheries-independent surveys of the Monument River were available from 1986 through 1987 and from 2004 through 2010. As with alewives, age-specific data were not available for 1986 and 1987. None of the blueback herring sampled from 2004 to 2010 had more than one spawning mark. Repeat spawner rates for both male and female blueback herring were higher in 1986 and 1987 (20–38%) than in recent years (4–14%;Tables 2.23 and 2.24), similar to what was observed for alewives.

Mystic River: Repeat spawner data for alewives have been collected since 2004 and for blueback herring since 2005 as part of fishery independent surveys of the river. Both species had up to three spawning marks on their scales. For alewives, the percentage of repeat spawners ranged from 0-32.4% for males and from 0-35.7% for females (Tables 2.21 and2.22). For blueback herring, the percentage of repeat spawners ranged from 5.7-27.4% for males and from 2.7 – 35.0% for females (Tables 2.23 and 2.24.). There was no statistically significant trend for either species over this time-period.

Nemasket River: Repeat spawner data for alewives collected from the Nemasket River were available from 2004 through 2010. Male alewife repeat spawners were between 4 and 8 years old, while females ranged in age from 5 to 8 years. Both male and female alewife repeat spawners had from one to three spawning marks. Repeat spawner rates for males and females were similarly variable from 2004 through 2010, ranging between 9% and 44% (Tables 2.21 and 2.22). There was no statistically significant trend for either sex over this time-period. No repeat spawner data were available for blueback herring from the Nemasket River.

Town Brook: Repeat spawner data for alewives collected by the fisheries-independent survey of Town Brook were available from 2004 through 2010. Male alewives that previously spawned ranged from 4 to 6 years in age, while females ranged in age from 4 to 7 years. Of alewives that had spawned previously, most had only one spawning mark. The percentage of male alewives that previously spawned ranged from 4.41% to 32.3% (Table 2.21). Repeat spawner rates for female alewives ranged from 7.94% to 31.1% (Table 2.22). There was no statistically significant trend for either species over this time-period. Blueback herring repeat spawner data were only available for 2005 for Town Brook (Tables 2.23 and 2.24). All of the blueback herring sampled were virgin spawners, although the sample size was very low.

**Rhode Island**

Rhode Island has been collecting repeat spawning data from river herring sampled from fishways in Gilbert Stuart Stream and Nonquit Pond. The data were not available by species, so calculated repeat spawner rates represent alewives and blueback herring combined.

Gilbert Stuart Stream: Repeat spawner data collected during sampling of the fishway at Gilbert Stuart Stream were available for intermittent years from 1984 through 1989 and were available for all years from 1991 – 2010. Male repeat spawners ranged from 3 to 7 years in age while female repeat spawners ranged in age from 3 to 8 years. Male and female repeat spawners had from one to three spawning marks, and most had only one spawning mark. Repeat spawner rates have been variable for both male and female river herring through the time series (Tables 2.25 and 2.26; Figure 2.59). The percentage of males that had previously spawned ranged from a low of 4.44% in 2005 to a high of 81.4% in 1986. Rates of repeat spawner for females ranged from a low of 3.3% in 2009 to a high of 59.3% in 1992. The Mann-Kendall test demonstrated a statistically significant downward trend over time for both male and female repeat spawner rates.

Nonquit Pond: Repeat spawner data has been collected from river herring sampled at the Nonquit Pond fishway since 2000 and were available through 2009. Male repeat spawners ranged in age from 4 to 5 years and most had only one spawning mark. Estimated repeat spawner rates for male river herring were variable, ranging from 0% to 15.6% over the time series. The Mann-Kendall test indicated no significant trend in the male repeat spawner rates over the time series. Female repeat spawners were between 4 and 6 years in age and, like the male repeat spawners, most had one spawning mark. Repeat spawner rates for females ranged from 0 to 25.0% and showed a general decrease from 2000 through 2007. The Mann-Kendall test indicated there was no statistically significant trend in repeats spawner rates for the Nonquit.

**New York**

River herring repeat spawner data collected from fisheries-independent surveys of the Hudson River Watershed in New York were combined over all gears and areas sampled.

Hudson River: Repeat spawner data for alewives sampled from the Hudson River were available from 1999 through 2001. Male alewives that previously spawned ranged in age from 4 to 10 years, while female repeat spawners ranged from 5 to 10 years in age. The male alewives had as many as five spawning marks, while the females had no more than four. The estimated repeat spawner rates for female alewives exceeded the male rates over the short time series (Table 2.27).

Repeat spawner data on blueback herring collected from the Hudson River were available from 1989 through 1990 and from 1999 through 2001. Male blueback herring repeat spawners ranged from 3 to 9 years in age and had from one to four spawning marks. Female blueback herring that previously spawned ranged from 3 to 10 years old with one to four spawning marks. Repeat spawner rates were generally higher in the earlier years available (1989 and 1990) for both male and female blueback herring (Tables 2.23 and 2.24).

**South Carolina**

Santee River: Repeat spawner data for blueback herring sampled from the Santee River were available from 1978 through 1983. Repeat spawner data for alewives were not available from the Santee River. However, the gear used to collect the fish varied among those years. In 1978, a pound net was used. A haul seine was used in 1979. From 1980 through 1983, samples were collected with a gill net. Repeat spawner rates based on data collected by the different gear types are not comparable due to differences in selectivity. As such, only data collected by gill net are summarized here since only one year of data was available from each of the other gears, though repeat spawner rates estimated for all gears are reported in the tables at the end of this report.

Male and female blueback herring that previously spawned ranged in age from 4 to 7 years and had marks indicating from one to three previous spawning events. Repeat spawner rates were variable between 1980 and 1983, ranging from 9.2% to 30.7% for males and from 17.1% to 33.7% for females).

#### 2.6.2.2 Fisheries Dependent Repeat Spawner Rates

A summary of the available repeat spawner data for river herring collected by fisheries-dependent surveys is presented in Table 2.17.. Annual estimates of repeat spawner rates based on data from these surveys are presented in Tables 2.28 through 2.31.

**Maryland**

Nanticoke River (Pound & Fyke Net): Repeat spawner data for river herring collected during sampling of the pound net and fyke net fisheries on the Nanticoke River were available for most years from 1989 through 2010. Male alewives that previously spawned were between 4 and 8 years old and had from one to four spawning marks. Female alewife repeat spawners ranged from 4 to 9 years in age and had from one to five spawning marks. Repeat spawner rates for male and female alewives were variable over the time series, ranging from 25.0% to 72.0% for males and from 41.8% to 84.9% for females (Tables 2.28 and 2.29; Figure 2.60). Rates for female alewife repeat spawners were consistently higher than rates for males, though showed similar fluctuations over time. Application of the Mann-Kendall test indicated no statistically significant trend over time for either the male or female alewife repeat spawner rates.

Male blueback herring repeat spawners sampled from pound nets in the Nanticoke River ranged in age from 4 to 11 years. In 2001, an 11 year-old male blueback herring was observed with eight spawn marks. Female blueback herring that previously spawned ranged from 4 to 10 years in age and had from one to six spawn marks. The percentage of male blueback herring that previously spawned ranged from a low of 13.2% in 2007 to a high of 85.8% in 1997 (Table 2.30; Figure 2.61). Female blueback herring repeat spawner rates ranged from a low of 20.0% in 2005 to a high of 83.4% in 1990. Repeat spawner rates for male and female blueback herring showed similar variations over the time series. The Mann-Kendall test indicated both sexes had experienced a statistically significant decline in percentage of repeat spawners.

**North Carolina**

Alligator River (Pound Net): Repeat spawner data for alewives collected by pound nets from the Alligator River were available for all years from 1972 to 1993, except 1974. Male alewife repeat spawners were 3 to 8 years old and had one to four spawning marks. Female alewives that previously spawned ranged from 3 to 10 years in age and had one to five spawning marks. Repeat spawner rates for male and female alewives were similar in magnitude (0–79%) and exhibited similar fluctuations over time (Tables 2.28

and 2.29; Figure 2.62). Application of the Mann-Kendall test for trend found no statistically significant trend over time in either the male or female alewife repeat spawner rates.

Repeat spawner data for blueback herring sampled from pound nets during fisheries-dependent sampling of the Alligator River were available for intermittent years from 1972 to 1991. Both male and female blueback herring that previously spawned ranged in age from 4 to 8 years and had from one to three spawning marks (Tables 2.30 and 2.31).

Chowan River (Pound Net): Fisheries-dependent repeat spawner data for alewives collected by pound nets from the Chowan River were available for 1972 through 1989, 1991 through 1994, and 1999 through 2009. Male alewife that previously spawned ranged in age from 4 to 8 years and had from one to three spawning marks. Repeat spawner rates for male alewives were highly variable over the time series, ranging from 0% to 66.7% (Table 2.28; Figure 2.62). Female alewife repeat spawners ranged from 3 to 8 years in age and had from one to five spawning marks. The female alewife repeat spawner rates were also variable and as high as 86.7% in 1991, although sample size was very low that year (Table 2.29; Figure 2.62). The Mann-Kendall test found no statistically significant trend over time in the percentage of male or female alewives that previously spawned.

Repeat spawner data for blueback herring collected during fisheries-dependent pound net sampling of the Chowan River were available for all years from 1972 through 2006. Male blueback herring repeat spawners were 3 to 8 years in age and had from one to four spawning marks. Repeat spawner rates for male blueback herring ranged from a low of 5.5% in 2008 to a high of 64.0% in 1979 (Table 2.30; Figure 2.63). Female blueback herring that previously spawned ranged from 4 to 9 years in age and had from one to four spawning marks. Female blueback herring repeat spawner rates were similar in magnitude to the male rates, ranging from a low of 1.69% in 1987 to a high of 77.8% in 1979 (Table 2.31; Figure 2.63). No statistically significant trends over time were detected in the male or female repeat spawner rates when the Mann-Kendall test was applied.

Scuppernong River (Pound Net): The fisheries-dependent pound net survey of the Scuppernong River collected repeat spawner data from alewives from 1972 through 1984 and from 1987 through 1993. Male alewife repeat spawners ranged from 3 to 7 years in age, while female repeat spawners were between 3 and 8 years old. Males had from one to three spawning marks and females had one to four spawning marks. Repeat spawner rates for male and female alewives were similar in magnitude (0–69%) and showed similar variability over the time series (Tables 2.28 and 2.29; Figure 2.62). The Mann-Kendall test found no evidence for a statistically significant upward or downward trend over time for the either the male or female alewife repeat spawner rates.

Blueback herring repeat spawner data collected during the Scuppernong River pound net survey were available for all years from 1972 through 1993. Male blueback herring that previously spawned ranged from 3 to 8 years in age, while females were between 4 and 9 years old. Male blueback herring repeat spawners had from one to three spawning marks and females had from one to four spawning marks. Repeat spawner rates for male and female blueback herring demonstrated similar fluctuations over the time series, ranging from 0% to 45.8% for males and from 0% to 61.5% for females (Tables 2.30 and Table 2.31; Figure 2.63). The Mann-Kendall test did not detect a significant trend over time for either the male or female blueback herring repeat spawner rates.

## 2.7 TRENDS IN TOTAL INSTANTANEOUS (Z) MORTALITY ESTIMATES

*Compiled and authored by: Dr. Gary A. Nelson, Massachusetts Division of Marine Fisheries*

### 2.7.1 Age-based Total Instantaneous (Z) Estimates

The Chapman-Robson survival estimator (Chapman and Robson, 1960), the least biased estimator of survival compared to catch curve analysis (Murphy, 1997; Dunn et al., 2002), was applied to the annual age-frequency data to generate a single estimate of survival rate for each state, river, species, sex and year. Z was estimated by the natural-log transformation of S. The first age-at-full recruitment was the age with the highest frequency. Only Z estimates made from data with three or more age-classes (including first fully-recruited age) were deemed valid. Linear and loess smoothers (Maindonald and Braun, 2003) were applied to all river estimates for a given state, species, and sex to indicate trends in the annual estimates. Estimates of Z are given in state reports and are summarized below.

**Maine**

Estimates of Z were made for male and female alewife from the Androscoggin and Sebasticook rivers using fisheries-independent data. Z for female alewife in the Androscoggin River declined slightly from around 2.0/yr in the late 1980s to around 0.83 during 1995-1997, and then increased slightly to about 1.3/yr thereafter (Figure 2.64). Z estimates for males showed little trend over time and averaged 1.5/yr over the time series (Figure 2.64). The time series of Zs for female and male alewife from the Sebasticook River were short, showed little trend, and averaged 1.6/yr for both sexes.

**New Hampshire**

Estimates of Z were made for male and female alewife and blueback herring from the Cocheco, Lamprey, Oyster and Winnicut rivers by using fisheries-independent data.

For alewife, declines in Z through 2000 were observed in the Cocheco and Lamprey rivers for both sexes (Figure 2.65). Since 2000, Z has increased slightly and has averaged 1.0/yr and 0.9/yr for females, and 1.2/yr and 1.0/yr for males in the Cocheco River and Lamprey River, respectively. The time series of Zs for female and male alewife from the Winnicut River were short, showed little trend, and averaged about 0.9/yr for females and 1.2/yr for males (Figure 2.65). For blueback herring, declines in Z were observed in the Cocheco River for both sexes, although since 2000, Z has increased slightly for males (Figure 2.65). Little trend in Z was evident for females and males from the Oyster River; average of Z was 1.1/yr for both sexes (Figure 2.65). The time series of Zs for female and male blueback herring from the Winnicut River were short, showed opposing trends, and averaged about 1.2/yr for females and 1.1/yr for males (Figure 2.65).

**Massachusetts**

Estimates of Z were made for female and male alewife and blueback herring from the Agawam River, Back River, Charles River, Mattapoisett River, Monument River, Mystic River, Nemasket River, Parker River, Stony Brook, and Town River by using fisheries-independent data. For alewife, Z estimates averaged 1.1/yr and 1.2/yr for female and males, respectively, from the Parker River during the 1970s (Figure 2.66). In the Monument River, estimates of Z for females increased from 0.9/yr in the late 1980s to 1.22/yr in 1999, and then declined to an average of 1.1/yr in the late 2000s (Figure 2.66). Z estimates for males increased from 0.91/yr to an average 1.4/yr in the late 2000s (Figure 2.66). In the remaining rivers, the time series of Zs were short and showed little trend. The average of Z during 2004-2010 for these rivers was 1.3/yr for both sexes. For blueback herring, estimates of Z for female and males from the Monument River showed little trend over time (Figure 2.67). Average Z was 1.1/yr and 1.3/yr for females and males, respectively. The time series of Zs for the remaining rivers were short, showed little trend and averaged 1.2/yr and 1.3/yr for females and males, respectively.

**New York**

Estimates of Z were made for female and male blueback herring from the Hudson River and tributaries collected during 1989 and 1990. Estimates for males were 1.33/yr and 0.89/yr in 1989 and 1990, respectively. For females, Z estimates were 1.36/yr and 1.21/yr in 1989 and 1990, respectively (Figure 2.68). The average Z over the two years was 1.1/yr for males and 1.3/yr for females.

**Maryland**

Estimates of Z were made for female and male alewife and blueback herring from the Nanticoke River by using fisheries-independent data. Except for the sharp rise in 2003 and 2004, total mortality for female alewife showed little trend over time (Figure 2.69). Estimates of Z for male alewife showed a very slight increase in mortality over time (Figure 2.69). The average Z was 1.0/yr for females and 1.1/yr for males. For blueback herring, Z estimates for females showed little trend (except a slight rise in 1997-1999) over time (average = 1.0/yr), but mortality rose from an average 0.8/yr during the early 1990s to an average of 1.6/yr during 2006-2010 for males (Figure 2.69).

**North Carolina**

Estimates of Z were made for alewife and blueback herring with sexes combined from the Chowan River, Alligator River, Meherrin River, Scuppernong River, and Albemarle Sound by using fisheries-dependent and fisheries-independent data. For alewife, estimates of Z from the Alligator River, Chowan River, Merherrin River and Suppernong River during the 1970s, 1980s, and 1990s averaged 1.3/yr, 1.0/yr, and 0.84/yr, respectively. During the 2000s, estimates of Z from the Chown River and Albemarle Sound averaged 0.96/yr. For the longest river time series (Chowan), only slight increases in mortality were observed (Figure 2.70). For blueback herring, estimates of Z from the Chowan River, Merherrin River and Suppernong River during the 1970s, 1980s, and 1990s averaged 0.9/yr in each period. During the 2000s, estimates of Z from the Chowan River and Albemarle Sound averaged 1.1/yr. For the longest river time series (Chowan), slight increases in mortality were observed over the time series (Figure 2.70).

**South Carolina**

Estimates of Z were made for blueback herring with sexes combined from the Cooper River by using fisheries-independent data. A slight decline in Zs was indicated by the loess smooth for blueback herring (Figure 2.71). The average Z over the time series was 1.67/yr.

### 2.7.2 Repeat Spawner Data-based Total Mortality (Z) Estimates

The Chapman-Robson survival estimator (Chapman and Robson, 1960), the least biased estimator of survival compared to catch curve analysis ( Murphy, 1997; Dunn et al., 2002), was applied to the repeat-spawner frequency data of most states to generate a single estimate of survival rate (S) for each species, sex and year. The exception was data for New York to which standard catch curve analysis (linear regression) were applied. Z was estimated by the natural-log transformation of S. Only Z estimates made from data with three or more repeat spawner classes (including first fully-recruited class) were deemed valid.

<u>Massachusetts</u> – Estimates of Z were made for female and male alewife and blueback herring from the Back River, Monument River, Mystic River, Nemasket River, and Town River by using fisheries-independent data. For alewife, average Z estimates for male and female alewife from the Monument River were 0.9/yr and 1.1/yr, respectively, during 1986-1987 and increased to averages of 2.1/yr and 2.4/yr , respectively, during 2007-2010 (Figure 2.72). For the remaining rivers, the time series were short and showed variable trends. The average Zs for females and males from these rivers were 1.6/yr for both sexes. For blueback herring, there were few valid Z estimates available for trend analysis. The average Zs for males and females in all rivers were 1.4/yr and 1.6/yr, respectively (Figure 2.73).

Rhode Island – Estimates of Z were made for alewives (combined sexes) from the Gilbert-Stuart River and Nonquit River. For Gilbert-Stuart alewives, Z appeared to decline slightly from 1975 through the early 1990s (average Z=1.3/yr) (Figure 2.74). Starting in 2000, Z estimates increased and averaged 2.2/yr through 2010, suggesting increased mortality. A shorter time series was available for the Nonquit River, but it showed a slight increase in mortality since 2000. The average Z for this system from 2000-2010 was 2.6/yr (Figure 2.74).

New York – Estimates of Z were made for female and male alewives collected during 1989-1990 and blueback herring collected during 1989-1990 and 1999-2001 from the Hudson River and tributaries. There was very little trend in the Z estimates for female and male alewives (Figure 2.75). The average Z over 1999-2001 was 1.2/yr for female alewife and 1.3/yr for male alewife. For blueback herring, the average Z of females declined from 1.6/yr in 1989-1990 to 1.0/yr in 1999-2001; however, the average Z for males increased from 1.2/yr in 1989-1990 to 1.6/yr in 1999-2001 (Figure 2.75).

Maryland - Estimates of Z were made for female and male alewives and blueback herring from the Nanticoke River using fisheries-independent data. For alewives, estimates of Z for females and males showed an increase from an average Z of 0.75/yr and 0.84/yr, respectively, in 1990-1993 to an average Z of 1.9yr and 1.7/yr, respectively, in 2000-2002 (Figure 2.76). Since 2003, the Z estimates declined to an average of 1.2/yr for each sex during 2007-2010. The average Z over each time series was 1.2/yr for females and 1.2/yr for males. For blueback herring, estimates of Z for females and males showed an increase from an average Z of 0.8/yr and 0.8/yr, respectively, in 1989-1993 to average Z of 1.1/yr and 1.5/yr, respectively, in 2000-2002 (Figure 2.76). Since 2003, the Z estimates have declined slightly to an average of 1.0/yr for females and 1.1 for males during 2007-2010. The average Z over the time series was 1.0/yr for females and 1.1/yr for males.

North Carolina - Estimates of Z were made for alewives and blueback herring from the Chowan River, Alligator River, Meherrin River, Scuppernong River, and Albemarle Sound using fisheries-dependent and fisheries-independent data. For alewives, estimates of Z from the Chowan River and Scuppernong River for females and males during the 1970s, 1980s, and 1990s averaged 1.2/yr and 1.6/yr, respectively, 1.4/yr and 1.5/yr, respectively, and 0.8/yr and 1.5/yr, respectively (Figure 2.77). During the 2000s, estimates of Z from the Chowan River and Albemarle Sound averaged 1.13/yr for both sexes. For the longest river time series (Chowan), mortality appeared to increase through 1990 and then decline to current averages of 1.2/yr for females and 1.4/yr for males. For blueback herring, estimates of Z from the Chowan River, Meherrin River and Scuppernong River during the 1970s, 1980s, and 1990s averaged 1.2/yr for females and 1.3/yr for males, 1.2/yr for female and 1.4/yr for males, 1.2/yr for females and 1.2/yr for males, respectively. During the 2000s, estimates of Z from the Chowan River and Albemarle Sound averaged 1.1/yr for females and 1.5/yr for males. For the longest river time series (Chowan), mortality showed little trend over time.

South Carolina – Estimates of Z were made for male and female blueback herring from the Santee River by using fisheries-dependent data. Although the Z estimates for female and male blueback herring showed opposing decreasing and increasing trends (Figure 2.78), the wide variation in the estimates and shortness of the time series suggests general trends may not be accurate. The average Z was 1.58/yr and 1.77/yr for female and male blueback herring, respectively.

## 2.8 TRENDS IN IN-RIVER EXPLOITATION RATES

*Analyzed and authored by: Dr. Gary A. Nelson, Massachusetts Division of Marine Fisheries*

In-river exploitation rates of the spawning runs were calculated for five rivers (Damariscotta River (ME - alewife), Union River (ME – alewife), Monument River (MA: both species combined), Mattapoisett River (MA - alewife), and Nemasket River (MA – alewife)) by dividing in-river harvest by total run size (escapement plus harvest) for a given year. Exploitation rates were highest (range: 0.53-.0.98) in the Damariscotta River and Union River prior to 1985, while exploitation was lowest (range: 0.26-0.68) in the Monument River (Figure 2.79). Exploitation declined in all rivers through 1991-92. Exploitation rates of both species in the Monument River and of alewives in the Mattapoisett River and Nemasket River were variable (average = 0.16) and, except for the Nemasket River, declined generally through 2005 until the Massachusetts moratorium was imposed (Figure 2.79). Exploitation rates of alewives in the Damariscotta River were low (<0.05) during 1993-2000, but they increased steadily through 2004 and remained >0.34 through 2008 (Figure 2.79). Exploitation in the Damariscotta dropped to 0.15 in 2009-2010. Exploitation rates of alewives in the Union River declined through 2005 but have remained above 0.50 since 2007 (Figure 2.79).

## 2.9 INDEX OF RELATIVE RIVER HERRING EXPLOITATION

*Analyzed and authored by: Dr. John Sweka, US Fish and Wildlife Service*

An index of relative exploitation was developed for the coastwide population of river herring. The NEFSC bottom trawl data was used to calculate a minimum swept area estimate of total biomass for spring surveys (1976 – 2010). Minimum swept area estimates are stratified total biomass estimates calculated by expanding the biomass caught within each NEFSC bottom trawl stratum to the area of the stratum and then summing over all strata. Spring surveys were used because river herring are more readily caught during the spring than during the fall surveys (see NEFSC trawl report section). Estimated total catch was calculated from total reported landings (Section 2.1.2), NAFO landings reported from other countries (Section 2.1.2), plus total incidental catch derived via hindcasting methods using the survey-scaling method (NEFSC 2008, Palmer et al. 2008Estimated total catch was divided by total swept area estimates of biomass to yield an index of relative exploitation. The relative exploitation index was developed for the coastwide population rather than regional populations because estimates of total incidental catch could not be partitioned among regions or discrete river stocks. It should be noted that there is potential for double-counting some of the incidental catch when it is added to the reported landings from the states and NAFO. The method of estimating total incidental catch (retained and discarded) from observer coverage uses total landings from ocean fisheries as the raising factor, and thus any reported river herring landings from federal ocean fisheries would theoretically be included in the incidental catch estimate.

Minimum swept area estimates of total biomass fluctuated greatly between 1976 and 1995 and were lowest between 1988 and 1990. Total biomass estimates remained fairly stable between 2000 and 2008, but then increased in 2009 (Figure 2.80). Total catch estimates showed a consistent decline from 1976 – 2010, decreasing from a high of 8,933 MT in 1976 to a low of 637 MT in 1996 (Figure 2.81). Relative exploitation also fluctuated greatly from 1975 – 1994, but decreased in 1995 and remained stable until 2008 at which point another decrease occurred in 2009 and 2010 (Figure 2.82). The highest relative exploitation occurred when total biomass was lowest in the late 1980s – early 1990s.

Total catch estimates were often greater than minimum swept area estimates of total biomass resulting in relative exploitation rates > 1.0. Catches of river herring from the NEFSC bottom trawl were not corrected by any assumed catchability coefficients, and as the survey stops at Cape Hatteras, NC, estimates do not include the southern range of the stock. Therefore total biomass estimates likely greatly underestimated the true total biomass of river herring. If we assume total biomass estimates are proportional to the true biomass, the calculated relative exploitation values provide an indication of recent trends in river herring exploitation. The high relative exploitation levels seen around 1990 correspond to decreasing run sizes seen in several rivers in the early- to mid-1990s (e.g. the Connecticut, Monument, Gilbert, Taylor and Oyster rivers (Section 2.2.1). Also, the low relative exploitation values observed over the last decade correspond to a period of lower exploitation estimated in some of the variants of the depletion-based stock reduction assessment model (Section 2.11).

## 2.10 TOTAL MORTALITY (Z) BENCHMARKS

*Analyzed and authored by: Dr. Gary Nelson, Massachusetts Division of Marine Fisheries and Dr. Katie Drew, Atlantic States Marine Fisheries Commission*

River herring are subject to many different sources of mortality, some anthropogenic (e.g., directed and incidental fishing mortality, habitat loss, dam and passage mortality), and some natural (e.g., predation). We can estimate total mortality (Z) for alewives and blueback herring in a number of river systems from age structure and repeat spawner data; however, we often cannot partition this total mortality into its various fishing and non-fishing components.

We developed total mortality benchmarks based on spawning stock biomass per recruit analyses in order to provide reference points for our empirical measurements of Z. In addition, the rates of fishing mortality (*F*), exploitation rate (*u*), and total mortality that cause run-specific river herring populations to collapse due to declining recruitment at low spawning stock biomass were obtained from previously-derived estimates in Crecco and Gibson (1990), updates of their methods, literature values, or using stock assessment models.

### 2.10.1 Data and Methods

#### 2.10.1.1 Spawning stock biomass per recruit analyses

Estimates of spawning stock weight-at-age from Maine, Rhode Island, and North Carolina were based on observed average weight-at-age from fishery independent river sampling (Table 2.32). The sample sizes of weight-at-age for New Hampshire, Massachusetts, Maryland, and South Carolina were insufficient, so estimates of spawning stock weight-at-age were developed by converting observed length-at-age to weight-at-age. Massachusetts and Maryland's data were converted with state-specific length-weight relationships. Massachusetts's length-weight relationship was used to convert New Hampshire's length-at-age data. South Carolina's observed length-at-age data was converted to weight-at-age using a length-weight relationship developed from the subset of NC's data that covered the same time period (1975-1983). New Hampshire, Maryland, Rhode Island, and North Carolina have all shown declines in mean size-at-age, so only the earliest available five years of data were used for those states.

The cumulative proportion of fish that spawned for the first time at each age was estimated from repeat spawner marks and used as a maturity schedule; all states had these data available. The repeat spawner data was pooled over all years for each state.

Two values of natural mortality were used: 0.3 and 0.7. The lower value of 0.3 is consistent with estimates based on the maximum observed age of alewife and blueback (Hewitt and Hoenig, 2005), while the higher value 0.7 is more in line with what has been used in other river herring assessments (e.g., Gibson and Myers, 2003a,c). Sensitivity analyses were done to compare age-varying to age-constant values of *M*.

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

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

Fishing selectivity was assumed to be 1.0 for all ages. Fishing mortality in this analysis was assumed to represent both directed in-river fishing on mature adults and incidental catch of juveniles in the ocean, as well as other sources of mortality, such as passage mortality and increased predation.

#### 2.10.1.2 Z-collapse analyses

C & G S-R - Crecco and Gibson (1990) estimated the alpha parameter of the Shepherd stock recruitment function using spawning stock biomass and recruitment numbers generated from total run size and harvest data of several river herring runs. Since many runs did not have age data for every year, they assumed a constant age composition over all years and estimated the numbers at age on the run. To calculate recruitment, they summed estimates of virgin 3-6 year old fish for each cohort. Spawning stock biomass (in pounds) was the sum of escapement abundance for each age-class within each year multiplied by the average weight of an adult river herring (0.35 lbs for blueback; 0.45 lbs for alewife). Yield-per-recruit and biomass per recruit production models were then used to derive $F_{collapse}$. $u_{collapse}$ calculated directly from $F_{collapse}$ by 1-exp(-$F_{collapse}$). $Z_{collapse}$ was derived by adding the total instantaneous mortality rate used in the assessment (M=1.0) to $F_{collapse}$.

C& G M1 - Crecco and Gibson (1990) used a second method to estimate alpha parameters. Based on Eberhardt (1977), they calculated alpha from an estimated intrinsic rate of increase value ($r_m$), average weight, and average generation time for river herring. The intrinsic rate of increase was estimated by fitting the model $N_t$=C*exp($r_m$*t) to apparent ascending exponential growth in annual fishway counts ($N_t$) and time (t). $F_{collapse}$ was calculated by using a linear relationship between $F_{collapse}$ and alpha derived from the C & G S-R method and the new estimate of alpha.

C& G M2 – Similar to C & G M1 except the intrinsic rate of increase was estimated from life history models relating $r_m$ to average weight, average generation time, or growth.

M1 – The method of C & G M1 was used but the intrinsic rate of increase was estimated for the same period (population size estimates changed) or for new periods of increases. In this method, a natural mortality value of 1.0 was added to $F_{collapse}$ to get $Z_{collapse}$.

M3 – Gibson and Myers (2003c) applied mixed effects modeling to stock-recruitment data of alewife from different runs to derive a best estimate of alpha (34.1 in kilograms), $F_{collapse}$ (1.46) and $u_{collapse}$ (0.77) that could be used for runs for which stock-recruitment data are not available. The natural mortality rate of 1.0 was used for adults.

M4 – Stock assessment models were developed for the Chowan River blueback herring stock, the Monument River alewife stock, and the Damariscotta River alewife stock. $F_{collapse}$ was derived using the estimate of alpha from the Beverton-Holt model fit to model estimates of stock-recruitment and by using spawning stock biomass per recruit analyses to find the *F* that produced the inverse SPR that matched the alpha parameter (see Gibson and Myers, 2003c). When weight data were not available (Damariscotta River) the SPR analysis for Massachusetts alewives was used to determine $F_{collapse}$. $Z_{collapse}$ was determined by adding the *M* of 0.7 for Chowan River and 0.7 for the Monument River and Damariscotta River to $F_{collapse}$.

M5 – Similar to C & G S-R, stock-recruitment data were updated for runs with age data and run size estimates. Age data (proportions) were used to apportion each year's run size to age classes. If age data were missing, the average proportions from all years with data were used. Since the age composition data used in the 1990 assessment were not given in the document, the stock-recruitment data were re-calculated based on new age data and the following equation from Gibson and Myers (2003b) to calculate recruitment (R) in each year (t):

$$R_t = \sum_{a=3}^{6} \frac{N_{t+a,a}}{\exp^{-M(a-3)}}$$

where N is age-class (a) run size of virgin fish (derived using field estimates of proportions mature at age) and *M* is natural mortality (0.7). The Beverton-Holt S-R equation (Gibson and Myers, 2003b) was fitted to the recruitment and female spawning stock biomass (kilograms) data. $F_{\text{collapse}}$ was calculated by using spawning stock biomass per recruit analyses (from the Monument River) to find the *F* that produced the inverse SPR that matched the alpha parameter. Resulting stock-recruitment data and model fits are shown in Figure 2.93 for the three rivers to which this method was applied.

### 2.10.2 Results

#### 2.10.2.1 Spawning stock biomass per recruit

SPR reference points for age-specific *M* were almost identical to estimates of age-constant *M*, as long as the age-specific values were scaled to leave the same percentage of the population alive at the oldest age class as the age constant *M*. For ease of calculating *Z*-benchmarks, and consistency with the assumptions underlying our empirical estimates of *Z*, results are presented for the age-constant values of *M*. Not suprisingly the higher value of *M* (0.7) resulted in higher values of $Z_{40\%\text{SPR}}$ and $Z_{20\%\text{SPR}}$.

Empirical estimates of *Z* from some rivers were above the highest $Z_{20\%\text{SPR}}$ benchmarks for their entire time-series, while other rivers' status depended on the value of *M* chosen for the analysis (Figure 2.83 – Figure 2.92). Fifteen of the 27 rivers with *Z* estimates available in 2009 were above the $Z_{20\%\text{SPR},\ M=0.7}$ benchmark (Table 2.33).

#### 2.10.2.2 Z-collapse

All estimates of $F_{\text{collapse}}$, $u_{\text{collapse}}$ and $Z_{\text{collapse}}$ are tabularized by species, river and method in Tables 2.34 and 2.35. Also shown are the estimates of $r_m$ and alpha for the various methods. For some rivers, estimates of $F_{\text{collapse}}$, $u_{\text{collapse}}$ and $Z_{\text{collapse}}$ from the different methods varied widely. Where applicable, the minimum, maximum and average $Z_{\text{collapse}}$ values were plotted for each river (Androscoggin values were used for the Sebasticook River) and compared to age-based *Z* estimates for alewife (Figure 2.94) and blueback herring (Figure 2.95). For alewives, most age-based *Z* estimates were well-below the $Z_{\text{collapse}}$ values, although $Z_{\text{collapse}}$ values were exceeded during one or two years in two rivers (Sebasticook River and Monument River)(2.89). This suggests that current total mortality is not high enough to cause the abundances of alewives to decline. For blueback herring, the *Z* estimates for the Chowan River stock in 1987 exceeded the minimum and average $Z_{\text{collapse}}$ values and approached the maximum value, suggesting that total mortality may have been high enough in one year to have crashed the stock (Figure 2.95).

#### 2.10.2.3 Discussion

Estimates of $Z_{\text{collapse}}$ were much higher than the estimates of $Z_{20\%\text{SPR}}$ at the corresponding value of M. In recent years, the majority of the rivers examined were above the $Z_{20\%\text{SPR}}$ benchmark but below the $Z_{\text{collapse}}$ threshold. No rivers exceeded the $Z_{\text{collapse}}$ threshold, and some were below the $Z_{20\%\text{SPR}}$ and $Z_{40\%\text{SPR}}$ benchmarks as well. However, there is uncertainty in our estimates of current *Z*, due to both ageing error and the potential for violations in the assumptions of the Chapman-Robson method, such as constant recruitment.

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

Additionally, these benchmarks are sensitive to the selectivity pattern assumed for the fishing mortality. A population can sustain a higher $F$ if that $F$ is applied to older, mature ages rather than juveniles. The $F$ in these analyses represents a combination of fishing and other anthropogenic and non-anthropogenic sources of mortality, most of which we cannot quantify at the moment. Improving our understanding of the selectivity patterns of these different sources of mortality would improve our benchmark estimates as well as provide guidance on the best way to reduce excess mortality on these stocks.

## 2.11 DEPLETION-BASED STOCK REDUCTION ASSESSMENT OF ATLANTIC COAST RIVER HERRING

Depletion-based stock reduction analysis (DBSRA) is a technique proposed by Dick and MacCall (2010, 2011) to generate sustainable yield reference points for data-poor groundfish stocks in the Pacific northwest. It is a variation on stochastic stock reduction analysis (Walters et al., 2006) that uses a production model rather than an age-structured model to describe the underlying population dynamics.

In this approach, a population is described by a model, in this case the Pella-Tomlinson surplus production model:

$$B_{t+1} = B_t + \gamma \cdot m \cdot \left(\frac{B_t}{K}\right) - \gamma \cdot m \cdot \left(\frac{B_t}{K}\right)^n - C_t \qquad (1)$$

$n$ is the shape parameter that defines where the maximum productivity of the stock occurs relative to $K$, the carrying capacity or virgin biomass:

$$\frac{B_{MSY}}{K} = n^{\frac{1}{(1-n)}}$$

When $n$=2, the Pella-Tomlinson model is equivalent to the Schaefer model, where $B_{MSY}$ = 0.5$K$. When $n$ < 2, the maximum productivity of the stock occurs at a biomass less than half of $K$, whereas when $n$ > 2, the maximum occurs at greater than half of $K$. The parameter $\gamma$ is entirely dependent on $n$:

$$\gamma = \frac{n^{\left(\frac{n}{n-1}\right)}}{n-1} \qquad (2)$$

$m$ represents the maximum sustainable yield of the stock. Dick and MacCall reparameterized $m$ as a function of $n$, $K$, and $u_{MSY}$:

$$m = K \cdot n^{\left(\frac{1}{1-n}\right)} \cdot u_{MSY} \qquad (3)$$

We can select reasonable values for $n$ and $u_{MSY}$, and then ask the question: if the population sustains $y$ years of observed catch, what did the virgin population size have to be in order to both sustain those catches without being driven to extinction and end up at some known fraction of $K$ at the end of the time series?

Selecting point values for $n$ and $u_{MSY}$, as well as for the final target $B_y/K$ ratio, will give us one solution. By instead drawing values from distributions for those parameters, we can incorporate our uncertainty about those parameters into the final estimates of $K$, and by extension $B_{MSY}$ and $u_{MSY}$.

### 2.11.1 Data and Methods

It is very difficult to separate total river herring landings into alewife and blueback herring components, especially for historical landings. Additionally, we are currently not able to attribute ocean landings of river herring to specific river stocks. For that reason, this model treats the coastwide meta-complex of alewife and blueback herring stocks as a single species stock.

The drawn parameters and their distributions are summarized in Table 2.36 and graphed in Figure 2.92.

Dick and MacCall (2011) assume the population starts out at *K*; that is, you have a complete time-series of catch. Given the long history of river herring exploitation, we've modified the algorithm slightly to start out at a fraction of *K* that is drawn from a beta distribution with a mean of 0.75. A fixed value of 1 was used for a sensitivity run.

For *n*, we assumed a lognormal distribution with a median of 2 (representing the classic Schaefer production curve). This translates into a $B_{MSY}/K$ ratio between 0.3 and 0.7, with a median of 0.5.

$u_{MSY}$ was drawn from a beta distribution with a mean of 0.6, based on the river-specific estimates of $U_{MSY}$ for alewife developed by Gibson and Myers (2003c). Sensitivity analyses were performed using a mean of 0.35, based on estimates developed for Massachusetts alewife and North Carolina blueback herring in this assessment, and a mean of 0.1 as a lower bound.

The status of the stock in the final year ($B_{2010}/K$) was drawn from a beta distribution with a mean of 0.1, based on trends in landings and run counts over time. Sensitivity runs using 1% and 50% of *K* were also performed.

Total catch from 1887 – 2010 was used in this analysis. The data used to reconstruct the time-series included historical state records of landings, NMFS port sampling, NAFO reported ocean landings from non-US countries, and estimates of ocean incidental catch. It should be noted that there is the potential to double-count some of the reported landings when combined with estimates of total incidental catch, as some of the retained ocean bycatch may be reported when landed.

Estimates of incidental catch from bottom trawls were based on data from the Northeast Fishery Observer Program (NEFOP) from 1989 forward. Estimates of incidental catch from the mid-water trawl fleets were based on the NEFOP data from 2005 forward, when the high-volume fishery sampling methods were deemed adequate (see Appendix 3). Due to differences in sampling methodology for midwater fleets prior to 2005 and a lack of fisheries observer data prior to 1989 for bottom trawl fleets, hindcast estimates of incidental catch were developed back to 1975 using the survey-scaling method (NEFSC 2008, Palmer et al. 2008):

$$\hat{C}_{j,t,h} = \bar{r}_{c,j,base,h} * K_{t,h} * \left(\frac{I_{j,t}}{\bar{I}_{j,base}}\right) \qquad (4)$$

where:

*C* is the annual incidental catch of species *j* for fleet *h* in year *t*;

$\bar{r}_c$ is the average combined t/k ratio (total catch / kept weight of all species) of species *j* over a specified range of years, *base*, for fleet *h*, weighted by the number of observed trips;

*K* is the total kept weight of all species for fleet *h* in year *t*;

*I* is the average NEFSC bottom trawl survey biomass index of species *j* over a range of years, *base*.

The average combined ratio was calculated for 1989 – 1993 for the bottom trawl fleets (due to regulation changes after 1993) and for 2005 – 2010 for the mid-water trawl fleets (due to the observer program's methodological changes for high volume fisheries in 2005). This ratio was scaled using the NEFSC trawl survey index of river herring abundance as described by Palmer et al. (2008), and multiplied by the total kept landings of a given fleet to estimate river herring incidental catch each year.

For years in which observed catch was zero (only in the earliest part of the time-series), we used instead the median of the non-zero values of the first 35 years of the time-series, on the assumption that those zeros were due to non-reporting rather than being true years of zero-catch.

Dick and MacCall (2011) assume that catch is known without error, which is not the case with river herring. River herring landings, particularly at the beginning of the time-series, are not known precisely. Years of zero catch or very low catch are most likely due to underreporting, but even years of higher catch are not based on a complete census of river herring fisheries. To incorporate some of that uncertainty into this analysis, the catch history was also drawn from a series of lognormal distributions that used each year of the observed time-series of catch as the median. We assumed a high CV for the early years of the time-series and a lower CV for later periods, reflecting better reporting of landings, and later, more monitoring of bycatch (Table 2.37 ; Figure 2.93 ). The model was run with and without the hindcast estimates of bycatch. In addition, to examine the effects of underreporting of early catch, we performed two sets of sensitivity runs: (1) one that retained the entire time-series, but inflated the pre-1950 years, and (2) one that started the time-series in 1950, the earliest year landings based on port sampling are available.

In inflating the time-series, outlier years were also modified. Years that had zero catch, or catches less than the 25$^{th}$ percentile of the non-zero catch prior to 1950 had their reported catch replaced by the median of the non-zero catches for that time period. Additionally, years that had catches greater than the 95$^{th}$ percentile of non-zero catch for that time-period were replaced with the 95$^{th}$ percentile of catch. This modification of outliers helped smooth the trend of catches and reduce the excessively “spikey” catch-history resulting from incomplete reporting.

Historical records of catch were most consistently reported from Maryland and Virginia. In recent years, landings from MD, VA, and the PRFC account for about 25% to 40% of total reported catch, depending on the years averaged over. Based on these numbers, we inflated the total catch of the pre-1950 years by 200% and 400% (Figure 2.98)

From these distributions, 50,000 combinations of variables were drawn, and ADMB routine was used to estimate $K$ by minimizing the difference between the logs of the observed and expected ratio of $B_{2010}/K$ . When the population became extinct ($B_t \leq 0$), or the squared difference of the observed and predicted $B_{2010}/K$ ratios was greater than 10% of the observed value, the runs were excluded from further analysis.

### 2.11.2 Results

Overall rates of success – runs that ended at the correct $B_{2010}/K$ ratio and did not drive the population extinct – were low. The majority of runs that failed did so because the model was too optimistic about the status of the stock in 2010 relative to $K$ (Figure 2.99). The model performed best with low estimates of $u_{MSY}$. When the mean of the $u_{MSY}$ distribution was 0.6 or 0.4 the vast majority of the runs were considered failures. The mean of the $u_{MSY}$ distribution was much lower for successful runs than the original parameter space (Figure 2.100, Table 2.38). Although the higher values of $u_{MSY}$ are more consistent with other assessments of river herring, the lower value of 0.1 was used as the mean of the distribution for the rest of the sensitivity runs and the results discussed here.

Biomass trajectories were sensitive to the assumed final status of the stock (Figure 2.101 - Figure 2.106), but estimates of $K$ and related management benchmarks $u_{MSY}$ and $B_{MSY}$ appeared more robust (2.103, Table 2.38). Starting the time-series in 1950 showed a similar trend in biomass and exploitation rate over the post-1950 time-period (Figure 2.107) and produced estimates of *K* and *MSY* that were similar to the other runs that started earlier (Figure 2.110, Table 2.38).

Increasing the early catch reduced the success rate of the model runs and changed the trend of biomass and exploitation rate in the early years (Figure 2.108). Increased catch resulted in a flat or declining trend from the beginning of the time-series, instead of the slight increase with the lower levels of catch. Estimates of *K* were similar to other runs for the 200% increase in catch, but much higher for the 400% increase (Figure 2.110, Table 2.38). Estimates of *MSY* were higher for the increased catch as well, but also had higher uncertainty, making them more similar to the previous runs.

### 2.11.3 Discussion

This model is not adequate for assessing the current status of the stock, as current status is one of the inputs to the model. While we might be comfortable saying that $B_{2010}/K$ is less than 50%, based on landings and run count data, it is much more difficult to say how much less – is the stock at 10% of *K*? At 1% of *K*? The model produces reasonable trends and estimates for both of those values.

The model estimates of *K* and related management benchmarks are more robust. The sensitivity analyses performed resulted in estimates of *K* and *MSY* that were similar in most cases. The model showed the most sensitivity to the level of catch in the early time series.

$u_{MSY}$ was the parameter that influenced the success of the runs the most. Successful runs had a much narrower distribution of $u_{MSY}$ values than the initial input distributions, with a mean of 0.06. This is a much lower MSY exploitation rate than has been estimated for alewife and blueback herring in other assessments (e.g., Gibson and Myers 2003c; See "Status of River Herring in Massachusetts" and "Status of River Herring in North Carolina" in this report), although those reference points were based on per-recruit modeling that assumed that only mature fish were subject to fishing mortality. This estimate of $u_{MSY}$ is also lower than the estimates of $F_{40\%SPR}$ that were developed for this assessment based on per-recruit modeling that assumed that all age classes were vulnerable to fishing (see Benchmark section for more details).

This is most likely because the $u_{MSY}$ parameter has a large influence on the modeled productivity of the stock. Biomass declined sharply in the 1960s, and with that decline came a decline in observed landings. At higher values of $u_{MSY}$, the model predicted the stock should have recovered faster, returning nearly to virgin levels by the end of the time-series. Dick and MacCall (2011) noted that the Pella-Tomlinson model is often overly optimistic about production levels at low stock sizes, especially when the shape parameter is less than 2 (i.e., $B_{MSY}$ occurs at less than half of *K*). They proposed using a production model based on Beverton and Holt stock recruitment parameters to describe the population dynamics when the stock was at low levels. We did not use this approach as we do not have a reliable stock-recruitment relationship for river herring, but the effects of the underlying model structure on estimates of *K* and $u_{MSY}$ need to be explored further.

This model currently estimates only one value of *K*. However, carrying capacity and stock productivity may have changed over time, due to environmental factors such as increased damming of rivers, and due to changes in the species composition of the river herring "stock." Although alewives and blueback herring share similar life-histories, they do exhibit different maximum sizes, different migration timing, and different spawning habitat preferences, which may make them differentially vulnerable to the myriad sources of mortality acting on them.

## 3.0 CONCLUSIONS

Assessment of river herring along the U.S. Atlantic coast is difficult. River herring have a complex life history and life history characteristics vary spatially among different river systems (Munroe 2002). Also, factors that influence population dynamics differ among rivers, such as differences among agencies in harvest regulations, the degree of historic habitat alterations, and potential sources of mortality such as predation (Walter et al. 2003). The fate of river-specific stocks during marine migrations is still largely unknown as is the stock composition of river herring in bycatch of ocean fisheries. Among-system differences and uncertainty in the marine life stages of river herring combined with the great variation in the amount, types, and quality of data collected by different agencies makes assessment a daunting task and limits the types of stock assessment models that can be applied. In this assessment we were relegated to largely employing trend analyses and comparing trends across systems to make generalizations about the status of river herring.

The decline of river herring is not unique as declines in many other diadromous species have been observed in the North Atlantic basin (see Limburg and Waldman 2009 for a review). River herring have declined coast-wide as evidenced from fishery-dependent data and estimates of run sizes. Commercial landings of river herring peaked in the late 1960s, declined rapidly through the 1970s and 1980s and have remained at levels less than 3% of the peak over the past decade. Commercial catch-per-unit-effort (CPUE) time series that overlap the decline in in commercial landing during the 1970s and 1980s also show a decline. Estimates of run sizes varied among rivers, but in general, declining trends in run size were evident in many rivers over the last decade. Differences in the trends of run sizes may be due to differences in management such as improved fish passage or stocking of adult fish into ponds above dams (e.g., Maine rivers). The DB-SRA model runs also showed sharp declines in coast-wide biomass during the early 1970s.

Fisheries-independent surveys did not show consistent trends and were quite variable both within and among surveys. A problem with the majority of fisheries-independent surveys was that the length of their time series did not overlap the period of peak commercial landings that occurred prior to 1970. The general lack of consistent trends across fisheries-independent surveys may be due to the fact that these surveys began after river herring populations had been reduced and we are currently only observing inter-annual variation at low stock sizes and fisheries-independent surveys missed large changes in abundance that would have occurred when landings peaked prior to 1970.

Although fisheries-independent surveys often showed contradictory trends, those surveys that showed declines tended to be from areas south of Long Island. For example, trawl surveys in southern regions showed declining trends more frequently compared to those in northern regions. Also, YOY seine survey indices declined in New Jersey (blueback herring), Maryland (both species), District of Columbia (alewife) and North Carolina (both species). Fisheries-independent gill-net CPUE in the Rappahannock River, and electrofishing CPUE in the St. Johns River have also declined. Nye et al. (2009) also observed a northward shift in the distribution of alewife and American shad and found that changes in the distribution of multiple species in the NEFSC trawl surveys were correlated with large-scale warming and climatic conditions such as the Atlantic Multi-decadal Oscillation. This regional pattern in trends suggests that changes in abundance of river herring may also be influenced by climate change.

Conclusions about trends in mortality are uncertain. Biological data from river herring suggest total mortality may be increasing. The maximum ages of river herring has generally declined along the coast and the percent of repeat spawners has declined in a few rivers (alewife in Gilbert Stuart Steam and Monument River, and blueback herring in the Nanticoke River). Also, mean lengths and mean length-at-age declined in many rivers which may be an indication of increasing mortality (Beverton and Holt 1957), an indication of decreasing growth rates, or a combination of both. The statistical catch-at-age model for the Monument River, MA indicated increasing mortality due to factors other than fishing increased after 1999. However, age-based estimates of total instantaneous mortality ($Z$) generally did not show any trends. The lack of trends in age-based $Z$ estimates could be due in part to relatively short time series of data or inconsistencies and uncertainties in aging methods through time. Also, age-based $Z$ estimates were only performed on data sets that had three or more year classes which may have eliminated some data sets from these analyses that have experienced truncation of age distributions due to increasing mortality. Comparisons of $Z$ estimates to benchmarks determined through spawning stock biomass per recruit analyses showed that the majority of the rivers examined were above the $Z_{20\%SPR}$ benchmark but below the $Z_{collapse}$ threshold. No rivers exceeded the $Z_{collapse}$ threshold in recent years.

Estimates of total (retained + discarded) incidental catch of alewife and blueback herring in other ocean fisheries are most certain from 2005–2010 as this was the period of time when improvements in the Northeast Fisheries Observer Program occurred in the high volume midwater trawl fisheries. The average combined total incidental catch of alewife and blueback herring during this time period was 459 MT annually (range: 244 – 672 MT). The average total reported U.S. landings during the same time period was 751 MT annually (range: 481 – 1060 MT). Total reported U.S. landings include landings reported from state waters and landings reported by NMFS. Some unknown fraction of the total incidental catch is reported by NMFS and included in the U.S. landings, making direct comparisons uncertain. More specifically, the majority of river herring caught incidentally in the midwater trawl fleets is retained, but an unknown proportion of this retained catch is reported as river herring by the dealers. In a limited number of comparisons, some trips that listed river herring as landed on the VTR reports did not list river herring on the corresponding dealer reports. Therefore, it is unclear what proportion of reported landings is distinct from estimates of total incidental catch, making direct comparisons difficult. Also, incidental catch of “Herring NK [not known]” ranged from seven to 328 MT (15,400 – 723,108 pounds) between 2005 and 2010, and the proportion of river herring in this species category is unknown. Although better estimates catch of river herring in non-targeted ocean fisheries have been obtained in recent years, the impact of this catch upon stock status remains largely unknown.

Exploitation of river herring appears to be declining or remaining stable. In-river exploitation was highest in Maine rivers (Damariscotta and Union) and has fluctuated, but it is currently lower than levels seen in the 1980s. Also, in-river exploitation in Massachusetts rivers (Monument and Mattapoisett) was declining at the time a moratorium was imposed in 2005. The coast-wide index of relative exploitation also declined following a peak in the late 1980s and has remained fairly stable over the past decade. Exploitation rates declined in the DB-SRA model runs except when the input biomass-to-$K$ ratio in 2010 was 0.01. Exploitation rates estimated from the statistical catch-at-age model for blueback herring in the Chowan River (see NC state report) also showed a slight declining trend from 1999 to 2007 at which time a moratorium was instituted. There appears to be a consensus among various assessment methodologies that exploitation has decreased in recent times. The decline in exploitation over the past decade is not surprising because river herring populations are at low levels and more restrictive regulations or moratoria have been enacted by states.

Past high exploitation may also be a reason for the high amount of variation and inconsistent patterns observed in fisheries-independent indices of abundance. Fishing effort has been shown to increase variation in fish abundance through truncation of the age structure and recruitment becomes primarily governed by environmental variation (Hsieh et al. 2006; Anderson et al. 2008). When fish species are at very low abundances, as is believed for river herring, it is possible that the only population regulatory processes operating are stochastic fluctuations in the environment (Shepherd and Cushing 1990).

Multiple factors are likely responsible for river herring decline such as overfishing, inadequate fish passage at dams, predation, pollution, water withdrawals, acidification, changing ocean conditions, and climate change. It is difficult to partition mortality into these possible sources and evaluate importance in the decline of river herring. To sustain the resilience of fish populations in the face of multiple threats, Brander (2007) suggested that age and geographic structure must be preserved rather than relying solely on management of biomass. Thus, the recovery of river herring will need to address multiple factors including anthropogenic habitat alterations, predation by native and non-native predators, and exploitation by fisheries.

In summary, the major conclusions drawn from available data and observations during this assessment are:

- River herring populations have greatly declined as evidenced by a 93% decrease in U.S. commercial landings since the 1970s.
- High levels of U.S. commercial landings from the 1950s to 1970s (mean of 22,000 MT/year) compared to the last 10 years (mean of 775 MT/year) suggests that stocks were considerably larger during this period in order to support this level of harvest. Declining catch per effort suggests that the decline is likely driven by decreasing abundance. However, some of this decline was likely driven by decreased effort.
- Additional declines in run sizes occurred in 10 out of 17 rivers from 1999 – 2010.
- Fisheries-independent surveys often showed contradictory trends in abundance indices. Most surveys began after the majority of the decline in landings occurred and current monitoring programs measure what remains of these greatly reduced stocks.
- The NEFSC trawl survey, which is the only coastwide fisheries-independent survey, showed increasing trends in relative abundance beginning in 2008.
- Observed trends in biological data (e.g., decline in mean length, mean length-at-age, and percent repeat spawners) are characteristic of declining populations undergoing increasing total mortality.
- Conclusions about trends in aged-based $Z$ estimates remain uncertain due to issues with aging methodologies and the narrow age distributions that were available to calculate Z estimates.
- There is uncertainty surrounding benchmark Z values, but they likely reflect current productivity levels of the stocks.
- Estimated total incidental catch (retained + discards) of river herring in non-targeted ocean fisheries averaged 459 MT (1.01 million pounds) from 2005 to 2010. The age structure and stock composition of this catch is uncertain, but is known to include both immature and mature fish.

- Incidental catch of "Herring NK [not known]" in non-targeted ocean fisheries ranged from seven to 328 MT (15,400 – 723,108 pounds) between 2005 and 2010. The proportion of river herring in this species category is unknown.
- Lack of accurate detailed reporting makes determination of the amount of retained incidental catch that is reported as landings uncertain, thereby making comparisons between reported landings and total incidental catch difficult.
- Exploitation rates have declined in the last decade likely due to the lower abundance of river herring and enactment of stricter harvest regulations and moratoria.
- At low levels, stocks are sensitive to both biotic and abiotic perturbations that truncate age structure thereby reducing population resilience.
- Recovery of river herring stocks will need to address multiple factors (e.g., fish passage, predation, water quality, climate change, etc.) in addition to harvest.

## 3.1 Stock Status

The coastwide meta-complex of river herring stocks on the US Atlantic coast is depleted to near historic lows. A depleted status indicates that there was evidence for declines in abundance due to a number of factors, but the relative importance of these factors in reducing river herring stocks could not be determined. Combined factors such as intense historic fishing pressure, continued exploitation (both directed and incidental), ineffective fish passage resulting in the loss of riverine habitat, changing ocean conditions due to climate change, and increased abundance of native and non-native predator species are likely responsible for depleted river herring stocks and continue to hinder recovery of the stocks. This assessment has illustrated trends in river herring populations, biological characteristics, and commercial catch, but more work is needed to evaluate the synergistic effects of the many factors that may be responsible for the decline in river herring.

Of the 52 in-river stocks of alewife and blueback herring for which data were available, 22 were depleted, 1 stock was increasing, and the status of 28 stocks could not be determined because the time-series of available data was too short. In most recent years, 2 were increasing, 4 were decreasing, and 9 were stable with 38 rivers not having enough data to assess recent trends.

Overfished and overfishing status could not be determined for the coastwide stock complex, as estimates of total biomass, fishing mortality rates and corresponding reference points could not be developed.

Due to the poor condition of many river herring stocks, management actions to reduce total mortality are needed. These could include reductions in directed commercial or recreational fishery mortalities, reductions in total incidental catch (retained and discarded fish), habitat restoration, and improvements in upriver and downstream fish passage.

## 3.2 Future Benchmark Assessment

We recommend an update of trend analyses in 5 years and the next benchmark assessment for river herring be conducted in 10 years (finalized in 2022). Due to the high variability of fisheries independent surveys, a benchmark assessment at a shorter timeframe (e.g. 5 years) will likely not show any significant changes in indices of abundance. Any population changes resulting from closures of fisheries in 2012; improved access to historic spawning grounds; and additional beneficial management measures, such as sustainable fishing plans and action by the federal councils, cannot be expected to result in any population change until at least one cohort of river herring has grown to maturity (assuming age at maturity is 3 – 6 years). A 10 year timeframe for the next benchmark assessment will also allow a longer time series of estimated total incidental catch in non-targeted ocean fisheries to be evaluated.

## 4.0 RESEARCH RECOMMENDATIONS

### 4.1 Short Term

- Improved reporting of harvest by waterbody and gear.
- Improve methods to develop biological benchmarks used in assessment modeling (fecundity-at-age, mean weight-at-age for both sexes, partial recruitment vector/maturity schedules) for river herring stocks.
- Continue to assess current aging techniques for river herring, using known-age fish, scales, otoliths and spawning marks.
- Encourage studies to quantify and improve fish passage efficiency and support the implementation of standard practices.
- Continue genetic analyses to determine population stock structure along the coast and enable determination of river origin of incidental catch in non-targeted ocean fisheries.
- Develop models to predict the potential impacts of climate change on river herring distribution and stock persistence.
- Develop and implement monitoring protocols and analyses to determine river herring population responses and targets for rivers undergoing restoration (dam removals, fishways, supplemental stocking, etc.).
- Investigate additional sources of historic catch data of the U.S. small pelagic fisheries to better represent or construct earlier harvest of river herring.

### 4.2 Long Term

- Conduct biannual aging workshops to maintain consistency and accuracy in aging fish sampled in state programs.
- Explore use of peer-reviewed stock assessment models for use in additional river systems in the future as more data become available.
- Expand observer and port sampling coverage to quantify additional sources of mortality for alosine species, including bait fisheries, as well as rates of incidental catch in other fisheries.
- Determine and quantify which stocks are impacted by mixed stock fisheries (including bycatch fisheries). Methods to be considered could include otolith microchemistry, oxytetracycline otolith marking, genetic analysis, and/or tagging.
- Validate the different values of M for river herring stocks and improve methods for calculating M.

- Summarize existing information on predation by striped bass and other species and quantify consumption through modeling (e.g., MSVPA), diet, and bioenergetics studies.
- Investigate the relation between juvenile river herring production and subsequent year class strength, with emphasis on the validity of juvenile abundance indices, rates and sources of immature mortality, migratory behavior of juveniles, and life history requirements.
- Evaluate and ultimately validate large-scale hydroacoustic methods to quantify river herring escapement (spawning run numbers) in major river systems.
- Develop comprehensive angler use and harvest survey techniques for use by Atlantic states with open or future fisheries to assess recreational harvest of river herring.
- Development of better fish culture techniques and supplemental stocking strategies for river herring.
- Evaluate the performance of hatchery fish in river herring restoration.
- Investigate contribution of landlocked versus anadromous produced fish.

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Table 2.1 Weight (pounds) and value (2010 U.S. dollars) of historic commercial river herring landings along the Atlantic Coast, 1880–1938.

| Year | Weight (*pounds*) | Value (*2010 USD*) |
|---|---|---|
| **1880** | 45,684,333 | |
| | | |
| **1887** | 44,488,198 | |
| **1888** | 110,157,673 | |
| **1889** | 31,026,997 | |
| **1890** | 52,087,765 | |
| **1891** | 59,552,578 | |
| **1892** | 4,893,370 | |
| | | |
| **1896** | 62,066,622 | |
| **1897** | 67,831,500 | |
| **1898** | 9,624,005 | |
| | | |
| **1901** | 34,479,005 | |
| **1902** | 20,038,618 | |
| **1903** | | |
| **1904** | 31,717,124 | |
| **1905** | 8,743,284 | |
| **1909** | | |
| **1915** | 29,780,912 | 6,738,751 |
| | | |
| **1920** | 23,738,788 | 2,826,638 |
| **1921** | 1,157,661 | 365,859 |
| **1922** | | |
| **1923** | 7,570,397 | 340,473 |
| **1924** | 4,025,055 | 576,395 |
| **1925** | 25,611,161 | 2,613,220 |
| **1926** | 2,495,315 | 579,598 |
| **1927** | 14,160,197 | 1,875,382 |
| **1928** | 12,737,137 | 2,113,179 |
| **1929** | 35,290,479 | 5,537,500 |
| **1930** | 40,732,957 | 5,405,739 |
| **1931** | 42,198,587 | 5,181,211 |
| **1932** | 31,659,383 | 2,837,625 |
| **1933** | 29,934,419 | 2,631,902 |
| **1934** | 26,191,500 | 3,051,319 |
| **1935** | 20,163,400 | 2,358,873 |
| **1936** | 24,217,700 | 3,762,031 |
| **1937** | 30,022,800 | 4,231,013 |
| **1938** | 39,126,800 | 5,430,785 |

Table 2.2 Annual reported coastwide commercial landings (lb) of river herring by state, 1887-2007.

| Year | ME | NH | MA | RI | CT | NY | NJ | DE | MD | PRFC | VA | NC | SC | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1887 | | | 4,130,000 | | | | | | | | | 17,822,075 | | 21,952,075 |
| 1888 | | | 6,292,000 | | | | | | | | | 16,349,527 | | 22,641,527 |
| 1889 | | | 3,911,000 | | | | | | | | | 14,386,800 | | 18,297,800 |
| 1890 | | | | | | | | | | | | 16,480,263 | | 16,480,263 |
| 1891 | | | | | | | | | | | | | | |
| 1892 | | | 3,651,000 | | | | | | | | | | | 3,651,000 |
| 1893 | | | | | | | | | | | | | | |
| 1894 | | | | | | | | | | | | | | |
| 1895 | | | | | | | | | | | | | | |
| 1896 | | | 5,356,000 | | | | | | | | | | | 5,356,000 |
| 1897 | | | 4,779,000 | | | | | | | | | 15,641,770 | | 20,420,770 |
| 1898 | | | 2,900,000 | | | | | | | | | | | 2,900,000 |
| 1899 | | | | | | | | | | | | | | |
| 1900 | | | | | | | | | | | | | | |
| 1901 | | | | | | | | | | | | | | |
| 1902 | | | 4,517,000 | | | | | | | | | 11,033,475 | | 15,550,475 |
| 1903 | | | | | | | | | | | | | | |
| 1904 | | | | | | 501,438 | | | | | | | | 501,438 |
| 1905 | | | 4,861,000 | | | 277,225 | | | | | | | | 5,138,225 |
| 1906 | | | | | | | | | | | | | | |
| 1907 | | | | | | | | | | | | | | |
| 1908 | | | 4,062,000 | | | 81,211 | | | | | | 11,068,500 | | 15,211,711 |
| 1909 | | | | | | 111,334 | | | | | | | | 111,334 |
| 1910 | | | | | | | | | | | | | | |
| 1911 | | | | | | | | | | | | | | |
| 1912 | | | | | | | | | | | | | | |
| 1913 | | | | | | 92,175 | | | | | | | | 92,175 |
| 1914 | | | | | | | | | | | | | | |
| 1915 | | | | | | | | | | | | | | |
| 1916 | | | | | | 21,762 | | | | | | | | 21,762 |
| 1917 | | | | | | 49,935 | | | | | | | | 49,935 |
| 1918 | | | | | | 88,224 | | | | | | 14,473,820 | | 14,562,044 |
| 1919 | | | 3,064,000 | | | | | | | | | | | 3,064,000 |
| 1920 | | | | | | 101,850 | | | | | | | | 101,850 |
| 1921 | | | | | | 10,852 | | | | | | | | 10,852 |

Table 2.2 Continued

| Year | ME | NH | MA | RI | CT | NY | NJ | DE | MD | PRFC | VA | NC | SC | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1922 | | | | | | 73,431 | | | | | | | | 73,431 |
| 1923 | | | | | | 50,747 | | | | | | 6,522,397 | | 6,573,144 |
| 1924 | | | 2,593,000 | | | 56,620 | | | | | | | | 2,649,620 |
| 1925 | | | | | | 92,188 | | | | | | | | 92,188 |
| 1926 | | | | | | 131,535 | | | | | | | | 131,535 |
| 1927 | | | | | | 140,094 | | | | | | 14,089,930 | | 14,230,024 |
| 1928 | | | 2,248,000 | | | 178,819 | | | | | | 7,628,706 | | 10,055,525 |
| 1929 | | | 1,386,000 | | | 146,835 | | | | | 12,570,056 | 10,767,457 | | 24,870,348 |
| 1930 | | | 1,790,000 | | | 138,504 | | | | | 15,387,018 | 9,820,647 | | 27,136,169 |
| 1931 | | | 2,212,000 | | | 185,707 | | | | | 17,239,070 | 7,993,550 | | 27,630,327 |
| 1932 | | | 1,164,000 | | | 91,432 | | | | | 13,852,493 | 6,584,000 | | 21,691,925 |
| 1933 | | | 923,000 | | | 174,969 | | | | | 19,177,448 | | | 20,275,417 |
| 1934 | | | | | | 196,848 | | | | | 5,846,200 | 14,896,000 | | 20,939,048 |
| 1935 | | | 959,000 | | | 274,405 | | | | | 10,974,100 | | | 12,207,505 |
| 1936 | | | | | | 208,282 | | | | | 8,688,700 | 11,928,600 | | 20,825,582 |
| 1937 | | | 1,086,000 | | | 227,865 | | | | | 15,064,300 | 5,817,700 | | 22,195,865 |
| 1938 | | | 958,000 | | | 244,521 | | | | | 17,690,990 | 11,210,100 | | 30,103,611 |
| 1939 | | | 946,000 | | | 198,806 | | | | | 14,830,800 | 7,714,300 | | 23,689,906 |
| 1940 | | | 879,000 | | | 173,453 | | | | | 11,433,300 | 8,707,900 | | 21,193,653 |
| 1941 | | | | | | 222,975 | | | | | 11,951,000 | | | 12,173,975 |
| 1942 | | | 984,000 | | | 150,422 | | | | | 9,257,900 | | | 10,392,322 |
| 1943 | 1,626,283 | | | | | 169,056 | | | | | | | | 1,795,339 |
| 1944 | | | 2,266,000 | | | 157,644 | | | | | 17,840,800 | | | 20,264,444 |
| 1945 | | | 988,000 | | | 123,619 | | | | | 14,619,100 | 8,022,100 | | 23,752,819 |
| 1946 | | | 1,249,000 | | | 131,302 | | | | | 12,028,300 | | | 13,408,602 |
| 1947 | | | 633,000 | | | 106,189 | | | | | 22,173,200 | | | 22,912,389 |
| 1948 | 345,650 | | 468,000 | | | 90,468 | | | | | 19,364,600 | | | 20,268,718 |
| 1949 | 1,514,067 | | 502,000 | | | 99,768 | | | | | 22,002,900 | | | 24,118,735 |
| 1950 | 1,481,827 | | 269,900 | 312,100 | 1,947,900 | 103,700 | 29,000 | | | | 28,701,700 | 6,422,500 | | 39,268,627 |
| 1951 | 2,828,680 | | 276,000 | 905,800 | 489,900 | 74,800 | 7,200 | | | | 32,604,000 | 12,534,500 | | 49,720,880 |
| 1952 | 2,010,698 | | 1,904,700 | 180,900 | 1,061,500 | 90,300 | 600 | | | | 28,841,000 | 6,510,200 | | 40,599,898 |
| 1953 | 1,647,266 | | 5,534,700 | 216,300 | 340,300 | 70,753 | 8,600 | | | | 23,976,000 | 13,841,500 | | 45,635,419 |
| 1954 | 1,983,817 | | 3,020,200 | 17,000 | 972,700 | 83,500 | | | | | 27,930,100 | 12,758,000 | | 46,765,317 |
| 1955 | 1,775,060 | | 2,621,100 | 46,100 | 890,300 | 102,000 | 22,900 | | | | 21,842,600 | 12,647,900 | | 39,947,960 |
| 1956 | 2,462,945 | | 8,921,500 | 54,500 | 79,400 | 67,904 | 22,300 | | | | 22,106,500 | 12,553,400 | | 46,268,449 |

Table 2.2 Continued

| Year | ME | NH | MA | RI | CT | NY | NJ | DE | MD | PRFC | VA | NC | SC | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1957 | 2,383,740 | 75,000 | 19,027,100 | 29,300 | 63,300 | 56,300 | 8,100 | | | | 18,757,600 | 11,773,200 | | 52,098,640 |
| 1958 | 1,560,240 | 60,000 | 33,814,700 | 11,400 | 9,500 | 66,100 | 1,400 | | | | 18,361,300 | 14,914,300 | | 68,738,940 |
| 1959 | 930,370 | 80,000 | 11,618,000 | 340,600 | 7,800 | 45,600 | 2,200 | | | | 17,447,000 | 14,153,700 | | 44,545,270 |
| 1960 | 966,235 | 95,000 | 17,651,100 | | 20,000 | 38,200 | 3,000 | | | 2,702,618 | 15,464,000 | 12,815,000 | | 49,660,153 |
| 1961 | 1,278,895 | 100,000 | 20,838,200 | | 6,000 | 33,800 | 16,500 | | | 4,257,685 | 15,525,800 | 11,951,100 | | 53,907,980 |
| 1962 | 1,137,420 | 125,000 | 8,275,700 | | 19,000 | 38,200 | 20,300 | | | 7,598,422 | 24,460,500 | 14,302,400 | | 55,851,942 |
| 1963 | 898,100 | 150,000 | 11,735,100 | 129,300 | 3,400 | 32,300 | 3,400 | | | 4,995,001 | 26,085,400 | 15,099,600 | | 58,981,601 |
| 1964 | 903,677 | 75,000 | 5,528,800 | 140,000 | 14,800 | 37,000 | 14,200 | | | 8,162,444 | 26,640,000 | 7,560,900 | | 49,001,821 |
| 1965 | 1,615,460 | 125,000 | 6,935,300 | 210,000 | 24,100 | 23,600 | 21,500 | | | 9,959,891 | 36,200,300 | 12,825,800 | | 67,815,951 |
| 1966 | 1,153,180 | 75,000 | 6,633,200 | 192,500 | 6,600 | 4,188,000 | 12,400 | | | 11,127,487 | 28,534,800 | 12,519,300 | | 64,367,467 |
| 1967 | 1,255,897 | 65,000 | 5,431,900 | 185,500 | 23,400 | 4,400 | 9,000 | | | 8,580,234 | 28,107,400 | 18,486,000 | | 62,083,731 |
| 1968 | 1,498,447 | 40,600 | 116,700 | 190,000 | 32,800 | 7,000 | 8,400 | | | 7,477,581 | 32,319,400 | 15,524,900 | | 57,175,228 |
| 1969 | 1,404,055 | 37,500 | 100,000 | 214,900 | 10,600 | 9,200 | 5,100 | | | 3,433,438 | 30,445,700 | 19,761,700 | 2,451,000 | 57,835,693 |
| 1970 | 1,066,975 | 31,000 | 1,156,300 | 143,600 | 122,300 | 11,000 | 7,500 | | | 6,184,858 | 19,045,700 | 11,521,400 | 320,500 | 39,580,133 |
| 1971 | 1,406,720 | 25,000 | 222,300 | 52,600 | 25,000 | 68 | 9,500 | | | 5,858,125 | 10,285,100 | 12,721,900 | 1,387,200 | 31,968,513 |
| 1972 | 1,445,200 | 24,000 | 1,907,400 | 34,000 | 22,800 | 400 | 14,700 | | | 5,720,951 | 10,450,800 | 11,237,143 | 989,800 | 31,823,194 |
| 1973 | 1,680,954 | 21,500 | 695,400 | 15,100 | 14,300 | 21,600 | 7,000 | | | 2,005,057 | 5,984,856 | 7,925,898 | 363,000 | 18,713,165 |
| 1974 | 2,232,790 | | 228,500 | 36,100 | 17,000 | 16,900 | 10,600 | | | 3,529,221 | 9,796,576 | 6,209,542 | 88,300 | 22,165,529 |
| 1975 | 1,626,670 | | 1,716,900 | 41,500 | 25,200 | 15,300 | 9,300 | | | 5,758,824 | 5,766,024 | 5,952,067 | 18,337 | 20,930,122 |
| 1976 | 1,894,860 | | 44,900 | 34,000 | 67,100 | 1,500 | 11,300 | | | 1,308,222 | 2,958,501 | 6,401,360 | 25,770 | 12,747,513 |
| 1977 | 2,091,850 | 210,000 | 131,800 | 35,300 | 61,300 | 6,000 | 10,600 | | | 473,531 | 908,962 | 8,523,813 | 29,770 | 12,272,926 |
| 1978 | 1,704,075 | 165,000 | 701,300 | 26,200 | 39,800 | 700 | 2,400 | | | 1,467,743 | 739,333 | 6,607,153 | 33,630 | 11,322,334 |
| 1979 | 1,329,615 | | 52,300 | 11,700 | 62,700 | 1,000 | 6,600 | | | 997,360 | 706,015 | 5,119,150 | 144,049 | 8,430,489 |
| 1980 | 1,449,405 | | 144,000 | 7,400 | 55,100 | 900 | 18,600 | | 76,961 | 662,951 | 668,812 | 6,218,523 | 469,256 | 9,771,908 |
| 1981 | 1,408,720 | | 84,000 | 0 | 52,700 | 64,900 | 13,800 | | 68,000 | 84,143 | 449,494 | 4,753,723 | 406,534 | 7,386,014 |
| 1982 | 576,677 | 114,500 | 53,500 | 4,800 | 41,800 | 229,200 | 13,600 | | 102,973 | 493,039 | 773,836 | 9,437,703 | 205,970 | 11,933,098 |
| 1983 | 370,868 | 115,216 | 93,100 | 6,100 | 37,500 | 24,700 | 2,200 | | 116,412 | 1,728,810 | 413,501 | 5,868,332 | 578,964 | 9,240,487 |
| 1984 | 499,555 | 90,000 | 194,100 | 900 | 32,400 | 4,200 | 3,100 | | 107,965 | 899,275 | 464,344 | 6,516,109 | 554,342 | 9,276,290 |
| 1985 | 723,310 | 61,300 | 46,600 | 400 | 38,900 | 150 | 4,800 | 7,562 | 178,338 | 261,675 | 165,873 | 11,548,278 | 323,161 | 13,299,047 |
| 1986 | 937,720 | 26,990 | 32,400 | 0 | 40,100 | 2,900 | 4,200 | 5,522 | 105,380 | 1,198,669 | 315,768 | 6,814,323 | 231,702 | 9,688,684 |
| 1987 | 539,143 | 19,550 | 32,500 | 2,600 | 21,400 | 2,765 | 5,200 | 5,341 | 103,997 | 1,164,854 | 237,870 | 3,194,975 | 149,885 | 5,460,530 |
| 1988 | 625,975 | 12,087 | 42,580 | | 2,100 | 100 | 700 | 15,966 | 147,222 | 182,656 | 557,034 | 4,191,211 | 44,384 | 5,809,928 |
| 1989 | 625,765 | 11,200 | 255,700 | | 1,600 | 500 | 800 | 8,355 | 177,409 | 97,047 | 566,060 | 1,491,077 | 39,222 | 3,263,535 |
| 1990 | 436,625 | | 20,700 | | 1,150 | | 42,494 | 17,177 | 196,686 | 49,734 | 461,527 | 1,157,625 | 42,165 | 2,425,883 |
| 1991 | 361,480 | | 20,300 | | 1,200 | | 9,994 | 25,858 | 191,728 | 365,966 | 355,148 | 1,575,378 | 21,671 | 2,928,723 |

Table 2.2 Continued

| Year | ME | NH | MA | RI | CT | NY | NJ | DE | MD | PRFC | VA | NC | SC | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1992 | 438,042 | 9,802 | 18,700 | | 3,200 | | 3,069 | 31,730 | 316,734 | 162,885 | 255,412 | 1,723,178 | 219,578 | 3,172,528 |
| 1993 | 165,375 | 2,676 | 18,900 | | 2,440 | | 2,659 | 17,295 | 154,413 | 144,752 | 221,121 | 916,235 | 415,885 | 2,059,075 |
| 1994 | 83,318 | | | | 2,000 | | 328 | 16,697 | 96,072 | 80,258 | 115,733 | 644,334 | 300,108 | 1,338,848 |
| 1995 | 2,940 | | | 403 | 14,044 | 209 | 795 | 19,523 | 137,321 | 113,504 | 174,823 | 453,984 | 457,154 | 1,374,700 |
| 1996 | 136,395 | | | 750 | 252 | 741 | 4,449 | 20,518 | 108,232 | 80,447 | 96,585 | 529,503 | 584,357 | 1,562,229 |
| 1997 | 281,977 | | 180 | | | 6,317 | 4,515 | 13,641 | 190,851 | 59,949 | 174,192 | 334,809 | 313,586 | 1,380,017 |
| 1998 | 386,365 | 25,994 | | | | 12,234 | 7,371 | 17,607 | 151,026 | 18,501 | 44,582 | 521,930 | 412,512 | 1,572,128 |
| 1999 | 312,375 | | | | | 6,051 | 1,377 | 6,215 | 85,919 | 26,656 | 47,145 | 443,494 | 260,534 | 1,189,766 |
| 2000 | 246,680 | | | 574 | 77,985 | 98,845 | 2,246 | 13,444 | 136,899 | 33,370 | 20,918 | 332,336 | 325,463 | 1,288,760 |
| 2001 | 646,660 | | | | 20 | 39,293 | 3,915 | 29,925 | 193,907 | 35,723 | 38,655 | 306,761 | 62,961 | 1,357,820 |
| 2002 | 819,554 | | | 12 | | 40,716 | 4,669 | 12,148 | 54,946 | 55,086 | 240,515 | 174,860 | 29,937 | 1,432,443 |
| 2003 | 613,385 | | | | | 40,076 | 3,667 | 6,271 | 117,709 | 20,132 | 218,274 | 199,716 | 129,135 | 1,348,365 |
| 2004 | 543,172 | | 89 | | | 36,685 | 7,131 | 4,878 | 60,926 | 19,739 | 260,645 | 188,541 | 66,735 | 1,188,541 |
| 2005 | 107,654 | | | | | 26,984 | 4,326 | 3,570 | 33,696 | 8,507 | 196,770 | 250,021 | 152,215 | 783,743 |
| 2006 | 705,377 | | | | | 23,505 | 3,414 | 3,785 | 32,418 | 6,819 | 144,028 | 109,847 | 82,794 | 1,111,987 |
| 2007 | 580,688 | | | | | 28,571 | 223 | 2,916 | 55,768 | 6,011 | 159,023 | 1,103 | 152,547 | 986,849 |
| 2008 | 1,220,459 | 8,137 | | | | 21,164 | 1,890 | 3,011 | 28,240 | 5,476 | 136,803 | 1,270 | 25,612 | 1,443,925 |
| 2009 | 1,383,130 | 9,443 | | | | 21,953 | 489 | 1,452 | 28,173 | 8,925 | 194,777 | | 468,877 | 2,107,776 |
| 2010 | 1,327,375 | 7,469 | | | | 11,375 | 1,322 | 429 | 28,511 | 898 | 172,476 | | 490,984 | 2,033,370 |

Table 2.3 Annual reported coastwide commercial landings (lb) of river herring by gear, 1887-2010.

| Year | Gill Net | Other | Pound Net | Purse Seine | Seine | Unknown | Total |
|---|---|---|---|---|---|---|---|
| 1887 | 71,780 | 78,000 | 7,185,255 | | 10,487,040 | 4,130,000 | 21,952,075 |
| 1888 | 68,200 | 70,500 | 6,827,313 | | 9,383,514 | 6,292,000 | 22,641,527 |
| 1889 | 65,800 | 70,500 | 6,073,160 | | 8,177,340 | 3,911,000 | 18,297,800 |
| 1890 | 64,040 | 74,000 | 7,189,424 | | 9,152,799 | | 16,480,263 |
| 1891 | | | | | | | |
| 1892 | | | | | | 3,651,000 | 3,651,000 |
| 1893 | | | | | | | |
| 1894 | | | | | | | |
| 1895 | | | | | | | |
| 1896 | | | | | | 5,356,000 | 5,356,000 |
| 1897 | 175,832 | 46,601 | 9,554,989 | | 5,864,348 | 4,779,000 | 20,420,770 |
| 1898 | | | | | | 2,900,000 | 2,900,000 |
| 1899 | | | | | | | |
| 1900 | | | | | | | |
| 1901 | | | | | | | |
| 1902 | 55,900 | 42,500 | 7,473,770 | | 3,461,305 | 4,517,000 | 15,550,475 |
| 1903 | | | | | | | |
| 1904 | | | | | | 501,438 | 501,438 |
| 1905 | | | | | | 5,138,225 | 5,138,225 |
| 1906 | | | | | | | |
| 1907 | | | | | | | |
| 1908 | 164,000 | 328,500 | 8,085,000 | | 2,491,000 | 4,143,211 | 15,211,711 |
| 1909 | | | | | | 111,334 | 111,334 |
| 1910 | | | | | | | |
| 1911 | | | | | | | |
| 1912 | | | | | | | |
| 1913 | | | | | | 92,175 | 92,175 |
| 1914 | | | | | | | |
| 1915 | | | | | | | |
| 1916 | | | | | | 21,762 | 21,762 |
| 1917 | | | | | | 49,935 | 49,935 |
| 1918 | 373,345 | 256,710 | 12,254,728 | | 1,589,037 | 88,224 | 14,562,044 |
| 1919 | | | | | | 3,064,000 | 3,064,000 |
| 1920 | | | | | | 101,850 | 101,850 |
| 1921 | | | | | | 10,852 | 10,852 |
| 1922 | | | | | | 73,431 | 73,431 |
| 1923 | 270,127 | 56,100 | 4,560,355 | | 1,635,815 | 50,747 | 6,573,144 |
| 1924 | | | | | | 2,649,620 | 2,649,620 |

Table 2.3 Continued

| Year | Gill Net | Other | Pound Net | Purse Seine | Seine | Unknown | Total |
|---|---|---|---|---|---|---|---|
| 1925 | | | | | | 92,188 | 92,188 |
| 1926 | | | | | | 131,535 | 131,535 |
| 1927 | 777,525 | 250,000 | 8,576,150 | | 4,486,255 | 140,094 | 14,230,024 |
| 1928 | 262,030 | 125,900 | 5,369,100 | | 1,871,676 | 2,426,819 | 10,055,525 |
| 1929 | 1,056,000 | 87,037 | 7,862,560 | | 1,761,860 | 14,102,891 | 24,870,348 |
| 1930 | 671,200 | 186,320 | 6,799,500 | | 2,163,627 | 17,315,522 | 27,136,169 |
| 1931 | 784,800 | 182,500 | 4,795,250 | | 2,231,000 | 19,636,777 | 27,630,327 |
| 1932 | 377,500 | 284,000 | 4,591,000 | | 1,331,500 | 15,107,925 | 21,691,925 |
| 1933 | | | | | | 20,275,417 | 20,275,417 |
| 1934 | 1,054,300 | 561,000 | 11,850,200 | | 1,430,500 | 6,043,048 | 20,939,048 |
| 1935 | | | | | | 12,207,505 | 12,207,505 |
| 1936 | 687,900 | 277,400 | 9,963,100 | | 1,000,200 | 8,896,982 | 20,825,582 |
| 1937 | 320,000 | 102,700 | 4,876,800 | | 518,200 | 16,378,165 | 22,195,865 |
| 1938 | 158,100 | 63,600 | 8,958,100 | | 2,030,300 | 18,893,511 | 30,103,611 |
| 1939 | 293,000 | 13,200 | 6,361,500 | | 1,046,600 | 15,975,606 | 23,689,906 |
| 1940 | 341,500 | 30,300 | 6,992,500 | | 1,343,600 | 12,485,753 | 21,193,653 |
| 1941 | | | | | | 12,173,975 | 12,173,975 |
| 1942 | | | | | | 10,392,322 | 10,392,322 |
| 1943 | | | | | | 1,795,339 | 1,795,339 |
| 1944 | | | | | | 20,264,444 | 20,264,444 |
| 1945 | 1,279,000 | 34,900 | 5,876,900 | | 831,300 | 15,730,719 | 23,752,819 |
| 1946 | | | | | | 13,408,602 | 13,408,602 |
| 1947 | | | | | | 22,912,389 | 22,912,389 |
| 1948 | | | | | | 20,268,718 | 20,268,718 |
| 1949 | | | | | | 24,118,735 | 24,118,735 |
| 1950 | 295,100 | 75,900 | 6,097,300 | 25,100 | 2,459,000 | 30,316,227 | 39,268,627 |
| 1951 | 1,083,100 | 56,100 | 12,077,800 | 42,300 | 946,900 | 35,514,680 | 49,720,880 |
| 1952 | 134,900 | 318,900 | 6,180,200 | 87,000 | 2,935,800 | 30,943,098 | 40,599,898 |
| 1953 | 318,200 | 258,200 | 13,278,300 | 4,538,200 | 1,539,900 | 25,702,619 | 45,635,419 |
| 1954 | 565,600 | 61,100 | 11,829,100 | 2,843,000 | 1,469,100 | 29,997,417 | 46,765,317 |
| 1955 | 642,100 | 75,600 | 11,746,000 | 1,869,800 | 1,871,900 | 23,742,560 | 39,947,960 |
| 1956 | 644,700 | 94,000 | 11,443,900 | 8,752,500 | 673,700 | 24,659,649 | 46,268,449 |
| 1957 | 852,200 | 2,459,000 | 10,529,800 | 16,439,200 | 612,700 | 21,205,740 | 52,098,640 |
| 1958 | 2,483,100 | 206,200 | 12,166,700 | 32,482,400 | 1,411,500 | 19,989,040 | 68,738,940 |
| 1959 | 1,791,000 | 210,300 | 11,780,200 | 9,729,400 | 2,609,200 | 18,425,170 | 44,545,270 |
| 1960 | 1,614,700 | 45,800 | 11,143,000 | 16,151,300 | 1,531,300 | 19,174,053 | 49,660,153 |
| 1961 | 1,375,900 | 504,800 | 10,288,100 | 19,107,600 | 1,518,900 | 21,112,680 | 53,907,980 |
| 1962 | 1,714,800 | 8,500 | 12,443,100 | 6,123,200 | 2,307,500 | 33,254,842 | 55,851,942 |

Table 2.3 Continued

| Year | Gill Net | Other | Pound Net | Purse Seine | Seine | Unknown | Total |
|---|---|---|---|---|---|---|---|
| 1963 | 1,845,400 | 66,800 | 12,960,100 | 10,882,200 | 1,212,900 | 32,014,201 | 58,981,601 |
| 1964 | 1,145,600 | 342,000 | 5,883,300 | 3,998,600 | 1,875,000 | 35,757,321 | 49,001,821 |
| 1965 | 3,234,600 | 73,600 | 9,081,200 | 6,332,200 | 1,273,600 | 47,820,751 | 67,815,951 |
| 1966 | 103,300 | 96,100 | 12,417,500 | 6,106,400 | 628,300 | 45,015,867 | 64,367,467 |
| 1967 | 68,300 | 105,800 | 18,405,600 | 5,105,800 | 441,300 | 37,956,931 | 62,083,731 |
| 1968 | 999,100 | 97,200 | 13,619,600 | 0 | 1,148,500 | 41,310,828 | 57,175,228 |
| 1969 | 773,300 | 2,534,600 | 17,924,000 | 0 | 1,306,300 | 35,297,493 | 57,835,693 |
| 1970 | 32,200 | 723,500 | 10,896,900 | 813,600 | 797,900 | 26,316,033 | 39,580,133 |
| 1971 | 82,900 | 1,437,000 | 11,657,400 | 44,600 | 1,187,100 | 17,559,513 | 31,968,513 |
| 1972 | 50,411 | 1,606,000 | 10,868,387 | 1,171,700 | 494,645 | 17,632,051 | 31,823,194 |
| 1973 | 28,129 | 436,000 | 7,741,724 | 518,200 | 289,645 | 9,699,467 | 18,713,165 |
| 1974 | 83,177 | 330,500 | 5,868,038 | 0 | 297,727 | 15,586,087 | 22,165,529 |
| 1975 | 348,502 | 74,537 | 5,486,095 | 1,631,900 | 212,970 | 13,176,118 | 20,930,122 |
| 1976 | 238,653 | 77,133 | 7,374,278 | 0 | 191,288 | 4,866,161 | 12,747,513 |
| 1977 | 279,270 | 95,011 | 8,587,182 | 18,000 | 276,051 | 3,017,412 | 12,272,926 |
| 1978 | 1,023,578 | 49,306 | 6,943,967 | 619,700 | 239,275 | 2,446,508 | 11,322,334 |
| 1979 | 750,377 | 173,308 | 5,251,876 | 0 | 211,698 | 2,043,230 | 8,430,489 |
| 1980 | 815,574 | 520,910 | 6,016,233 | 0 | 204,513 | 2,214,678 | 9,771,908 |
| 1981 | 1,120,913 | 595,783 | 3,532,115 | 0 | 132,289 | 2,004,914 | 7,386,014 |
| 1982 | 1,688,488 | 250,712 | 8,212,091 | 0 | 85,521 | 1,696,286 | 11,933,098 |
| 1983 | 1,344,831 | 613,451 | 6,208,854 | 0 | 145,670 | 927,681 | 9,240,487 |
| 1984 | 1,904,467 | 609,336 | 5,490,371 | 110,800 | 82,152 | 1,079,164 | 9,276,290 |
| 1985 | 897,526 | 362,961 | 10,920,089 | 0 | 46,000 | 1,072,471 | 13,299,047 |
| 1986 | 891,699 | 296,054 | 7,094,263 | 0 | 40,700 | 1,365,968 | 9,688,684 |
| 1987 | 770,843 | 193,948 | 3,579,164 | 0 | 27,600 | 888,975 | 5,460,530 |
| 1988 | 1,880,424 | 101,287 | 2,490,086 | 0 | 7,100 | 1,331,031 | 5,809,928 |
| 1989 | 570,963 | 54,232 | 1,025,806 | 237,500 | 4,500 | 1,370,534 | 3,263,535 |
| 1990 | 382,173 | 71,788 | 832,090 | 0 | 2,500 | 1,137,332 | 2,425,883 |
| 1991 | 559,926 | 39,873 | 1,408,074 | 0 | 2,500 | 918,350 | 2,928,723 |
| 1992 | 259,589 | 341,893 | 1,554,989 | 0 | 2,800 | 1,013,257 | 3,172,528 |
| 1993 | 129,950 | 433,824 | 949,132 | 0 | 2,601 | 543,568 | 2,059,075 |
| 1994 | 194,427 | 342,861 | 503,902 | 0 | 206 | 297,451 | 1,338,847 |
| 1995 | 178,736 | 478,116 | 387,695 | 0 | 21 | 330,132 | 1,374,700 |
| 1996 | 141,353 | 586,866 | 487,598 | 0 | 10 | 346,402 | 1,562,229 |
| 1997 | 139,755 | 320,775 | 261,630 | 0 | 4 | 657,852 | 1,380,016 |
| 1998 | 163,166 | 414,188 | 393,197 | 0 | 0 | 601,578 | 1,572,129 |
| 1999 | 110,348 | 263,108 | 363,435 | 0 | 0 | 452,867 | 1,189,758 |
| 2000 | 107,001 | 407,738 | 266,528 | 0 | 0 | 505,588 | 1,286,855 |

Table 2.3 Continued

| Year | Gill Net | Other | Pound Net | Purse Seine | Seine | Unknown | Total |
|---|---|---|---|---|---|---|---|
| 2001 | 98,832 | 72,127 | 245,985 | 0 | 0 | 922,430 | 1,339,374 |
| 2002 | 88,627 | 38,551 | 144,924 | 0 | 0 | 1,153,896 | 1,425,998 |
| 2003 | 95,162 | 145,761 | 119,455 | 0 | 3,846 | 984,141 | 1,348,365 |
| 2004 | 91,165 | 107,297 | 111,112 | 0 | 6,395 | 870,785 | 1,186,754 |
| 2005 | 84,068 | 167,392 | 169,305 | 0 | 1,278 | 361,701 | 783,744 |
| 2006 | 42,221 | 123,359 | 74,937 | 0 | 0 | 869,275 | 1,109,792 |
| 2007 | 4,152 | 152,213 | 6,843 | 0 | 148,375 | 673,143 | 984,726 |
| 2008 | 278 | 145,758 | 59,911 | 0 | 18,025 | 1,170,998 | 1,394,970 |
| 2009 | 178,278 | 12,010 | 21,932 | | 23,975 | 1,392,834 | 1,629,029 |
| 2010 | 151,772 | 12,218 | 771,749 | | 19,709 | 958 | 956,406 |

Table 2.4 Reported landings (pounds) of river herring in ICNAF/NAFO Areas 5 and 6 by country.

| Year | Bulgaria | Germany | Poland | USSR | USA | Grand Total |
|---|---|---|---|---|---|---|
| 1967 | - | - | - | 14,356,355 | 57,220,393 | 71,576,748 |
| 1968 | - | - | - | 49,184,626 | 55,141,455 | 104,326,081 |
| 1969 | 1,133,164 | 249,120 | - | 78,322,824 | 55,974,794 | 135,679,902 |
| 1970 | 1,481,491 | 418,874 | - | 42,083,609 | 36,047,415 | 80,031,389 |
| 1971 | 2,290,579 | 18,538,481 | 4,905,235 | 24,887,729 | 28,227,698 | 79,059,161 |
| 1972 | 1,128,755 | 7,674,213 | 4,162,285 | 14,755,388 | 2,707,249 | 30,427,889 |
| 1973 | 1,787,931 | 3,593,498 | 7,167,155 | 2,347,899 | 22,729,426 | 37,625,908 |
| 1974 | 1,704,156 | 5,862,031 | 2,398,605 | 1,042,776 | 24,490,901 | 36,054,028 |
| 1975 | 1,219,144 | 4,675,957 | 136,685 | 2,290,579 | 23,803,066 | 32,125,431 |
| 1976 | 564,378 | 2,777,796 | 30,864 | 537,922 | 14,290,217 | 18,201,178 |
| 1977 | - | 152,117 | - | 264,552 | 13,584,745 | 14,001,415 |
| 1978 | - | - | - | 46,297 | 12,632,358 | 12,702,905 |
| 1979 | - | - | - | 26,455 | 9,607,647 | 9,634,102 |
| 1980 | - | - | 2,205 | - | 10,498,305 | 10,504,919 |
| 1981 | - | - | 22,046 | - | 7,087,789 | 7,109,835 |
| 1982 | - | - | 178,573 | - | 12,784,475 | 12,963,048 |
| 1983 | - | - | 169,754 | - | 9,224,046 | 9,393,801 |
| 1984 | - | 17,637 | 436,511 | - | 9,003,586 | 9,457,734 |
| 1985 | - | 50,706 | 346,122 | - | 2,206,805 | 2,603,633 |
| 1986 | - | 37,478 | 103,616 | - | 8,988,154 | 9,133,658 |
| 1987 | - | 59,524 | 48,501 | - | 4,261,492 | 4,490,770 |
| 1988 | - | 63,933 | 66,138 | - | 5,251,357 | 5,443,157 |
| 1989 | - | 50,706 | 52,910 | - | 3,362,015 | 3,465,631 |
| 1990 | - | 30,864 | - | - | 2,892,435 | 2,923,300 |
| 1991 | - | - | - | - | 2,925,504 | 2,925,504 |
| 1992 | - | - | - | - | 3,209,898 | 3,209,898 |
| 1993 | - | - | - | - | 551,150 | 551,150 |
| 1994 | - | - | - | - | - | - |
| 1995 | - | - | - | - | - | - |
| 1996 | - | - | - | - | - | - |
| 1997 | - | - | - | - | - | - |
| 1998 | - | - | - | - | - | - |
| 1999 | - | - | - | - | - | - |
| 2000 | - | - | - | - | - | - |
| 2001 | - | - | - | - | - | - |
| 2002 | - | - | - | - | 284,393 | 284,393 |
| 2003 | - | - | - | - | - | - |
| 2004 | - | - | - | - | - | - |
| 2005 | - | - | - | - | - | - |
| 2006 | - | - | - | - | - | - |
| 2007 | - | - | - | - | 315,258 | 315,258 |
| 2008 | - | - | - | - | 286,598 | 286,598 |
| 2009 | - | - | - | - | 509,263 | 509,263 |
| 2010 | - | - | - | - | - | - |

*: Italy, the Netherlands, Romania, and Spain also reported catch, but only in one or two years; they are included in the Grand Total

Table 2.5 Marine Recreational Statistics Survey estimates of harvest (A+B1) and release (B2) numbers of blueback herring and alewives by year for each state with at least one record.

Blueback Herring

| | ME | | NH | | MA | | RI | | CT | | NY | | NJ | | DE | | MD | | VA | | FL | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases |
| 1982 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1983 | 83.1699 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1984 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1985 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1986 | 0 | 0 | 0 | 0 | 804.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1987 | 0 | 0 | 0 | 0 | 63118 | 20162.79 | 0 | 0 | 9871.86 | 0 | 0 | 0 | 925.49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1988 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2767.75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1989 | 0 | 0 | 0 | 0 | 638.96 | 0 | 613.87 | 0 | 77180.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1990 | 0 | 0 | 0 | 0 | 0 | 5632.021 | 10580 | 61.39103 | 43929.5 | 5802.006 | 235787 | 17107.86 | 79891 | 6857.352 | 0 | 0 | 0 | 0 | 57122.4 | 0 | 14351.66 | 0 |
| 1991 | 0 | 0 | 0 | 0 | 561.95 | 0 | 0 | 0 | 0 | 0 | 16451 | 0 | 0 | 0 | 0 | 1815.509 | 0 | 0 | 3741.23 | 0 | 0 | 0 |
| 1992 | 0 | 0 | 0 | 0 | 0 | 0 | 15817 | 0 | 0 | 0 | 0 | 0 | 3151.8 | 0 | 0 | 0 | 0 | 328.7029 | 0 | 0 | 0 | 0 |
| 1993 | 0 | 0 | 0 | 0 | 4524.9 | 1181.653 | 1118.1 | 559.0456 | 0 | 0 | 3562.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1994 | 0 | 0 | 0 | 0 | 725.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2516.832 | 0 |
| 1995 | 0 | 0 | 0 | 0 | 352.33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2389.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1996 | 0 | 0 | 0 | 0 | 5504.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1694.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1997 | 0 | 0 | 0 | 0 | 9496.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1998 | 0 | 0 | 0 | 0 | 0 | 738.5005 | 3937.7 | 0 | 4091.35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1999 | 0 | 0 | 0 | 0 | 0 | 0 | 21776 | 20511.36 | 6984.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 403.8252 | 0 | 0 |
| 2000 | 0 | 2392.033 | 0 | 0 | 0 | 0 | 165602 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3134.75 | 0 | 0 | 0 | 0 | 0 |
| 2001 | 0 | 0 | 196.44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2002 | 0 | 0 | 0 | 0 | 0 | 0 | 8135.6 | 0 | 0 | 0 | 0 | 8419.334 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2003 | 0 | 0 | 3014.7 | 0 | 56360 | 19392.09 | 83028 | 0 | 0 | 0 | 0 | 0 | 1081.7 | 0 | 0 | 0 | 1705.33 | 0 | 0 | 0 | 0 | 0 |
| 2004 | 0 | 0 | 0 | 340.6983 | 0 | 0 | 14215 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2005 | 0 | 0 | 0 | 0 | 11657 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2006 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 49.6782 | 812.7003 | 0 | 0 | 0 | 0 |
| 2007 | 1020.34 | 0 | 0 | 0 | 0 | 1191.508 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 87.19442 | 0 | 0 | 0 | 30.70385 | 0 | 0 |
| 2008 | 21497.9 | 0 | 0 | 0 | 0 | 18543.79 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 500.6518 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2009 | 0 | 0 | 217.04 | 224.444 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 178.65 | 0 | 0 | 0 | 93.7678 | 0 | 0 | 0 | 0 | 0 |
| 2010 | | | | | | | | | | | | | | | | | | | | | | |
| | All PSEs>0.71 | | All PSEs>1.00 | | All PSEs>0.46 | | All PSEs>0.35 | | All PSEs>0.57 | | All PSEs>0.49 | | All PSEs>0.47 | | All PSEs>0.71 | | All PSEs=1.00 | | All PSEs>0.51 | | All PSEs=1.00 | |

Alewife

| | ME | | NH | | MA | | RI | | CT | | NY | | NJ | | DE | | MD | | VA | | SC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases | Harvest | Releases |
| 1982 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1983 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1984 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1985 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14097 | 0 | 0 | 0 | 0 | 0 | 7431.15 | 0 | 0 | 0 | 0 | 0 |
| 1986 | 0 | 0 | 0 | 0 | 32506 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 69984.4 | 0 | 0 | 0 | 0 | 0 |
| 1987 | 344166 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 44637.12 | 0 | 0 | 0 | 0 | 0 | 0 | 2709877 | 0 | 0 | 0 | 0 | 0 |
| 1988 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 798.574 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1989 | 0 | 5598.748 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 85.758 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1990 | 3573.69 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1991 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 79944 | 0 | 26074.2 | 833.6246 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1992 | 2716.21 | 0 | 0 | 0 | 9410.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 119733 | 0 | 0 | 0 |
| 1993 | 3523.13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1109.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1994 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2936.664 | 0 | 0 | 0 | 0 | 0 | 1240.427 | 880.406 | 895.533 | 0 | 0 |
| 1995 | 0 | 0 | 209.43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 934.384 | 2054.32 | 0 | 0 |
| 1996 | 0 | 389.9613 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 307.3791 | 307.3791 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1997 | 0 | 1014.183 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1997.2 | 0 | 0 | 0 | 0 | 0 |
| 1998 | 0 | 0 | 0 | 0 | 0 | 0 | 19660 | 0 | 0 | 0 | 1107.9 | 0 | 0 | 0 | 626.5681 | 0 | 895.052 | 0 | 0 | 0 | 0 | 5080.46 |
| 1999 | 0 | 728.1016 | 0 | 0 | 0 | 0 | 0 | 0 | 2793.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2000 | 61388.4 | 9354.419 | 0 | 0 | 0 | 0 | 36992 | 0 | 0 | 0 | 16049 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2001 | 26225.4 | 1133.318 | 6875.3 | 0 | 2124.4 | 0 | 0 | 0 | 0 | 0 | 8377.3 | 11820.71 | 0 | 0 | 0 | 0 | 1175.09 | 1254.893 | 0 | 0 | 0 | 0 |
| 2002 | 0 | 2437.342 | 0 | 0 | 0 | 0 | 22824 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 189.1938 | 0 | 6609.58 | 638.7772 | 0 | 0 | 0 | 0 |
| 2003 | 7982.26 | 5519.622 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 198883 | 1398.878 | 0 | 0 | 0 | 0 |
| 2004 | 4886.69 | 672.0239 | 0 | 0 | 237564 | 0 | 106116 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 968.817 | 1073.944 | 0 | 0 | 0 | 0 |
| 2005 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2006 | 0 | 11544.42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2211.11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2007 | 12636.5 | 0 | 35414 | 3645.529 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2008 | 49239.3 | 22871.04 | 9954.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7970.913 | 0 | 0 | 0 | 0 |
| 2009 | 62474.6 | 9356.966 | 1637.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2010 | | | | | | | | | | | | | | | | | | | | | | |
| | All PSEs>0.48 | | All PSEs>0.51 | | All PSEs>0.35 | | All PSEs>0.33 | | All PSEs=1.00 | | All PSEs>0.51 | | All PSEs>0.61 | | All PSEs>0.64 | | All PSEs>0.47 | | All PSEs=1.00 | | All PSEs=1.00 | |

Table 2.6 Proportion of 2005-2010 incidental catch of river herring by region, fleet and quarter.

| | Bottom trawl | | | Gillnet | | | Paired MWT | Single MWT | Total MWT | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | lg | med | sm | xlg | lg | sm | all | all | | |
| **Mid-Atlantic (SA >= 600)** | **0.001** | **0.001** | **0.055** | **0.000** | **0.000** | **0.000** | **0.291** | **0.092** | **0.383** | **0.439** |
| Q1 | 0.000 | 0.000 | 0.017 | 0.000 | 0.000 | 0.000 | 0.265 | 0.082 | 0.347 | 0.365 |
| Q2 | 0.000 | 0.000 | 0.010 | 0.000 | 0.000 | 0.000 | 0.017 | 0.008 | 0.025 | 0.036 |
| Q3 | 0.000 | 0.000 | 0.020 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.002 | 0.022 |
| Q4 | 0.000 | 0.000 | 0.009 | 0.000 | 0.000 | 0.000 | 0.008 | 0.000 | 0.008 | 0.017 |
| **New England (SA <= 500)** | **0.004** | **0.000** | **0.182** | **0.000** | **0.000** | **0.000** | **0.266** | **0.109** | **0.374** | **0.561** |
| Q1 | 0.001 | 0.000 | 0.069 | 0.000 | 0.000 | 0.000 | 0.026 | 0.016 | 0.043 | 0.113 |
| Q2 | 0.001 | 0.000 | 0.030 | 0.000 | 0.000 | 0.000 | 0.057 | 0.056 | 0.114 | 0.145 |
| Q3 | 0.001 | 0.000 | 0.045 | 0.000 | 0.000 | 0.000 | 0.049 | 0.006 | 0.055 | 0.101 |
| Q4 | 0.001 | 0.000 | 0.038 | 0.000 | 0.000 | 0.000 | 0.133 | 0.030 | 0.163 | 0.202 |
| **Grand Total** | **0.005** | **0.001** | **0.237** | **0.000** | **0.000** | **0.000** | **0.556** | **0.200** | **0.757** | **1.000** |

Table 2.7 Species-specific total annual incidental catch (MT) and the associated coefficient of variation across all fleets and regions. Midwater trawl estimates were only included beginning in 2005.

| | Alewife | | American shad | | Blueback herring | | Herring NK | | Hickory Shad | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Catch | CV | Catch | CV | Catch | CV | Catch | CV | Catch | CV |
| 1989 | 20.35 | 0.49 | 58.92 | 0.60 | 19.60 | 0.39 | 7.08 | 1.03 | 0.00 | |
| 1990 | 55.31 | 0.68 | 25.81 | 0.34 | 78.94 | 0.44 | 331.34 | 0.72 | 0.00 | |
| 1991 | 68.24 | 0.48 | 104.27 | 0.25 | 115.41 | 0.37 | 110.46 | 0.48 | 39.35 | 0.00 |
| 1992 | 30.56 | 0.36 | 79.80 | 0.29 | 458.17 | 0.44 | 387.54 | 0.39 | 0.00 | |
| 1993 | 40.47 | 0.51 | 50.96 | 0.52 | 210.56 | 0.40 | 18.60 | 0.46 | 0.00 | |
| 1994 | 5.45 | 0.30 | 70.31 | 0.67 | 40.16 | 0.33 | 9.79 | 0.59 | 0.24 | 0.31 |
| 1995 | 6.36 | 0.48 | 17.17 | 0.41 | 213.50 | 0.43 | 51.89 | 1.44 | 0.02 | 1.42 |
| 1996 | 482.01 | 1.07 | 39.99 | 0.38 | 1803.43 | 2.10 | 28.68 | 0.43 | 26.64 | 0.82 |
| 1997 | 41.25 | 1.01 | 37.00 | 0.67 | 982.04 | 0.65 | 67.60 | 4.25 | 18.27 | 0.90 |
| 1998 | 80.88 | 1.47 | 55.31 | 0.43 | 49.32 | 1.27 | 0.42 | 0.65 | 39.19 | 1.45 |
| 1999 | 3.86 | 0.96 | 15.72 | 0.41 | 206.66 | 0.59 | 128.81 | 1.26 | 56.79 | 0.58 |
| 2000 | 28.37 | 0.67 | 74.39 | 1.82 | 55.46 | 0.37 | 21.96 | 0.53 | 0.06 | 0.80 |
| 2001 | 93.02 | 1.05 | 61.92 | 0.42 | 120.13 | 0.47 | 2.10 | 0.42 | 80.62 | 0.38 |
| 2002 | 2.72 | 3.86 | 24.07 | 0.41 | 173.23 | 0.31 | 76.51 | 1.85 | 1.41 | 1.05 |
| 2003 | 248.43 | 1.46 | 21.37 | 0.91 | 332.48 | 0.56 | 15.31 | 1.21 | 14.30 | 0.89 |
| 2004 | 99.74 | 0.93 | 18.16 | 0.35 | 81.54 | 0.47 | 176.74 | 0.74 | 35.03 | 0.78 |
| 2005 | 347.43 | 0.42 | 78.24 | 0.32 | 220.04 | 0.38 | 7.18 | 0.60 | 19.41 | 0.38 |
| 2006 | 57.61 | 0.91 | 29.29 | 4.37 | 187.48 | 0.67 | 232.02 | 1.16 | 13.35 | 0.81 |
| 2007 | 484.02 | 0.79 | 55.08 | 0.45 | 180.13 | 1.47 | 105.31 | 2.08 | 4.77 | 0.98 |
| 2008 | 145.03 | 0.43 | 52.38 | 0.32 | 526.59 | 0.57 | 327.99 | 0.40 | 7.83 | 0.65 |
| 2009 | 158.66 | 0.26 | 59.54 | 0.45 | 202.02 | 0.30 | 180.05 | 0.91 | 10.89 | 0.83 |
| 2010 | 118.50 | 0.20 | 46.12 | 0.17 | 125.02 | 0.20 | 86.50 | 0.32 | 1.12 | 0.65 |

Table 2.8 Trawl surveys for river herring. Only those surveys with 10 or more years of data were included in ARIMA model analysis.

| Species | Age | Survey | Season | Duration | n | Index Units |
|---|---|---|---|---|---|---|
| Alewife | Adult | DE Deleware River and Bay Adult finfish survey | All | 1966 - 2010 | 33 | Arithmetic Mean Catch per Nautical Mile Towed |
| | Age1 | DE Delaware River and Bay Juvenile finfish survey | All | 1991 - 2010 | 19 | Geometric Mean Count Per Tow |
| | | Massachusetts DMF Inshore North Cape Cod | Spring | 1978 - 2010 | 33 | Mean Number per Tow |
| | | Massachusetts DMF Inshore South Cape Cod | Spring | 1978 - 2010 | 33 | Mean Number per Tow |
| | All | Ches. Bay Multispecies Monitoring and Assessment Program | Spring | 2002 - 2010 | 9 | Number per square nautical mile |
| | | CT DEP Long Island Sound Trawl Survey | Fall | 1984 - 2009 | 26 | Geometric Mean Count Per Tow |
| | | CT DEP Long Island Sound Trawl Survey | Spring | 1984 - 2010 | 27 | Geometric Mean Count Per Tow |
| | | ME-MH Fall Inshore Gulf of Maine | Fall | 2000 - 2010 | 11 | Stratified Mean Catch Per Tow |
| | | ME-MH Fall Inshore Gulf of Maine | Spring | 2001 - 2010 | 10 | Stratified Mean Catch Per Tow |
| | | New Jersey Ocean Trawl Survey | All | 1989 - 2009 | 21 | Geometric Mean CPUE |
| | | NEFSC bottom trawl-Coast | Fall | 1975 - 2010 | 36 | Mean number per tow |
| | | NEFSC bottom trawl-Coast | Spring | 1976 - 2011 | 36 | Mean number per tow |
| | | NEFSC bottom trawl-North | Spring | 1976 - 2011 | 36 | Mean number per tow |
| | | NEFSC bottom trawl-South | Spring | 1976 - 2011 | 36 | Mean number per tow |
| | | Northeast Area Monitoring and Assessment Program | Fall | 2007 - 2009 | 3 | Number per 25K square miles |
| | | Northeast Area Monitoring and Assessment Program | Spring | 2008 - 2010 | 3 | Number per 25K square miles |
| | | Rhode Island Combined Coastal Trawl Survey | All | 1979 - 2010 | 32 | Arithmetic Mean Catch Per Tow |
| | YOY | DE Delaware River and Bay Juvenile finfish survey | All | 1990 - 2010 | 21 | Geometric Mean Count Per Tow |
| | | North Carolina DMF Western Sound | Summer-Fall | 1982 - 2009 | 28 | Arithmetic Mean CPUE |

Table 2.8 Continued.

| Species | Age | Survey | Season | Duration | n | Index Units |
|---|---|---|---|---|---|---|
| Blueback | Adult | DE Deleware River and Bay Adult finfish survey | All | 1966 - 2010 | 33 | Arithmetic Mean Catch per Nautical Mile Towed |
| | Age1 | DE Delaware River and Bay Juvenile finfish survey | All | 1991 - 2010 | 19 | Geometric Mean Count Per Tow |
| | | Massachusetts DMF Inshore North Cape Cod | Spring | 1978 - 2010 | 33 | Mean Number per Tow |
| | | Massachusetts DMF Inshore South Cape Cod | Spring | 1978 - 2010 | 33 | Mean Number per Tow |
| | All | Ches. Bay Multispecies Monitoring and Assessment Program | Spring | 2002 - 2010 | 9 | Number per square nautical mile |
| | | CT DEP Long Island Sound Trawl Survey | Fall | 1984 - 2009 | 26 | Geometric Mean Count Per Tow |
| | | CT DEP Long Island Sound Trawl Survey | Spring | 1984 - 2010 | 27 | Geometric Mean Count Per Tow |
| | | ME-MH Fall Inshore Gulf of Maine | Fall | 2002 - 2010 | 9 | Stratified Mean Catch Per Tow |
| | | ME-MH Fall Inshore Gulf of Maine | Spring | 2001 - 2010 | 10 | Stratified Mean Catch Per Tow |
| | | New Jersey Ocean Trawl Survey | All | 1989 - 2009 | 21 | Geometric Mean CPUE |
| | | NEFSC bottom trawl-Coast | Fall | 1975 - 2010 | 36 | Mean number per tow |
| | | NEFSC bottom trawl-Coast | Spring | 1976 - 2011 | 36 | Mean number per tow |
| | | NEFSC bottom trawl-North | Spring | 1976 - 2011 | 36 | Mean number per tow |
| | | NEFSC bottom trawl-South | Spring | 1976 - 2011 | 36 | Mean number per tow |
| | | Northeast Area Monitoring and Assessment Program | Fall | 2007 - 2009 | 3 | Number per 25K square miles |
| | | Northeast Area Monitoring and Assessment Program | Spring | 2008 - 2010 | 3 | Number per 25K square miles |
| | | Rhode Island Combined Coastal Trawl Survey | All | 1979 - 2010 | 32 | Arithmetic Mean Catch Per Tow |
| | YOY | DE Delaware River and Bay Juvenile finfish survey | All | 1990 - 2010 | 21 | Geometric Mean Count Per Tow |
| | | North Carolina DMF Western Sound | Summer-Fall | 1982 - 2009 | 28 | Arithmetic Mean CPUE |

Table 2.9 Summary statistics from ARIMA model fits to **alewife** trawl survey data. $Q_{0.25}$ is the 25$^{th}$ percentile of the fitted values; P(<0.25) is the probability of the final year of the survey being below $Q_{0.25}$ with 80% confidence; r1 - r3 are the first three autocorrelations; $\theta$ is the moving average parameter; SE is the standard error of $\theta$; and $\sigma^2_c$ is the variance of the index.

| Survey | Season | Age | FinalYear | n | P(<0.25) | $Q_{0.25}$ | r1 | r2 | r3 | $\theta$ | SE | $\sigma^2_c$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CT DEP Long Island Sound Trawl Survey | Fall | All ages | 2009 | 26 | 0.031 | -1.850 | -0.58 | 0.12 | -0.11 | 0.78 | 0.11 | 1.13 |
| CT DEP Long Island Sound Trawl Survey | Spring | All ages | 2010 | 27 | 0.000 | -0.054 | -0.42 | -0.18 | 0.25 | 0.63 | 0.15 | 0.32 |
| DE Delaware River and Bay Juvenile finfish survey | All | Age 0 | 2010 | 21 | 0.004 | -1.826 | -0.57 | 0.04 | -0.01 | 1.00 | 0.28 | 2.36 |
| DE Delaware River and Bay Juvenile finfish survey | All | Age 1 | 2010 | 19 | 0.450 | -2.954 | -0.76 | 0.55 | -0.42 | 0.74 | 0.15 | 2.50 |
| DE Deleware River and Bay Adult finfish survey | All | Adult | 2010 | 33 | 0.084 | -0.550 | -0.37 | -0.15 | 0.25 | 0.91 | 0.22 | 1.17 |
| Massachusetts DMF Inshore North Cape Cod | Spring | Age 1 | 2010 | 33 | 0.019 | 1.959 | -0.33 | -0.23 | 0.13 | 0.90 | 0.18 | 1.12 |
| Massachusetts DMF Inshore South Cape Cod | Spring | Age 1 | 2010 | 33 | 0.167 | -0.618 | -0.35 | 0.05 | -0.11 | 1.00 | 0.12 | 2.24 |
| ME-NH Fall Inshore Gulf of Maine | Fall | All ages | 2009 | 10 | 0.002 | 5.501 | -0.48 | 0.23 | -0.12 | 0.66 | 0.28 | 0.16 |
| ME-NH Fall Inshore Gulf of Maine | Spring | All ages | 2010 | 10 | 0.036 | 4.861 | -0.64 | 0.31 | -0.32 | 1.00 | 0.38 | 0.15 |
| New Jersey Ocean Trawl Survey | All | All ages | 2009 | 21 | 0.000 | 1.305 | -0.37 | -0.09 | 0.02 | 1.00 | 0.18 | 0.43 |
| NMFS bottom trawl-Coast | Fall | All | 2010 | 36 | 0.000 | 0.276 | -0.55 | 0.18 | -0.18 | 0.78 | 0.09 | 0.63 |
| NMFS bottom trawl-Coast | Spring | All | 2011 | 36 | 0.000 | 1.908 | -0.26 | 0.08 | 0.08 | 0.46 | 0.18 | 0.26 |
| NMFS bottom trawl-North | Fall | All | 2010 | 36 | 0.000 | 0.638 | -0.53 | 0.14 | -0.16 | 0.77 | 0.09 | 0.55 |
| NMFS bottom trawl-North | Spring | All | 2011 | 36 | 0.000 | 1.595 | -0.21 | 0.05 | 0.07 | 0.48 | 0.18 | 0.26 |
| NMFS bottom trawl-South | Fall | All | 2010 | 36 | 0.000 | -4.605 | -0.48 | -0.02 | -0.01 | 1.00 | 0.21 | 0.03 |
| NMFS bottom trawl-South | Spring | All | 2011 | 36 | 0.446 | 1.452 | -0.28 | -0.14 | -0.06 | 0.80 | 0.16 | 0.97 |
| North Carolina DMF Western Sound | Summer-Fall | Age 0 | 2009 | 28 | 0.824 | -2.419 | -0.29 | -0.05 | -0.05 | 0.34 | 0.22 | 3.44 |
| Rhode Island Coastal Trawl Survey | All | All ages | 2010 | 32 | 0.000 | -0.519 | -0.55 | -0.04 | 0.18 | 0.46 | 0.14 | 1.66 |

Table 2.10 Summary statistics from ARIMA model fits to **blueback herring** trawl survey data. $Q_{0.25}$ is the 25th percentile of the fitted values; P(<0.25) is the probability of the final year of the survey being below $Q_{0.25}$ with 80% confidence; r1 - r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; and $\sigma^2_c$ is the variance of the index.

| Survey | Season | Age | FinalYear | n | P(<0.25) | $Q_{0.25}$ | r1 | r2 | r3 | θ | SE | $\sigma^2_c$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CT DEP Long Island Sound Trawl Survey | Fall | All ages | 2009 | 26 | 0.243 | -2.084 | -0.37 | -0.31 | -0.30 | 0.92 | 0.13 | 0.79 |
| CT DEP Long Island Sound Trawl Survey | Spring | All ages | 2010 | 27 | 0.054 | -1.942 | -0.02 | 0.04 | 0.02 | 0.38 | 0.21 | 1.14 |
| DE Delaware River and Bay Juvenile finfish survey | All | Age 0 | 2010 | 21 | 0.365 | -3.927 | -0.73 | 0.49 | -0.44 | 0.58 | 0.16 | 1.27 |
| DE Delaware River and Bay Juvenile finfish survey | All | Age 1 | 2010 | 19 | 0.000 | -3.602 | -0.52 | -0.03 | 0.04 | 1.00 | 0.28 | 1.74 |
| DE Deleware River and Bay Adult finfish survey | All | Adult | 2010 | 33 | 0.161 | -2.709 | -0.30 | -0.01 | -0.05 | 0.35 | 0.24 | 1.72 |
| Massachusetts DMF Inshore North Cape Cod | Spring | Age 1 | 2010 | 33 | 0.002 | 0.775 | -0.41 | -0.19 | 0.03 | 1.00 | 0.10 | 1.57 |
| Massachusetts DMF Inshore South Cape Cod | Spring | Age 1 | 2010 | 33 | 0.303 | -2.583 | -0.02 | -0.14 | -0.13 | 0.88 | 0.16 | 3.05 |
| ME-NH Fall Inshore Gulf of Maine | Spring | All ages | 2010 | 10 | 0.211 | 2.640 | -0.60 | -0.60 | 0.25 | 0.79 | 0.32 | 1.07 |
| New Jersey Ocean Trawl Survey | All | All ages | 2009 | 21 | 0.000 | 1.329 | -0.39 | 0.09 | -0.07 | 0.30 | 0.24 | 0.13 |
| NMFS bottom trawl-Coast | Fall | All | 2010 | 36 | 0.000 | -2.973 | -0.35 | -0.06 | 0.03 | 0.67 | 0.15 | 1.95 |
| NMFS bottom trawl-Coast | Spring | All | 2011 | 36 | 0.009 | 0.618 | -0.51 | -0.03 | 0.19 | 0.75 | 0.20 | 0.71 |
| NMFS bottom trawl-North | Fall | All | 2010 | 36 | 0.000 | -2.738 | -0.34 | -0.07 | 0.04 | 0.72 | 0.13 | 2.45 |
| NMFS bottom trawl-North | Spring | All | 2011 | 36 | 0.000 | -0.734 | -0.50 | -0.12 | 0.27 | 0.77 | 0.10 | 0.95 |
| NMFS bottom trawl-South | Fall | All | 2010 | 36 | 0.162 | -4.337 | -0.50 | 0.01 | 0.00 | 1.00 | 0.09 | 0.57 |
| NMFS bottom trawl-South | Spring | All | 2011 | 36 | 0.162 | 1.214 | -0.61 | 0.19 | -0.01 | 0.82 | 0.14 | 1.34 |
| North Carolina DMF Western Sound | Summer-Fall | Age 0 | 2009 | 28 | 0.723 | 0.418 | -0.12 | -0.60 | 0.23 | 0.74 | 0.19 | 10.09 |
| Rhode Island Coastal Trawl Survey | All | All ages | 2010 | 32 | 0.393 | 0.151 | -0.47 | -0.08 | 0.11 | 0.77 | 0.16 | 2.21 |

Table 2.11 Summary of P(<0.25) values from Tables 1 & 2 comparing northern to southern trawl surveys for river herring. Coastwide NMFS surveys were not included in this summary. N is the number of surveys included in each region.

| Species | Region | n | Min. | Max. | Median | Average |
|---|---|---|---|---|---|---|
| Alewife | North | 9 | 0 | 0.167 | 0.002 | 0.028 |
| | South | 7 | 0 | 0.824 | 0.084 | 0.258 |
| Blueback | North | 8 | 0 | 0.393 | 0.133 | 0.151 |
| | South | 7 | 0 | 0.723 | 0.162 | 0.225 |

Table 2.12 Spearman rank correlations between river herring run counts and trawl surveys. Correlation analysis was restricted to rivers with count data that overlapped a trawl survey by at least 10 years. A total of 572 correlations were performed, of which only nine showed a significant positive Spearman rank correlation.

| species | State | river | Trawl Survey | Trawl Age | Trawl Season | n | $r_{Spearman}$ | *p* |
|---|---|---|---|---|---|---|---|---|
| Alewife | MA | Mattapoisett | Delaware River and Bay Juvenile Finfish Survey | Age 1 | All | 19 | 0.4965 | 0.0306 |
| | MA | Mattapoisett | Delaware River and Bay Adult Finfish Survey | Adult | All | 21 | 0.7364 | 0.0002 |
| | MA | Parker | Delaware River and Bay Adult Finfish Survey | Adult | All | 14 | 0.7275 | 0.0045 |
| | ME | Androscoggin | MA DMF Inshore North of Cape Cod | Age 1 | Spring | 27 | 0.5739 | 0.0021 |
| | RI | Gilbert | Rhode Island Combined Coastal Trawl Survey | All | All | 30 | 0.4016 | 0.0287 |
| Blueback | MA | Monument | North Carolina DMF Western Sound | YOY | Summer - Fall | 26 | 0.6143 | 0.0008 |
| | NC | Chowan | NMFS bottom trawl - South | All | Spring | 34 | 0.3482 | 0.0442 |
| Both | NH | Cocheco | NMFS bottom trawl - North | All | Fall | 35 | 0.3754 | 0.0270 |
| | NH | Cocheco | NMFS bottom trawl - North | All | Spring | 35 | 0.4863 | 0.0034 |
| | NH | Taylor | NMFS bottom trawl - South | All | Spring | 34 | 0.3455 | 0.0460 |

Table 2.13. Results of the Mann-Kendall test for trends in mean length by river (state), species and sex. n = sample size, S is the Mann-Kendall test statistics, and p is the two-tailed probability. Significant results are bolded. The sign of the test statistic indicates the direction of the trend.

| River (State) | Species | Sex | n | S | p |
|---|---|---|---|---|---|
| Androscoggin River (ME) | Alewife | Male | 20 | -25 | 0.43 |
| | | Female | 20 | -35 | 0.27 |
| Cocheco River (NH) | Alewife | Male | 19 | -5 | 0.888 |
| | | Female | 19 | 7 | 0.833 |
| | Blueback | Male | 17 | -44 | 0.076 |
| | | Female | 17 | -20 | 0.433 |
| Exeter River (NH) | Alewife | Male | 18 | -47 | 0.081 |
| | | Female | 18 | -43 | 0.111 |
| Lamprey River (NH) | Alewife | Male | 19 | 11 | 0.726 |
| | | Female | 19 | 33 | 0.262 |
| Oyster River (NH) | Blueback | Male | **19** | **-93** | **0.001** |
| | | Female | **19** | **-83** | **0.004** |
| Winnicut River (NH) | Alewife | Male | 12 | 2 | 0.945 |
| | | Female | 12 | 28 | 0.064 |
| | Blueback | Male | 12 | 2 | 0.945 |
| | | Female | 12 | -12 | 0.451 |
| Monument River (MA) | Alewife | Male | **25** | **-180** | **0.000** |
| | | Female | **25** | **-172** | **0.000** |
| | Blueback | Male | **22** | **-186** | **0.000** |
| | | Female | **25** | **-208** | **0.000** |
| Stony Brook (MA) | Alewife | Combined | **23** | **-184** | **0.000** |
| Hudson River (NY) | Alewife | Male | **19** | **-99** | **0.000** |
| | | Female | **19** | **-82** | **0.005** |
| | Blueback | Male | **17** | **-72** | **0.003** |
| | | Female | **18** | **-84** | **0.002** |
| Nanticoke River (MD) | Alewife | Male | 16 | 2 | 0.964 |
| | | Female | 16 | 16 | 0.499 |
| | Blueback | Male | **17** | **-76** | **0.002** |
| | | Female | **17** | **-82** | **0.001** |
| Chowan River (NC) | Alewife | Male | **31** | **-271** | **0.000** |
| | | Female | **32** | **-294** | **0.000** |
| | Blueback | Male | **36** | **-420** | **0.000** |
| | | Female | **36** | **-384** | **0.000** |
| Santee-Cooper River (SC) | | | | | |
| Commerical Cast net | Blueback | Male | 14 | -31 | 0.099 |
| | | Female | 14 | 20 | 0.297 |
| Fishlift | Blueback | Male | 19 | -56 | 0.053 |
| | | Female | **19** | **-70** | **0.015** |

Table 2.14 Results of the Mann-Kendall test for trends in mean lengths of alewife and blueback herring from the National Marine Fisheries bottom trawl survey by species and region. *n* = sample size, *S* is the Mann-Kendall test statistics, and *p* is the two-tailed probability. Significant results are bolded. The sign of the test statistic indicates the direction of the trend.

| Species | Region | n | S | p |
|---|---|---|---|---|
| Alewife | Coastwide Spring | 35 | **-257** | 0.0003 |
| Alewife | North Spring | 35 | **-195** | 0.0059 |
| Alewife | South Spring | 35 | -129 | 0.0691 |
| Alewife | Coastwide Fall | 36 | **-162** | 0.0283 |
| Alewife | North Fall | 36 | **-160** | 0.0303 |
| Alewife | South Fall | 4 | -2 | 0.7340 |
| Blueback | Coastwide Spring | 35 | 45 | 0.5320 |
| Blueback | North Spring | 35 | -76 | 0.2868 |
| Blueback | South Spring | 35 | **153** | 0.0308 |
| Blueback | Coastwide Fall | 38 | **-203** | 0.0111 |
| Blueback | North Fall | 32 | **-160** | 0.0100 |
| Blueback | South Fall | 7 | 9 | 0.5294 |

Table 2.15. Results of the Mann-Kendall test for trends in mean length by river (state), species, sex and age. n = sample size, S is the Mann-Kendall test statistics, and p is the two-tailed probability. Significant results are bolded. The sign of the test statistic indicates the direction of the trend.

| River (State) | Species | Sex | Age | n | S | p |
|---|---|---|---|---|---|---|
| Androscoggin (ME) | Alewife | Female | **3** | **10** | **-38** | **0.001** |
| | | | 4 | 16 | -7 | 0.787 |
| | | | 5 | 16 | 5 | 0.857 |
| | | | 6 | 12 | 2 | 0.945 |
| | | Male | 3 | 12 | -5 | 0.783 |
| | | | 4 | 16 | 19 | 0.417 |
| | | | 5 | 16 | -3 | 0.928 |
| | | | 6 | 13 | -16 | 0.360 |
| Cocheco (NH) | Alewife | Female | 3 | 8 | -6 | 0.536 |
| | | | **4** | **18** | **-55** | **0.041** |
| | | | **5** | **19** | **-65** | **0.025** |
| | | | **6** | **17** | **-54** | **0.029** |
| | | Male | 3 | 11 | -21 | 0.119 |
| | | | **4** | **19** | **-57** | **0.050** |
| | | | **5** | **19** | **-83** | **0.004** |
| | | | **6** | **14** | **-53** | **0.004** |
| | Blueback | Female | 3 | 6 | -5 | 0.452 |
| | | | 4 | 11 | -25 | 0.062 |
| | | | 5 | 10 | -19 | 0.107 |
| | | | 6 | * | * | * |
| | | Male | 3 | 9 | -14 | 0.175 |
| | | | **4** | **15** | **-45** | **0.029** |
| | | | **5** | **11** | **-39** | **0.003** |
| | | | 6 | * | * | * |
| Exeter (NH) | Alewife | Female | 3 | 6 | -6 | 0.221 |
| | | | 4 | **15** | **-49** | **0.017** |
| | | | **5** | **17** | **-52** | **0.036** |
| | | | **6** | **11** | **-34** | **0.010** |
| | | Male | **3** | **10** | **-27** | **0.020** |
| | | | 4 | 16 | -44 | 0.053 |
| | | | **5** | **16** | **-46** | **0.043** |
| | | | **6** | **12** | **-44** | **0.003** |
| Oyster (NH) | Blueback | Female | **3** | **14** | **-45** | **0.016** |
| | | | **4** | **18** | **-61** | **0.023** |
| | | | **5** | **19** | **-107** | **0.000** |
| | | | **6** | **15** | **-69** | **0.001** |
| | | Male | **3** | **19** | **-77** | **0.007** |
| | | | **4** | **19** | **-93** | **0.001** |
| | | | **5** | **19** | **-113** | **0.000** |
| | | | **6** | **13** | **-52** | **0.002** |
| Lamprey (NH) | Alewife | Female | **3** | **11** | **-35** | **0.008** |
| | | | **4** | **20** | **-103** | **0.001** |
| | | | **5** | **20** | **-86** | **0.000** |
| | | | 6 | 17 | -18 | 0.483 |
| | | Male | **3** | **14** | **-45** | **0.016** |
| | | | **4** | **20** | **-92** | **0.003** |
| | | | 5 | 19 | -33 | 0.263 |
| | | | 6 | 16 | -30 | 0.192 |
| Winnicut (NH) | Alewife | Female | 3 | * | * | * |
| | | | **4** | **9** | **-24** | **0.016** |
| | | | **5** | **8** | **-18** | **0.035** |
| | | | 6 | 5 | 5 | 0.452 |
| | | Male | 3 | 10 | -21 | 0.074 |
| | | | 4 | 11 | -13 | 0.350 |
| | | | 5 | 10 | -21 | 0.074 |
| | | | 6 | 8 | -4 | 0.710 |
| | Blueback | Female | 3 | * | * | * |
| | | | 4 | 9 | -12 | 0.251 |
| | | | 5 | 7 | -11 | 0.133 |
| | | | 6 | * | * | * |
| | | Male | 3 | 9 | -14 | 0.175 |
| | | | 4 | 12 | -18 | 0.243 |
| | | | 5 | 11 | -25 | 0.062 |
| | | | 6 | * | * | * |

* time series too short

Table 2.15. cont.

| River (State) | Species | Sex | Age | n | S | p |
|---|---|---|---|---|---|---|
| Monument (MA) | Alewife | Female | 3 | 15 | 11 | 0.620 |
| | | | 4 | 17 | -16 | 0.537 |
| | | | 5 | 17 | 10 | 0.711 |
| | | | 6 | 15 | -7 | 0.767 |
| | | Male | 3 | 17 | -37 | 0.138 |
| | | | 4 | 17 | -16 | 0.537 |
| | | | 5 | 17 | 12 | 0.650 |
| | | | 6 | 15 | 22 | 0.298 |
| | Blueback | Female | 3 | 11 | -3 | 0.876 |
| | | | 4 | 17 | -31 | 0.216 |
| | | | 5 | 17 | -21 | 0.410 |
| | | | 6 | 7 | -5 | 0.548 |
| | | Male | 3 | 17 | -4 | 0.902 |
| | | | 4 | 17 | 16 | 0.537 |
| | | | 5 | 17 | 30 | 0.232 |
| | | | 6 | 5 | -4 | 0.462 |
| Gilbert-Stuart (RI) | Alewife | Female | 3 | 8 | -12 | 0.173 |
| | | | 4 | **11** | **-29** | **0.029** |
| | | | 5 | **11** | **-23** | **0.087** |
| | | | 6 | 11 | -13 | 0.350 |
| | | Male | 3 | 11 | -21 | 0.119 |
| | | | 4 | **11** | **-31** | **0.019** |
| | | | 5 | 11 | -17 | 0.201 |
| | | | 6 | * | * | * |
| Nonquit (RI) | Alewife | Female | 3 | 10 | -10 | 0.419 |
| | | | 4 | 10 | -17 | 0.152 |
| | | | 5 | 10 | -9 | 0.474 |
| | | | 6 | 8 | -4 | 0.710 |
| | | Male | 3 | 10 | -15 | 0.210 |
| | | | 4 | 10 | -21 | 0.074 |
| | | | 5 | 9 | -16 | 0.117 |
| | | | 6 | 5 | -4 | 0.462 |
| Nanticoke (MD) | Alewife | Female | 3 | 20 | -16 | 0.626 |
| | | | 4 | 22 | -28 | 0.445 |
| | | | **5** | **22** | **-82** | **0.022** |
| | | | 6 | 22 | -59 | 0.098 |
| | | Male | 3 | 22 | 27 | 0.461 |
| | | | 4 | 22 | -49 | 0.174 |
| | | | **5** | **22** | **-71** | **0.047** |
| | | | 6 | 22 | -33 | 0.366 |
| | Blueback | Female | 3 | 22 | 1 | 1.000 |
| | | | 4 | 22 | -38 | 0.295 |
| | | | 5 | 21 | -47 | 0.161 |
| | | | 6 | 18 | -24 | 0.380 |
| | | Male | 3 | 19 | -15 | 0.623 |
| | | | 4 | 22 | -10 | 0.799 |
| | | | **5** | **22** | **-77** | **0.031** |
| | | | 6 | 22 | -43 | 0.226 |
| Chowan (NC) | Alewife | Female | **3** | **12** | **-51** | **0.001** |
| | | | **4** | **29** | **-236** | **0.000** |
| | | | **5** | **30** | **-279** | **0.000** |
| | | | **6** | **29** | **-206** | **0.000** |
| | | Male | **3** | **25** | **-175** | **0.000** |
| | | | **4** | **32** | **-331** | **0.000** |
| | | | **5** | **30** | **-235** | **0.000** |
| | | | **6** | **30** | **-237** | **0.000** |
| | Blueback | Female | **3** | **23** | **-171** | **0.000** |
| | | | **4** | **38** | **-463** | **0.000** |
| | | | **5** | **38** | **-409** | **0.000** |
| | | | **6** | **37** | **-363** | **0.000** |
| | | Male | **3** | **37** | **-460** | **0.000** |
| | | | **4** | **38** | **-502** | **0.000** |
| | | | **5** | **38** | **-396** | **0.000** |
| | | | **6** | **36** | **-241** | **0.001** |

Table 2.16 Summary of fisheries-independent data sources that have collected repeat spawner data from river herring. Species indicates whether data were available for alewives (A), blueback herring (B), or both species combined (river herring, R).

| State | Water Body | Gear | Species | Years From | Years To |
|---|---|---|---|---|---|
| Maine | Androscoggin River | Fishway | R | 2005 | 2007 |
| New Hampshire | Cocheco River | Fishway | A, B | 2000 | 2010 |
| New Hampshire | Exeter River | Fishway | A, B | 2000 | 2010 |
| New Hampshire | Lamprey River | Fishway | A | 2000 | 2010 |
| New Hampshire | Oyster River | Fishway | B | 2000 | 2010 |
| New Hampshire | Taylor River | Fishway | B | 2000 | 2005 |
| New Hampshire | Winnicut River | Fishway | A | 2000 | 2010 |
| Massachusetts | Mattapoisett River | Dip Net | A | 2006 | 2006 |
| Massachusetts | Monument River | Dip Net | A, B | 1986 | 1987 |
| Massachusetts | Monument River | Dip Net | A, B | 2003 | 2010 |
| Massachusetts | Mystic River | Dip Net | A, B | 2004 | 2010 |
| Massachusetts | Nemasket River | Dip Net | A | 2004 | 2010 |
| Massachusetts | Quashnet River | Dip Net | A, B | 2004 | 2004 |
| Massachusetts | Stoney Brook | Dip Net | A | 2004 | 2004 |
| Massachusetts | Town Brook | Dip Net | A, B | 2004 | 2010 |
| Rhode Island | Gilbert Stuart Stream | Fishway | R | 1984 | 2010 |
| Rhode Island | Nonquit Pond | Fishway | R | 2000 | 2009 |
| New York | Hudson River | Various, Combined | B | 1989 | 1990 |
| New York | Hudson River | Various, Combined | A, B | 1999 | 2001 |
| South Carolina | Santee River | Pound Net | B | 1978 | 1978 |
| South Carolina | Santee River | Haul Seine | B | 1979 | 1979 |
| South Carolina | Santee River | Gill Net | B | 1980 | 1983 |

Table 2.17. Summary of fisheries-dependent data sources that have collected repeat spawner data from river herring. Species indicates whether data were available for alewives (A), blueback herring (B), or both species combined (river herring, R).

| | | | | **Years** | |
|---|---|---|---|---|---|
| **State** | **Water Body** | **Gear** | **Species** | **From** | **To** |
| Maryland | Nanticoke River | Pound & Fyke Nets | A, B | 1989 | 2010 |
| North Carolina | Alligator River | Pound Net | A, B | 1972 | 1993 |
| North Carolina | Chowan River | Pound Net | A, B | 1972 | 2009 |
| North Carolina | Scuppernong River | Pound Net | A, B | 1972 | 1993 |

Table 2.18 Estimated rates of repeat spawning for male and female river herring (alewives and blueback herring combined) observed in Maine's fisheries-independent fishway survey of the Androscoggin River by sex and year.

| | **Maine** | |
|---|---|---|
| | Fishway | |
| | Androscoggin River | |
| **Year** | *Male* | *Female* |
| 2005 | 52.7 | 38.6 |
| 2006 | 58.0 | 57.9 |
| 2007 | 58.9 | 52.6 |

Table 2.19 Estimated rates of repeat spawning for male and female alewives observed in New Hampshire's fisheries-independent fishway survey of the Cocheco, Exeter, Lamprey and Winnicut Rivers by year.

| | New Hampshire | | | |
|---|---|---|---|---|
| | Fishway | | | |
| **Year** | Cocheco River | Exeter River | Lamprey River | Winnicut River |
| 2000 | 32.1 | 10.6 | 46.2 | 46.2 |
| 2001 | 43.6 | 37.5 | 58.6 | 58.6 |
| 2002 | 46.2 | 19.2 | 63.3 | 63.3 |
| 2003 | 30.6 | 38.9 | 51.4 | 51.4 |
| 2004 | 69.6 | 36.4 | 54.9 | 54.9 |
| 2005 | 54.2 | 21.9 | 51.6 | 51.6 |
| 2006 | 50.6 | 37.5 | 59.8 | 59.8 |
| 2007 | 31.2 | 17.5 | 57.1 | 57.1 |
| 2008 | 29.6 | 9.0 | 32.9 | 32.9 |
| 2009 | 30.4 | 11.7 | 50.8 | 50.8 |
| 2010 | 65.3 | 18.8 | 63.0 | 63.0 |

Table 2.20 Estimated rates of repeat spawning for blueback herring (both sexes combined) observed in New Hampshire's fisheries-independent fishway surveys of the Cocheco and Oyster Rivers by year. [-- indicates inadequate sample size.]

| | New Hampshire | |
|---|---|---|
| | Fishway | |
| **Year** | Cocheco River | Oyster River |
| 2000 | 44.00 | 34.97 |
| 2001 | 40.00 | 64.58 |
| 2002 | 20.75 | 36.17 |
| 2003 | 24.00 | 51.01 |
| 2004 | 41.18 | 69.53 |
| 2005 | 20.00 | 50.00 |
| 2006 | 12.50 | 42.55 |
| 2007 | 31.34 | 37.99 |
| 2008 | 37.50 | 27.59 |
| 2009 | -- | 38.66 |
| 2010 | -- | 52.56 |

Table 2.21 Estimated rates of repeat spawning for male alewife observed in Massachusetts' fisheries-independent dipnet surveys in select rivers by year.

| | **Massachusetts** | | | | | | |
|---|---|---|---|---|---|---|---|
| | Dip Net | | | | | | |
| **Year** | Mattapoisett River | Monument River | Mystic River | Nemasket River | Quashnet River | Stoney Brook | Town Brook |
| 1986 | | 38.6 | | | | | |
| 1987 | | 41.1 | | | | | |
| 1988 | | | | | | | |
| | | | | | | | |
| 2003 | | | | | | | |
| 2004 | | 6.5 | 32.4 | 43.9 | 4.6 | 12.1 | 16.9 |
| 2005 | | 3.7 | 30.0 | 33.8 | | | 9.7 |
| 2006 | 2.86 | 4.9 | 0.0 | 9.7 | | | 4.4 |
| 2007 | | 6.2 | 6.7 | 11.9 | | | 22.8 |
| 2008 | | 12.6 | 15.7 | 20.1 | | | 32.3 |
| 2009 | | 10.2 | 20.7 | 17.5 | | | 32.0 |
| 2010 | | 6.7 | 14.3 | 15.9 | | | 16.7 |

Table 2.22 Estimated rates of repeat spawning for female alewife observed in Massachusetts' fisheries-independent dipnet surveys in select rivers by year.

| | **Massachusetts** | | | | | | |
|---|---|---|---|---|---|---|---|
| | Dip Net | | | | | | |
| **Year** | Mattapoisett River | Monument River | Mystic River | Nemasket River | Quashnet River | Stoney Brook | Town Brook |
| 1986 | | 45.3 | | | | | |
| 1987 | | 43.6 | | | | | |
| 1988 | | | | | | | |
| | | | | | | | |
| 2003 | | | | | | | |
| 2004 | | 1.39 | 35.7 | 43.1 | 7.06 | 20.6 | 13.8 |
| 2005 | | 7.58 | 8.33 | 18.8 | | | 18.4 |
| 2006 | 4.17 | 15.8 | 0.0 | 9.7 | | | 7.9 |
| 2007 | | 8.4 | 12.7 | 13.5 | | | 16.9 |
| 2008 | | 14.9 | 24.5 | 21.6 | | | 29.5 |
| 2009 | | 13.5 | 28.6 | 30.4 | | | 31.1 |
| 2010 | | 13.3 | 15.4 | 22.8 | | | 20.7 |

Table 2.23 Estimated rates of repeat spawning for male blueback herring observed in Massachusetts, New York and South Carolina fisheries-independent surveys in select rivers by year and gear type.

| | **Massachusetts** | | | | **New York** | **South Carolina** | | |
|---|---|---|---|---|---|---|---|---|
| | Dip Net | | | | Various, Combined | Pound Net | Haul Seine | Gill Net |
| **Year** | Monument River | Mystic River | Quashnet River | Town Brook | Hudson River | Santee River | Santee River | Santee River |
| 1978 | | | | | | 31.6 | | |
| 1979 | | | | | | | 0 | |
| 1980 | | | | | | | | 10.0 |
| 1981 | | | | | | | | 30.7 |
| 1982 | | | | | | | | 25.3 |
| 1983 | | | | | | | | 9.18 |
| 1984 | | | | | | | | |
| 1985 | | | | | | | | |
| 1986 | 21.6 | | | | | | | |
| 1987 | 20.0 | | | | | | | |
| 1988 | | | | | | | | |
| 1989 | | | | | 35.1 | | | |
| 1990 | | | | | 21.4 | | | |
| 1991 | | | | | | | | |
| 1992 | | | | | | | | |
| 1993 | | | | | | | | |
| 1994 | | | | | | | | |
| 1995 | | | | | | | | |
| 1996 | | | | | | | | |
| 1997 | | | | | | | | |
| 1998 | | | | | | | | |
| 1999 | | | | | 21.4 | | | |
| 2000 | | | | | 6.33 | | | |
| 2001 | | | | | 11.7 | | | |
| 2002 | | | | | | | | |
| 2003 | | | | | | | | |
| 2004 | 6.25 | | 100 | | | | | |
| 2005 | 8.00 | 5.71 | | 0 | | | | |
| 2006 | 13.80 | 20.91 | | | | | | |
| 2007 | 6.17 | 17.72 | | | | | | |
| 2008 | 5.56 | 27.39 | | | | | | |
| 2009 | 3.53 | 12.96 | | | | | | |
| 2010 | 1.25 | 12.85 | | | | | | |

Table 2.24 Estimated rates of repeat spawning for female blueback herring observed in Massachusetts, New York and South Carolina fisheries-independent surveys in select rivers by year and gear type.

| | Massachusetts | | | | New York | South Carolina | | |
|---|---|---|---|---|---|---|---|---|
| | Dip Net | | | | Various, Combined | Pound Net | Haul Seine | Gill Net |
| **Year** | Monument River | Mystic River | Quashnet River | Town Brook | Hudson River | Santee River | Santee River | Santee River |
| 1978 | | | | | | 27.8 | | |
| 1979 | | | | | | | 30.0 | |
| 1980 | | | | | | | | 17.1 |
| 1981 | | | | | | | | 19.5 |
| 1982 | | | | | | | | 33.7 |
| 1983 | | | | | | | | 27.2 |
| 1984 | | | | | | | | |
| 1985 | | | | | | | | |
| 1986 | 38.5 | | | | | | | |
| 1987 | 38.7 | | | | | | | |
| 1988 | | | | | | | | |
| 1989 | | | | | 24.6 | | | |
| 1990 | | | | | 21.3 | | | |
| 1991 | | | | | | | | |
| 1992 | | | | | | | | |
| 1993 | | | | | | | | |
| 1994 | | | | | | | | |
| 1995 | | | | | | | | |
| 1996 | | | | | | | | |
| 1997 | | | | | | | | |
| 1998 | | | | | | | | |
| 1999 | | | | | 22.9 | | | |
| 2000 | | | | | 13.6 | | | |
| 2001 | | | | | 12.9 | | | |
| 2002 | | | | | | | | |
| 2003 | | | | | | | | |
| 2004 | 4.17 | | 100 | | | | | |
| 2005 | 5.00 | 2.70 | | 0 | | | | |
| 2006 | 14.29 | 16.13 | | | | | | |
| 2007 | 1.47 | 15.49 | | | | | | |
| 2008 | 5.97 | 35.71 | | | | | | |
| 2009 | 5.41 | 11.76 | | | | | | |
| 2010 | 1.49 | 15.25 | | | | | | |

Table 2.25 Estimated rates of repeat spawning for male river herring observed in Rhode Island's fisheries-independent fishway surveys in select rivers by year.

| | **Rhode Island** | |
|---|---|---|
| | Fishway | |
| **Year** | Gilbert Stuart Stream | Nonquit Pond |
| 1984 | 24.7 | |
| 1985 | 26.8 | |
| 1986 | 81.4 | |
| 1987 | | |
| 1988 | 16.4 | |
| 1989 | 27.3 | |
| 1990 | | |
| 1991 | 17.0 | |
| 1992 | 16.5 | |
| 2000 | 20.9 | 11.5 |
| 2001 | 18.8 | 5.26 |
| 2002 | 13.0 | 6.76 |
| 2003 | 6.58 | 15.6 |
| 2004 | 5.41 | 3.77 |
| 2005 | 4.44 | 0 |
| 2006 | 10.0 | 3.09 |
| 2007 | 7.06 | 8.18 |
| 2008 | 17.02 | 14.12 |
| 2009 | 13.43 | 20.27 |
| 2010 | 6.25 | |

Table 2.26 Estimated rates of repeat spawning for female river herring observed in Rhode Island's fisheries-independent fishway surveys in select rivers by year.

| Year | Rhode Island<br>Fishway<br>Gilbert Stuart Stream | <br><br>Nonquit Pond |
|---|---|---|
| 1984 | 20.5 | |
| 1985 | 31.4 | |
| 1986 | 58.1 | |
| 1987 | | |
| 1988 | 56.8 | |
| 1989 | 29.3 | |
| 1990 | | |
| 1991 | 36.6 | |
| 1992 | 59.3 | |
| 2000 | 19.0 | 16.7 |
| 2001 | 23.4 | 15.2 |
| 2002 | 26.2 | 11.3 |
| 2003 | 10.3 | 15.2 |
| 2004 | 11.1 | 6.06 |
| 2005 | 5.71 | 12.0 |
| 2006 | 34.4 | 0 |
| 2007 | 3.6 | 5.13 |
| 2008 | 25.6 | 25.0 |
| 2009 | 3.3 | 13.1 |
| 2010 | 9.09 | |

Table 2.27 Estimated rates of repeat spawning for male and female alewife observed in New York's fisheries-independent surveys in the Hudson River by year.

| Year | New York<br>Various Gear, Combined<br>Hudson River<br>Male | <br><br><br>Female |
|---|---|---|
| 1999 | 39.0 | 75.0 |
| 2000 | 4.08 | 15.4 |
| 2001 | 11.9 | 34.9 |

Table 2.28 Estimated rates of repeat spawning for male alewife observed in Maryland and North Carolina's fisheries-dependent surveys by river and year. [-- indicates inadequate sample size.]

| | **Maryland** | **North Carolina** | | |
|---|---|---|---|---|
| | Pound & Fyke Net | Pound Net | | |
| **Year** | Nanticoke River | Alligator River | Chowan River | Scuppernong River |
| 1972 | | 77.8 | 36.5 | 47.0 |
| 1973 | | 40.5 | 27.0 | 34.1 |
| 1974 | | | 13.5 | 4.55 |
| 1975 | | 20.3 | 41.7 | 10.1 |
| 1976 | | 20.2 | 40.4 | 14.9 |
| 1977 | | 28.2 | 13.8 | 22.7 |
| 1978 | | 37.9 | 13.8 | 0 |
| 1979 | | 65.1 | 28.2 | 20.0 |
| 1980 | | 38.6 | 42.4 | 36.7 |
| 1981 | | 20.5 | 21.1 | 15.4 |
| 1982 | | 28.7 | 28.4 | 51.0 |
| 1983 | | 36.6 | 26.7 | 30.0 |
| 1984 | | 18.8 | 32.5 | 21.7 |
| 1985 | | 61.1 | 15.0 | |
| 1986 | | 30.2 | 37.9 | |
| 1987 | | 0 | 0 | 0 |
| 1988 | | 38.5 | 27.5 | 35.7 |
| 1989 | 57.8 | 32.5 | 16.7 | 26.5 |
| 1990 | 67.1 | 36.7 | -- | 68.4 |
| 1991 | 44.6 | 28.5 | 66.7 | 25.0 |
| 1992 | 52.7 | 14.9 | 26.3 | 10.3 |
| 1993 | 62.4 | 17.4 | -- | 10.1 |
| 1994 | 50.8 | | -- | |
| 1995 | 45.5 | | | |
| 1996 | 35.1 | | | |
| 1997 | 52.3 | | | |
| 1998 | 51.5 | | | |
| 1999 | 63.6 | | 40.0 | |
| 2000 | 31.4 | | 20.3 | |
| 2001 | 50.0 | | 48.1 | |
| 2002 | 70.4 | | 57.4 | |
| 2003 | 64.6 | | 20.0 | |
| 2004 | 41.2 | | 39.7 | |
| 2005 | 34.3 | | 59.5 | |
| 2006 | 72.0 | | 13.0 | |
| 2007 | 25.0 | | 29.6 | |
| 2008 | 59.1 | | 20.3 | |
| 2009 | 31.0 | | 35.7 | |
| 2010 | 32.0 | | | |

Table 2.29 Estimated rates of repeat spawning for female alewife observed in Maryland and North Carolina's fisheries-dependent surveys by river and year. [-- indicates inadequate sample size.]

| | **Maryland** | **North Carolina** | | |
|---|---|---|---|---|
| | Pound & Fyke Net | Pound Net | | |
| **Year** | Nanticoke River | Alligator River | Chowan River | Scuppernong River |
| 1972 | | 46.7 | 51.3 | 58.3 |
| 1973 | | 43.4 | 37.3 | 56.8 |
| 1974 | | | 12.1 | 0 |
| 1975 | | 30.4 | 41.7 | 11.3 |
| 1976 | | 22.6 | 68.2 | 14.3 |
| 1977 | | 26.5 | 20.5 | 25.2 |
| 1978 | | 45.3 | 39.2 | 0 |
| 1979 | | 65.6 | 39.5 | 33.3 |
| 1980 | | 78.8 | 57.3 | 52.0 |
| 1981 | | 41.3 | 35.5 | 45.5 |
| 1982 | | 19.7 | 31.3 | 37.8 |
| 1983 | | 28.3 | 31.7 | 21.9 |
| 1984 | | 27.0 | 32.0 | 12.5 |
| 1985 | | 43.3 | 19.5 | |
| 1986 | | 27.6 | 45.8 | |
| 1987 | | 0 | -- | 0 |
| 1988 | | 53.7 | 20.8 | 28.6 |
| 1989 | 63.0 | 42.9 | 9.09 | 29.6 |
| 1990 | 73.9 | 50.9 | -- | 63.2 |
| 1991 | 55.5 | 48.5 | 86.7 | 45.2 |
| 1992 | 57.7 | 39.6 | 51.7 | 58.7 |
| 1993 | 75.5 | 40.0 | -- | 11.8 |
| 1994 | 66.7 | | -- | |
| 1995 | 55.4 | | | |
| 1996 | 58.7 | | | |
| 1997 | 61.2 | | | |
| 1998 | 57.6 | | | |
| 1999 | 74.2 | | -- | |
| 2000 | 41.8 | | 25.5 | |
| 2001 | 67.7 | | 34.5 | |
| 2002 | 84.9 | | 42.3 | |
| 2003 | 83.5 | | 36.7 | |
| 2004 | 66.1 | | 52.3 | |
| 2005 | 58.6 | | 57.1 | |
| 2006 | 84.8 | | | |
| 2007 | 55.0 | | 57.9 | |
| 2008 | 71.8 | | 30.0 | |
| 2009 | 58.2 | | 39.5 | |
| 2010 | 65.9 | | | |

Table 2.30 Estimated rates of repeat spawning for male blueback herring observed in Maryland and North Carolina's fisheries-dependent surveys by river and year.

| | **Maryland** | **North Carolina** | | |
|---|---|---|---|---|
| | Pound Net | Pound Net | | |
| **Year** | Nanticoke River | Alligator River | Chowan River | Scuppernong River |
| 1972 | | 55.2 | 43.1 | 35.9 |
| 1973 | | 41.2 | 43.7 | 13.8 |
| 1974 | | | 41.3 | 21.2 |
| 1975 | | | 15.2 | 6.99 |
| 1976 | | 21.6 | 33.8 | 10.3 |
| 1977 | | 41.8 | 18.4 | 21.4 |
| 1978 | | | 23.9 | 15.3 |
| 1979 | | | 64.0 | 20.6 |
| 1980 | | 0 | 50.5 | 34.3 |
| 1981 | | | 37.4 | 14.3 |
| 1982 | | | 29.3 | 30.8 |
| 1983 | | 66.7 | 33.9 | 21.8 |
| 1984 | | 7.41 | 20.8 | 18.8 |
| 1985 | | 28.6 | 42.7 | 45.6 |
| 1986 | | | 53.3 | 31.0 |
| 1987 | | | 11.0 | 0 |
| 1988 | | 0 | 19.8 | 6.25 |
| 1989 | 66.5 | | 22.6 | 18.4 |
| 1990 | 81.6 | | 24.3 | 41.4 |
| 1991 | 66.0 | 9.09 | 18.6 | 45.8 |
| 1992 | 75.2 | | 35.0 | 42.9 |
| 1993 | 82.7 | | 63.3 | 23.1 |
| 1994 | 51.3 | | 34.1 | |
| 1995 | 55.0 | | 41.7 | |
| 1996 | 56.1 | | 32.6 | |
| 1997 | 85.8 | | 22.2 | |
| 1998 | 70.8 | | 38.2 | |
| 1999 | 69.0 | | 53.3 | |
| 2000 | 40.7 | | 42.7 | |
| 2001 | 52.9 | | 38.6 | |
| 2002 | 67.2 | | 45.1 | |
| 2003 | 63.8 | | 41.1 | |
| 2004 | 30.4 | | 36.6 | |
| 2005 | 25.0 | | 23.2 | |
| 2006 | 73.1 | | 13.7 | |
| 2007 | 13.2 | | 53.2 | |
| 2008 | 36.1 | | 5.5 | |
| 2009 | 29.0 | | 21.7 | |
| 2010 | 27.3 | | | |

Table 2.31 Estimated rates of repeat spawning for female blueback herring observed in Maryland and North Carolina's fisheries-dependent surveys by river and year.

| | **Maryland** | **North Carolina** | | |
|---|---|---|---|---|
| | Pound & Fyke Net | Pound Net | | |
| **Year** | Nanticoke River | Alligator River | Chowan River | Scuppernong River |
| 1972 | | 61.9 | 44.0 | 32.1 |
| 1973 | | 38.2 | 46.9 | 23.3 |
| 1974 | | | 48.1 | 20.6 |
| 1975 | | | 28.6 | 9.64 |
| 1976 | | 39.7 | 42.4 | 23.3 |
| 1977 | | 38.4 | 21.4 | 35.7 |
| 1978 | | | 19.3 | 17.5 |
| 1979 | | | 77.8 | 37.5 |
| 1980 | | 20.0 | 57.9 | 34.1 |
| 1981 | | | 47.6 | 20.0 |
| 1982 | | | 36.2 | 25.0 |
| 1983 | | 21.4 | 37.1 | 44.1 |
| 1984 | | 13.0 | 37.5 | 19.4 |
| 1985 | | 0 | 48.1 | 46.3 |
| 1986 | | | 52.6 | 42.6 |
| 1987 | | | 1.69 | 0 |
| 1988 | | 25.0 | 36.0 | 36.8 |
| 1989 | 67.3 | | 33.3 | 27.3 |
| 1990 | 83.4 | | 27.0 | 44.4 |
| 1991 | 73.9 | 50.0 | 31.6 | 61.5 |
| 1992 | 74.7 | | 31.3 | 14.3 |
| 1993 | 80.7 | | 64.5 | 35.3 |
| 1994 | 56.2 | | 23.3 | |
| 1995 | 40.0 | | 41.9 | |
| 1996 | 61.0 | | 46.2 | |
| 1997 | 77.8 | | 47.9 | |
| 1998 | 67.1 | | 43.3 | |
| 1999 | 81.5 | | 59.7 | |
| 2000 | 41.2 | | 66.4 | |
| 2001 | 41.8 | | 37.4 | |
| 2002 | 65.9 | | 27.4 | |
| 2003 | 48.6 | | 36.8 | |
| 2004 | 44.4 | | 35.6 | |
| 2005 | 20.0 | | 25.8 | |
| 2006 | 54.8 | | 22.9 | |
| 2007 | 35.0 | | 65.7 | |
| 2008 | 43.8 | | 26.8 | |
| 2009 | 28.6 | | 37.6 | |
| 2010 | 40.0 | | | |

Table 2.32 Biological data used to calculate spawning stock biomass per recruit benchmarks for river herring.

| **Alewife** | **Maine** | | **Rhode Island** | | **New Hampshire** | | **Massachusetts** | | **Maryland** | | **North Carolina** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Age | Spawning Stock Weights | Maturity | Spawning Stock Weights | Maturity | Spawning Stock Weights | Maturity | Spawning Stock Weights | Maturity | Spawning Stock Weights | Maturity | Spawning Stock Weights | Maturity |
| 1 | - | 0.00 | - | 0.00 | - | 0.00 | - | 0.00 | - | 0.00 | - | 0.00 |
| 2 | - | 0.00 | 0.118 | 0.01 | - | 0.00 | - | 0.00 | - | 0.00 | 0.145 | 0.01 |
| 3 | 0.121 | 0.27 | 0.131 | 0.20 | 0.190 | 0.18 | 0.155 | 0.10 | 0.169 | 0.15 | 0.217 | 0.11 |
| 4 | 0.156 | 0.87 | 0.159 | 0.78 | 0.209 | 0.63 | 0.175 | 0.73 | 0.195 | 0.91 | 0.256 | 0.80 |
| 5 | 0.184 | 0.99 | 0.182 | 0.97 | 0.232 | 0.92 | 0.197 | 0.98 | 0.215 | 1.00 | 0.287 | 0.99 |
| 6 | 0.240 | 1.00 | 0.205 | 1.00 | 0.268 | 0.99 | 0.217 | 1.00 | 0.266 | 1.00 | 0.321 | 1.00 |
| 7 | 0.255 | 1.00 | | | 0.318 | 1.00 | 0.236 | 1.00 | 0.288 | 1.00 | 0.365 | 1.00 |
| 8 | 0.255 | 1.00 | | | | | 0.256 | 1.00 | 0.323 | 1.00 | 0.417 | 1.00 |
| 9 | 0.255 | 1.00 | | | | | | | 0.368 | 1.00 | | |
| %M&F before spawning | 0.33 | | 0.33 | | 0.33 | | 0.25 | | 0.17 | | 0.17 | |

| **Blueback** | **New Hampshire** | | **Maryland** | | **North Carolina** | | **South Carolina** | |
|---|---|---|---|---|---|---|---|---|
| Age | Spawning Stock Weights | Maturity | Spawning Stock Weights | Maturity | Spawning Stock Weights | Maturity | Spawning Stock Weights | Maturity |
| 1 | - | 0.00 | - | 0.000 | - | 0.00 | - | 0.00 |
| 2 | 0.117 | 0.01 | - | 0.000 | - | 0.00 | 0.093 | 0.01 |
| 3 | 0.157 | 0.37 | 0.137 | 0.098 | 0.177 | 0.10 | 0.176 | 0.13 |
| 4 | 0.185 | 0.82 | 0.164 | 0.926 | 0.189 | 0.76 | 0.234 | 0.53 |
| 5 | 0.205 | 0.97 | 0.181 | 1.000 | 0.205 | 0.99 | 0.271 | 0.90 |
| 6 | 0.249 | 1.00 | 0.216 | 1.000 | 0.230 | 1.00 | 0.291 | 1.00 |
| 7 | 0.278 | 1.00 | 0.265 | 1.000 | 0.257 | 1.00 | 0.304 | 1.00 |
| 8 | | | 0.271 | 1.000 | 0.275 | 1.00 | | |
| 9 | | | 0.340 | 1.000 | | | | |
| %M&F before spawning | 0.33 | | 0.25 | | 0.25 | | 0.17 | |

Table 2.33 Spawner-per-recruit Z benchmarks and 2009 estimates of Z by river system.

| Year | State | River | Species | Sex | Z | Benchmark Z40% (M=0.3) | Z20% (M=0.3) | Z40% (M=0.7) | Z20% (M=0.7) |
|---|---|---|---|---|---|---|---|---|---|
| 2009 | ME | Androscoggin | Alewife | Male | 1.6 | 0.47 | 0.62 | 0.93 | 1.12 |
| | | Androscoggin | Alewife | Female | 1.5 | 0.47 | 0.62 | 0.93 | 1.12 |
| | | Sebasticook | Alewife | Male | 1.67 | 0.47 | 0.62 | 0.93 | 1.12 |
| | NH | Cocheco | Alewife | Male | 0.86 | 0.46 | 0.6 | 0.92 | 1.11 |
| | | Cocheco | Alewife | Female | 0.65 | 0.46 | 0.6 | 0.92 | 1.11 |
| | | Lamprey | Alewife | Male | 1.09 | 0.46 | 0.6 | 0.92 | 1.11 |
| | | Oyster | Blueback | Male | 1.21 | 0.48 | 0.64 | 0.95 | 1.15 |
| | | Oyster | Blueback | Female | 1.01 | 0.48 | 0.64 | 0.95 | 1.15 |
| | | Winnicut | Alewife | Male | 1.45 | 0.46 | 0.6 | 0.92 | 1.11 |
| | | Winnicut | Alewife | Female | 0.99 | 0.46 | 0.6 | 0.92 | 1.11 |
| | | Winnicut | Blueback | Female | 1.67 | 0.48 | 0.64 | 0.95 | 1.15 |
| | MA | Monument | Alewife | Male | 1.31 | 0.46 | 0.61 | 0.92 | 1.11 |
| | | Mystic | Alewife | Male | 1.21 | 0.46 | 0.61 | 0.92 | 1.11 |
| | | Nemasket | Alewife | Male | 0.93 | 0.46 | 0.61 | 0.92 | 1.11 |
| | | Town | Alewife | Male | 0.87 | 0.46 | 0.61 | 0.92 | 1.11 |
| | | Monument | Alewife | Female | 1.08 | 0.46 | 0.61 | 0.92 | 1.11 |
| | | Mystic | Alewife | Female | 1.1 | 0.46 | 0.61 | 0.92 | 1.11 |
| | | Nemasket | Alewife | Female | 1.18 | 0.46 | 0.61 | 0.92 | 1.11 |
| | | Town | Alewife | Female | 1.26 | 0.46 | 0.61 | 0.92 | 1.11 |
| | RI | Gilbert-Stuart | Alewife | Both | 2.79 | 0.48 | 0.64 | 0.94 | 1.14 |
| | | Nonquit | Alewife | Both | 3.27 | 0.48 | 0.64 | 0.94 | 1.14 |
| | MD | Nanticoke | Alewife | Male | 1.12 | 0.46 | 0.61 | 0.93 | 1.13 |
| | | Nanticoke | Alewife | Female | 1.08 | 0.46 | 0.61 | 0.93 | 1.13 |
| | | Nanticoke | Blueback | Male | 1.65 | 0.47 | 0.61 | 0.92 | 1.11 |
| | | Nanticoke | Blueback | Female | 1.17 | 0.47 | 0.61 | 0.92 | 1.11 |
| | NC | Chowan | Alewife | Both | 1.52 | 0.48 | 0.62 | 0.93 | 1.12 |
| | | Albemarle FI | Alewife | Both | 1.42 | 0.48 | 0.62 | 0.93 | 1.12 |
| | | Chowan | Blueback | Both | 1.07 | 0.47 | 0.62 | 0.92 | 1.11 |
| | | Albemarle FI | Blueback | Both | 1.68 | 0.47 | 0.62 | 0.92 | 1.11 |

Table 2.34 Estimates of Fcollapse, Ucollapse, and Zcollapse for alewife by river and method.

| River | Method | Years | $r_m$ | α (lbs) | $F_{coll}$ | $U_{coll}$ | $Z_{coll}$ |
|---|---|---|---|---|---|---|---|
| Androscoggin | C & G M1 | | 0.38 | 10.2 | 1.33 | 0.74 | 2.33 |
| ME | M3 | | | 15.5 | 1.46 | 0.77 | 2.46 |
| Damariscotta[1] | C& G S-R | 1949-1989 | | 19.7 | 2.00 | 0.86 | 3.00 |
| ME | M1 | 1997-2004 | 0.23 | 5.6 | 1.06 | 0.65 | 2.06 |
| | M3 | | | 15.5 | 1.46 | 0.77 | 2.46 |
| | M4 | 1977-2010 | | 10.8 | 0.94 | 0.61 | 1.64 |
| Union | C & G M1 | | 0.47 | 14.3 | 1.59 | 0.80 | 2.59 |
| ME | M1 | 1993-2001 | 0.16 | 4.2 | 0.98 | 0.62 | 1.98 |
| | M3 | | | 15.5 | 1.46 | 0.77 | 2.46 |
| Cocheco | M1 | 1999-2003 | 0.36 | 9.4 | 1.29 | 0.72 | 2.29 |
| NH | M3 | | | 15.5 | 1.46 | 0.77 | 2.46 |
| | M5 | 1976-2004 | | 29.8 | 1.83 | 0.84 | 2.53 |
| Lamprey | C & G S-R | | | 19.7 | 1.90 | 0.85 | 2.90 |
| NH | C & G M1 | | 0.48 | 15.2 | 1.63 | 0.80 | 2.63 |
| | M1 | 1996-2004 | 0.25 | 6.0 | 1.09 | 0.66 | 2.09 |
| | M3 | | | 15.5 | 1.46 | 0.77 | 2.46 |
| | M5 | 1972-2004 | | 60.9 | 2.48 | 0.92 | 3.18 |
| Monument | C & G M2 | | | | 1.61 | 0.80 | 2.61 |
| MA | M1 | 1980-1996 | 0.10 | 3.2 | 0.93 | 0.60 | 1.93 |
| | M1 | 2006-2010 | 0.20 | 4.9 | 1.02 | 0.64 | 1.79 |
| | M3 | | | 15.5 | 1.46 | 0.77 | 2.46 |
| | M4 | 1983-2006 | | 16.5 | 1.29 | 0.72 | 1.99 |
| Nemasket | M1 | 2005-2010 | 0.25 | 6.0 | 1.09 | 0.61 | 2.09 |
| MA | M3 | | | 15.5 | 1.46 | 0.77 | 2.46 |
| Wankinco | M1 | 2007-2010 | 0.38 | 10.2 | 1.33 | 0.74 | 2.33 |
| MA | M3 | | | 15.5 | 1.46 | 0.77 | 2.46 |
| Annaquatuc- | C & G S-R | | | 8.8 | 1.10 | 0.67 | 2.10 |
| ket RI | C & G M1 | | 0.47 | 14.7 | 1.59 | 0.80 | 2.59 |
| | M3 | | | 15.5 | 1.46 | 0.77 | 2.46 |
| Gilbert-Stuart | M1 | 1985-1989 | 0.38 | 10.2 | 1.33 | 0.74 | 2.33 |
| RI | M1 | 1993-2000 | 0.36 | 9.4 | 1.28 | 0.72 | 2.28 |
| | M3 | | | 15.5 | 1.46 | 0.77 | 2.46 |

[1]Age and repeat spawner data from the Androscoggin River were used for the Damariscotta River to generate the recruitment and female spawning stock biomass data for 1977-2010 used in the M5 method.

Table 2.35 Estimates of Fcollapse, Ucollapse, and Zcollapse and required parameters for blueback herring by river and method.

| River | Method | Years | $r_m$ | α (lbs) | $F_{coll}$ | $U_{coll}$ | $Z_{coll}$ |
|---|---|---|---|---|---|---|---|
| Connecticut | C & G S-R | | | 28.2 | 2.20 | 0.89 | 3.20 |
| CT | C & G M1 | | 0.55 | 20.1 | 1.91 | 0.85 | 2.91 |
| Chowan | C & G S-R | | | 16.7 | 1.80 | 0.83 | 2.80 |
| NC | M4 | | | 10.2 | 0.91 | 0.60 | 1.61 |

Table 2.36 Drawn population parameters and their distributions for the base run

| Parameter | Description | Distribution | Expected value | Standard Deviation |
|---|---|---|---|---|
| **n** | Pella-Tomlinson shape parameter | Log-normal | 2.0 | 0.25 (log-scale) |
| **$U_{MSY}$** | Exploitation rate that produces MSY | Beta | 0.1 | 0.05 |
| **$B_0$/K ratio** | Ratio of starting biomass to K | Beta | 0.75 | 0.14 |
| **$B_{2010}$/K ratio** | Ratio of 2010 biomass to K | Beta | 0.1 | 0.05 |

Table 2.37: Assumed variability in observed catches

| Time period | Log-scale standard deviation |
|---|---|
| **1887-1949** | 0.4 |
| **1950-1988** | 0.3 |
| **1988-2004** | 0.2 |
| **2005-2010** | 0.1 |

Table 2.38 Management benchmarks (and 95% confidence interval) from different model configurations

| | $U_{MSY}$ | K | MSY | $B_{MSY}$ |
|---|---|---|---|---|
| **Base run** | 0.059 (0.014 - 0.10) | 687,796 MT (476,147 - 1,459,815 MT) | 20,077 MT (12,032 - 27,516 MT) | 340,489 MT (248,176 - 753,349 MT) |
| **Base run without hindcast bycatch** | 0.059 (0.012 – 0.11) | 686,178 MT (467,072 - 1,436,570 MT) | 20,027 MT (10,043 - 27,532 MT) | 339,003 MT (245,130 - 744,999 MT) |
| **$B_0$/K ratio = 1** | 0.058 (0.011 - 0.10) | 691,249 MT (493,795 - 1,414,648 MT) | 19,937 MT (7,820 – 26,794 MT) | 340,890 MT (251,286 - 718,364 MT) |
| **$B_{2010}$/K = 0.01** | 0.055 (0.012 – 0.087) | 707,563 MT (540,825 - 1,387,835 MT) | 19,898 MT (8,941 - 25,336 MT) | 354,706 MT (263,100 - 733,683 MT) |
| **$B_{2010}$/K=0.5** | 0.073 (0.044 – 0.19) | 634,400 MT (375,473 - 795,020 MT) | 22,698 MT (17,400 - 40,310 MT) | 312,174 MT (190,760 - 433,523 MT) |
| **$U_{MSY}$ = 0.35** | 0.065 (0.05 – 0.13) | 666,306 MT (412,661 - 732,268 MT) | 21,307 MT (17,139 - 29,175 MT) | 322,940 MT (213,067 - 426,656 MT) |

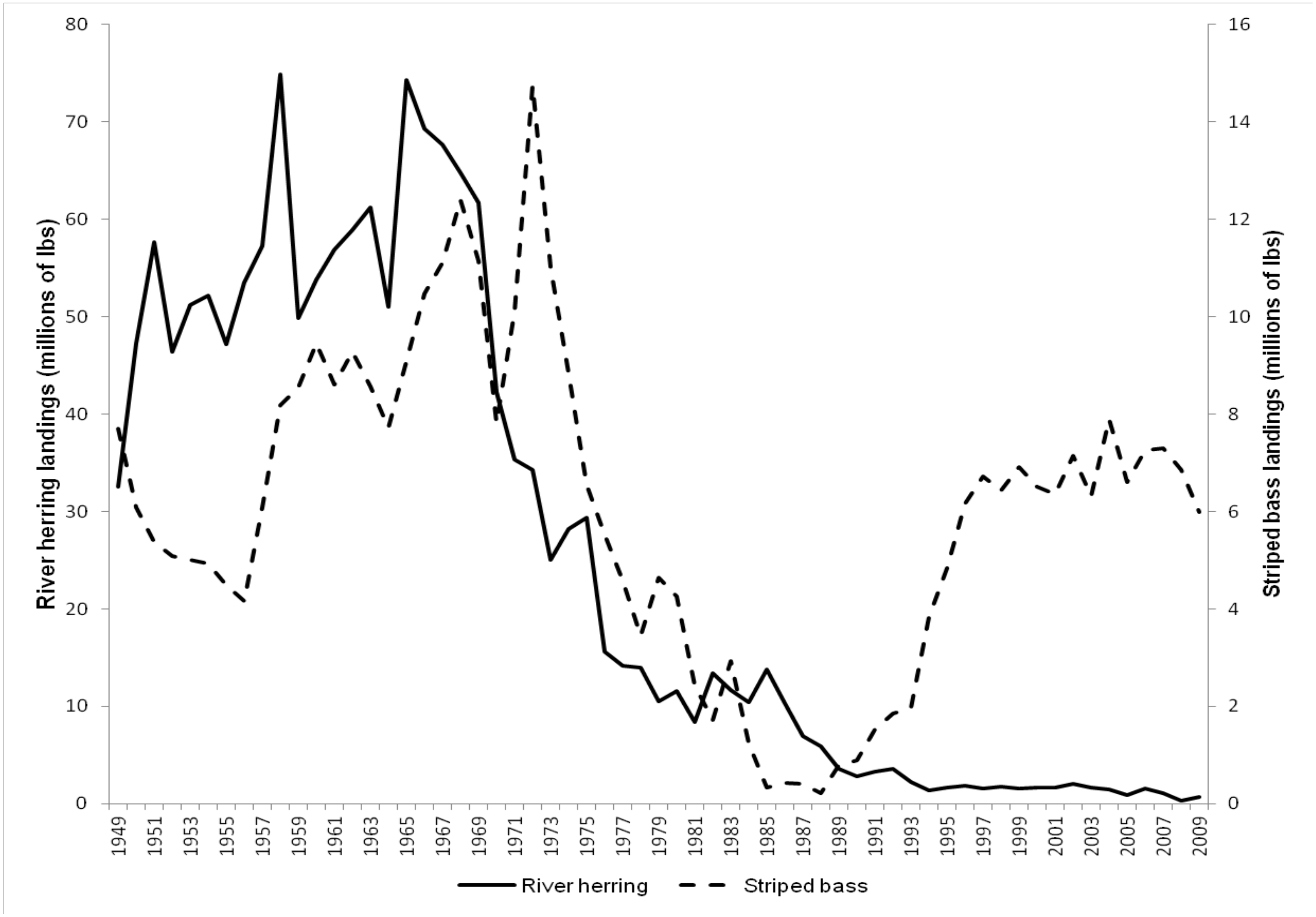



Figure 1.1 Reported landings (in millions of pounds) of river herring and striped bass since 1950.

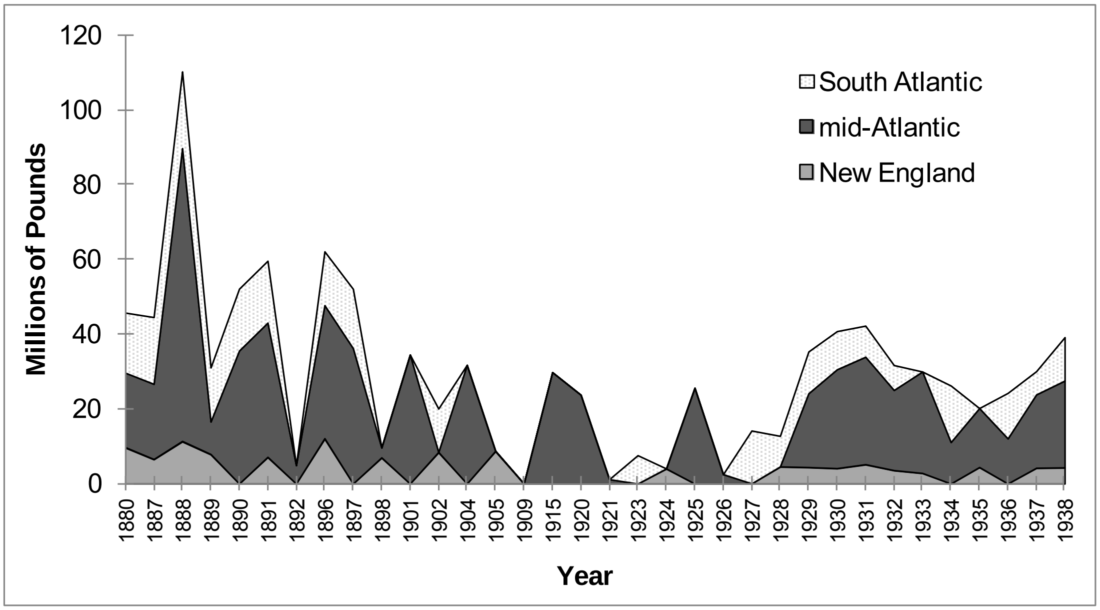



Figure 2.1 Annual commercial landings of river herring along the Atlantic Coast by region, 1880–1938.

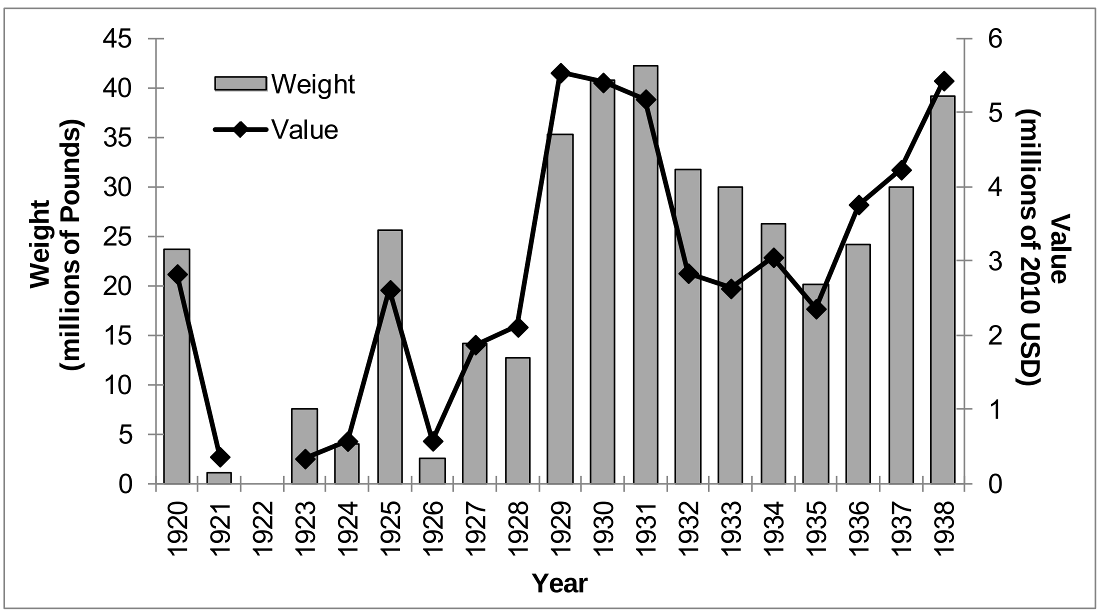



Figure 2.2 Annual commercial landings and value of river herring along the Atlantic Coast, 1920–1938.

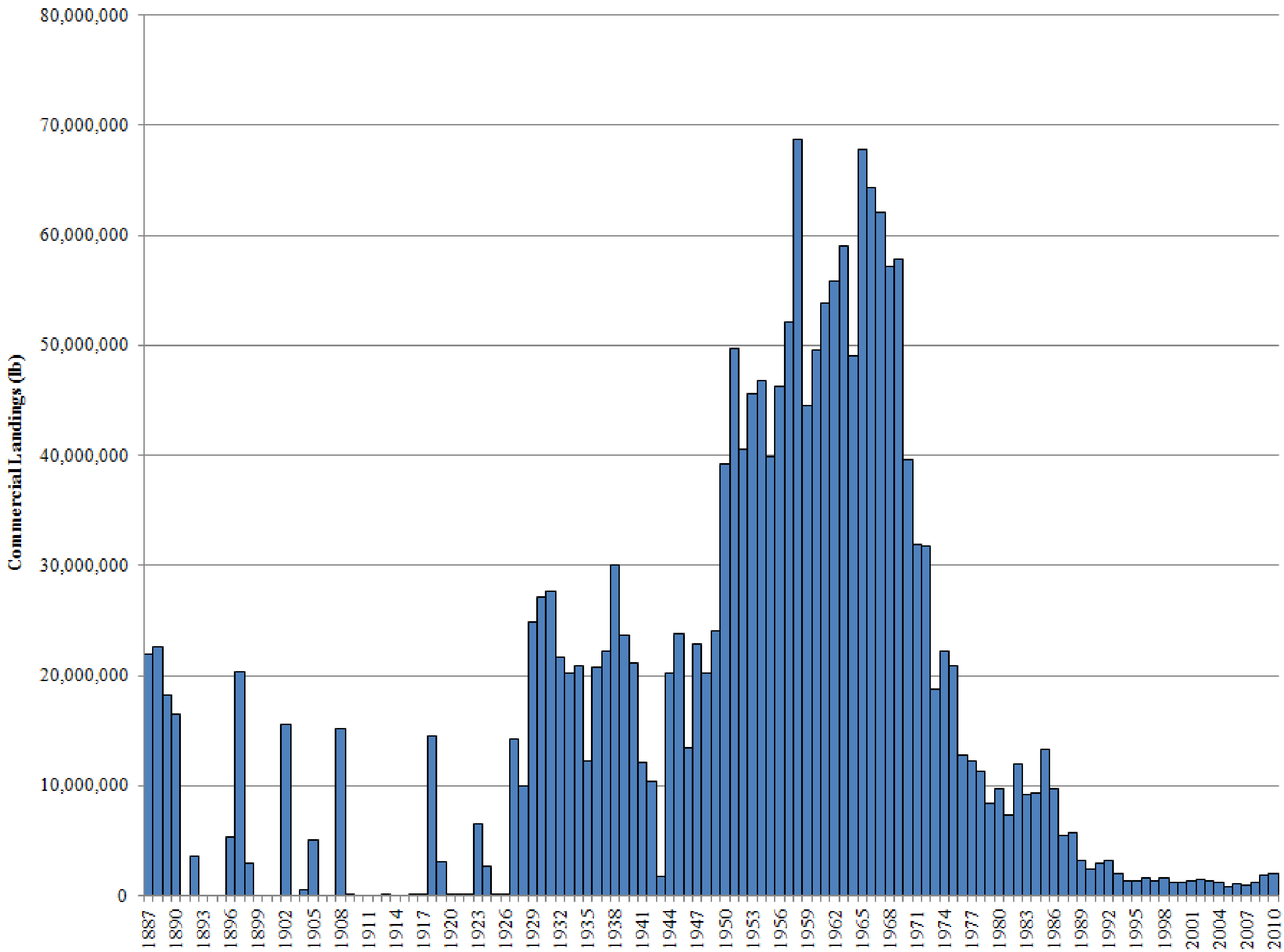



Figure 2.3 Domestic commercial landings of river herring from 1887 to 2010.

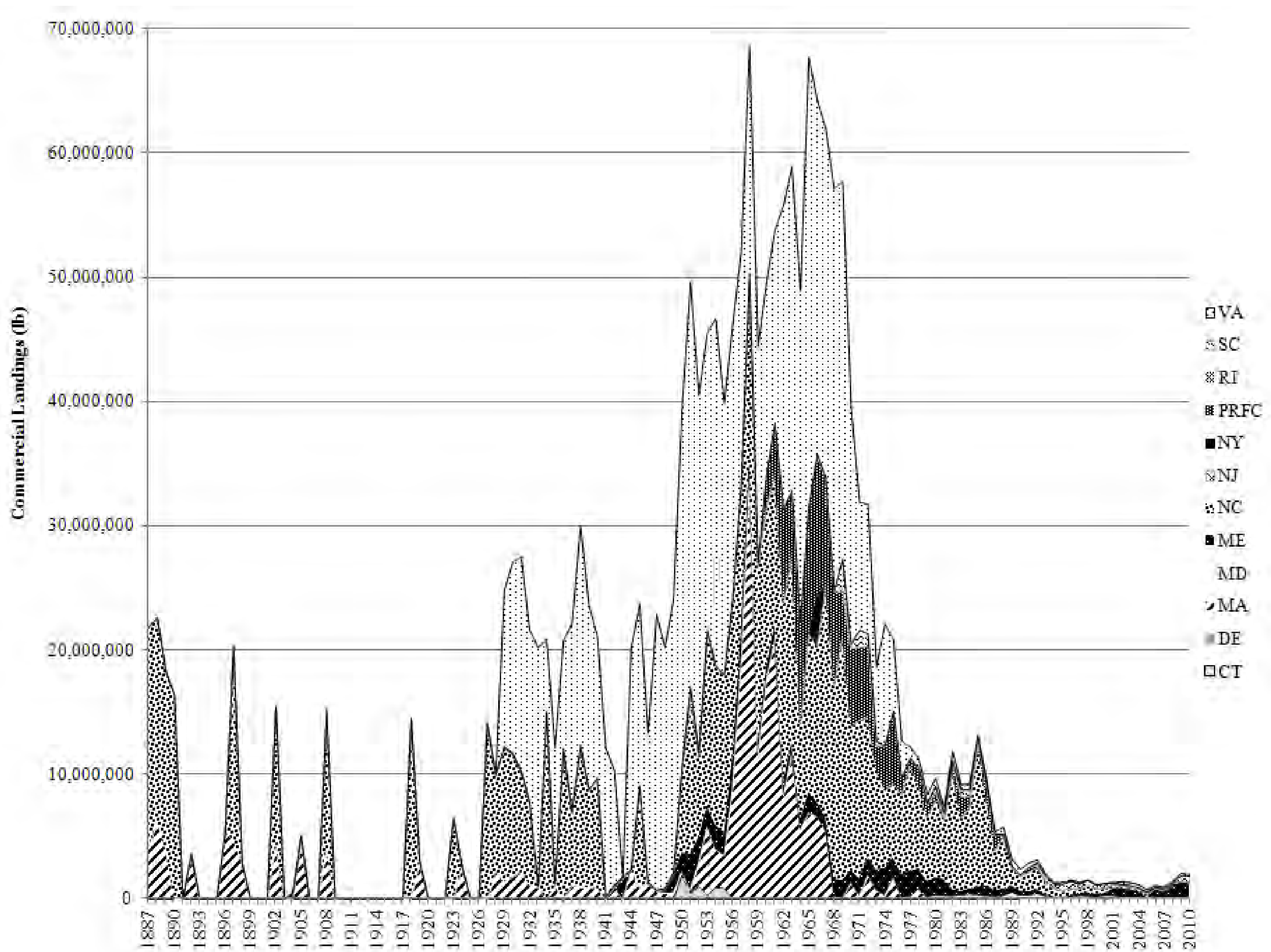



Figure 2.4 Domestic commercial landings of river herring by state from 1887 to 2010

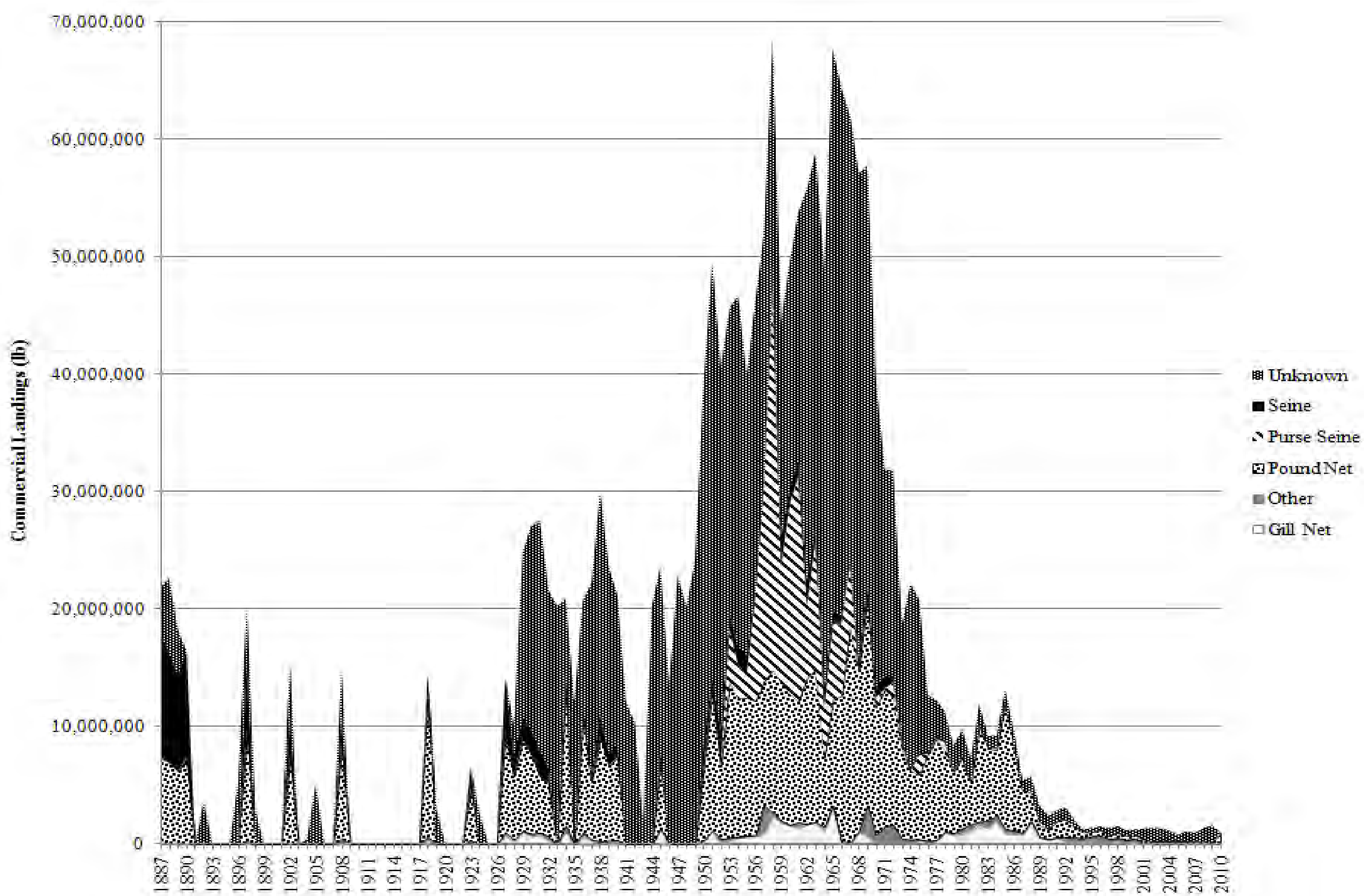



Figure 2.5. Domestic commercial landings of river herring by gear from 1887 to 2010.

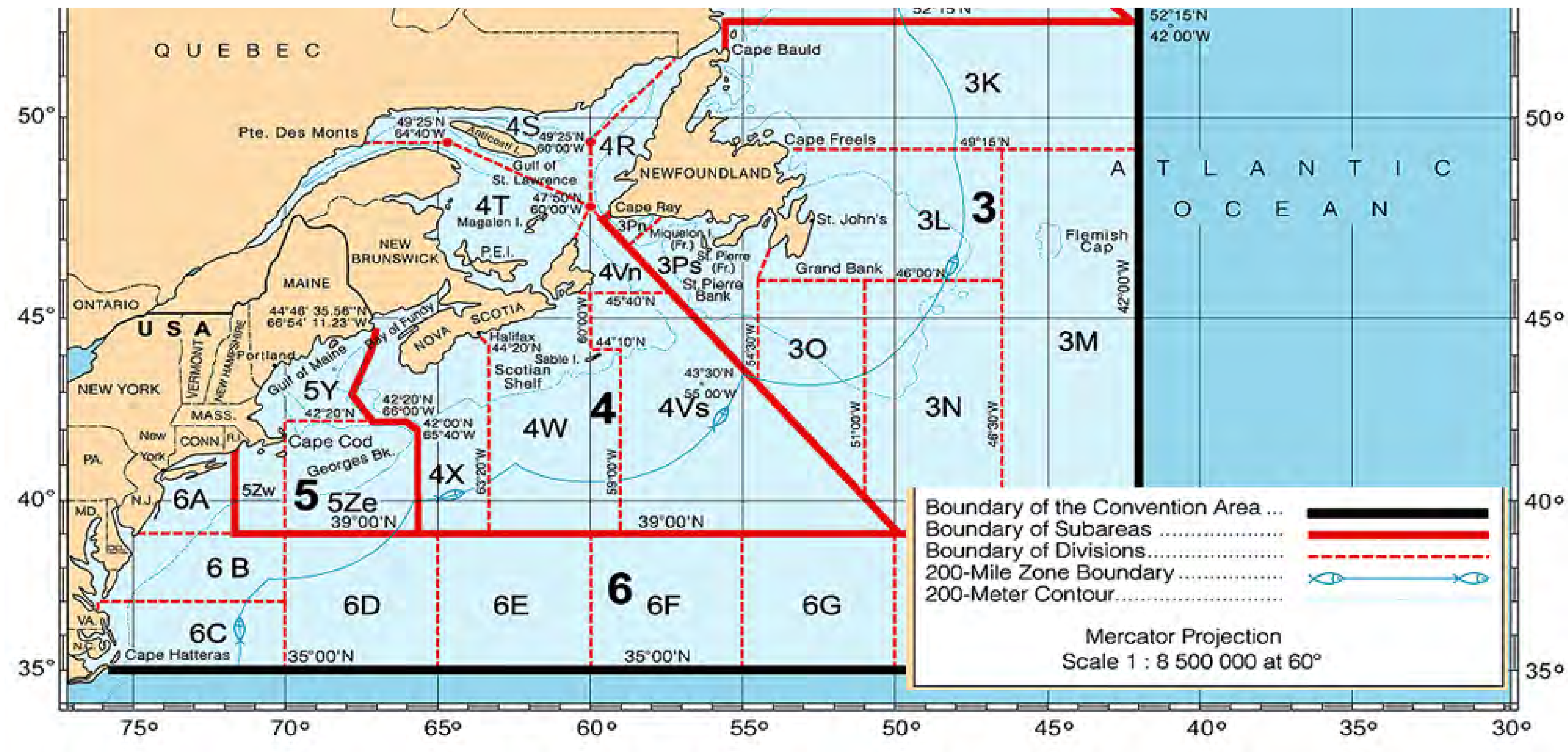



Figure 2.6 NAFO Convention areas off the coast of the US and Canada. The full convention area extends to the northern coast of Greenland

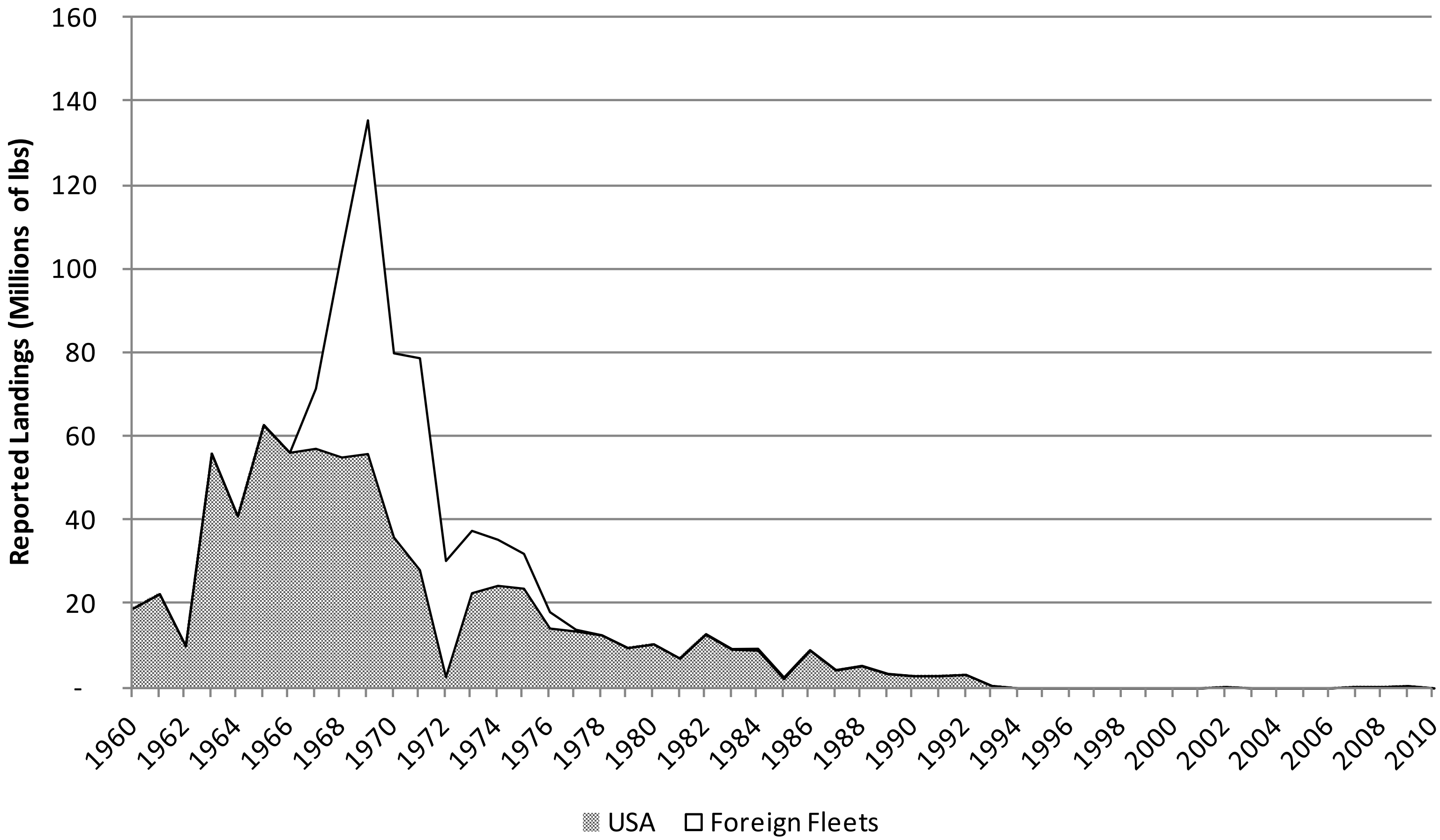



Figure 2.7 Landings (lbs) of river herring from NAFO areas 5 and 6 by fleet origin.

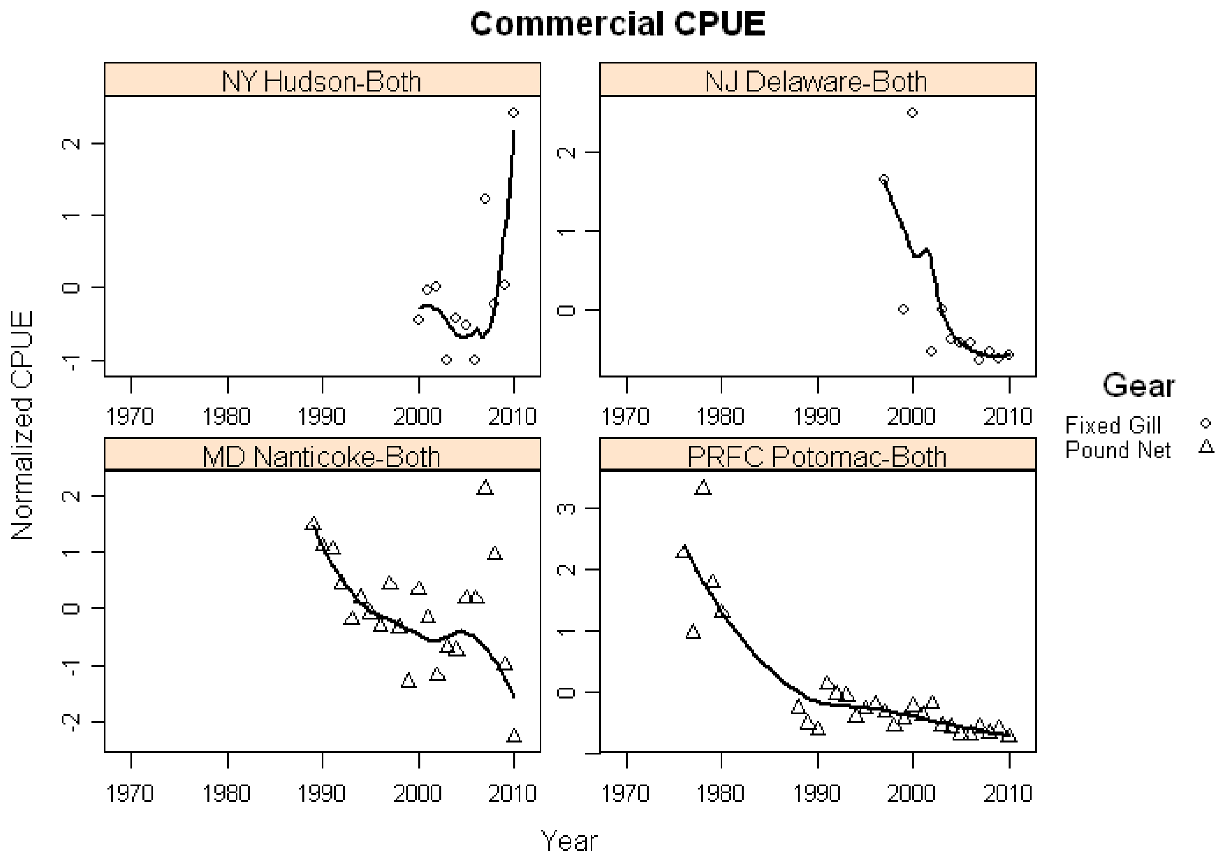



Figure 2.8. Normalized CPUE (catch-per-unit-effort) data for river herring in the Hudson River (NY), Delaware Bay (NJ), Nanticoke River (MD) and the Potomac River (PRFC) by year and gear type. Loess smooths are shown as indications of general trends.

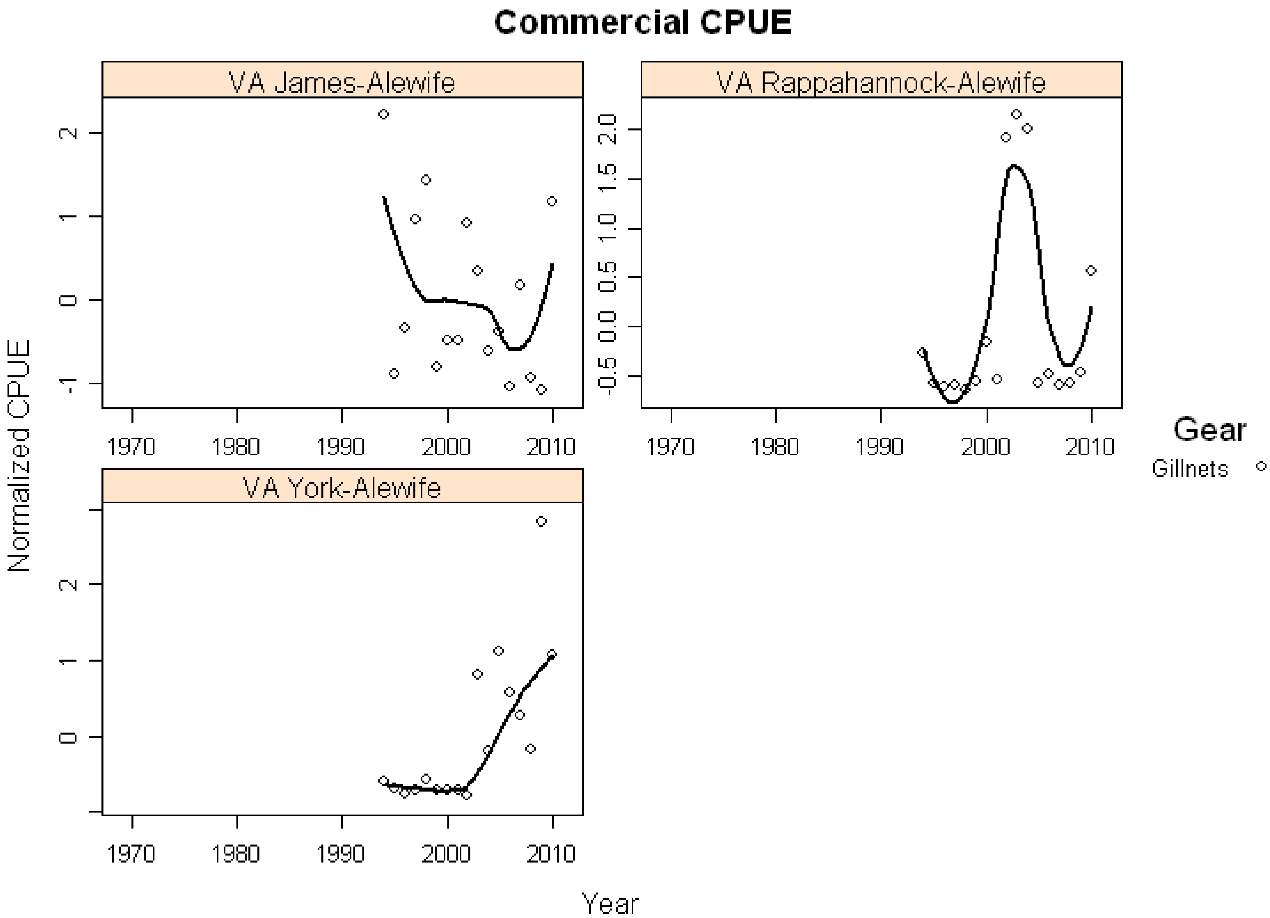



Figure 2.9 Normalized CPUE (catch-per-unit-effort) data for river herring in Virginia's James River, Rappahannock River, and York River by year and gear type. Loess smooths are shown as indications of general trends.

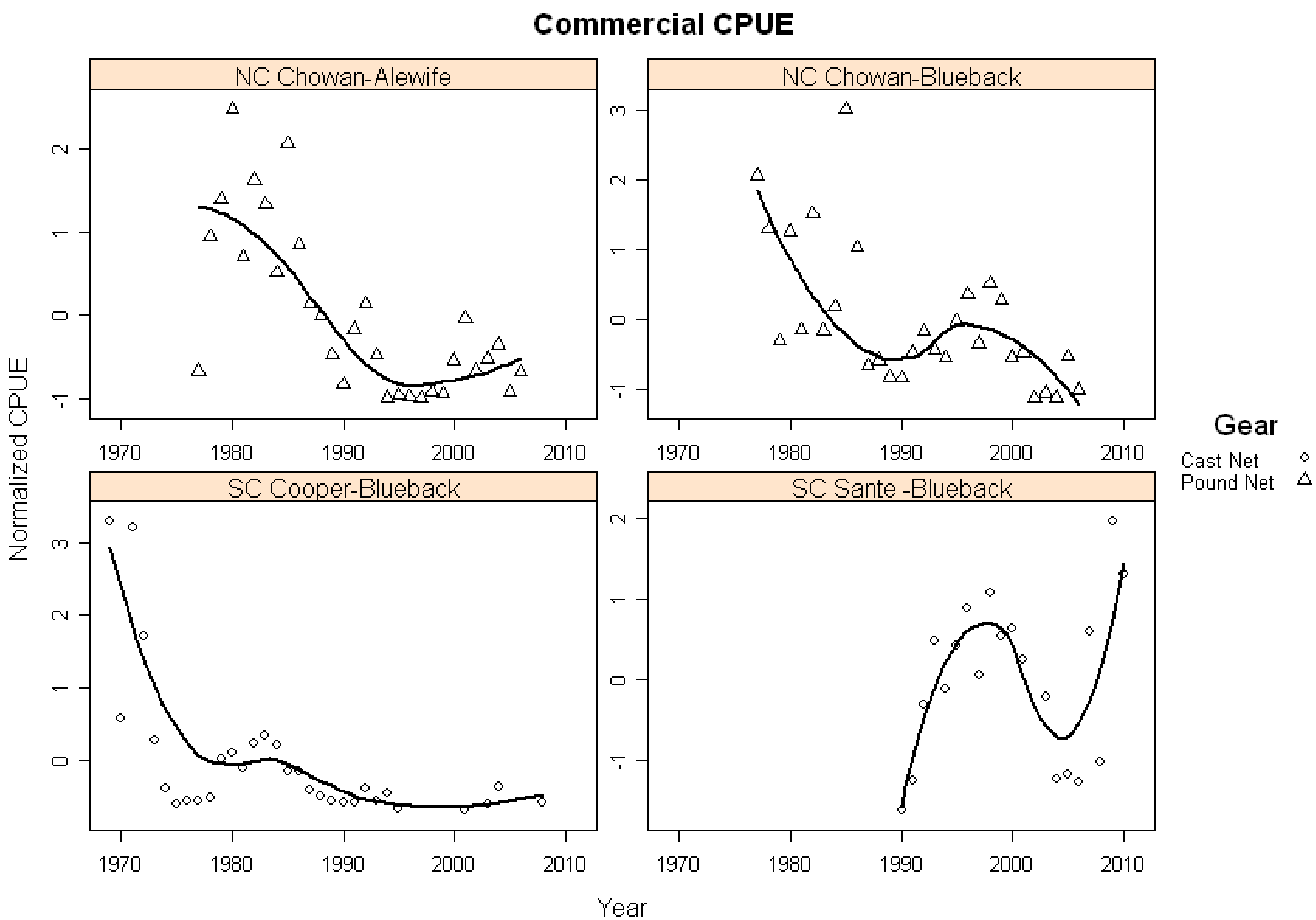



Figure 2.10 Normalized CPUE (catch-per-unit-effort) data for river herring in the Chowan River (NC), Cooper River (SC) and Santee River Diversion Canal (SC) by year and gear type. Loess smooths are shown as indications of general trends.

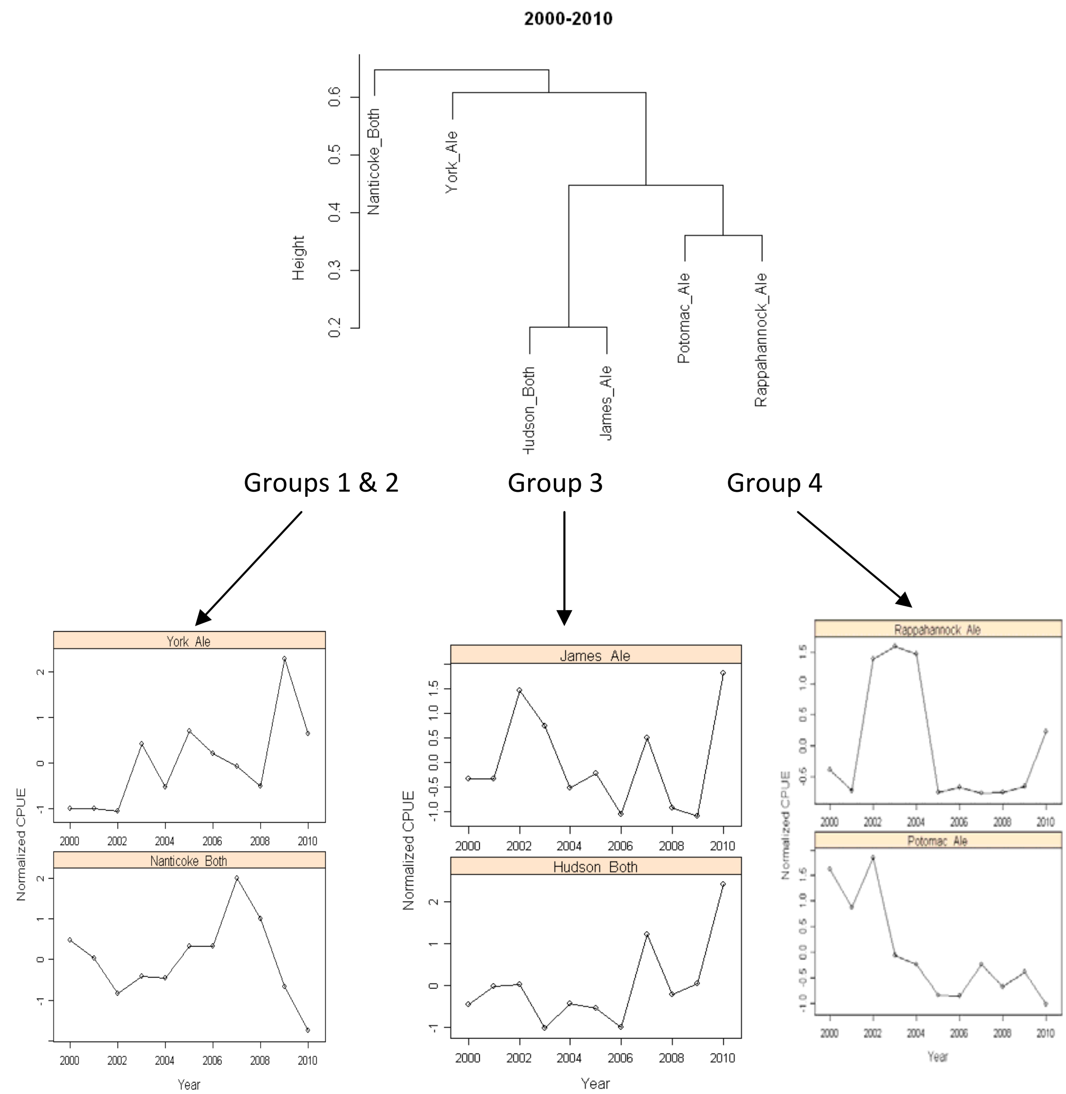



Figure 2.11 Results of cluster analysis of commercial CPUE trends for 2000-2010 showing the cluster dendrogram and plots of CPUE for each grouping.

**Mid-Atlantic** **New England**

a)

b)

c)

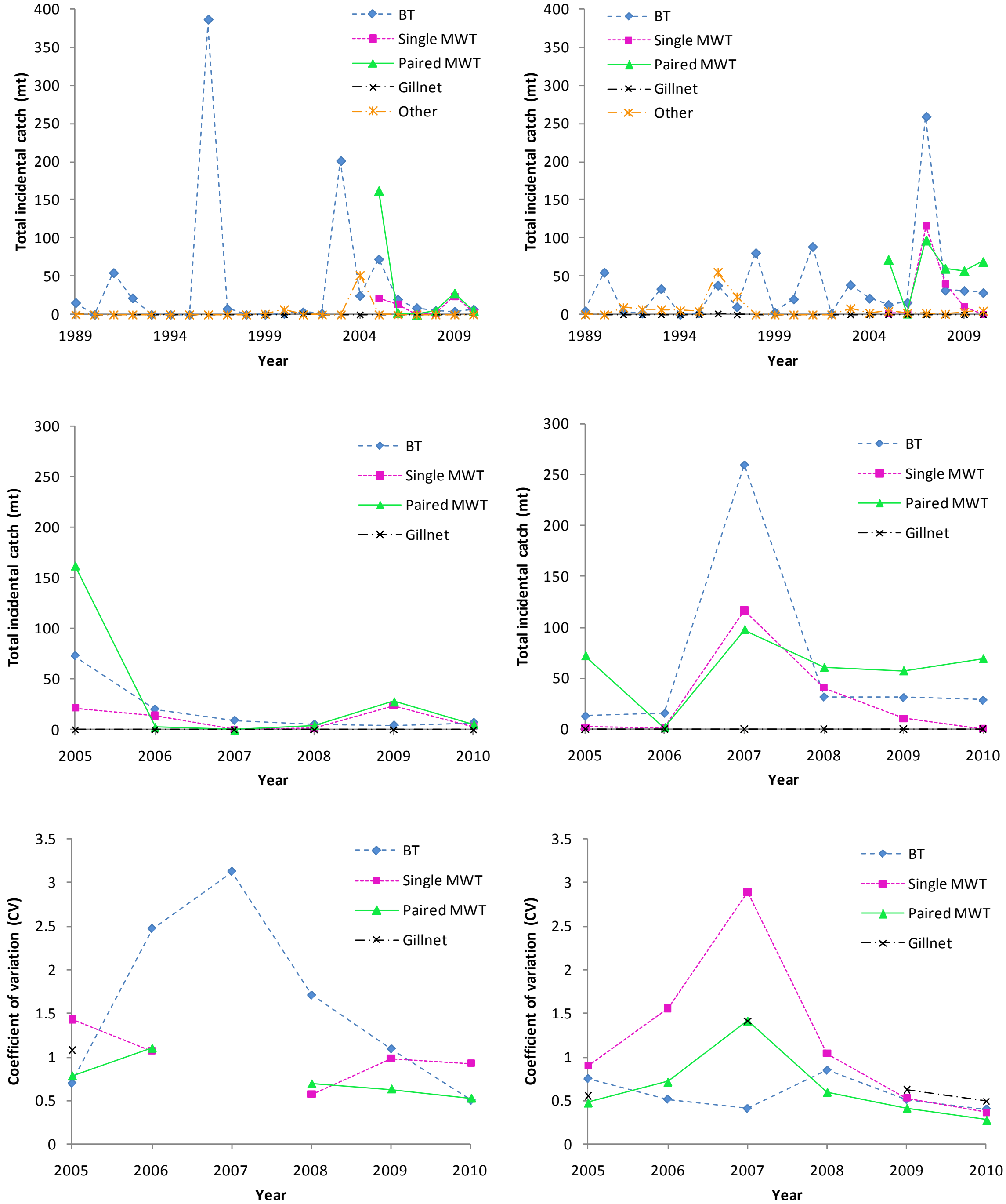



Figure 2.12. Alewife total annual incidental catch (MT) by region for the four gears with the largest catches from a) 1989 – 2010 and b) 2005 – 2010, and c) the corresponding estimates of precision. Midwater trawl estimates are only included beginning in 2005.

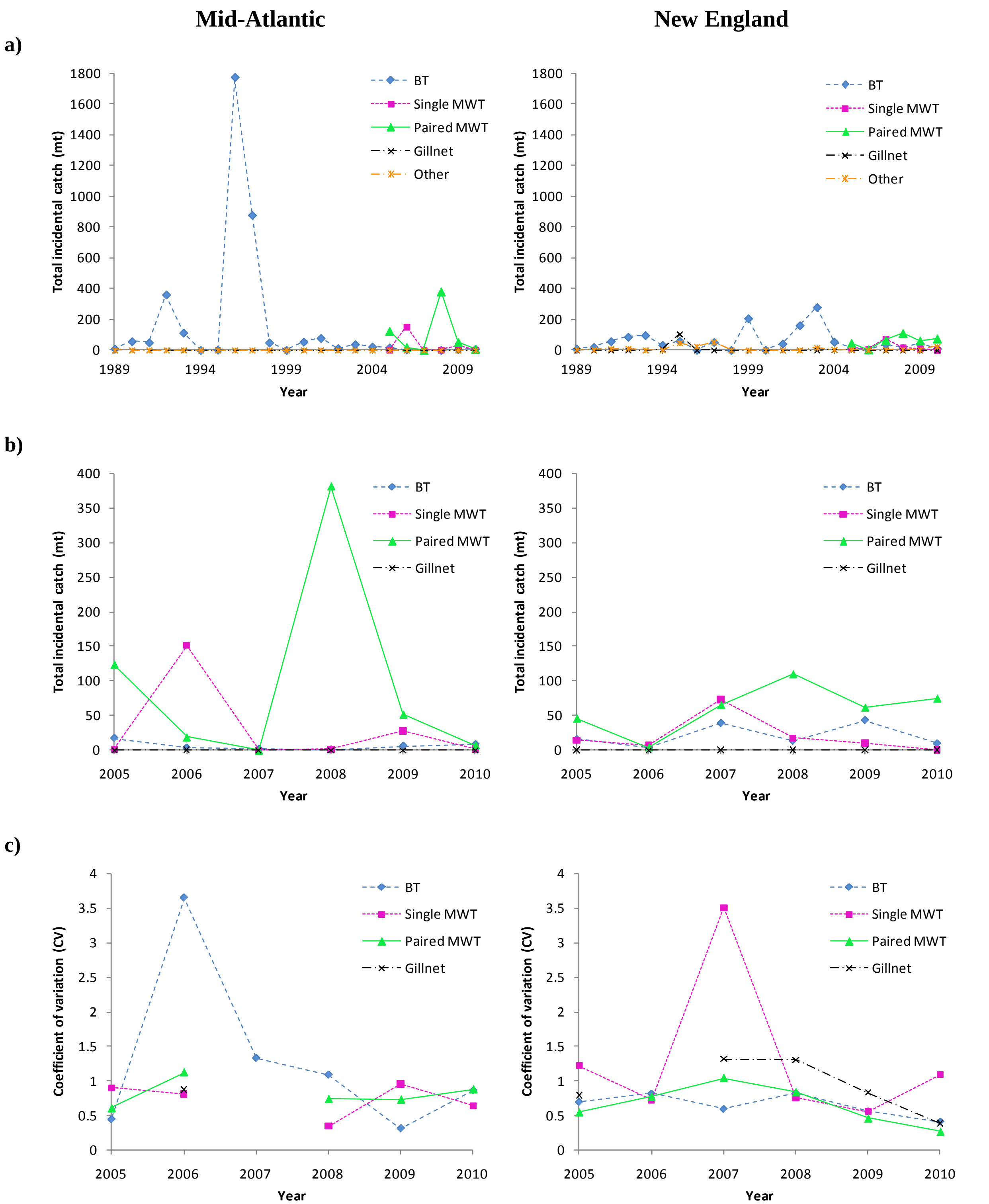



Figure 2.13. Blueback herring total annual incidental catch (MT) by region for the four gears with the largest catches from a) 1989 – 2010 and b) 2005 – 2010, and c) the corresponding estimates of precision. Midwater trawl estimates are only included beginning in 2005.

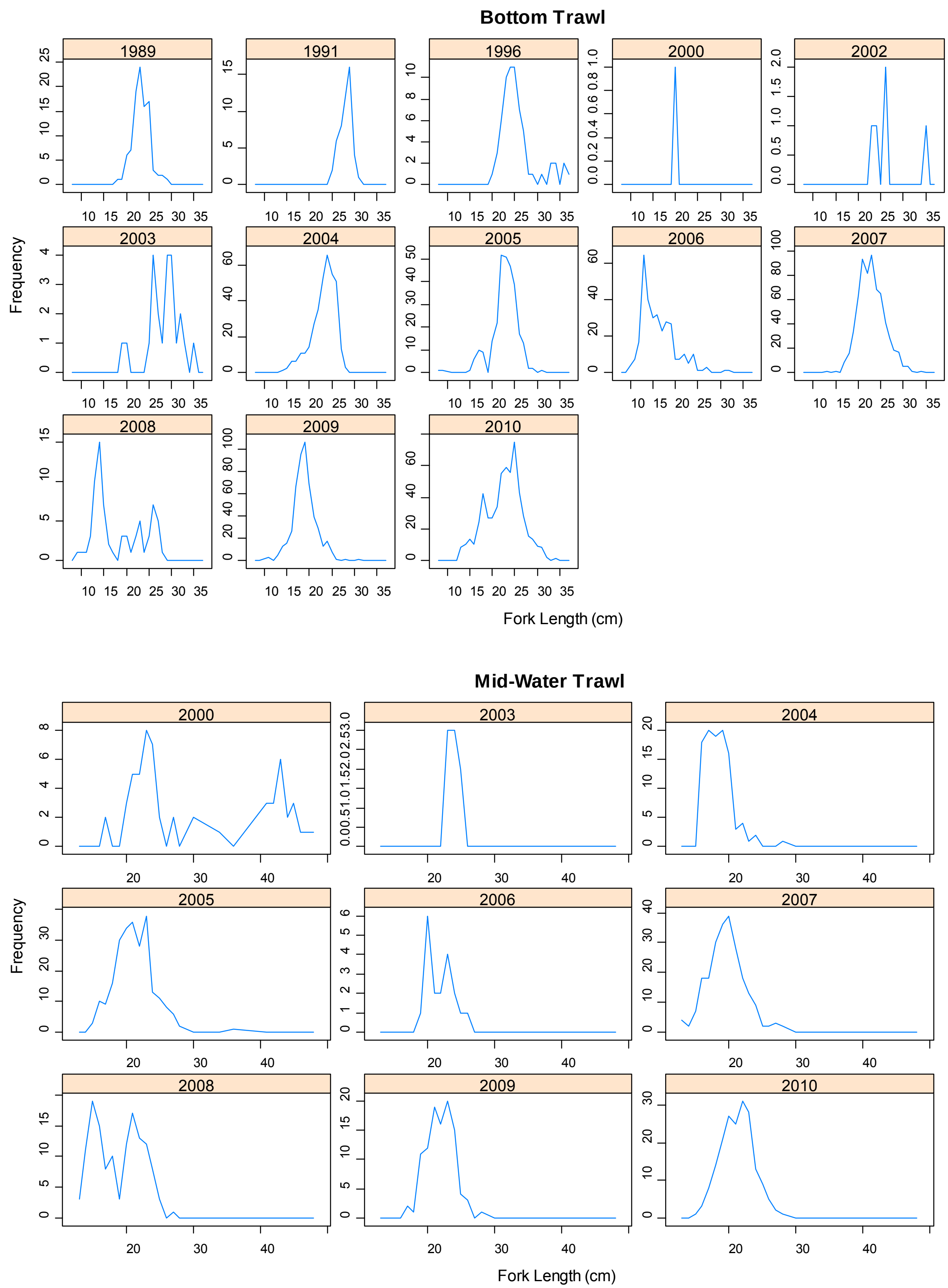



Figure 2.14: Length frequencies of alewife sampled by observers on bottom trawls (top) and mid-water trawls (bottom)

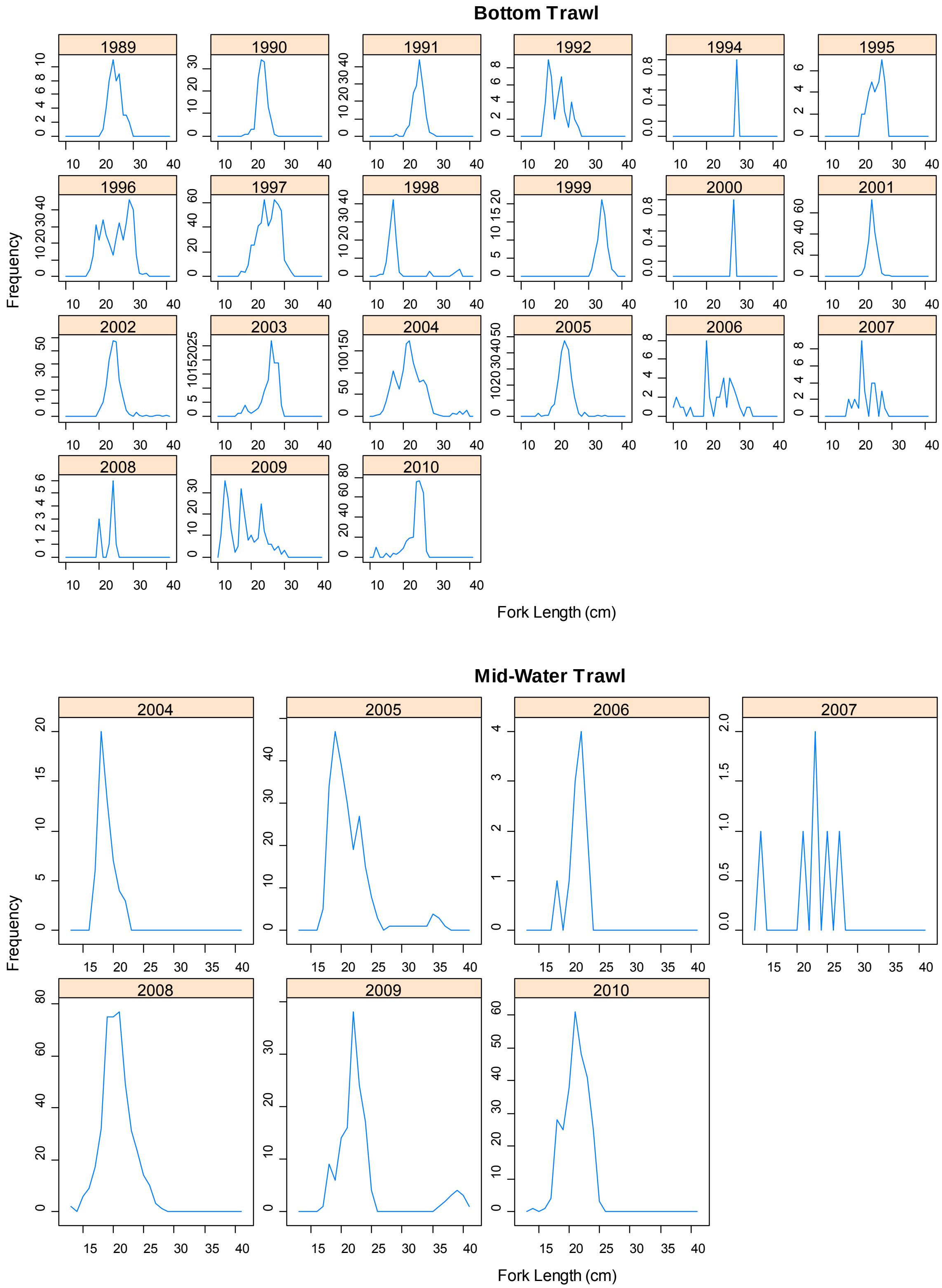



Figure 2.15: Length frequencies of blueback herring sampled by observers on bottom trawls (top) and mid-water trawls (bottom)

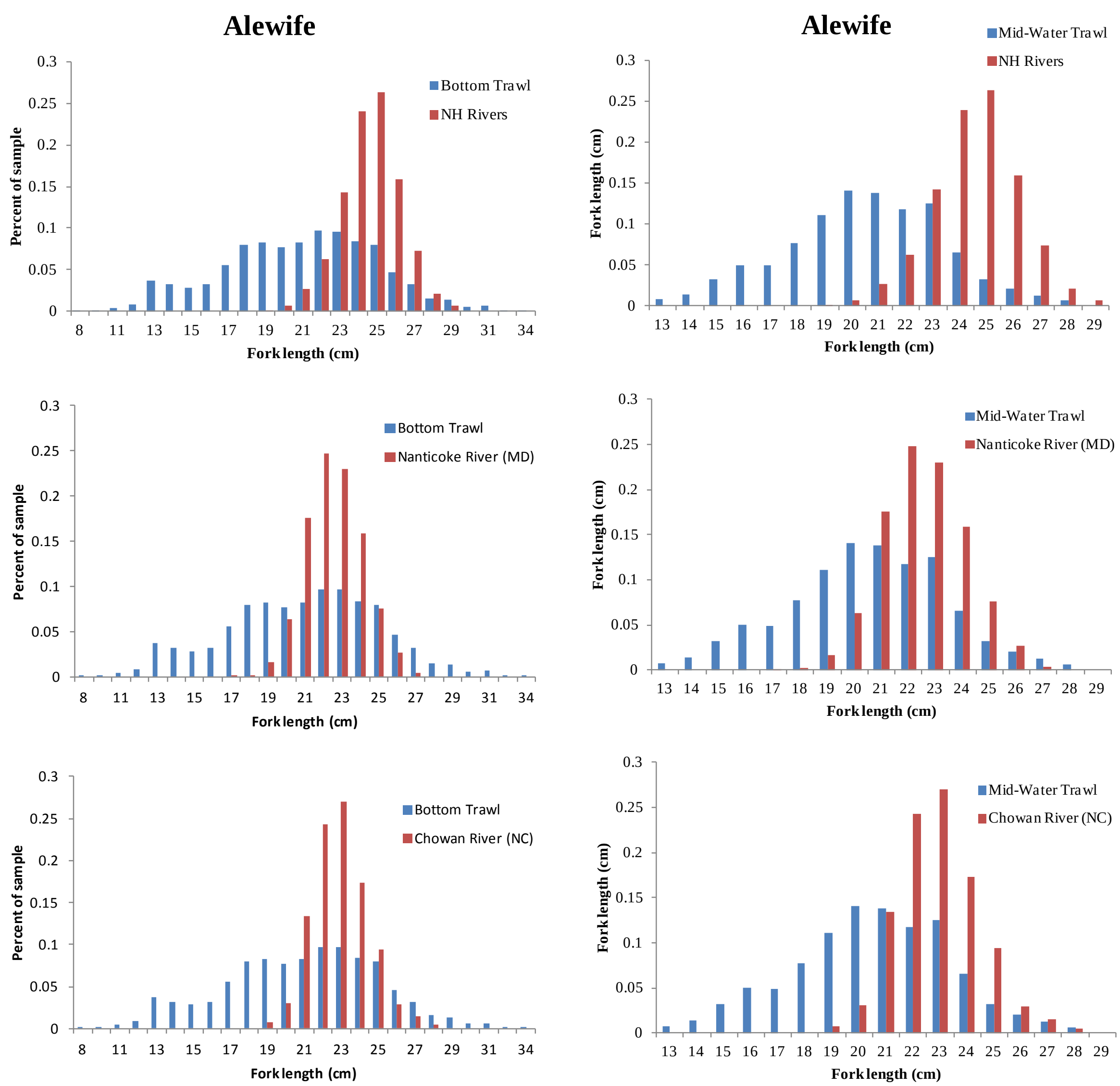



Figure 2.16: Length frequencies of alewife caught in bottom-trawls (left) and mid-water trawls (right) compared to river-caught fish from 2005 – 2010.

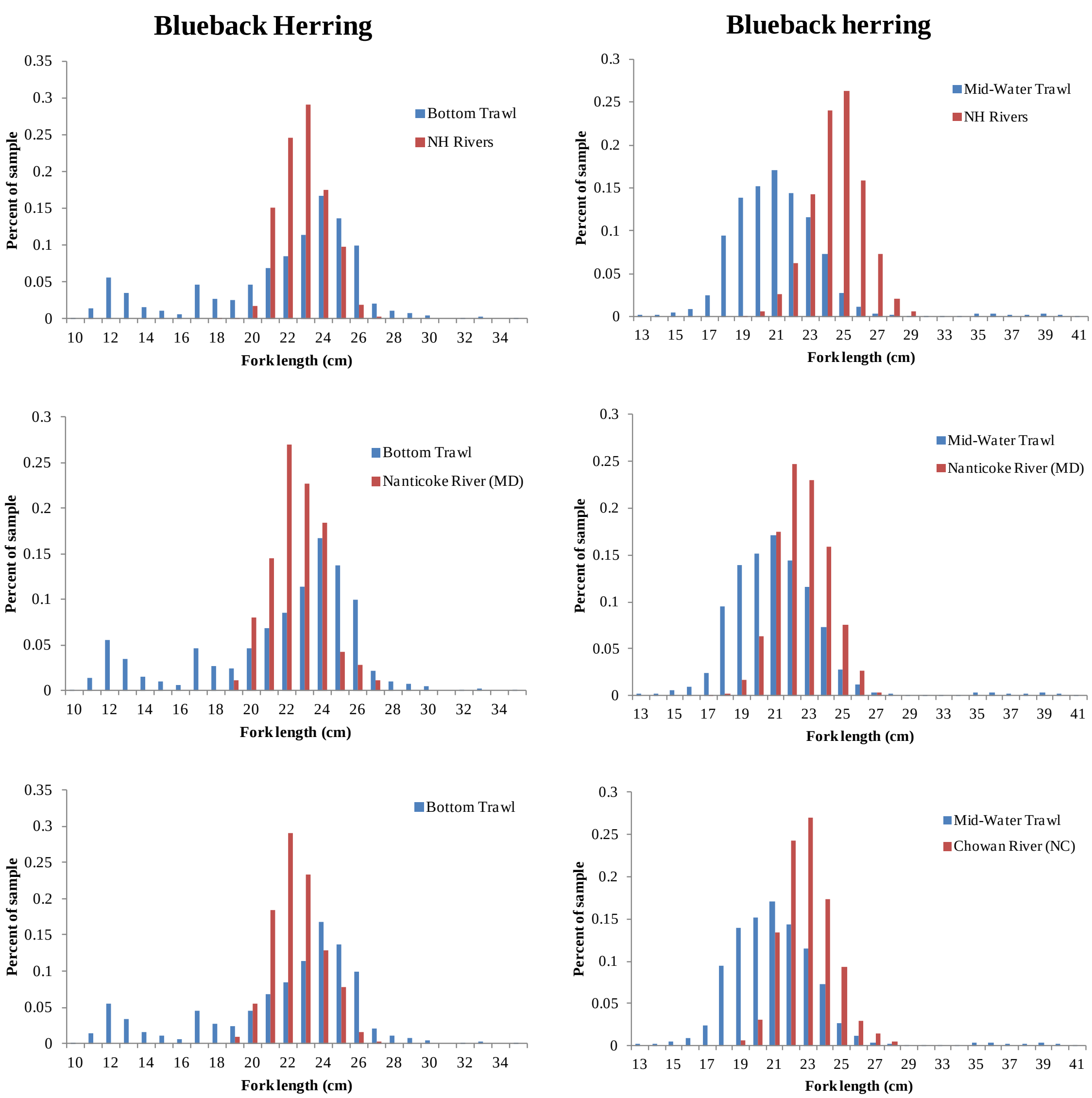



Figure 2.17: Length frequencies of blueback herring caught in bottom-trawls (left) and mid-water trawls (right) compared to river-caught fish from 2005 – 2010.

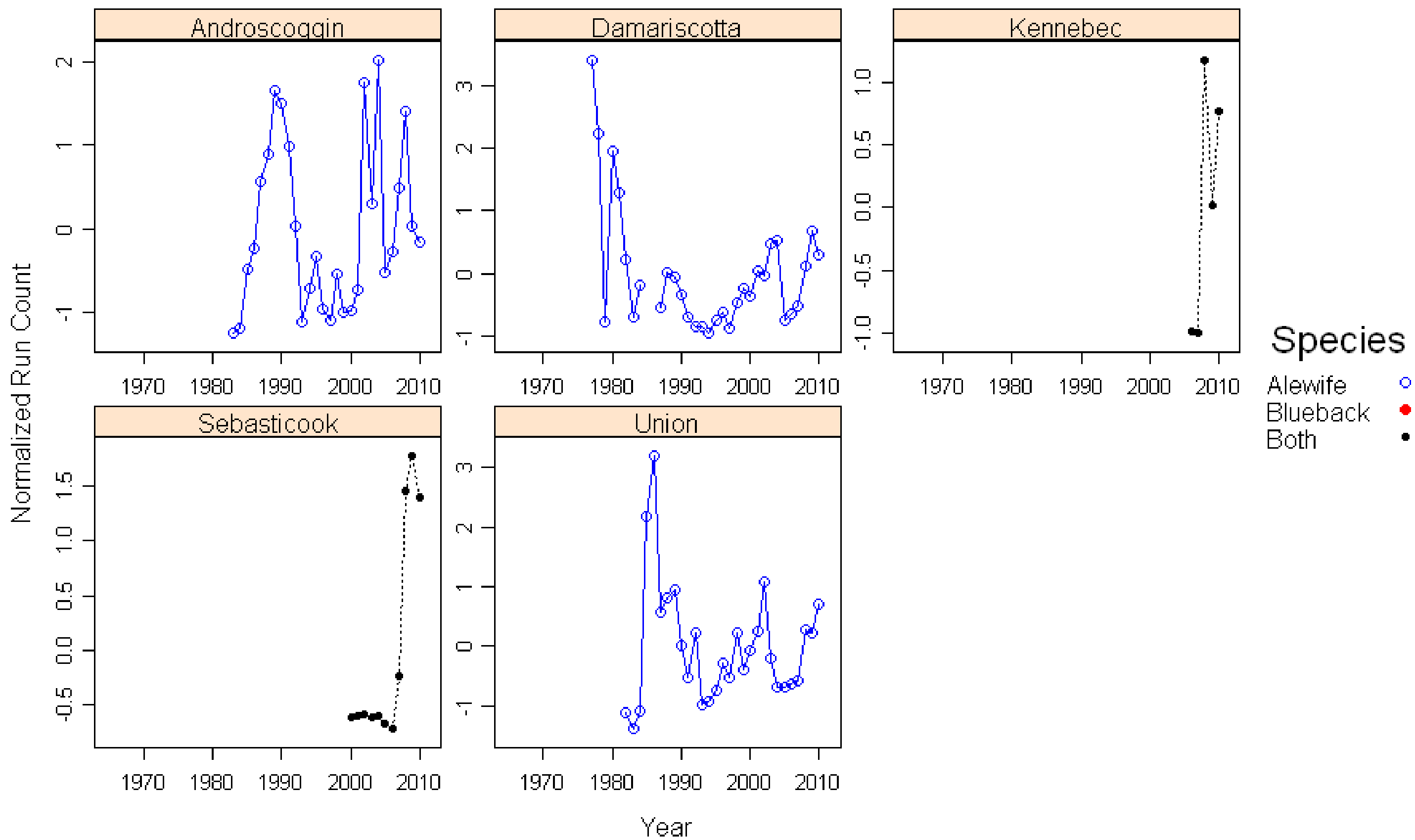



Figure 2.18. Plots of normalized run counts of alewife, blueback and combined species from Maine by river and year.

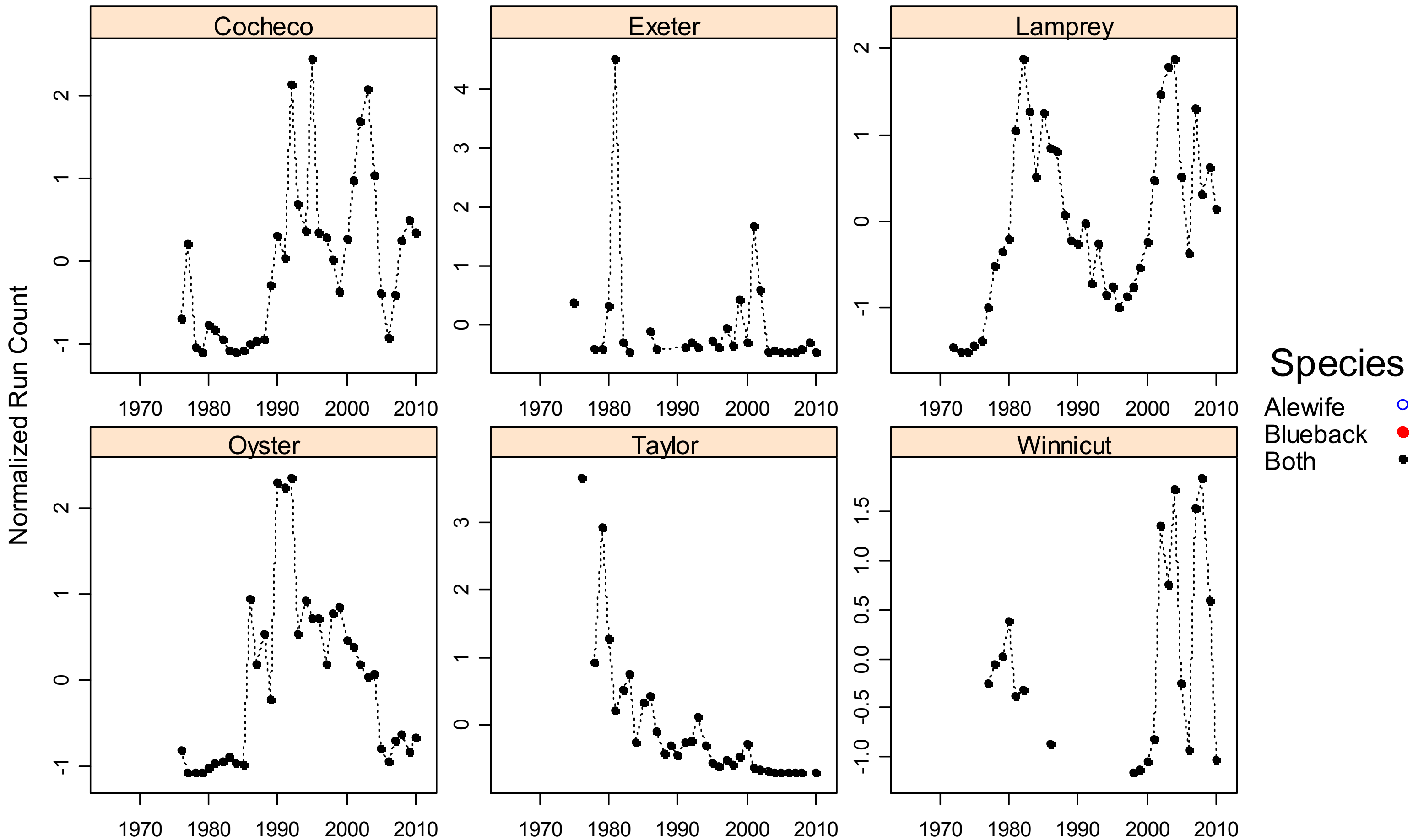



Figure 2.19 Plots of normalized run counts of alewife, blueback and combined species from New Hampshire by river and year.

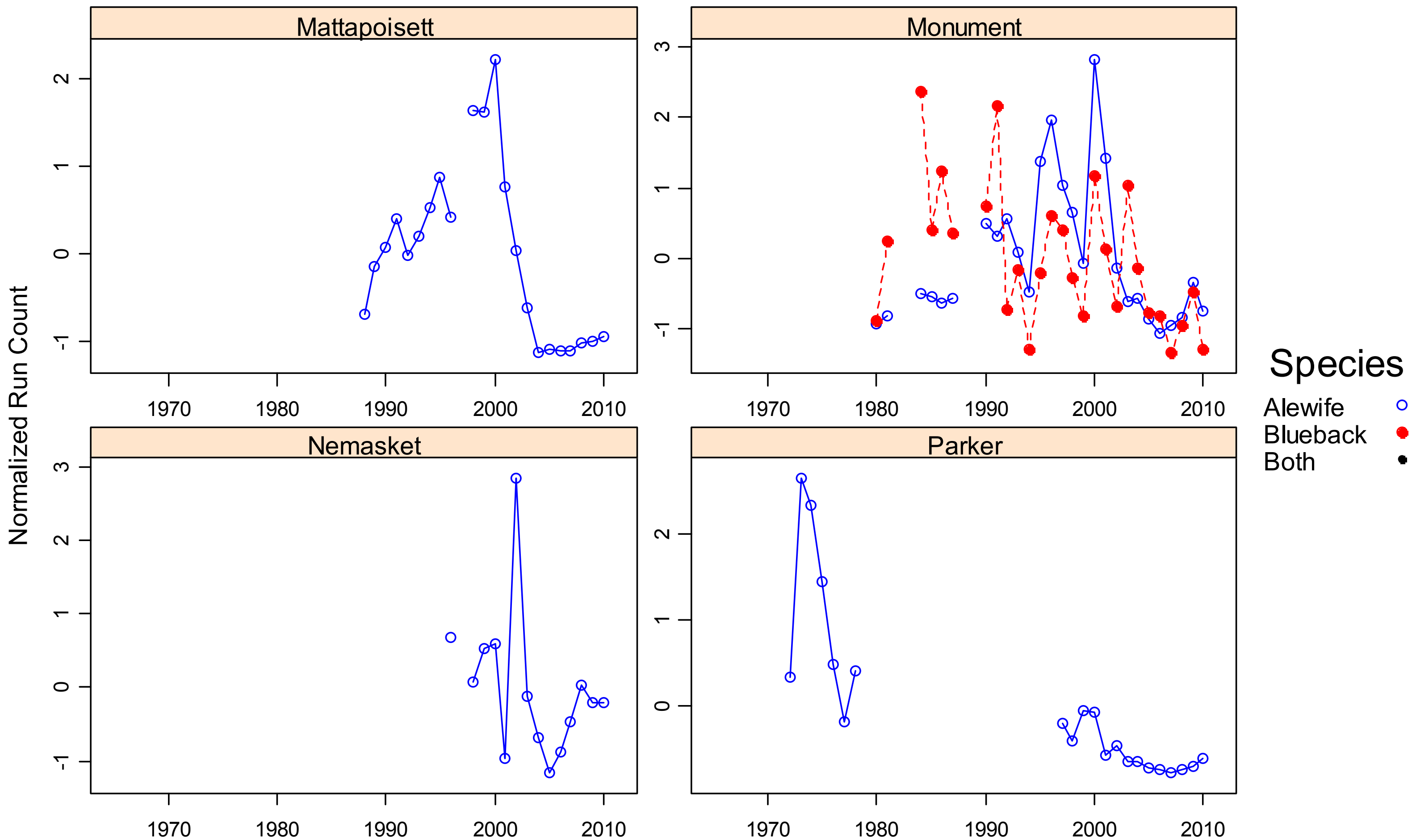



Figure 2.20 Plots of normalized run counts of alewife and blueback herring from Massachusetts by river and year.

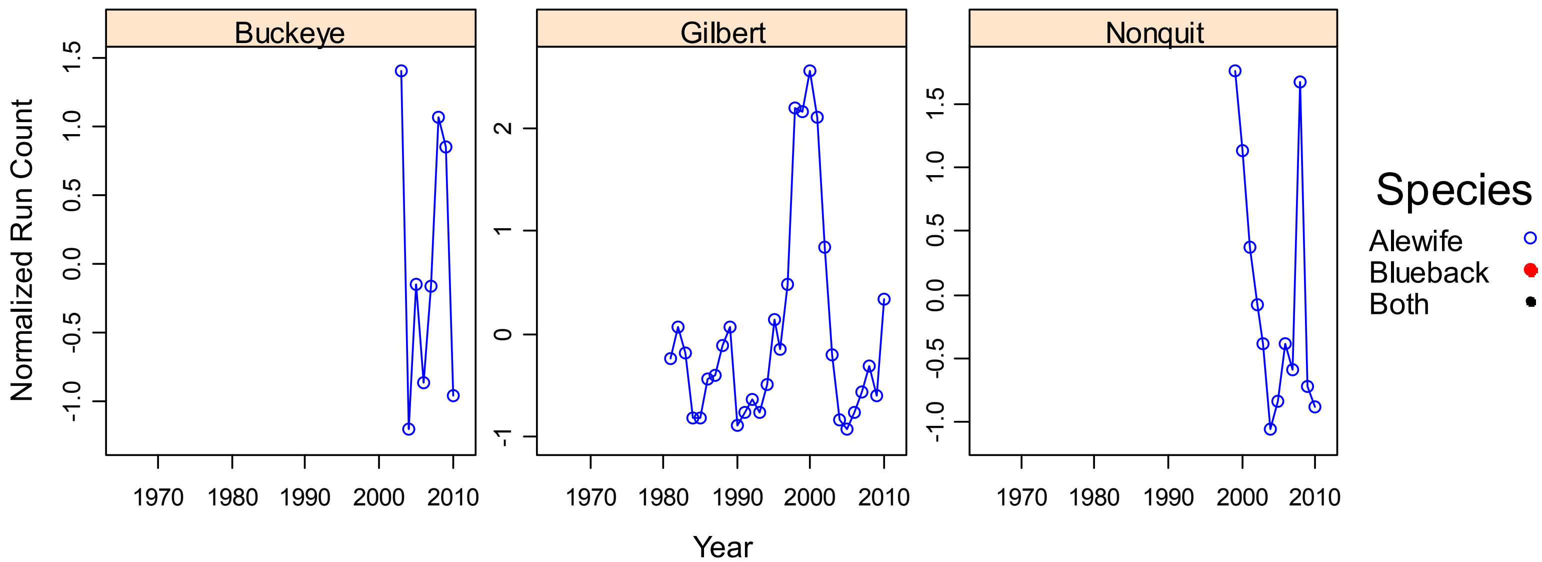



Figure 2.21 Plots of normalized run counts of alewife and blueback herring from Rhode Island by river and year.

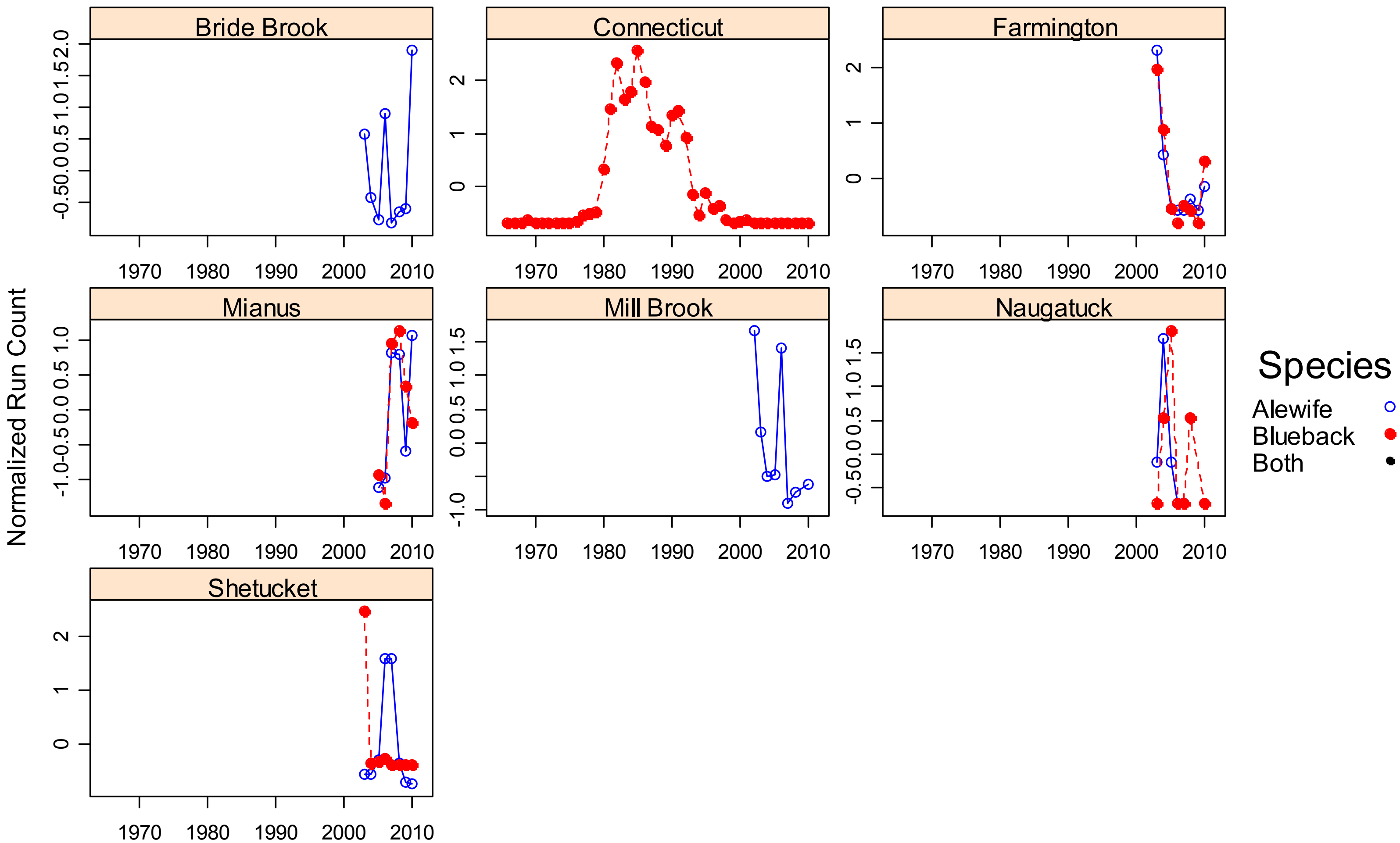



Figure 2.22 Plots of normalized run counts of alewife and blueback herring from Connecticut by river and year.

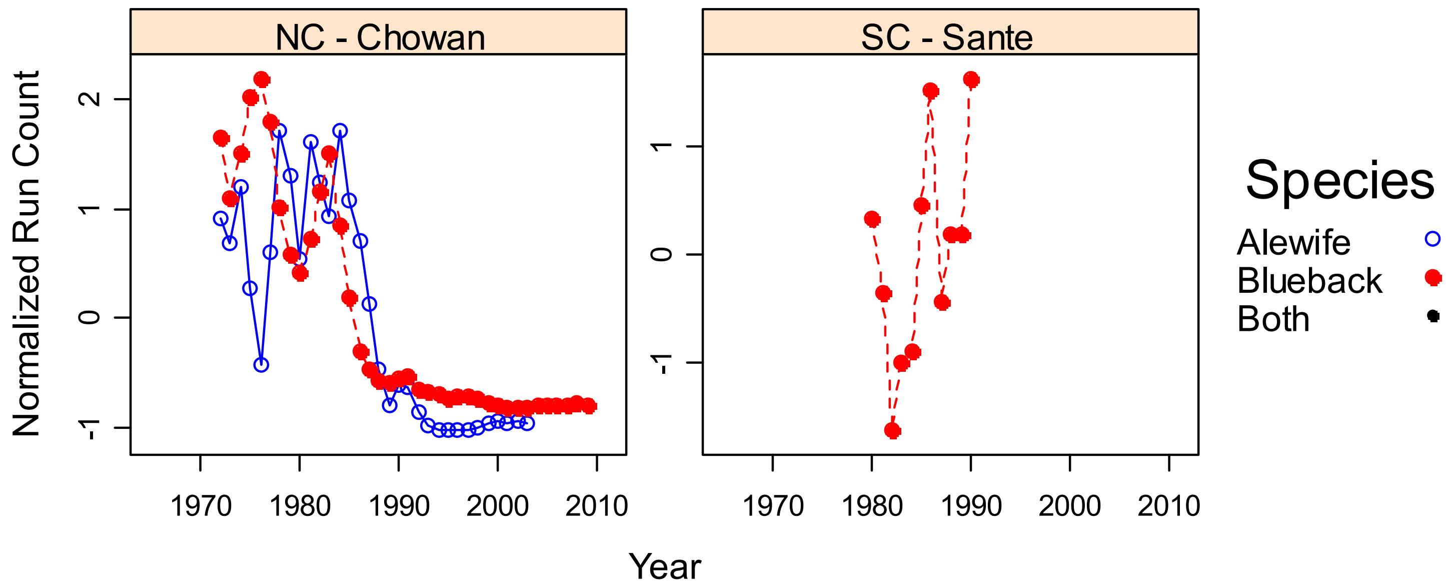



Figure 2.23 Plots of normalized run counts of alewife and blueback herring from North Carolina and South Carolina by river and year

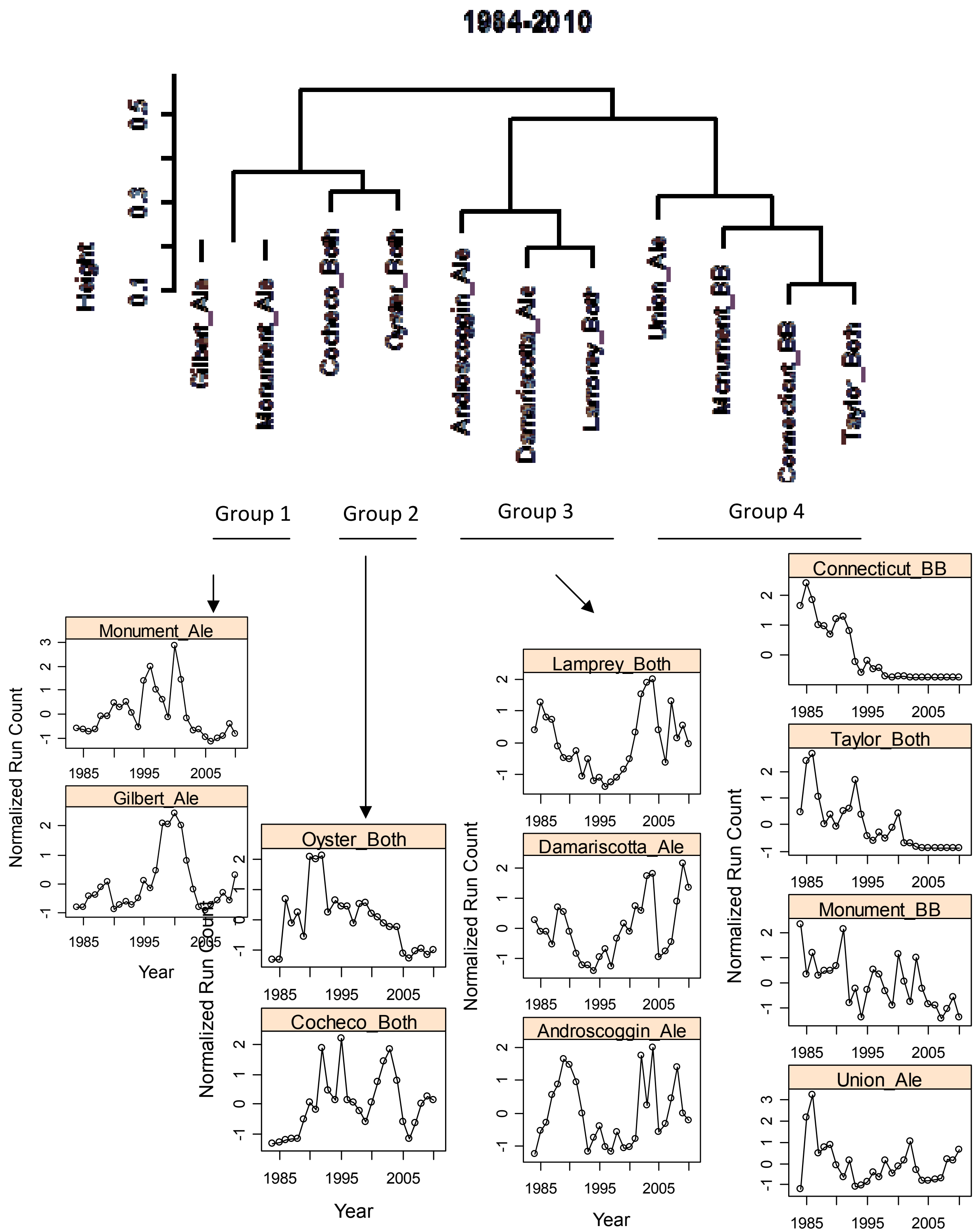



Figure 2.24 The resulting cluster dendrogram of river trends for 1984-2010 and plots of river counts for each grouping. .The dotted line indicates the level of similarity selected to define groups.

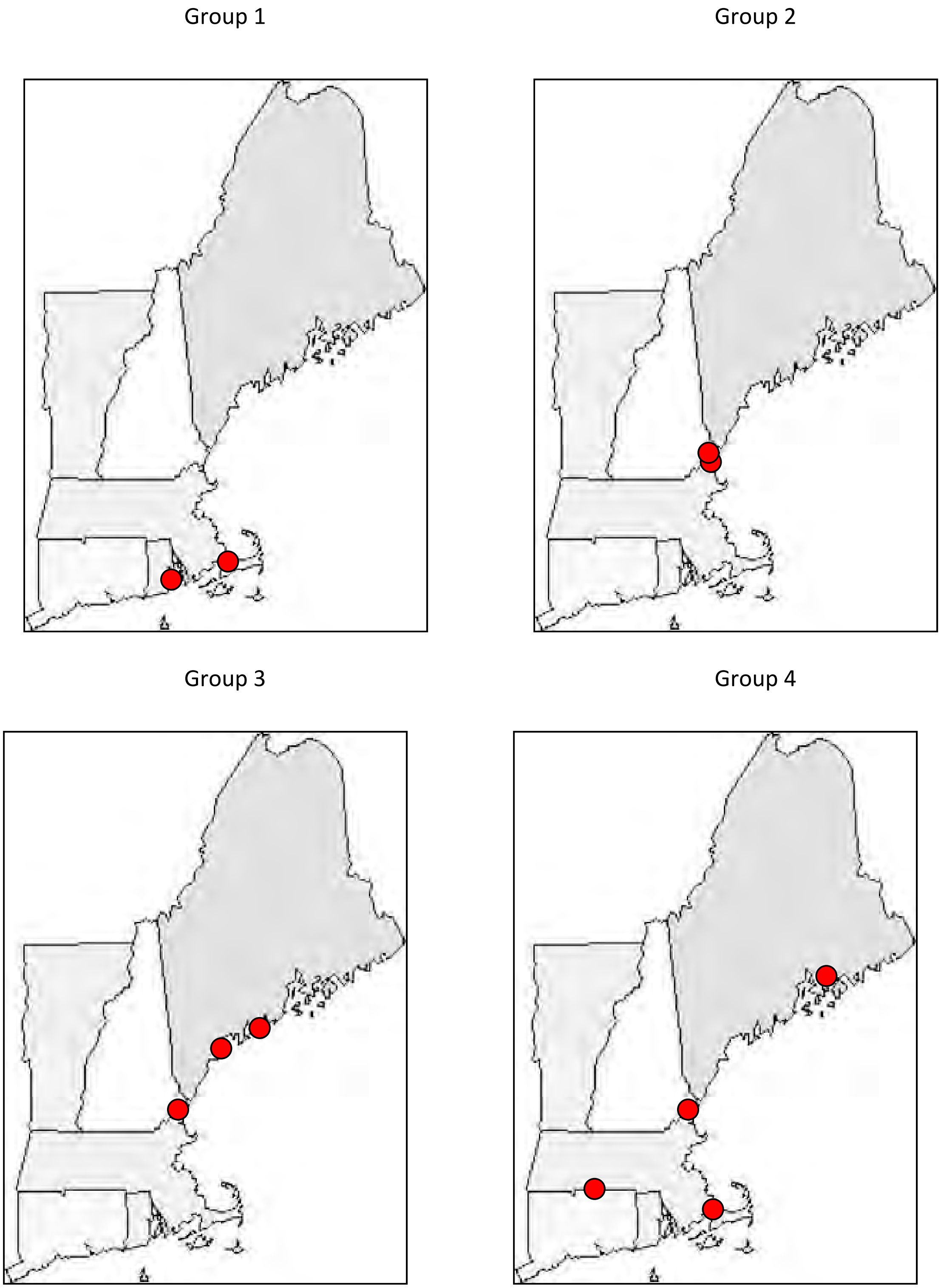



Figure 2.25.	Locations of rivers used in the 1984-2010 analysis by cluster group.

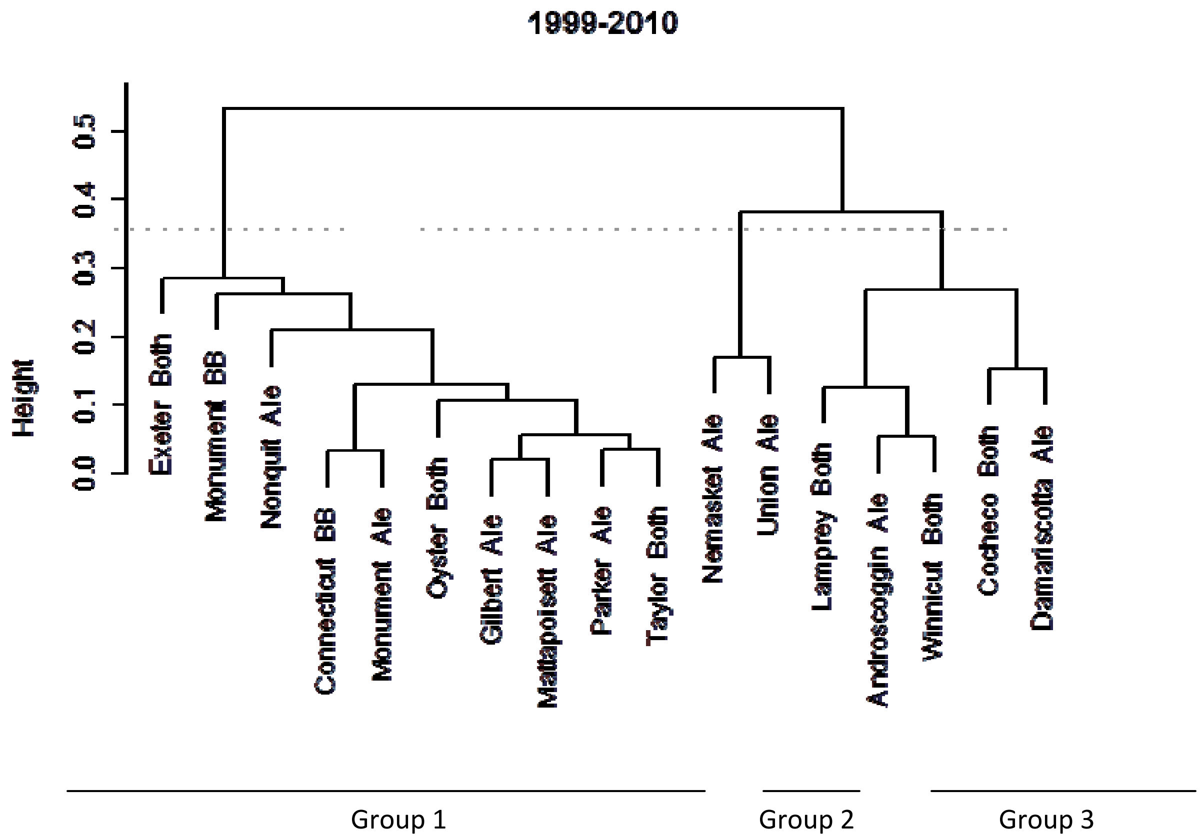



Figure 2.26. The resulting cluster dendrogram of river trends for 1999-2010. The dotted line indicates the level of similarity selected to define groups.

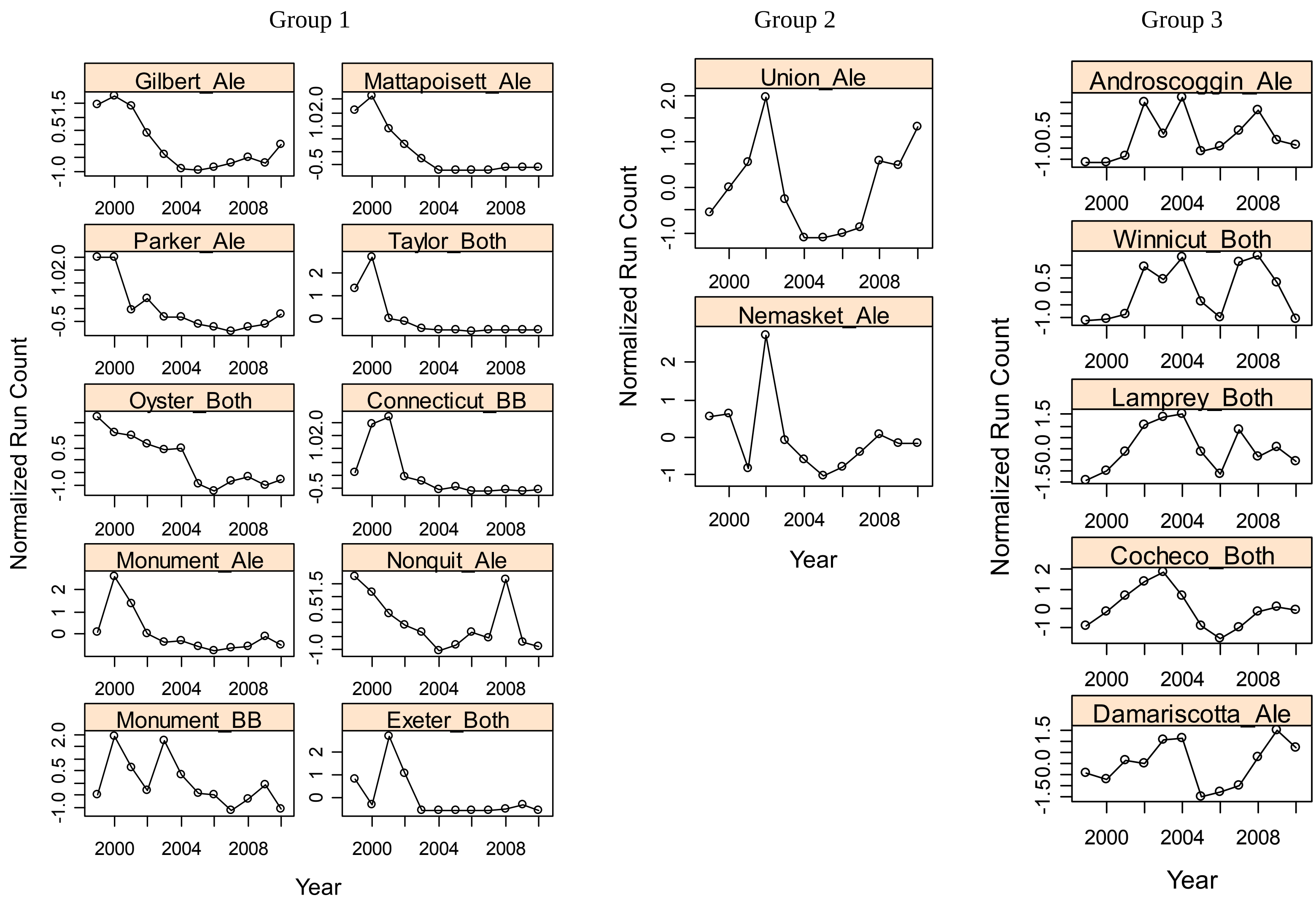
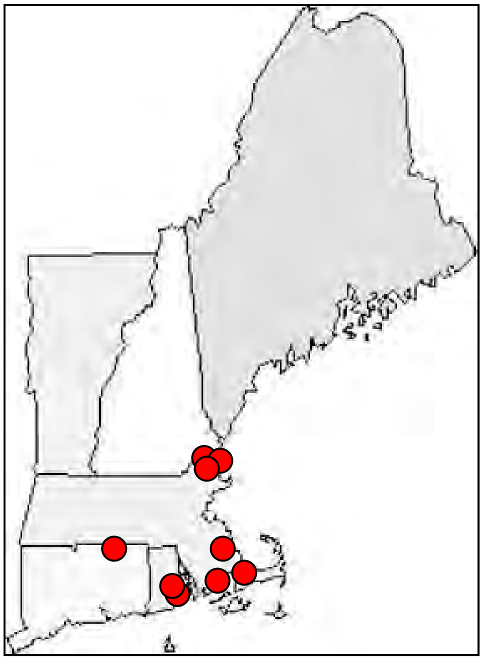



Figure 2.27 Plots of river counts for each grouping associated with the cluster analysis of data from 1999-2010.

Group 1



Group 2

Group 3

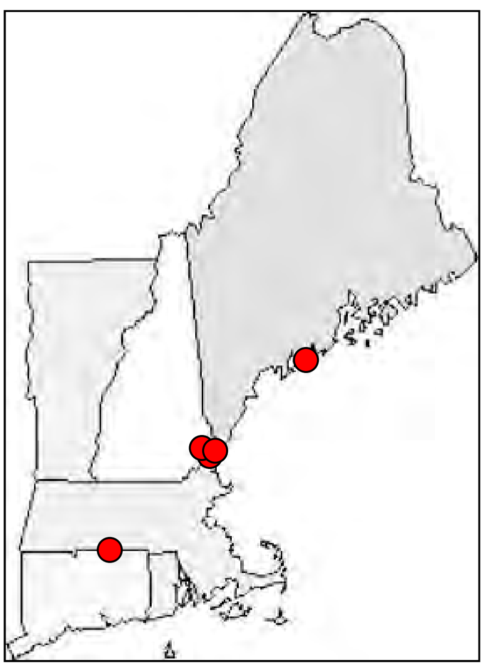


Figure 2.28. Locations of rivers used in the 1999-2010 analysis by cluster group.

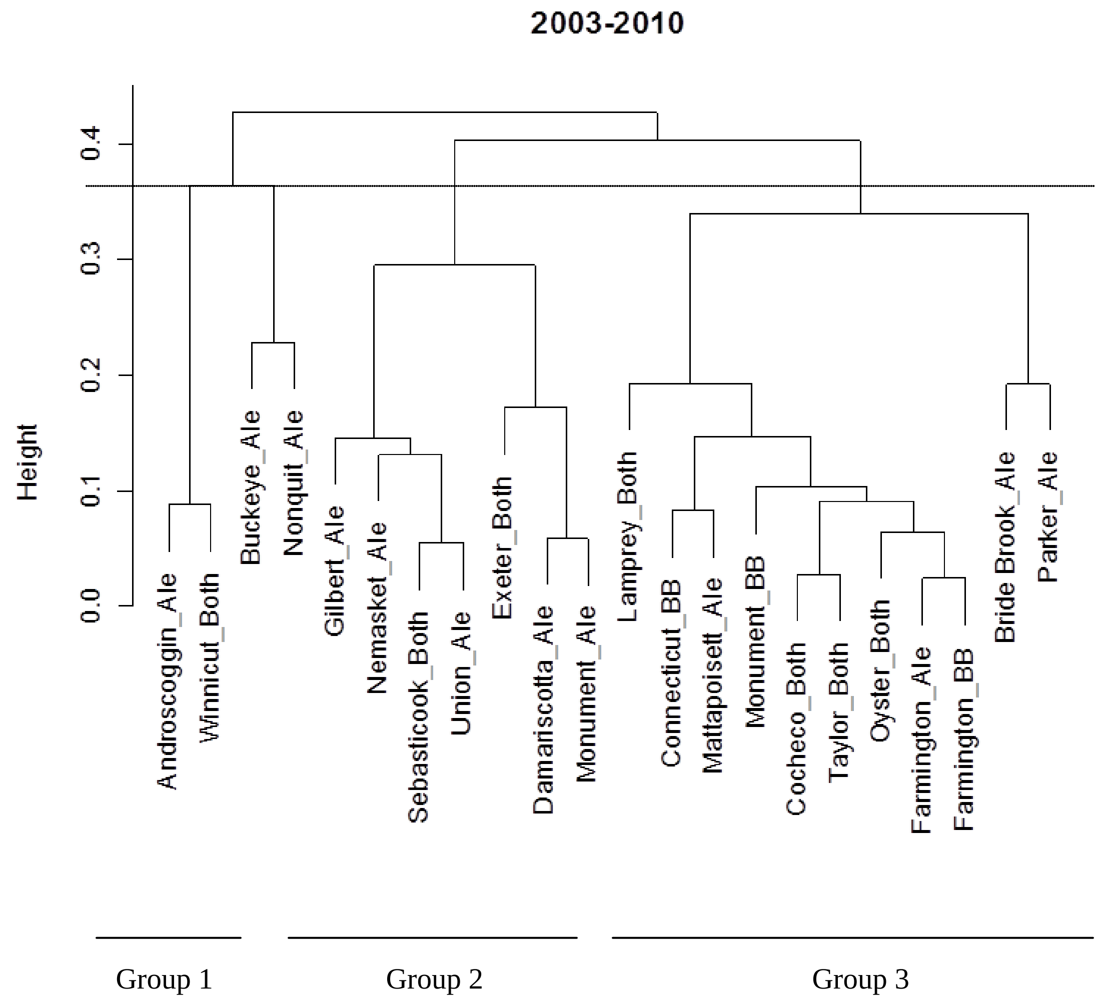



Figure 2.29. The resulting cluster dendrogram of river trends for 2003-2010. The dotted line indicates the level of similarity selected to define groups.

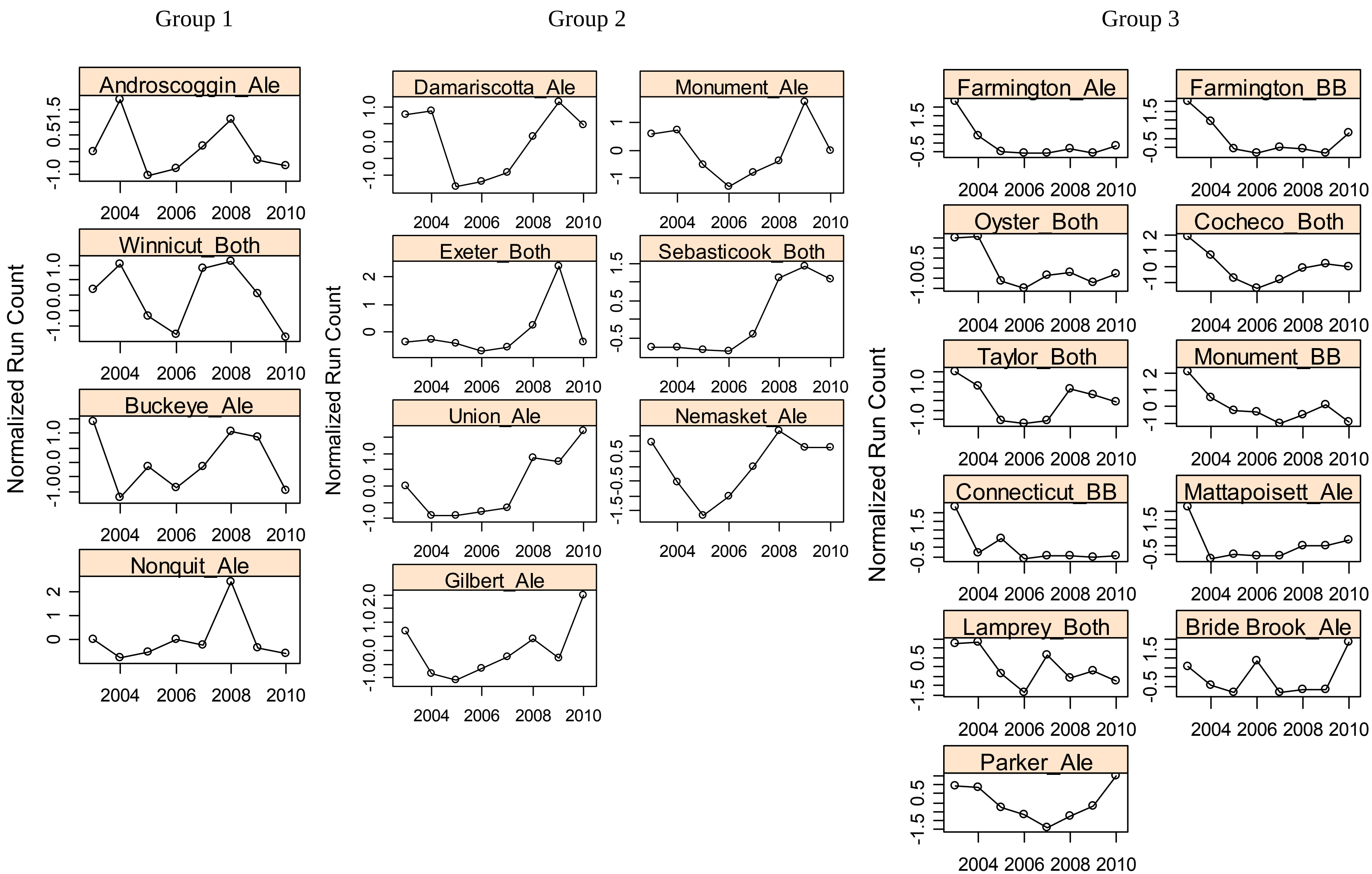



Figure 2.30 Plots of river counts for each grouping associated with the cluster analysis of data from 2003-2010.

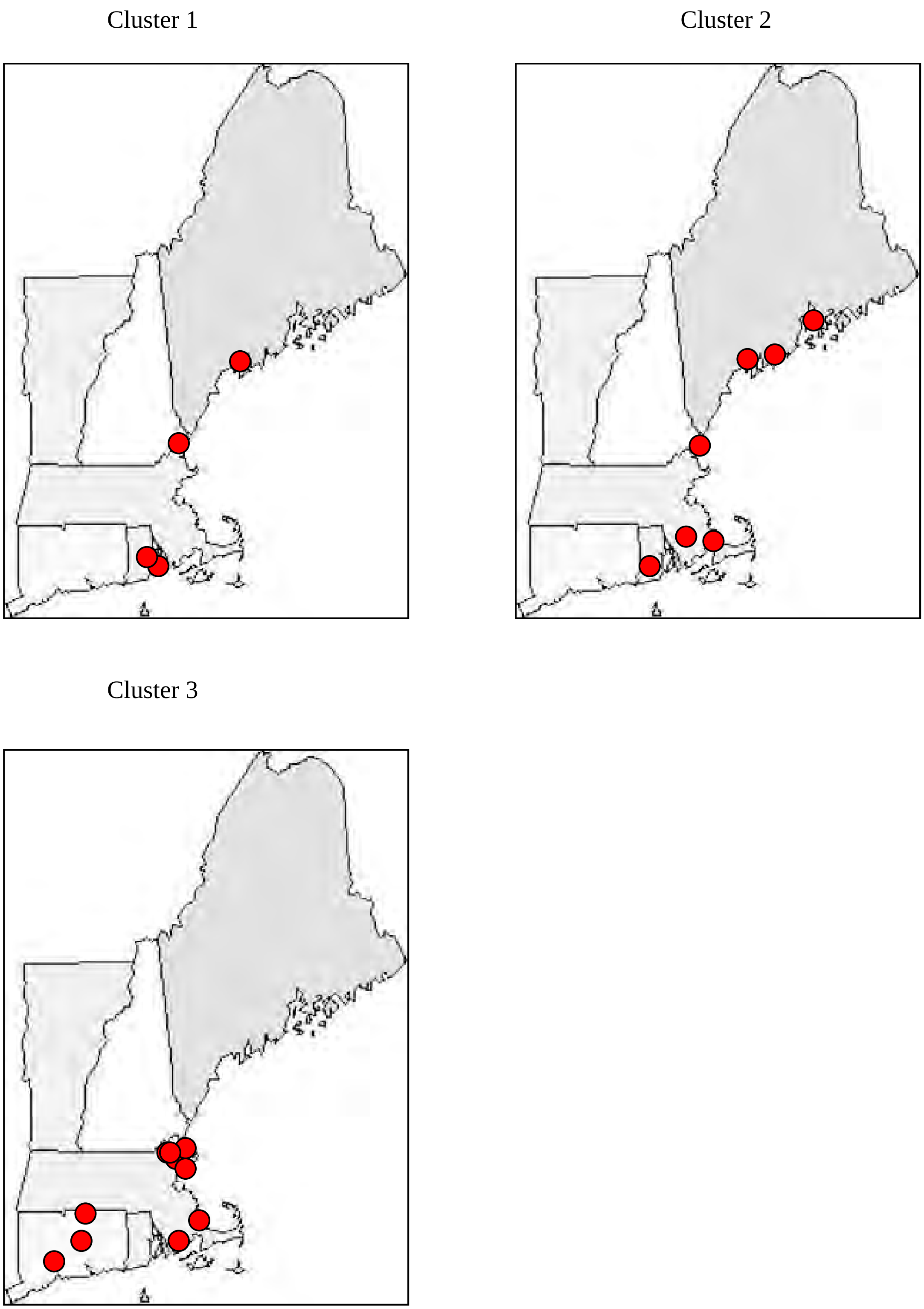



Figure 2.31 Locations of rivers used in the 2003-2010 analysis by cluster group.

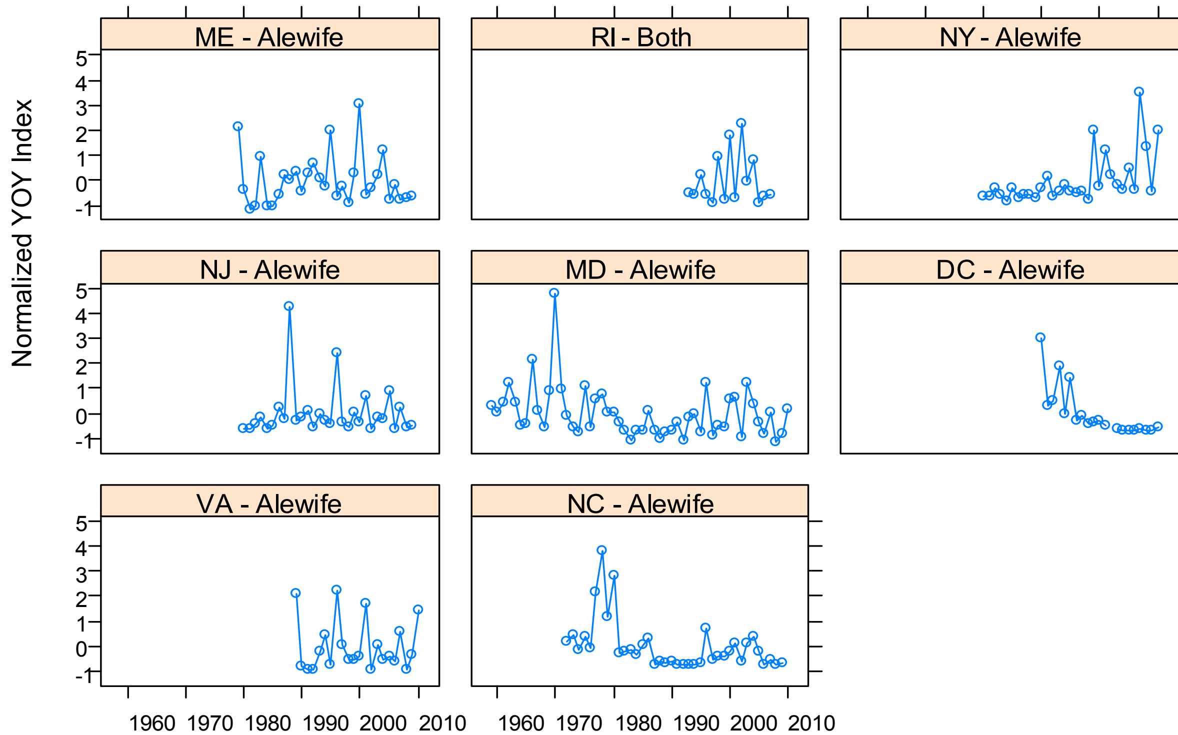



Figure 2.32 Normalized YOY indices of relative abundance for alewife from seine surveys.

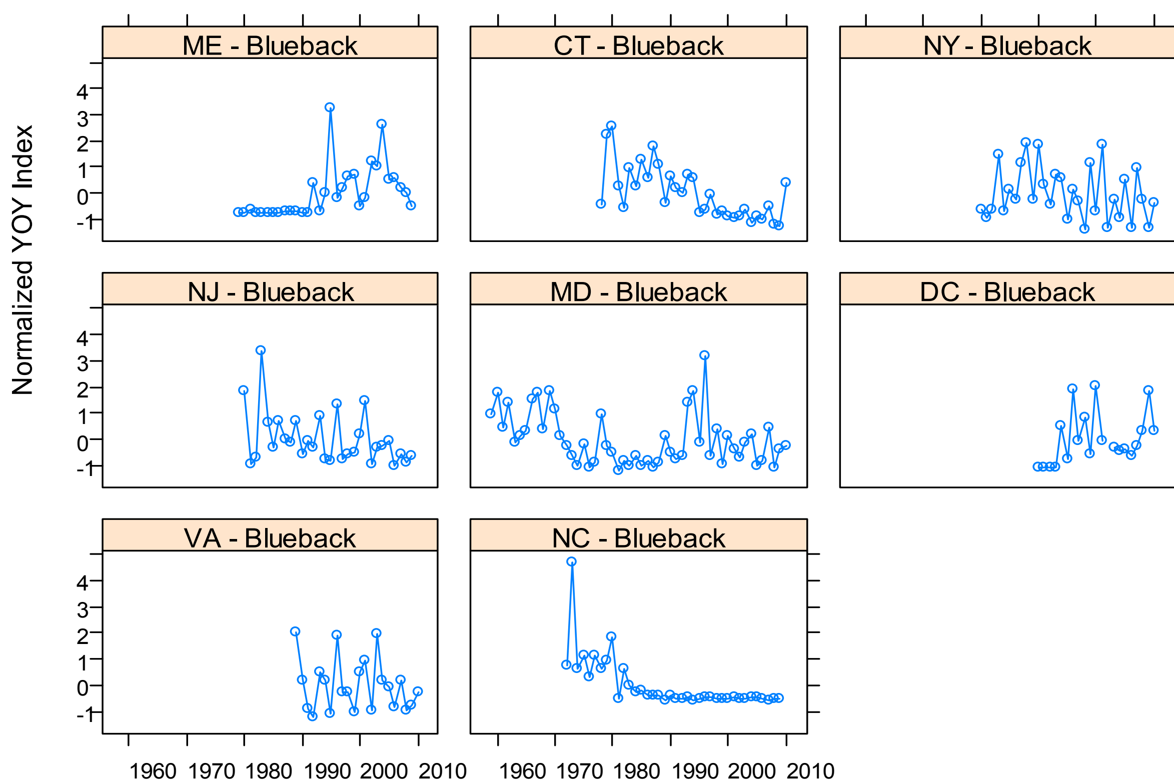



Figure 2.33 Normalized YOY indices of relative abundance for blueback herring from seine surveys.

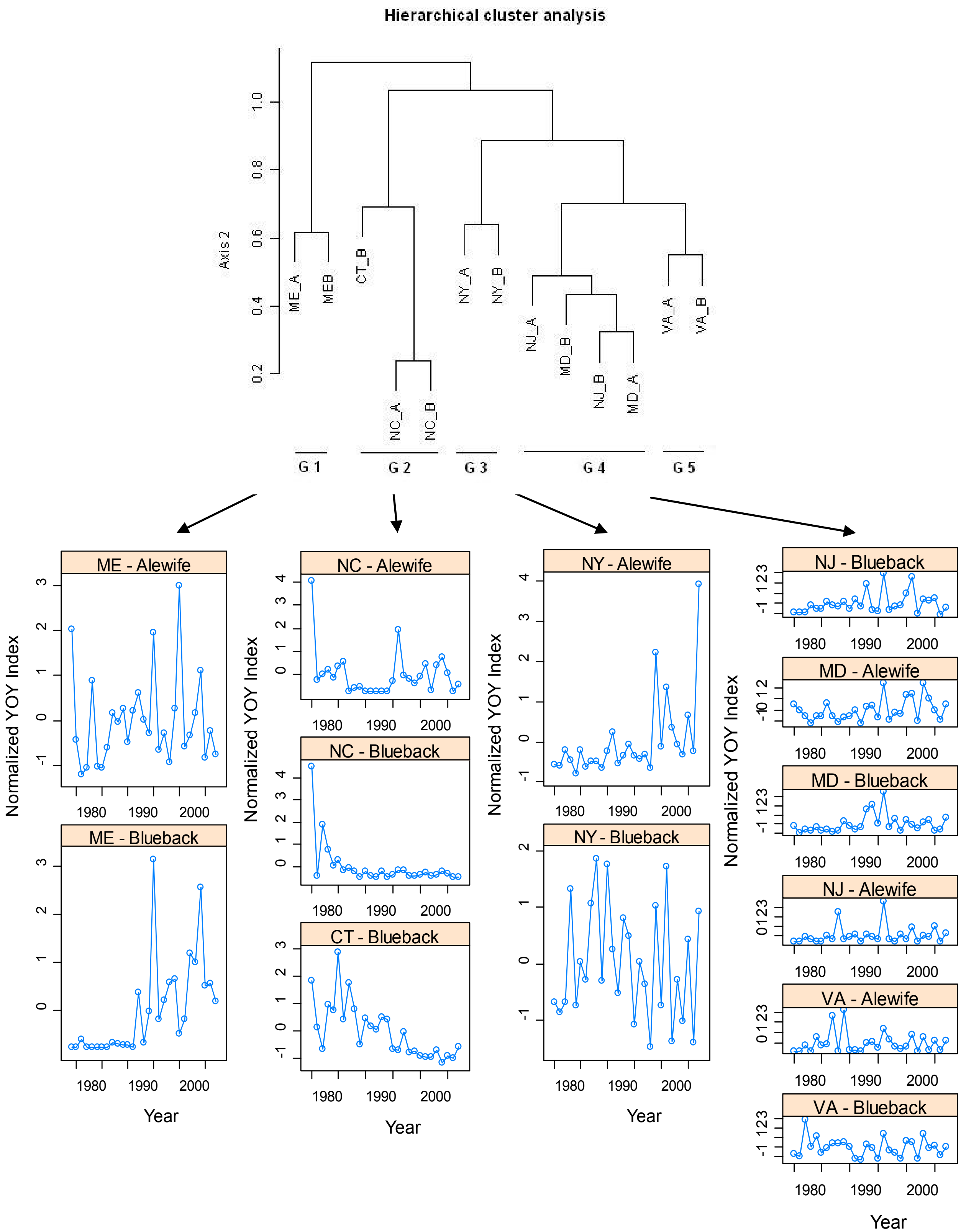



Figure 2.34 Results of cluster analysis of YOY seine indices of relative abundance, 1980-2007.

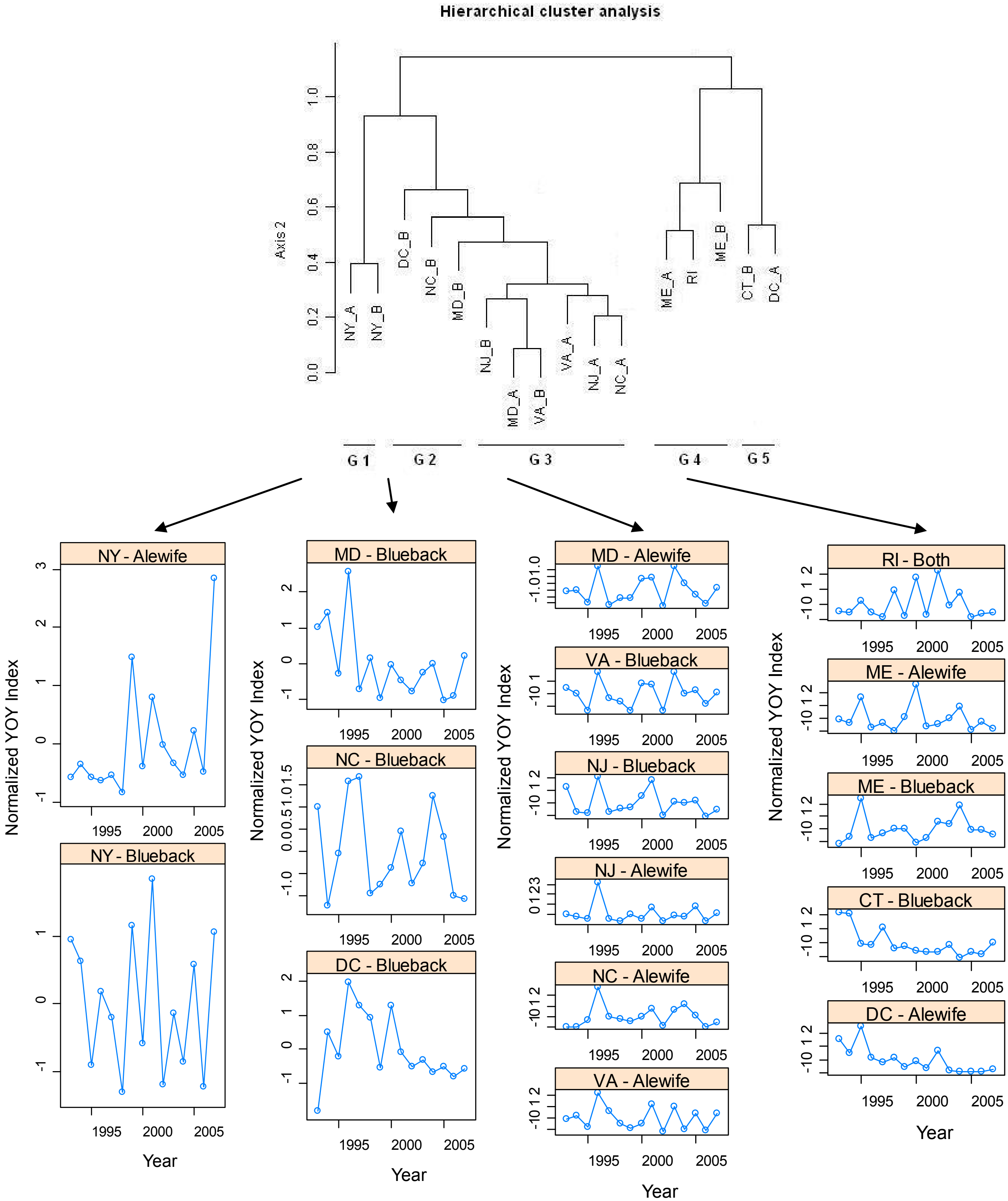



Figure 2.35 Results of cluster analysis of YOY seine survey trends for 1993-2007 showing the cluster dendrogram and plots of YOY indices for each grouping.

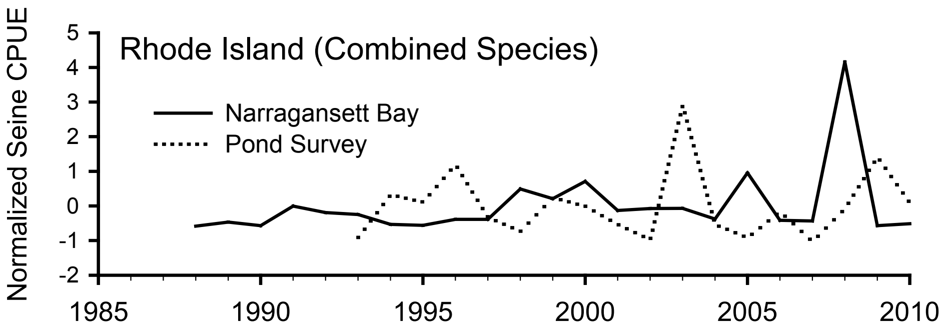



Figure 2.36 Normalized gillnet CPUE from Rhode Island, 1985-2010.

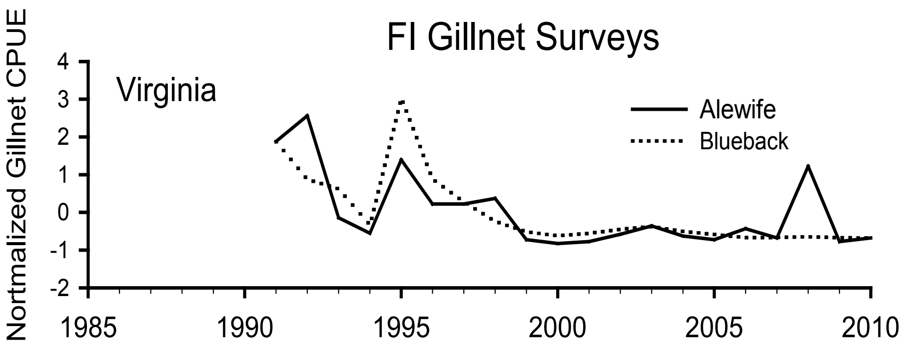



Figure 2.37. Normalized gillnet CPUE from Virginia, 1991-2010.

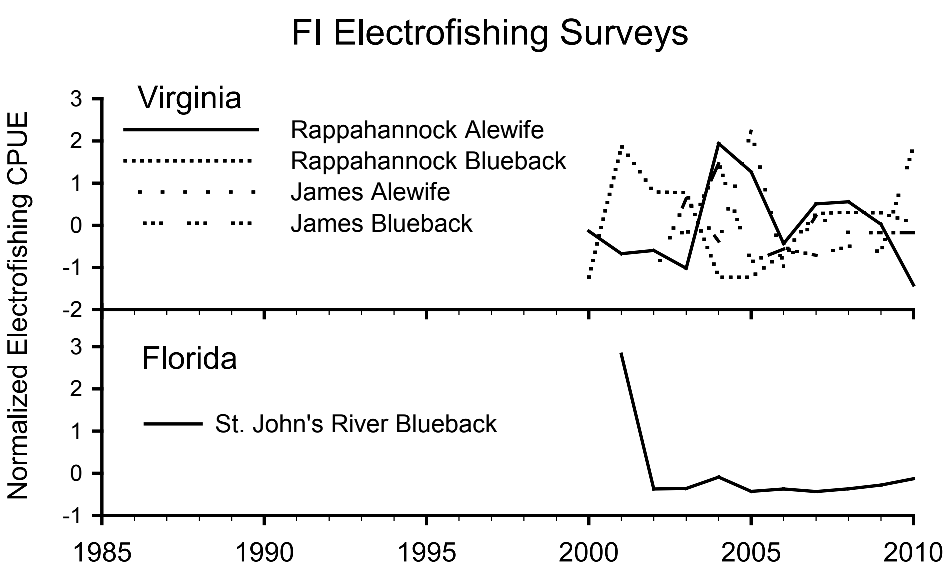



Figure 2.38. Comparison of normalized electrofishing surveys from Virginia and Florida, 2000-2010.

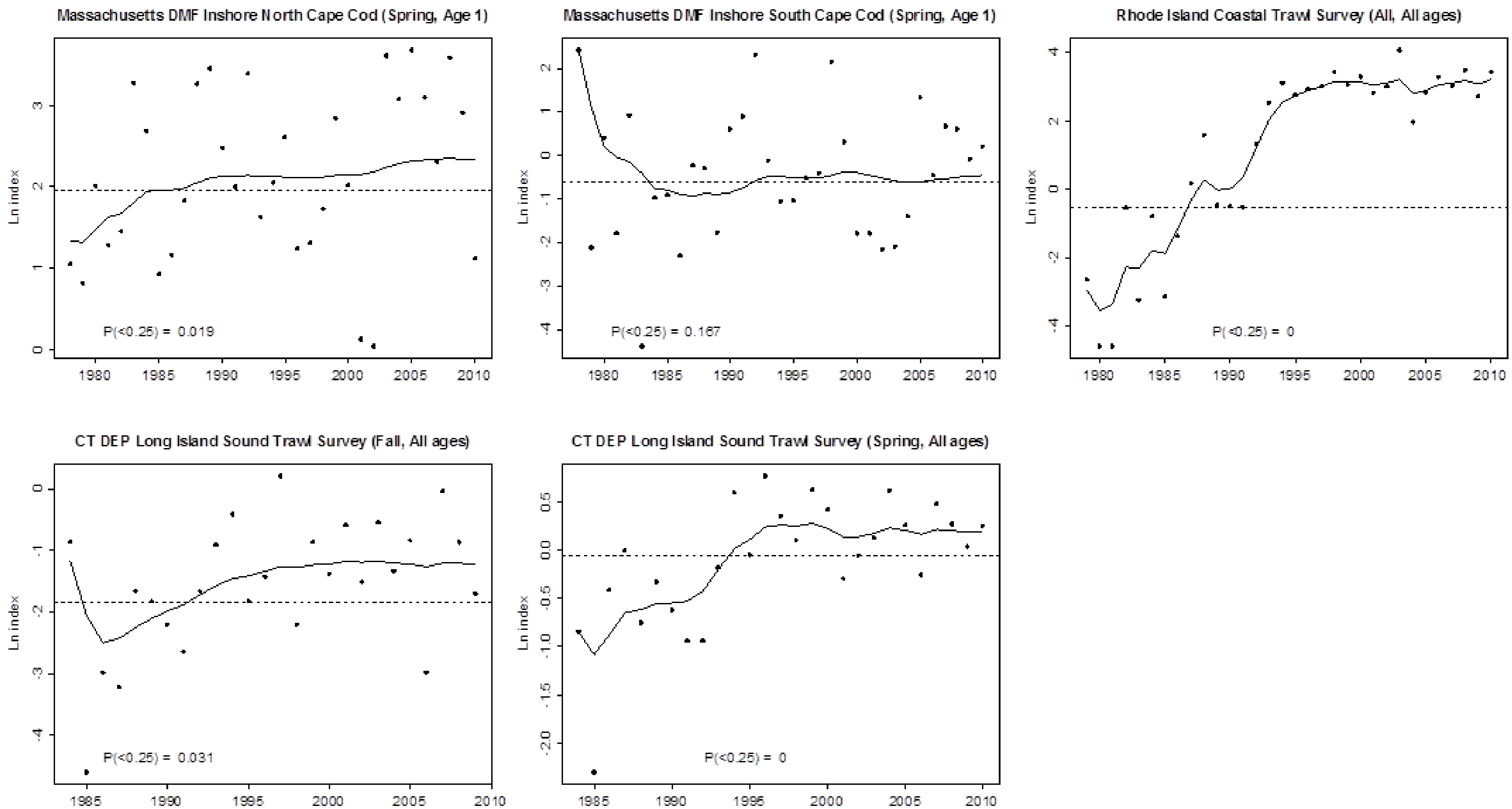



Figure 2.39 Autoregressive integrated moving average (ARIMA) model fits to log transformed **alewife** trawl survey indices from northern regions. The dotted horizontal lines correspond to the 25th percentile of the fitted values ($Q_{0.25}$). Text on the graphs represents the probability of the last year of the survey being less than $Q_{0.25}$ [P(<0.25)], the season of the trawl survey, and the ages of alewife in the trawl survey.

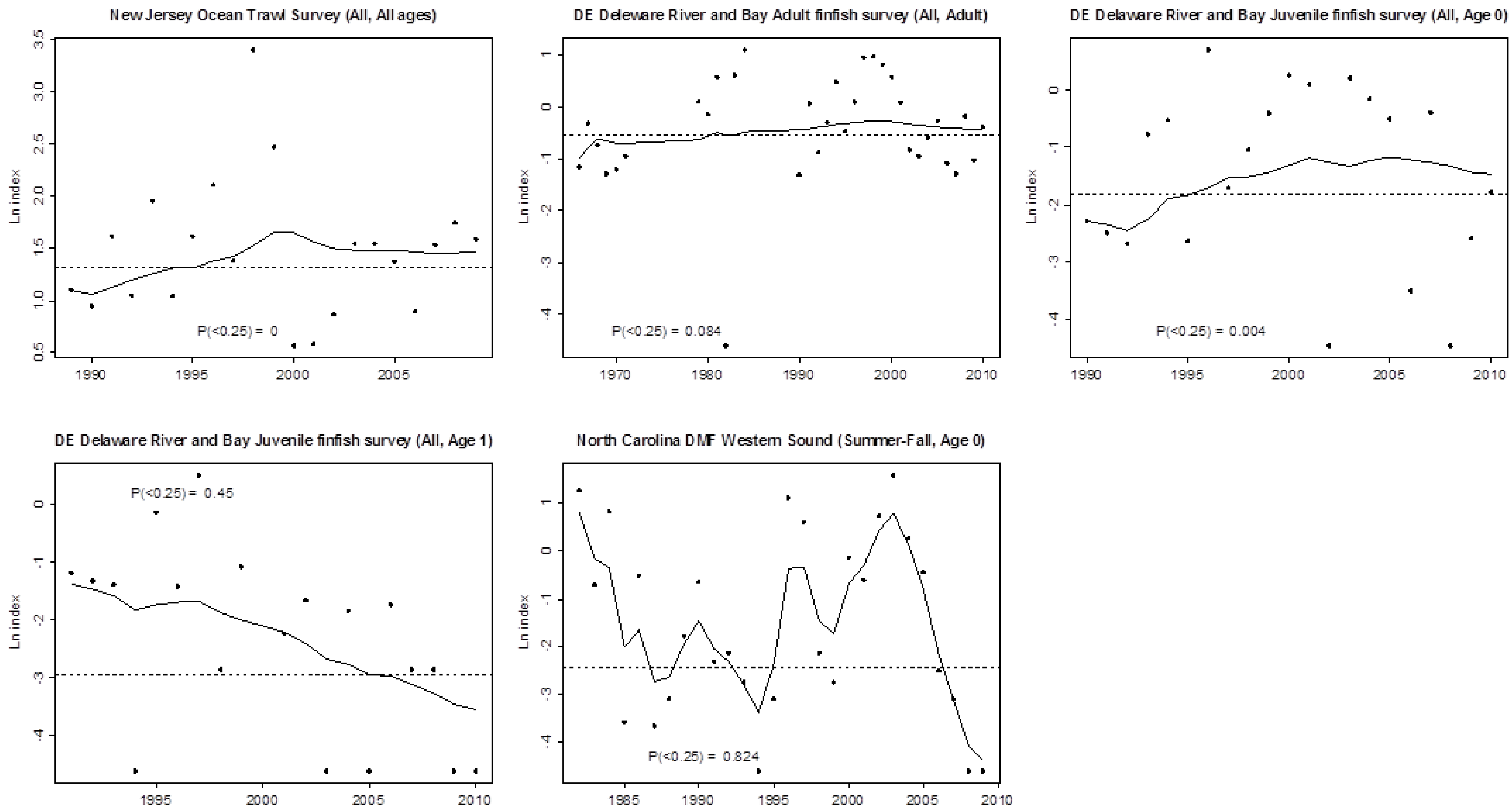



Figure 2.40 Autoregressive integrated moving average (ARIMA) model fits to log transformed **alewife** trawl survey indices from southern regions. The dotted horizontal lines correspond to the 25th percentile of the fitted values ($Q_{0.25}$). Text on the graphs represents the probability of the last year of the survey being less than $Q_{0.25}$ [P(<0.25)], the season of the trawl survey, and the ages of alewife in the trawl survey.

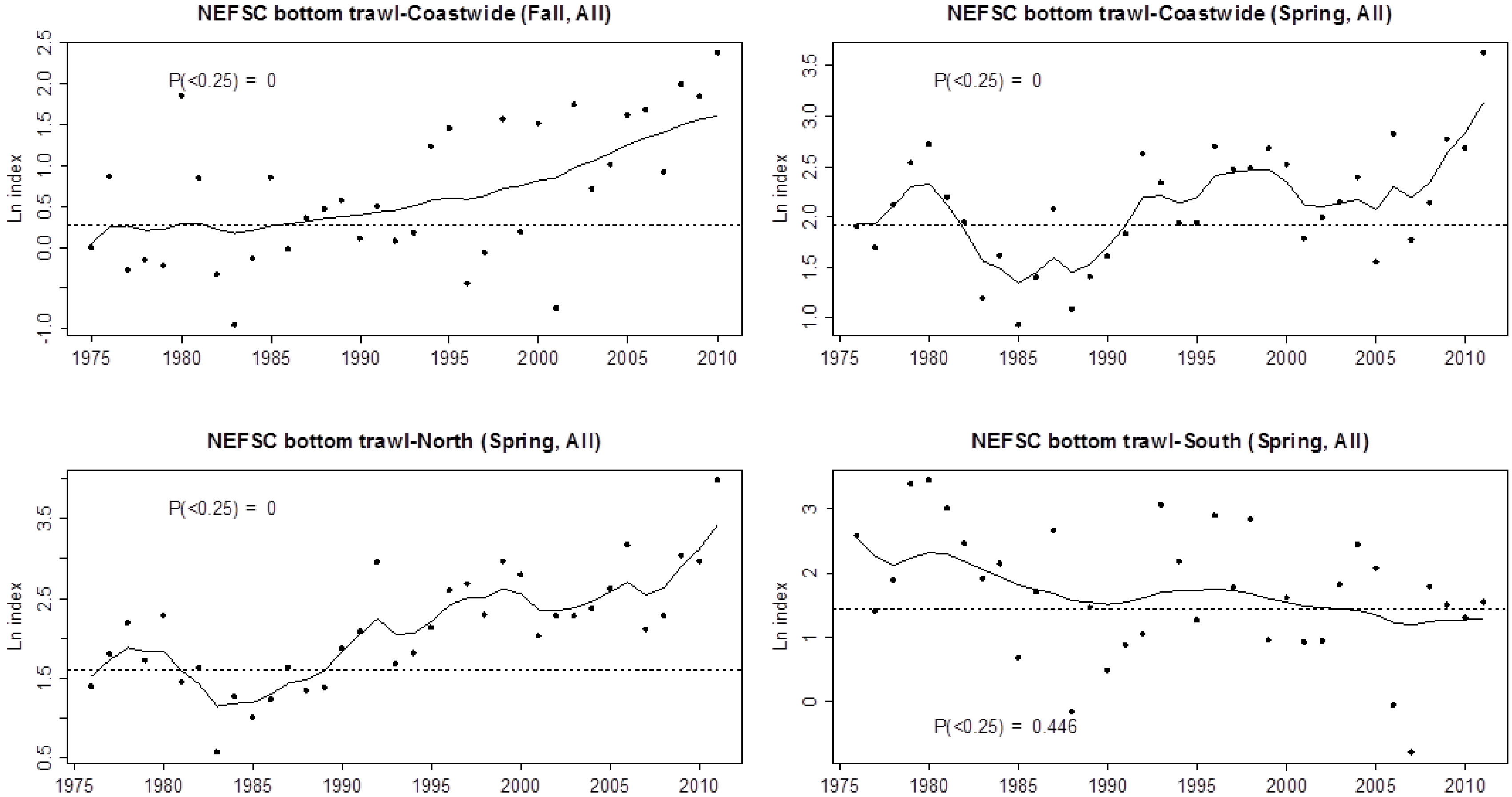



Figure 2.41 Autoregressive integrated moving average (ARIMA) model fits to log transformed **alewife** trawl survey indices from the NEFSC bottom trawl survey. The dotted horizontal lines correspond to the 25$^{th}$ percentile of the fitted values ($Q_{0.25}$). Text on the graphs represents the probability of the last year of the survey being less than $Q_{0.25}$ [P(<0.25)] and the season of the trawl survey. All ages were combined in the NEFSC data.

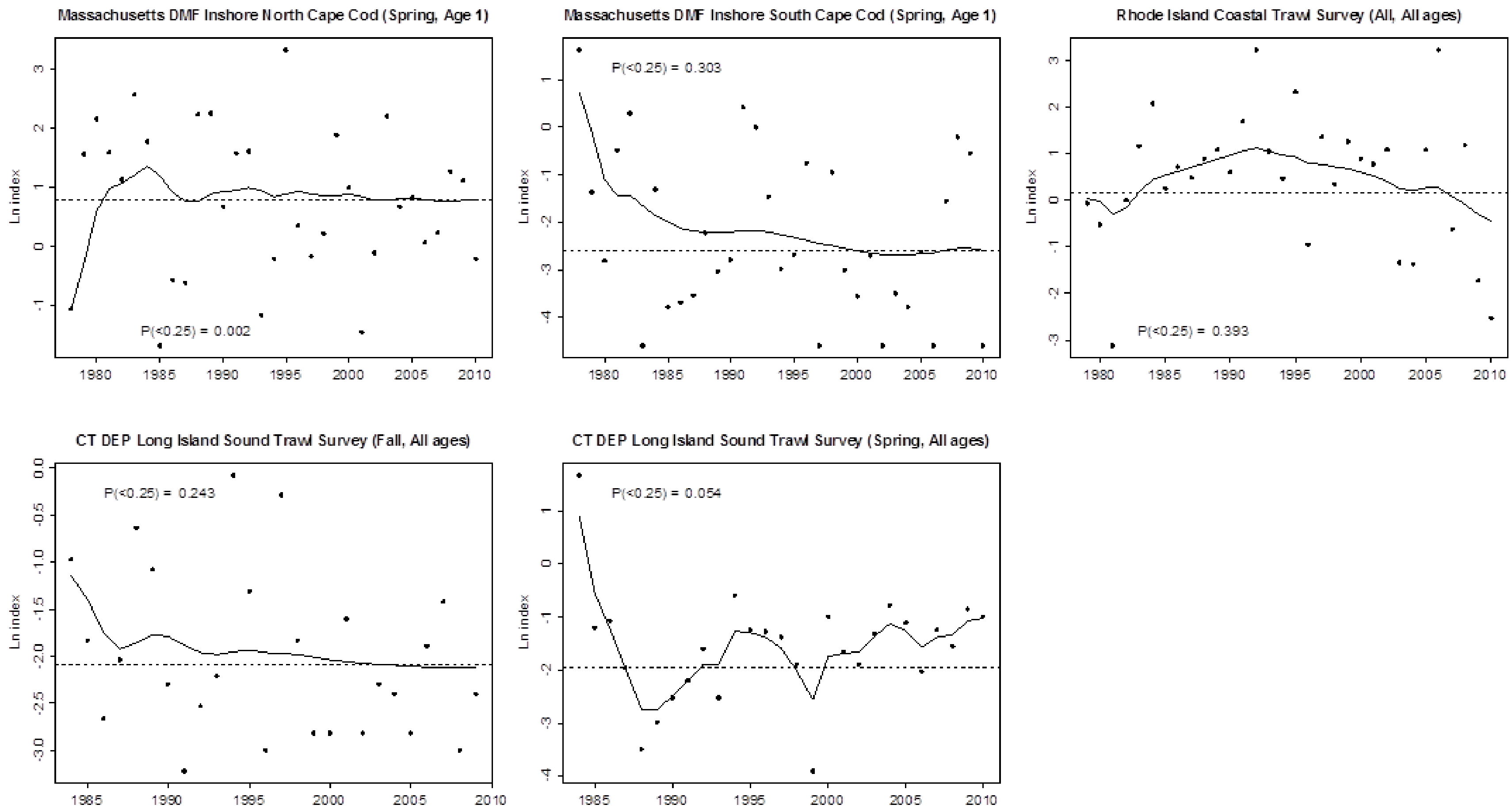



Figure 2.42 Autoregressive integrated moving average (ARIMA) model fits to log transformed **blueback herring** trawl survey indices from northern regions. The dotted horizontal lines correspond to the 25th percentile of the fitted values ($Q_{0.25}$). Text on the graphs represents the probability of the last year of the survey being less than $Q_{0.25}$ [P(<0.25)], the season of the trawl survey, and the ages of alewife in the trawl survey.

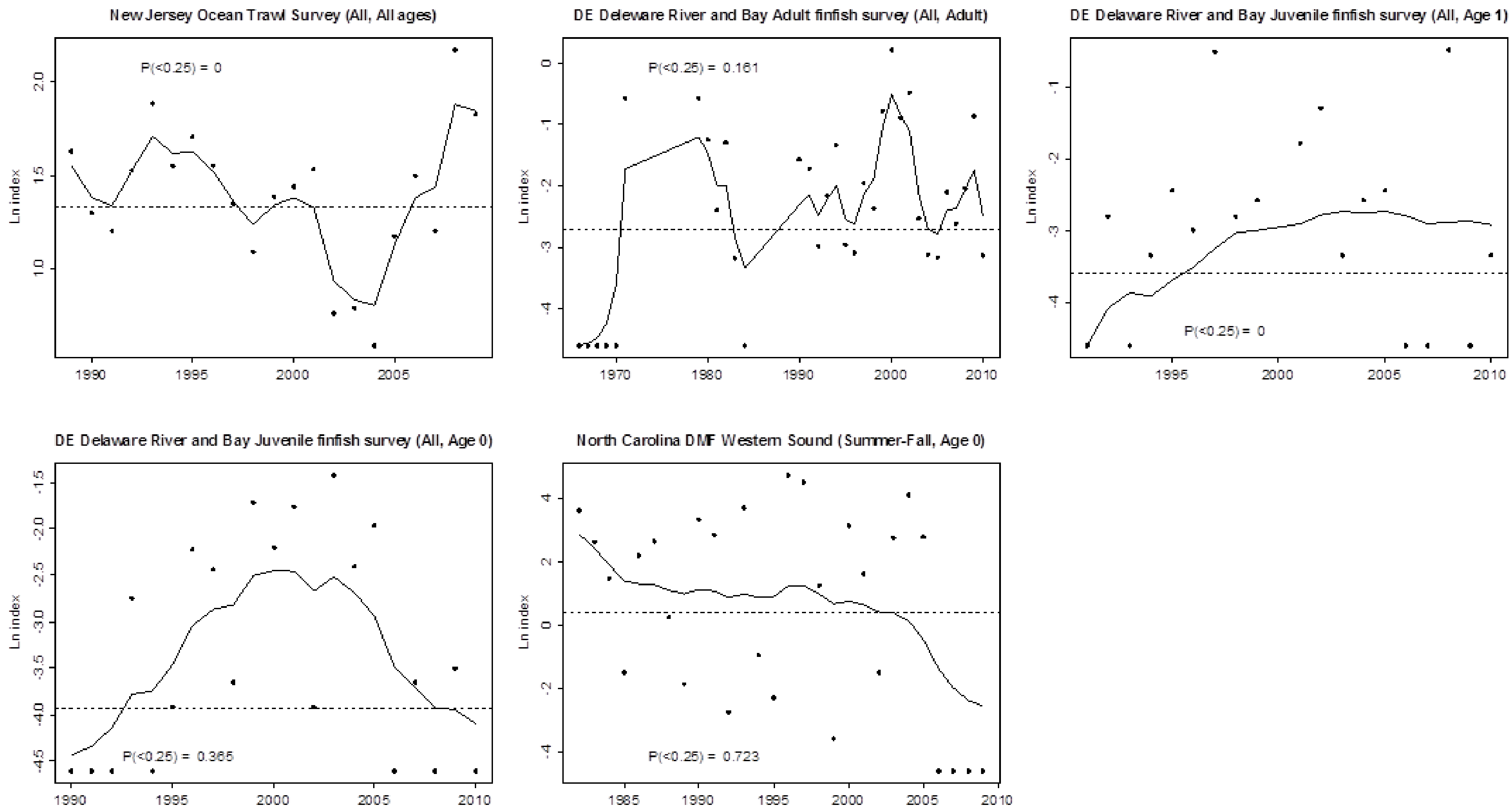



Figure 2.43 Autoregressive integrated moving average (ARIMA) model fits to log transformed **blueback herring** trawl survey indices from southern regions. The dotted horizontal lines correspond to the 25th percentile of the fitted values ($Q_{0.25}$). Text on the graphs represents the probability of the last year of the survey being less than $Q_{0.25}$ [P(<0.25)], the season of the trawl survey, and the ages of alewife in the trawl survey.

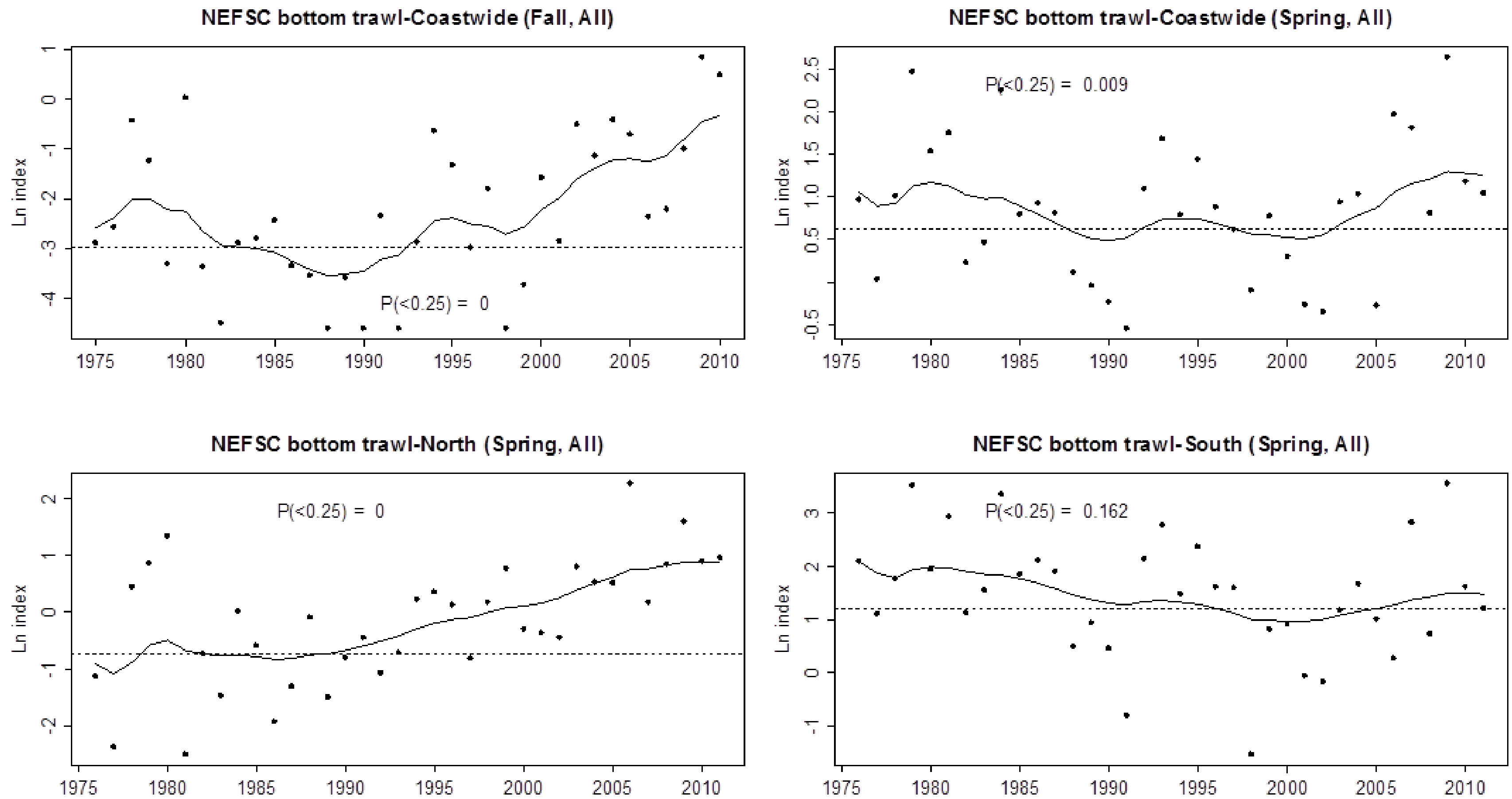



Figure 2.44 Autoregressive integrated moving average (ARIMA) model fits to log transformed **blueback herring** trawl survey indices from the NEFSC bottom trawl survey. The dotted horizontal lines correspond to the $25^{th}$ percentile of the fitted values ($Q_{0.25}$). Text on the graphs represents the probability of the last year of the survey being less than $Q_{0.25}$ [P(<0.25)] and the season of the trawl survey. All ages were combined in the NEFSC data.

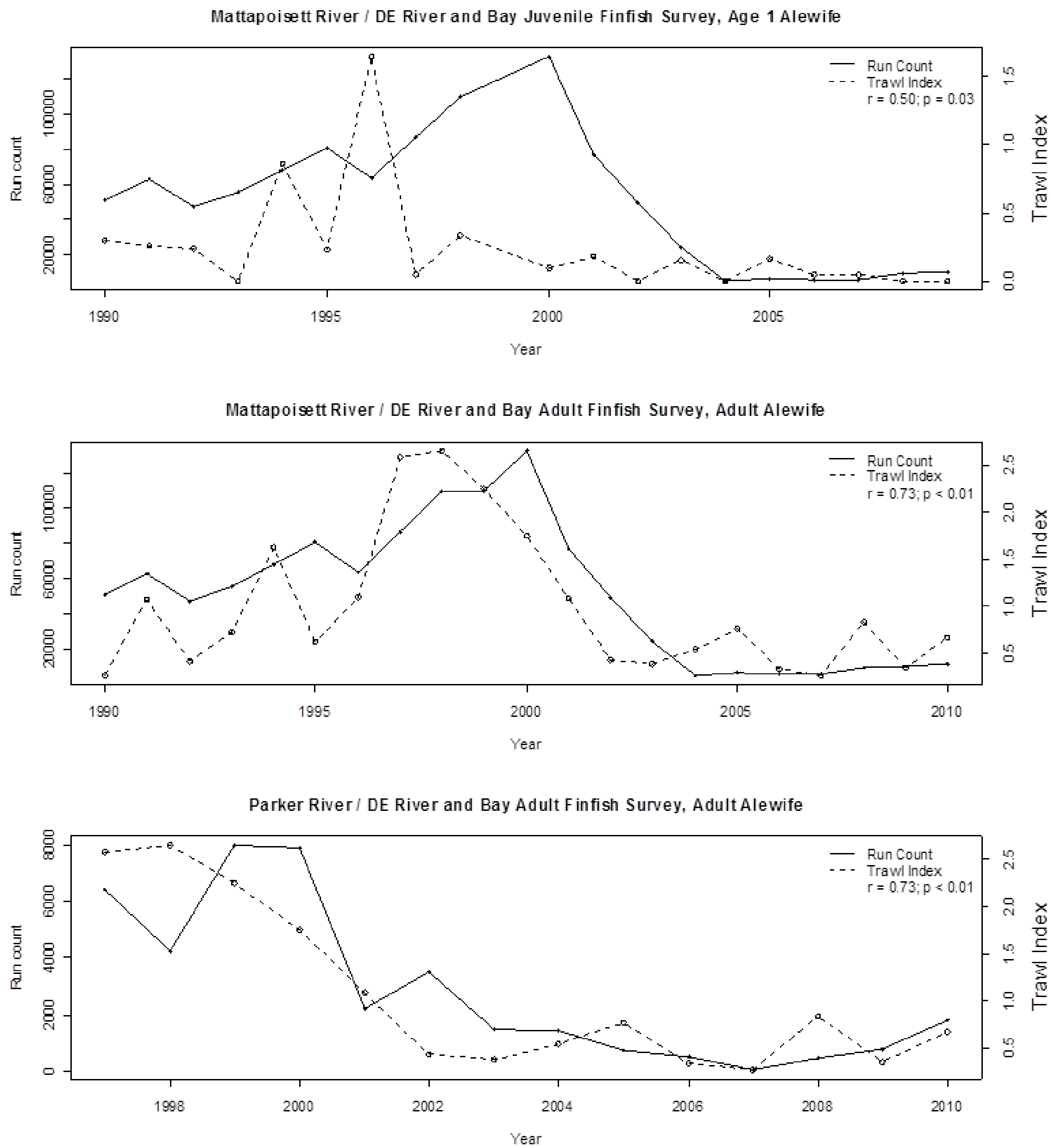
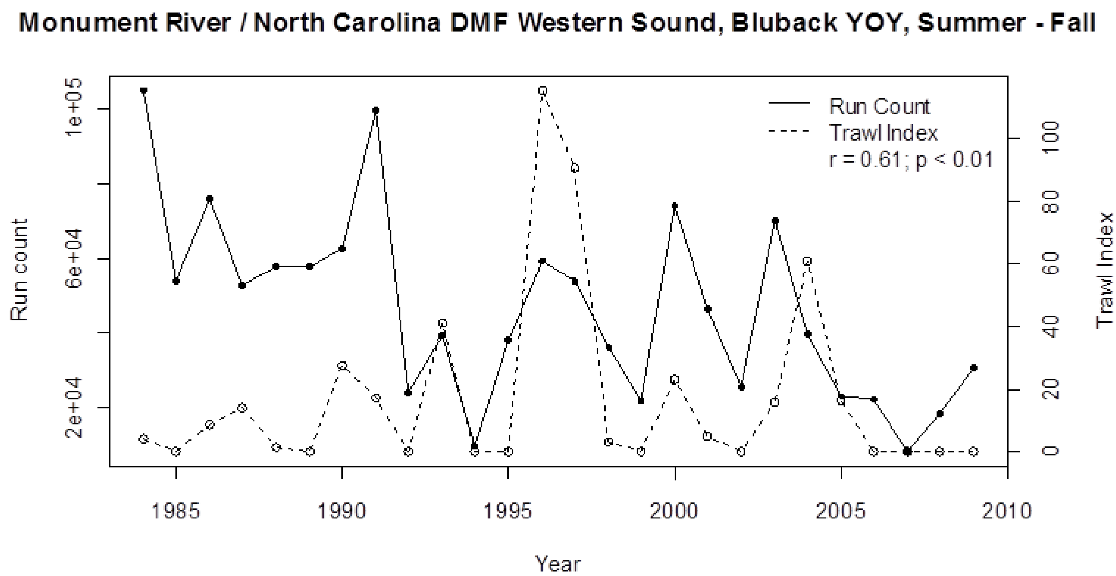



Figure 2.45 Alewife run counts in the Mattapoisett and Parker Rivers and corresponding trawl surveys showing a significant positive Spearman rank correlation coefficient.



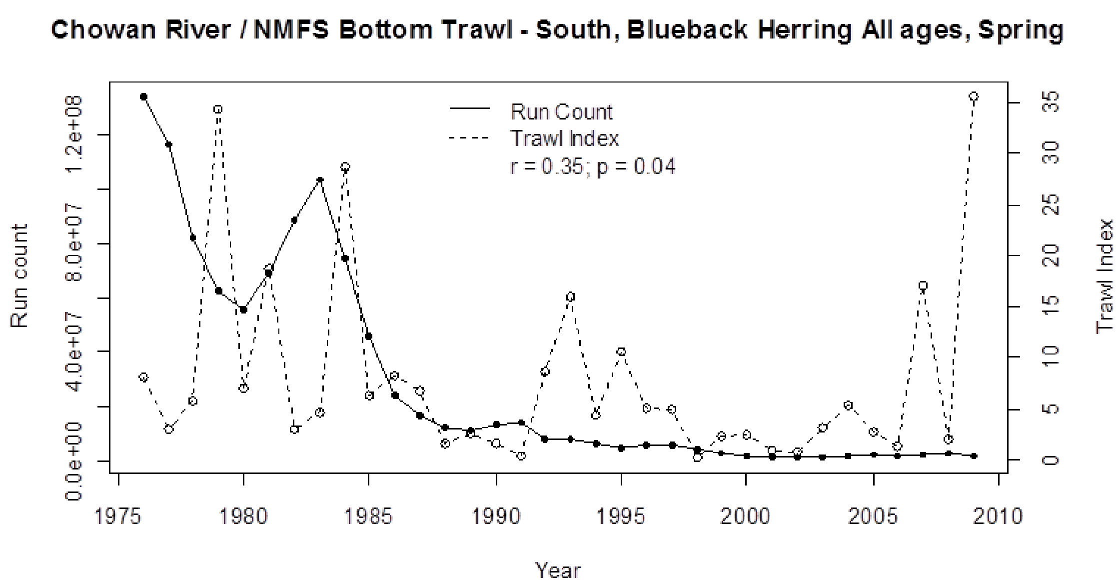




Figure 2.46 Blueback herring run counts in the Monument and Chowan Rivers and corresponding trawl surveys showing a significant positive Spearman rank correlation coefficient.

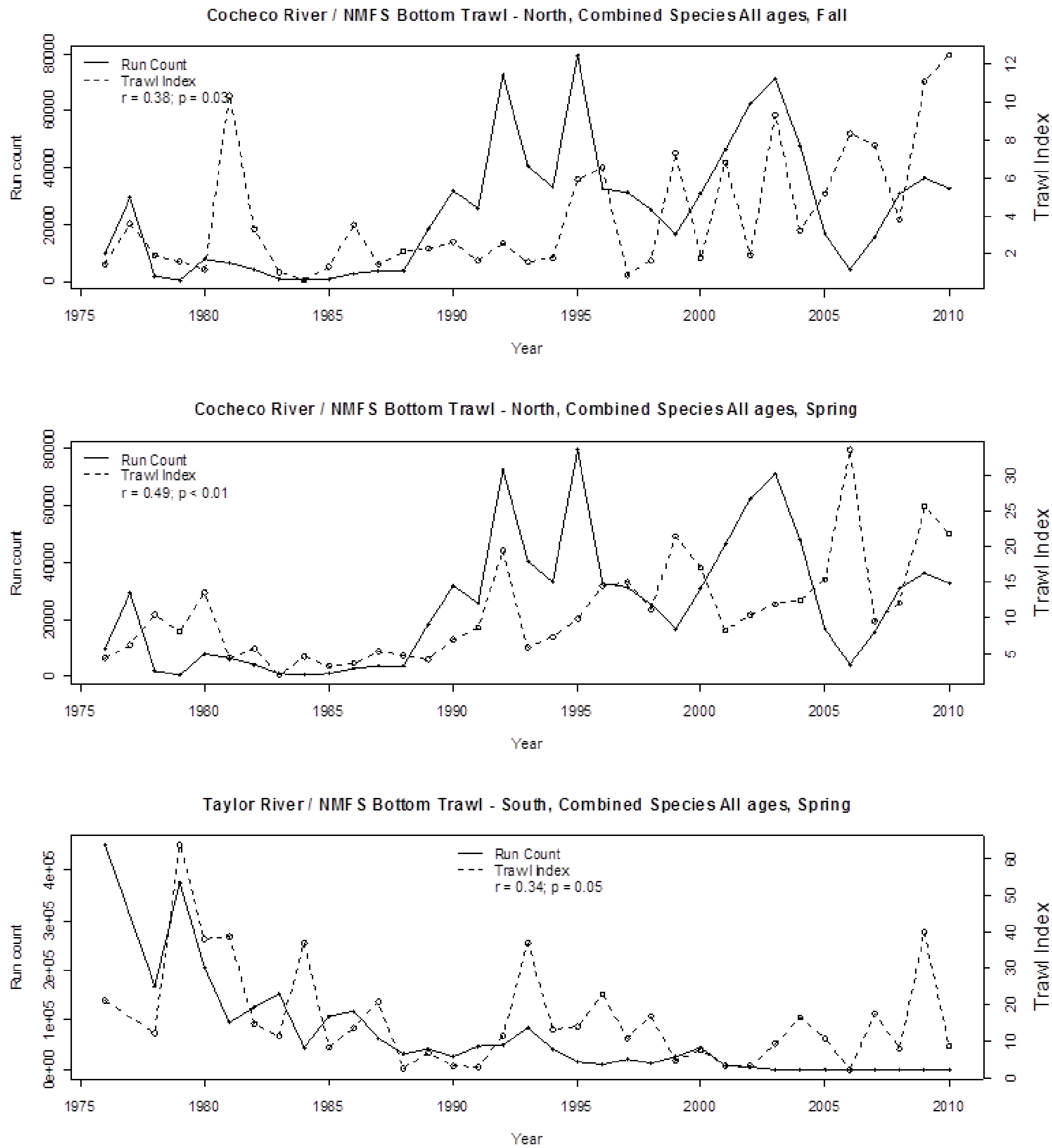
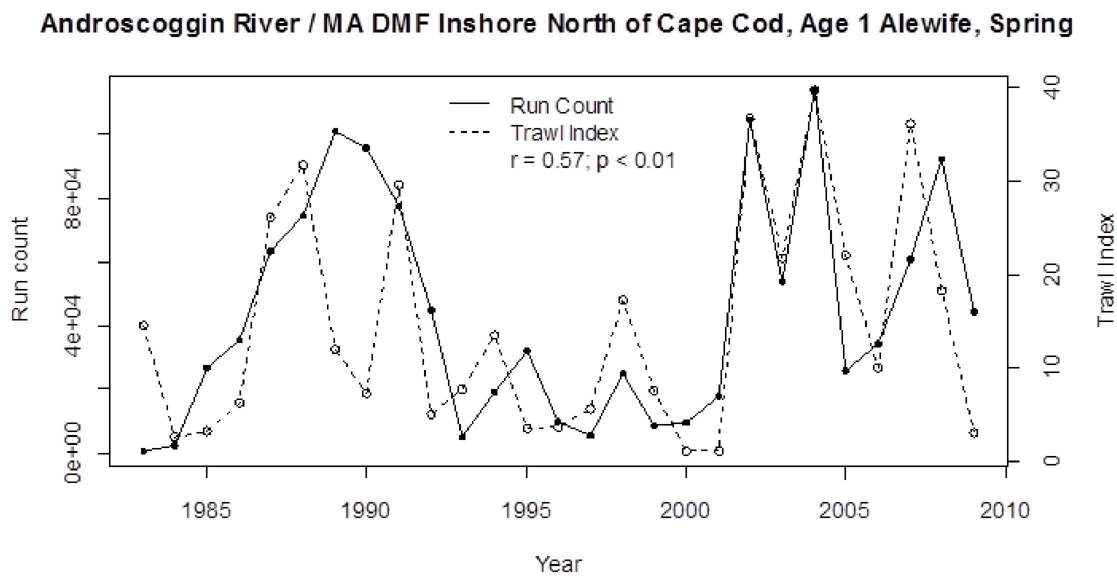



Figure 2.47 Combined species run counts in the Chocheco and Taylor Rivers and corresponding trawl surveys showing a significant positive Spearman rank correlation coefficient.



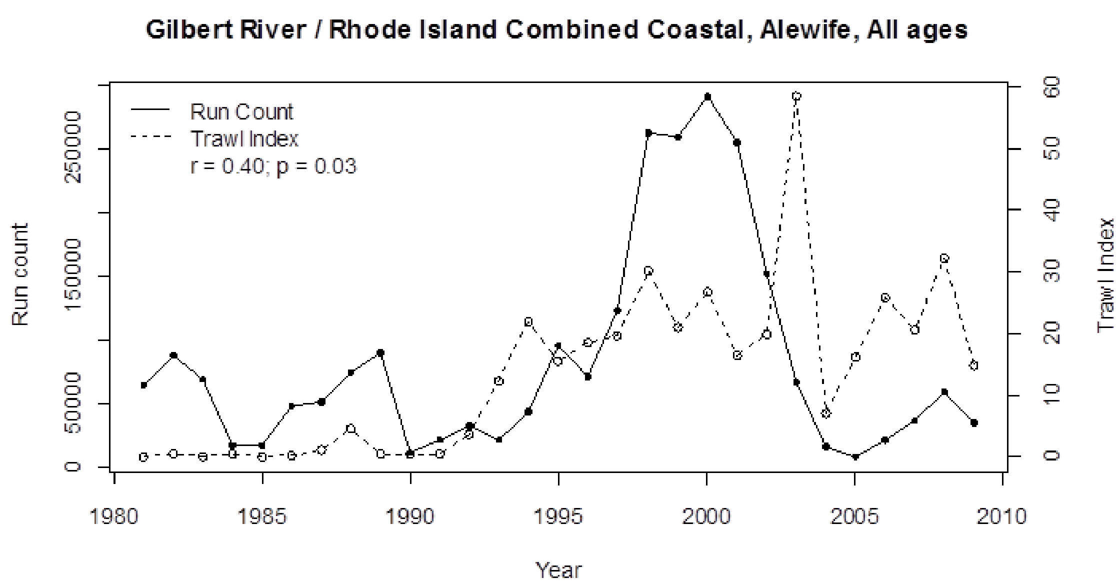




Figure 2.48 Alewife run counts in the Androscoggin and Gilbert Rivers and corresponding trawl surveys showing a significant positive Spearman rank correlation coefficient.

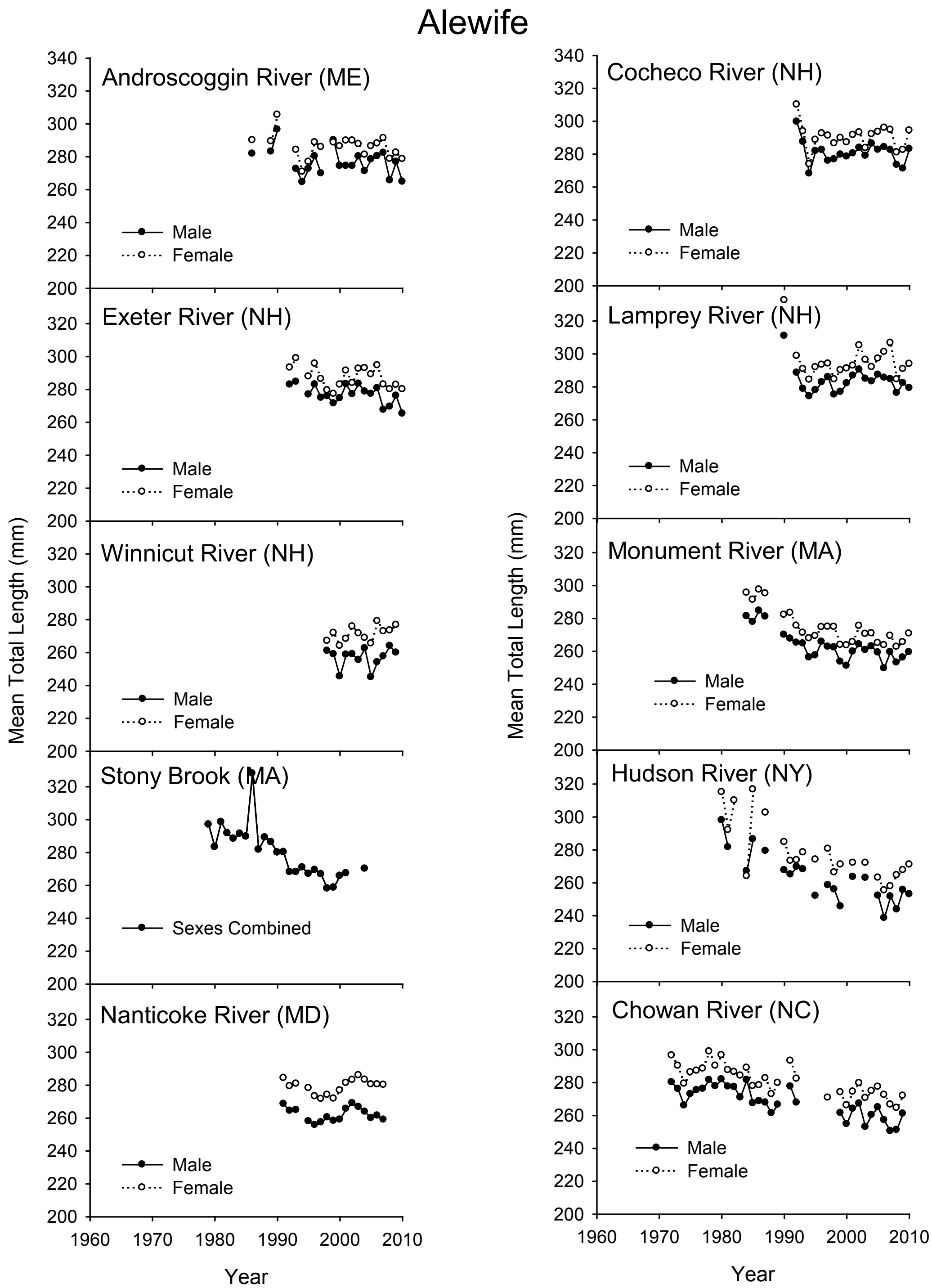



Figure 2.49. Mean lengths of male and female alewife by river and year.

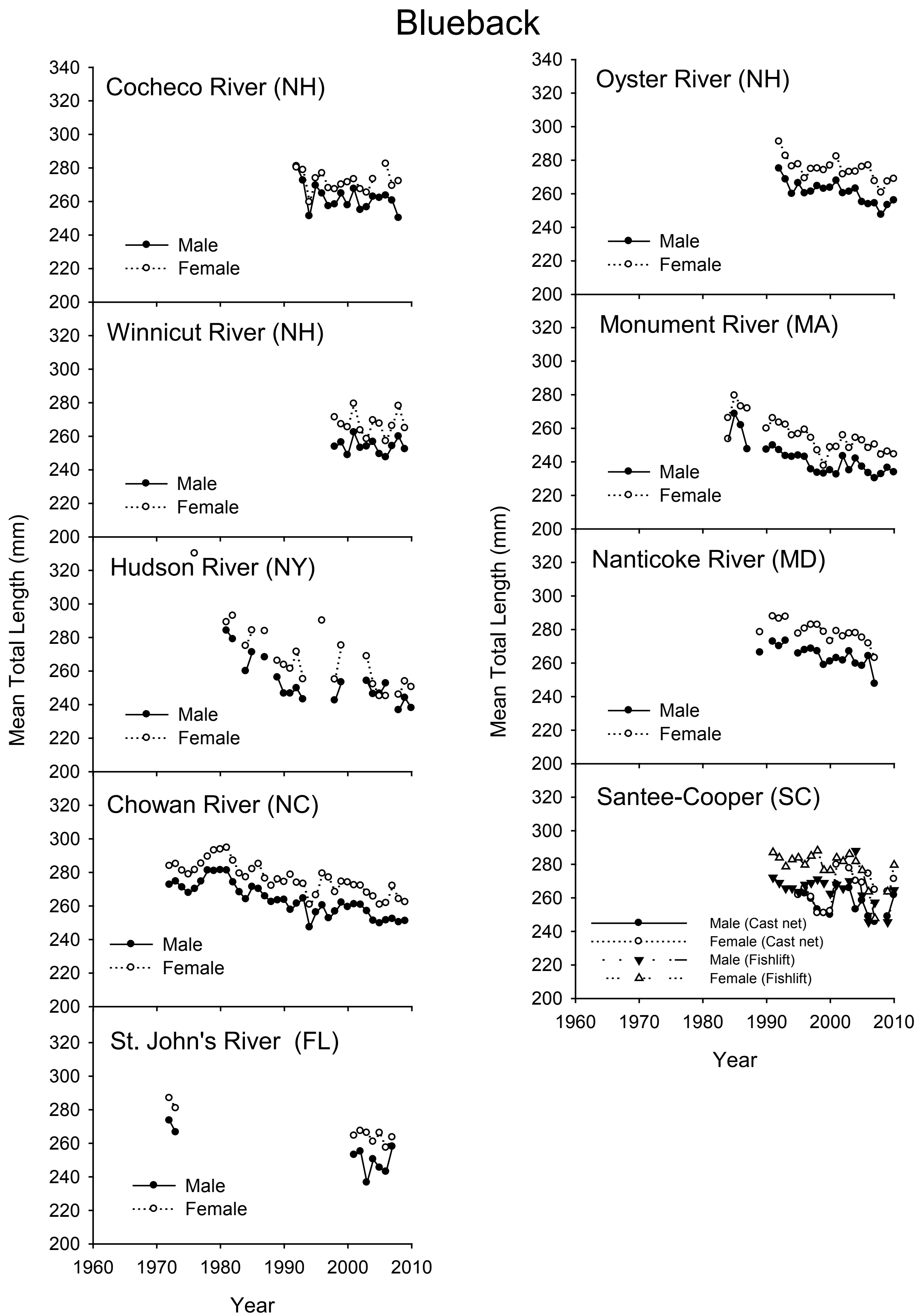



Figure 2.50. Mean lengths of male and female blueback herring by river and year.

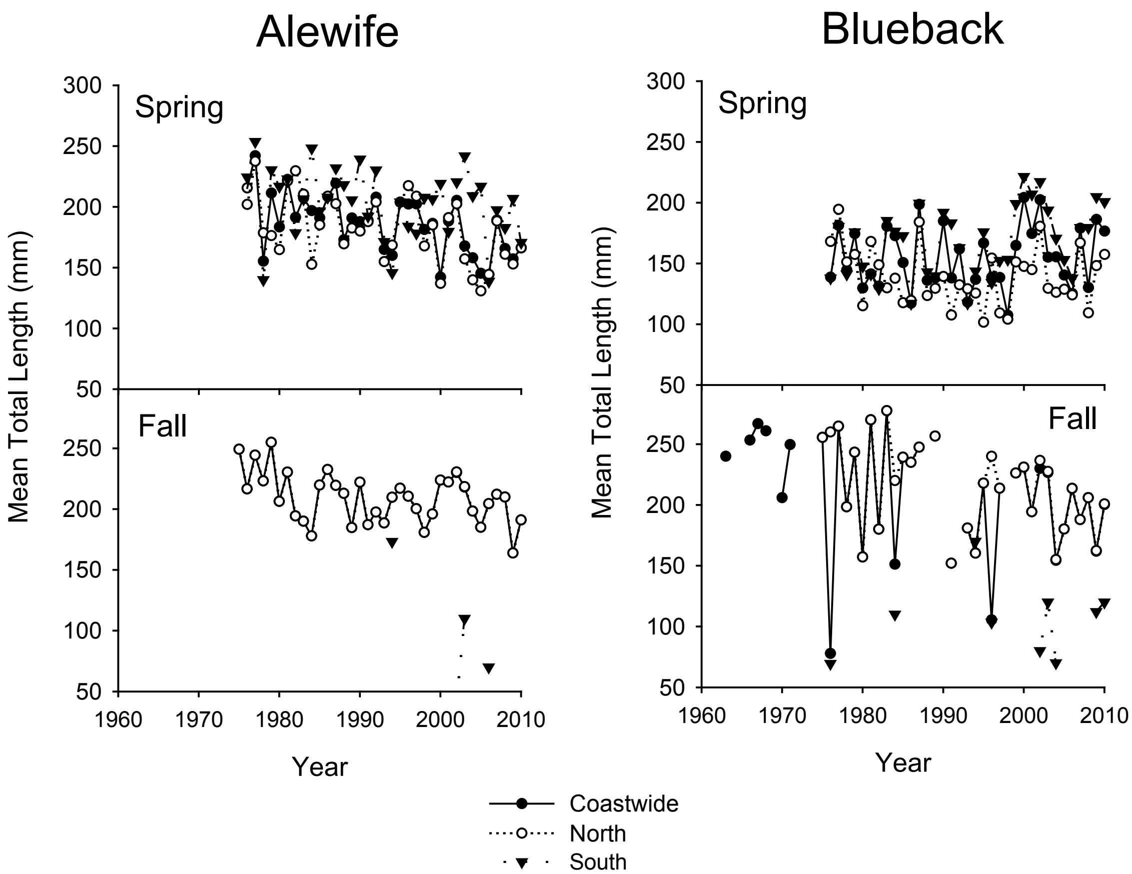



Figure 2.51. Mean lengths of alewife and blueback herring by region and year from the National Marine Fisheries Service bottom trawl survey.

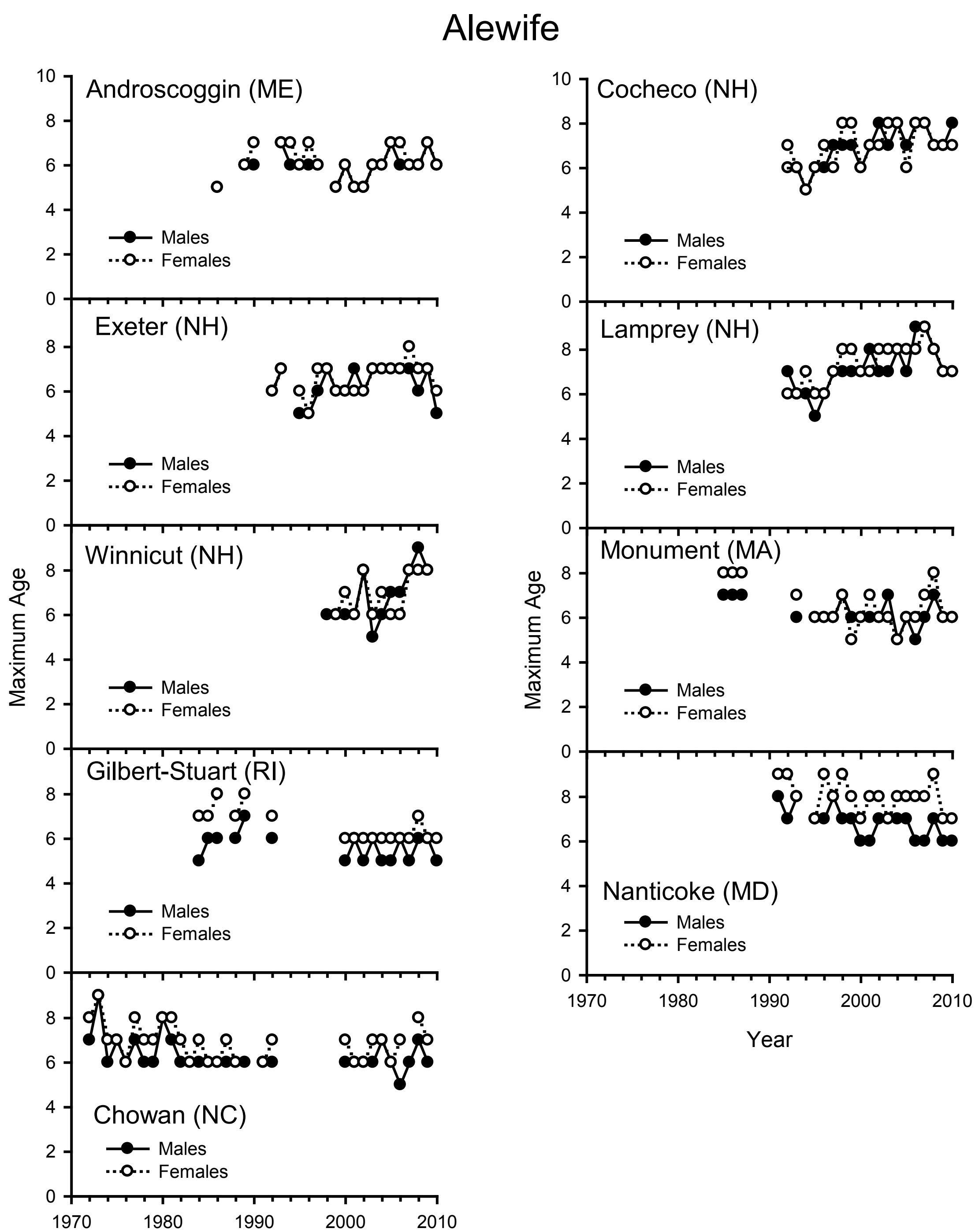



Figure 2.52. Maximum ages for male and female alewife by river.

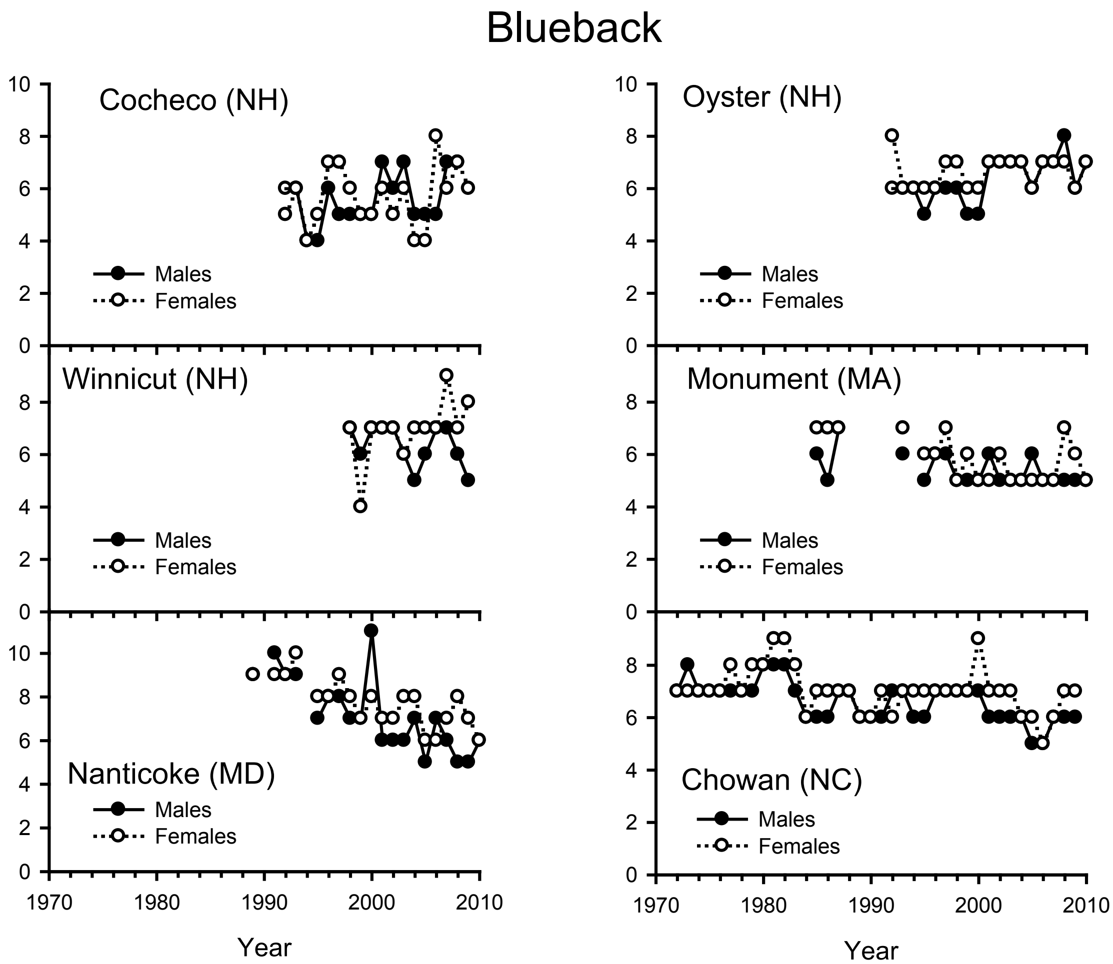



Figure 2.53. Maximum ages for male and female blueback by river.

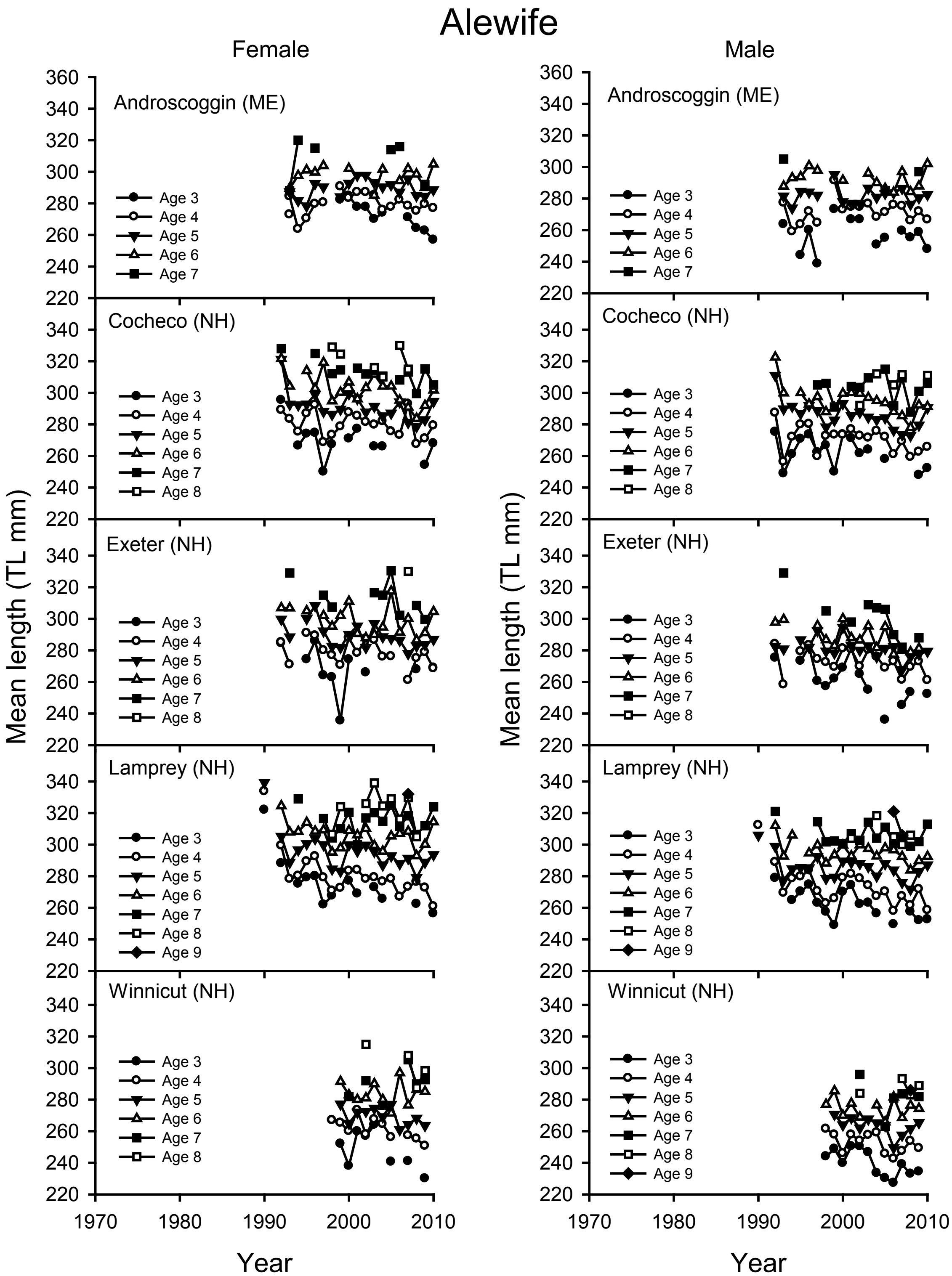



Figure 2.54. Mean lengths-at-age of male and female alewife from New Hampshire and Maine by sex, river, age and year.

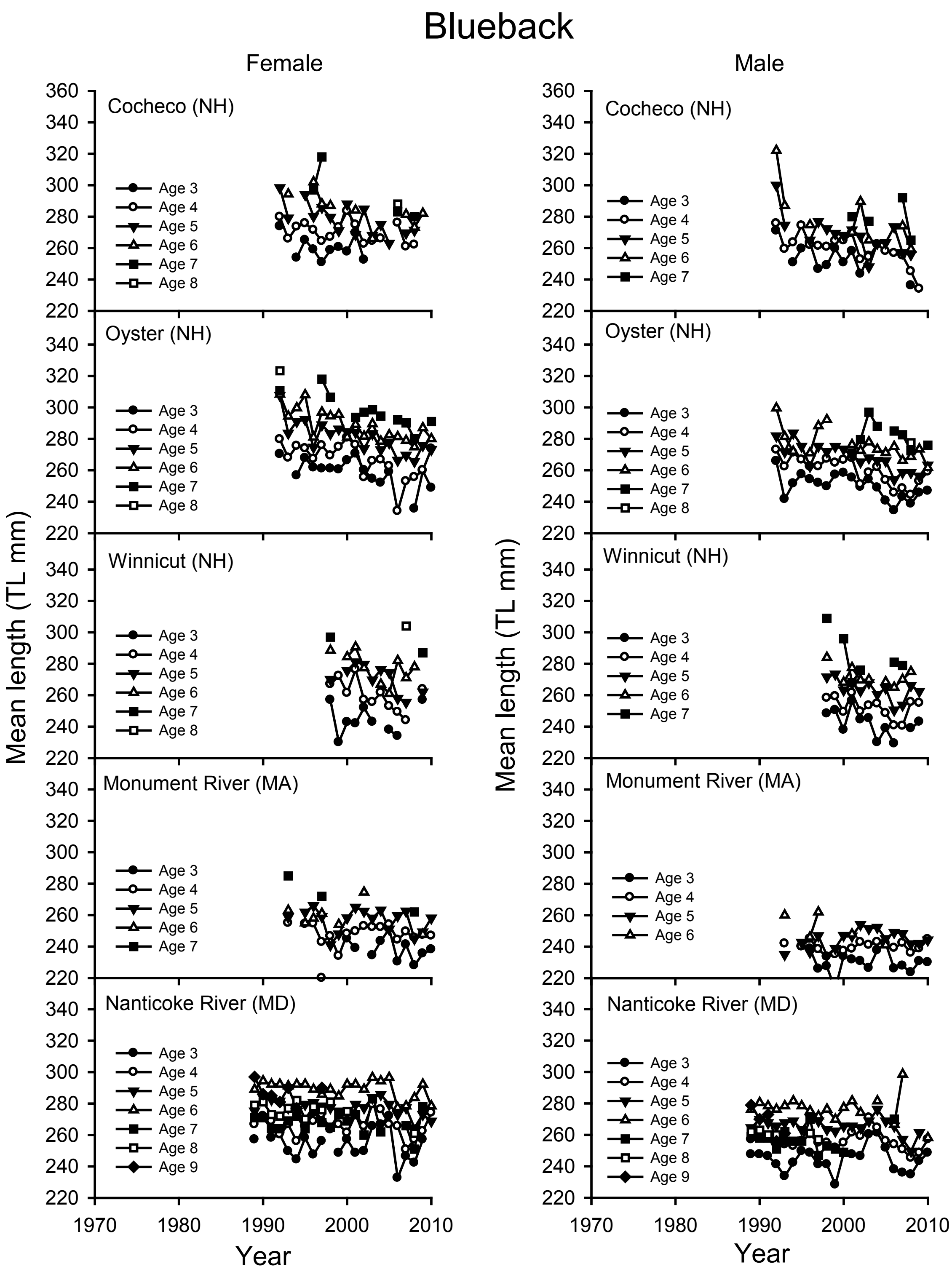



Figure 2.55 Mean lengths-at-age of male and female blueback herring from New Hampshire, Massachusetts, and Maryland by sex, river, age and year.

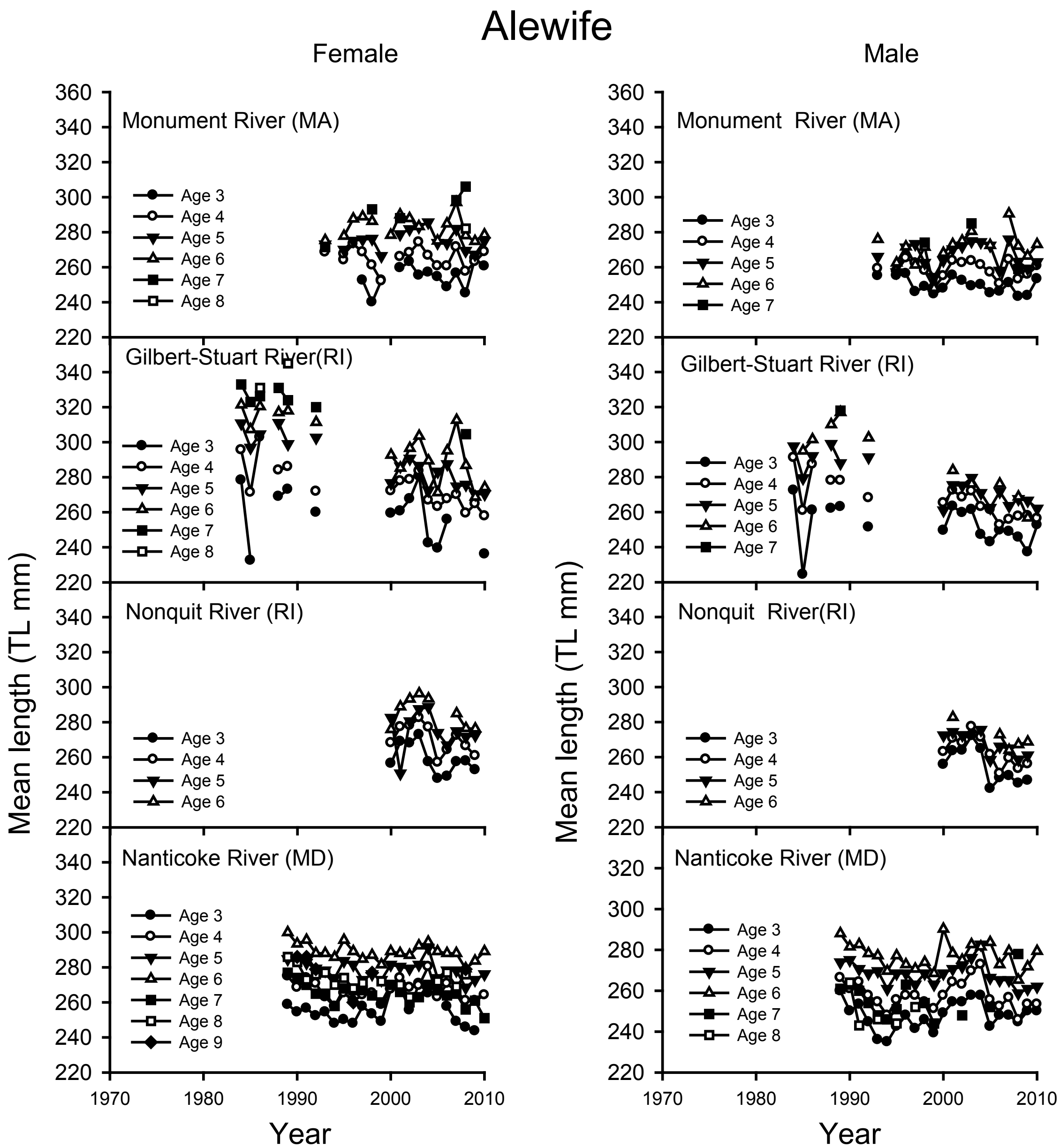



Figure 2.56. Mean lengths-at-age of male and female alewife from Massachusetts, Rhode Island and Maryland by sex, river, age and year.

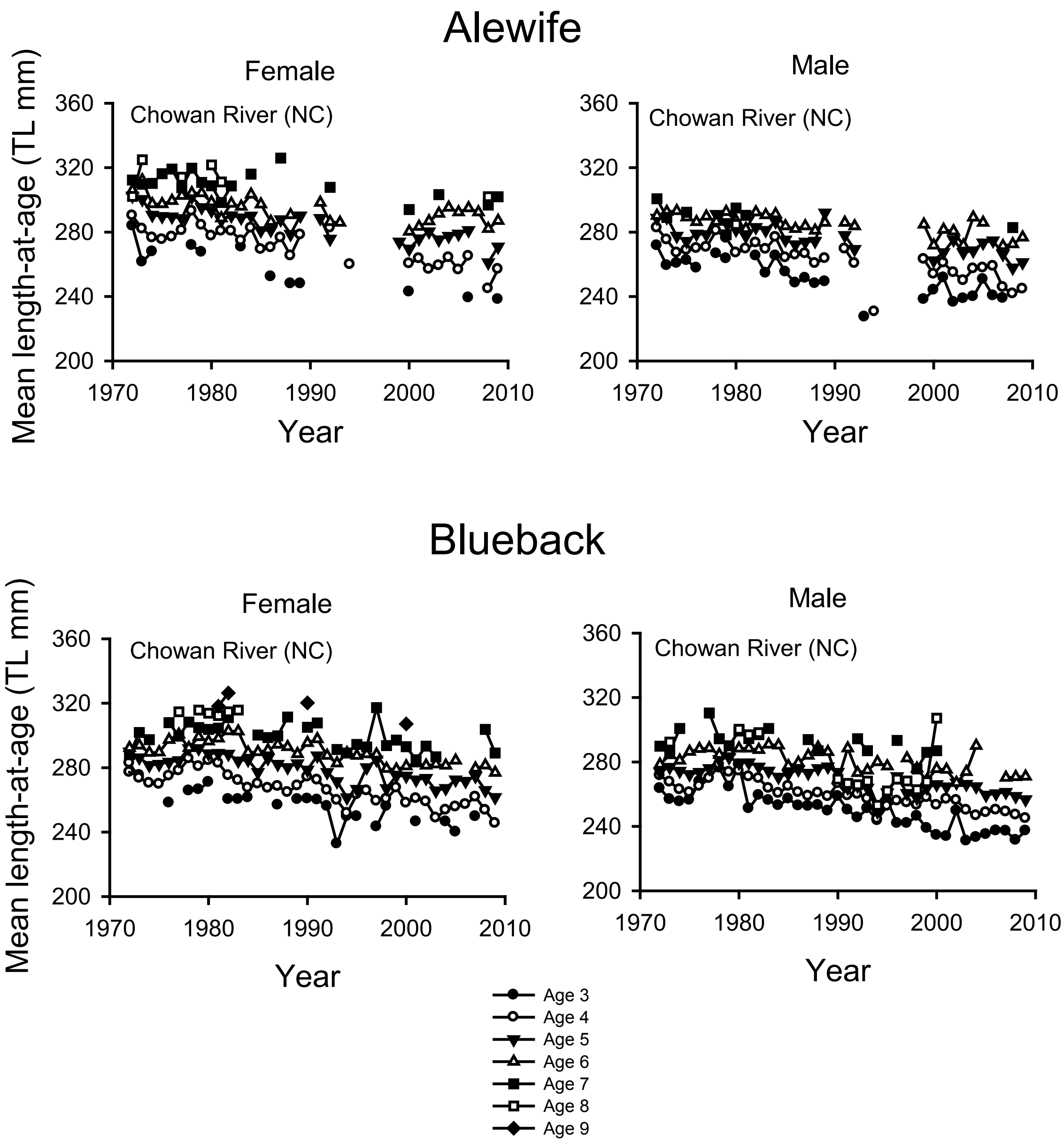



Figure 2.57. Mean lengths-at-age of male and female alewife and blueback herring from North Carolina by species, sex, age and year.

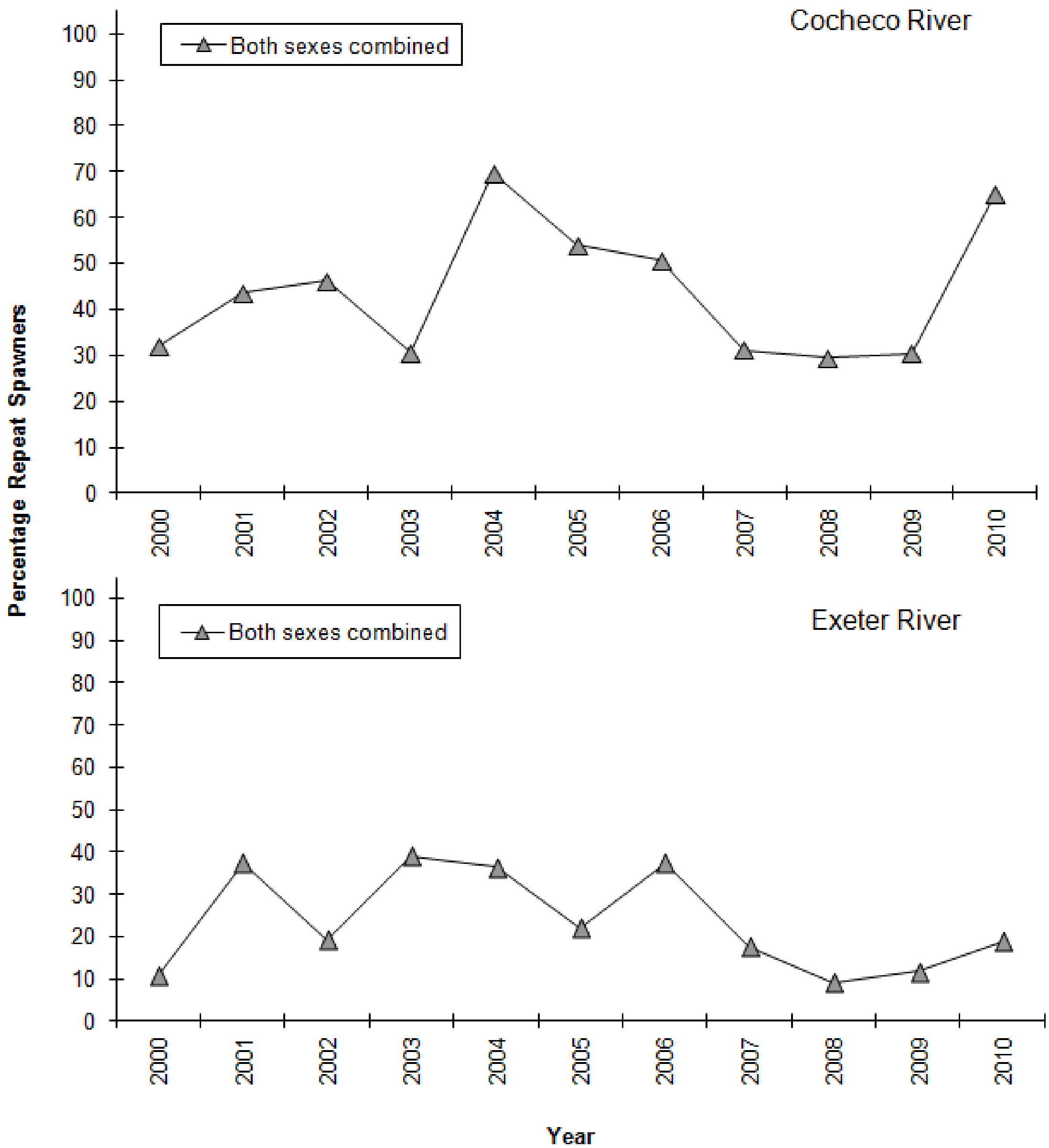



Figure 2.58. Annual repeat spawner rates for alewife observed in fisheries-independent surveys in New Hampshire by water body and year.

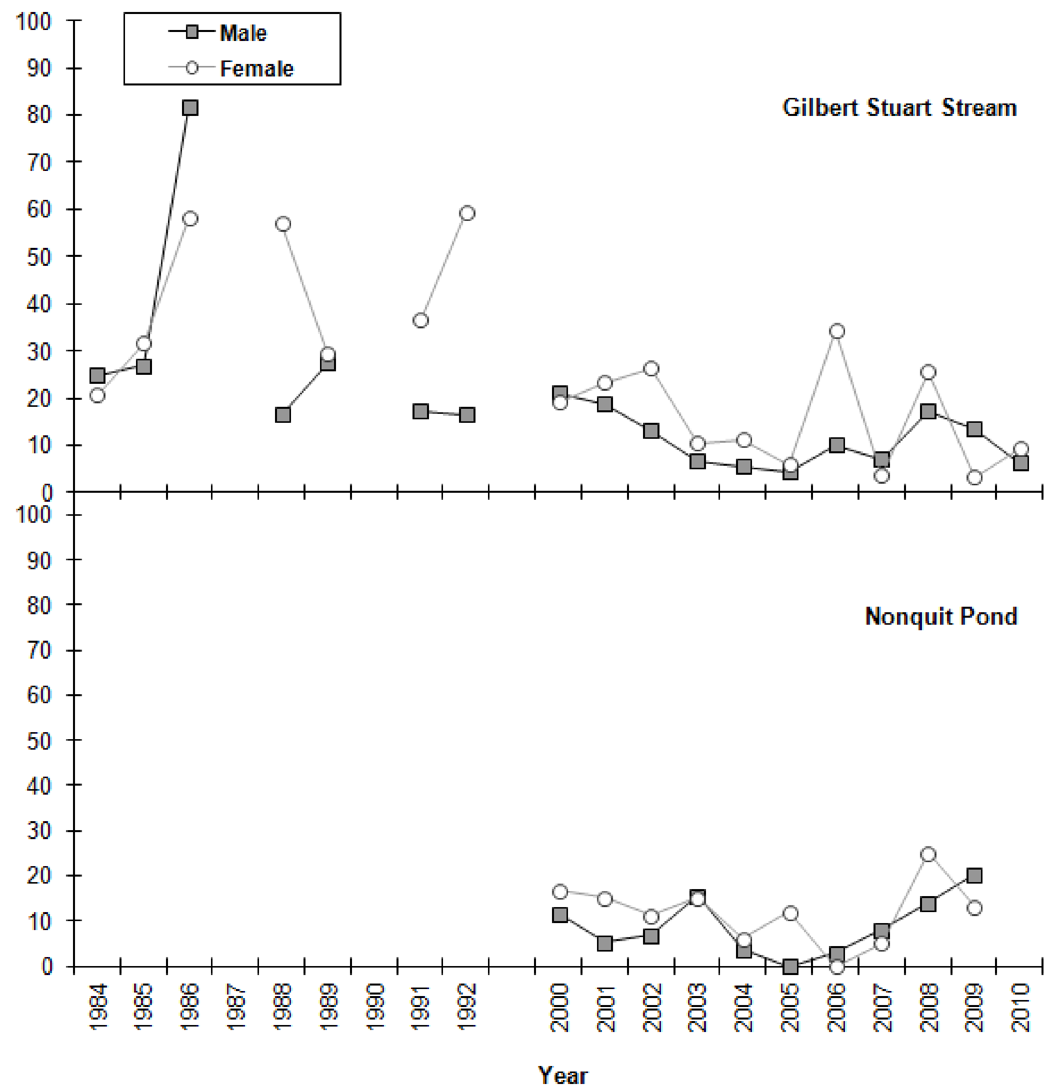



Figure 2.59. Annual repeat spawner rates for river herring (alewives and blueback herring combined) observed in fisheries-independent surveys in Rhode Island by water body, sex, and year.

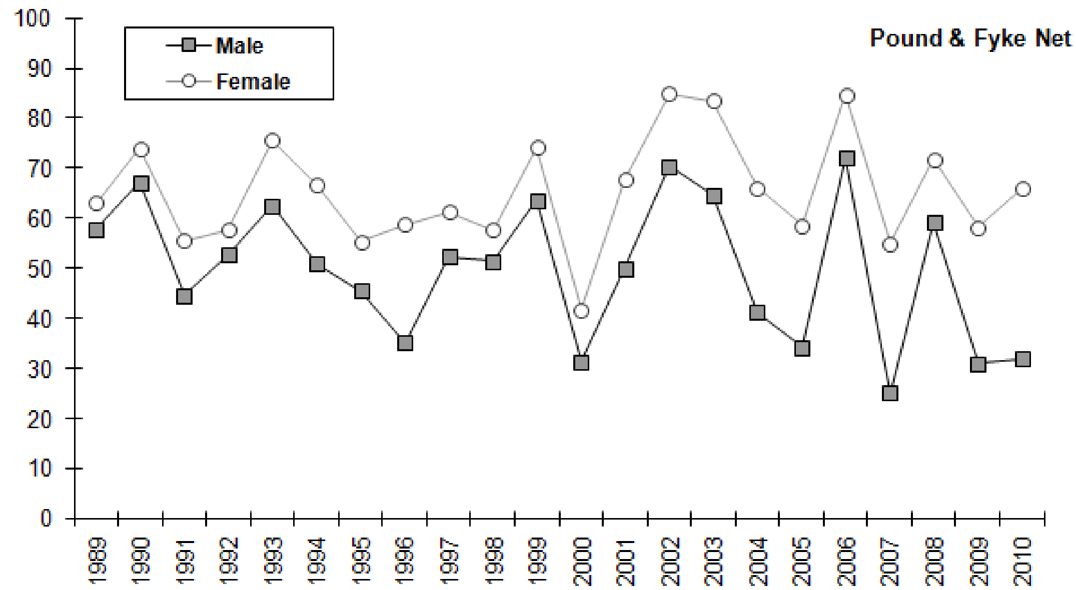



Figure 2.60. Annual repeat spawning rates for alewives observed in fisheries-dependent surveys of the Nanticoke River, MD by sex and year.

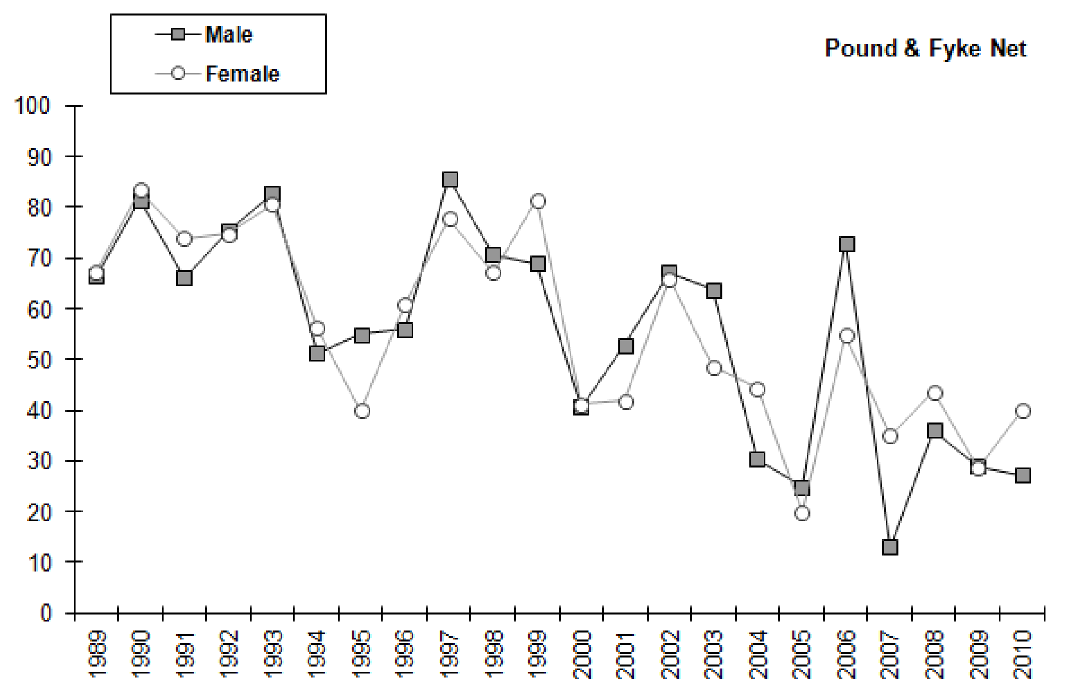



Figure 2.61. Annual repeat spawner rates for blueback herring observed in fisheries-dependent surveys of the Nanticoke River, MD by sex and year.

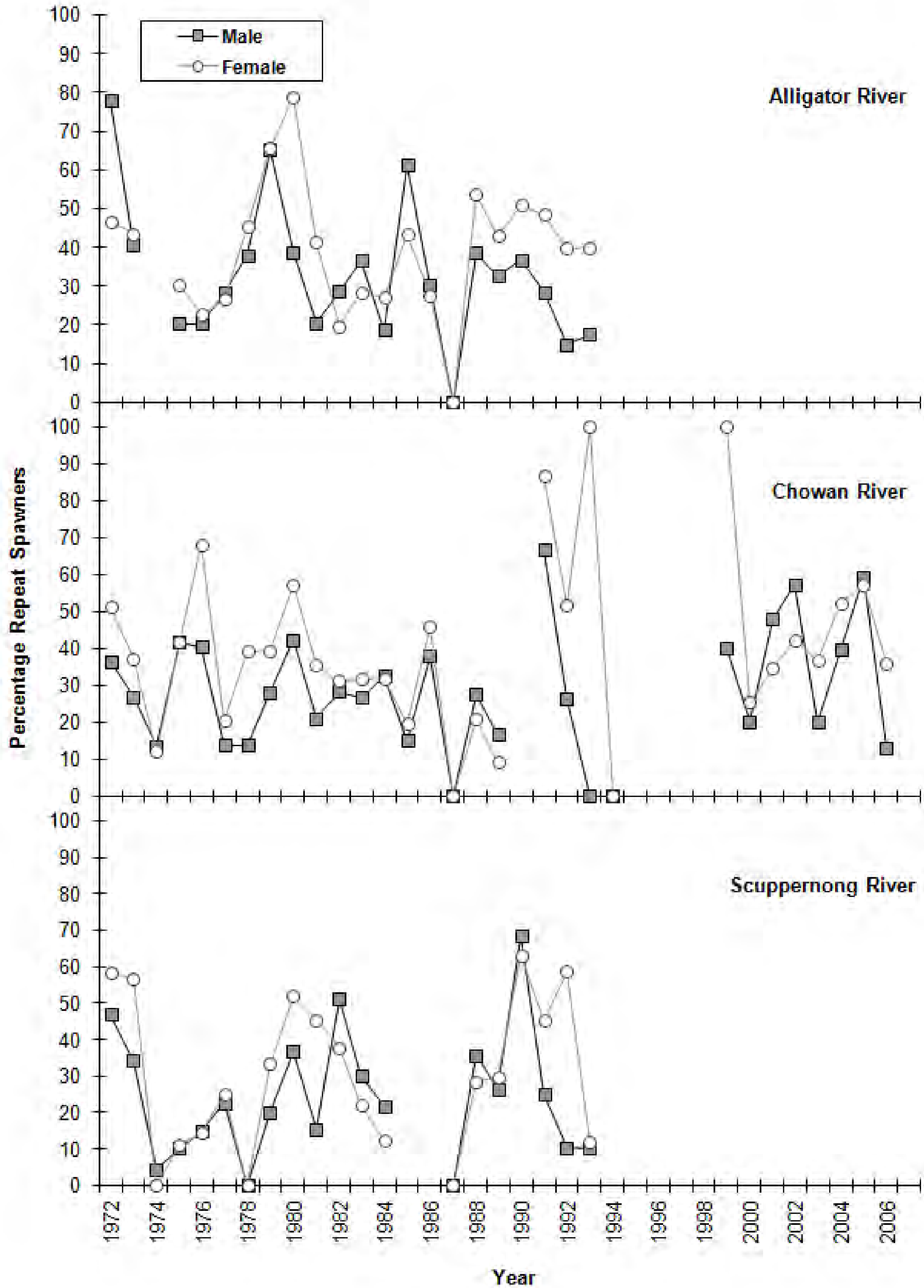



Figure 2.62. Annual repeat spawner rates for alewives observed in fisheries-dependent pound net surveys in North Carolina by water body, sex, and year.

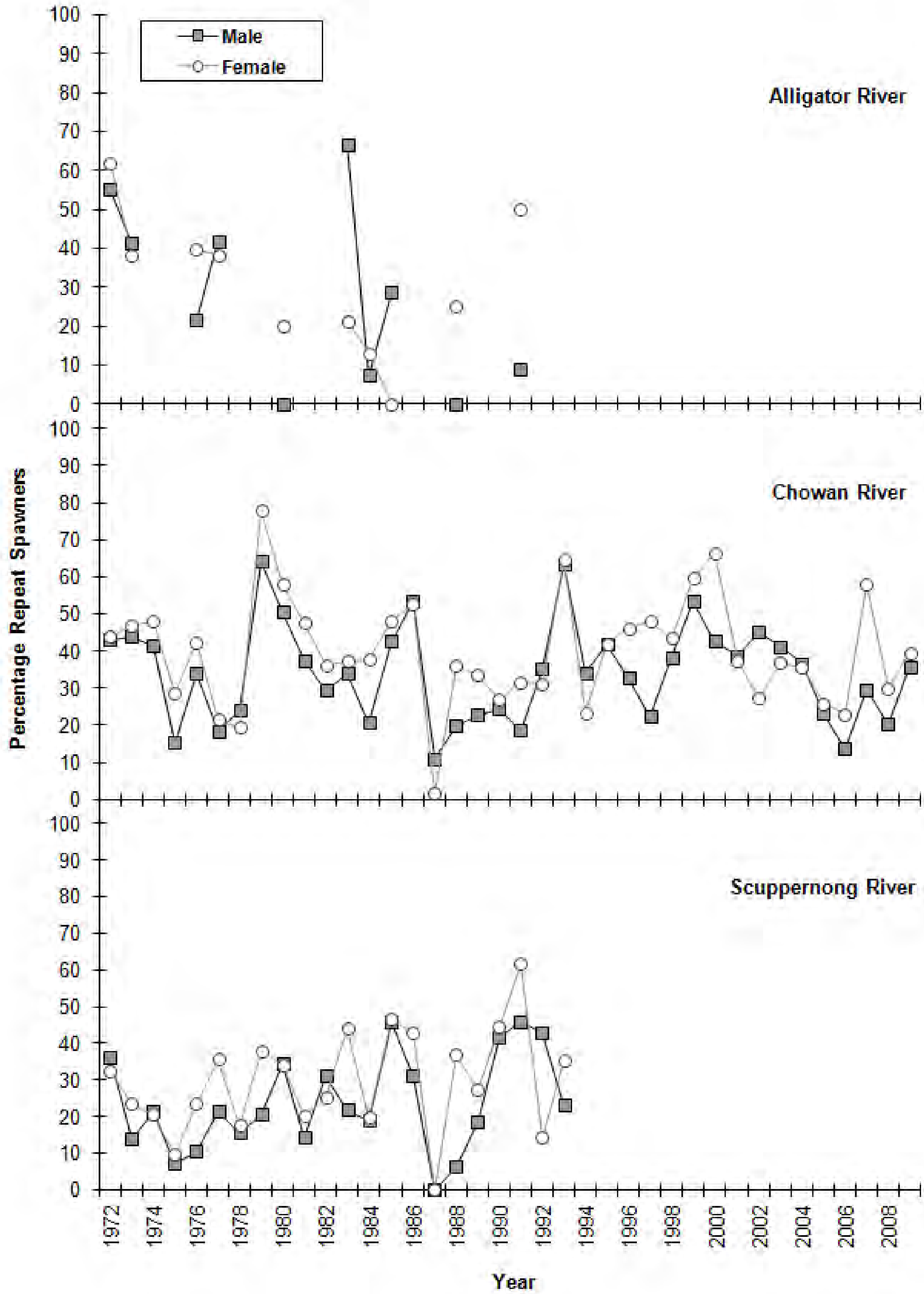



Figure 2.63. Annual repeat spawner rates for blueback herring observed in fisheries-dependent pound net surveys in North Carolina by water body, sex, and year.

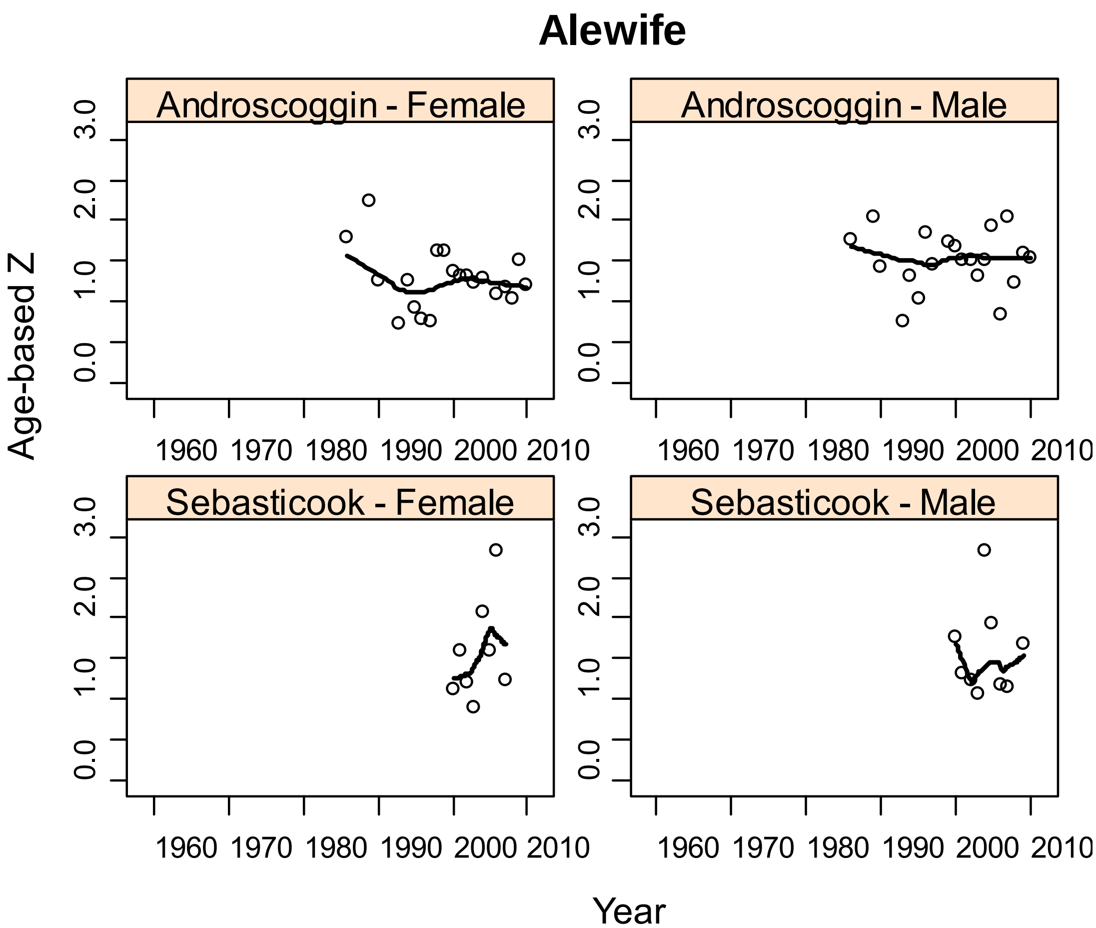



Figure 2.64. Age-based estimates of total instantaneous mortality (Z) for alewife from Maine by river, sex, and year. Linear or loess smooths are drawn to indicate trend.

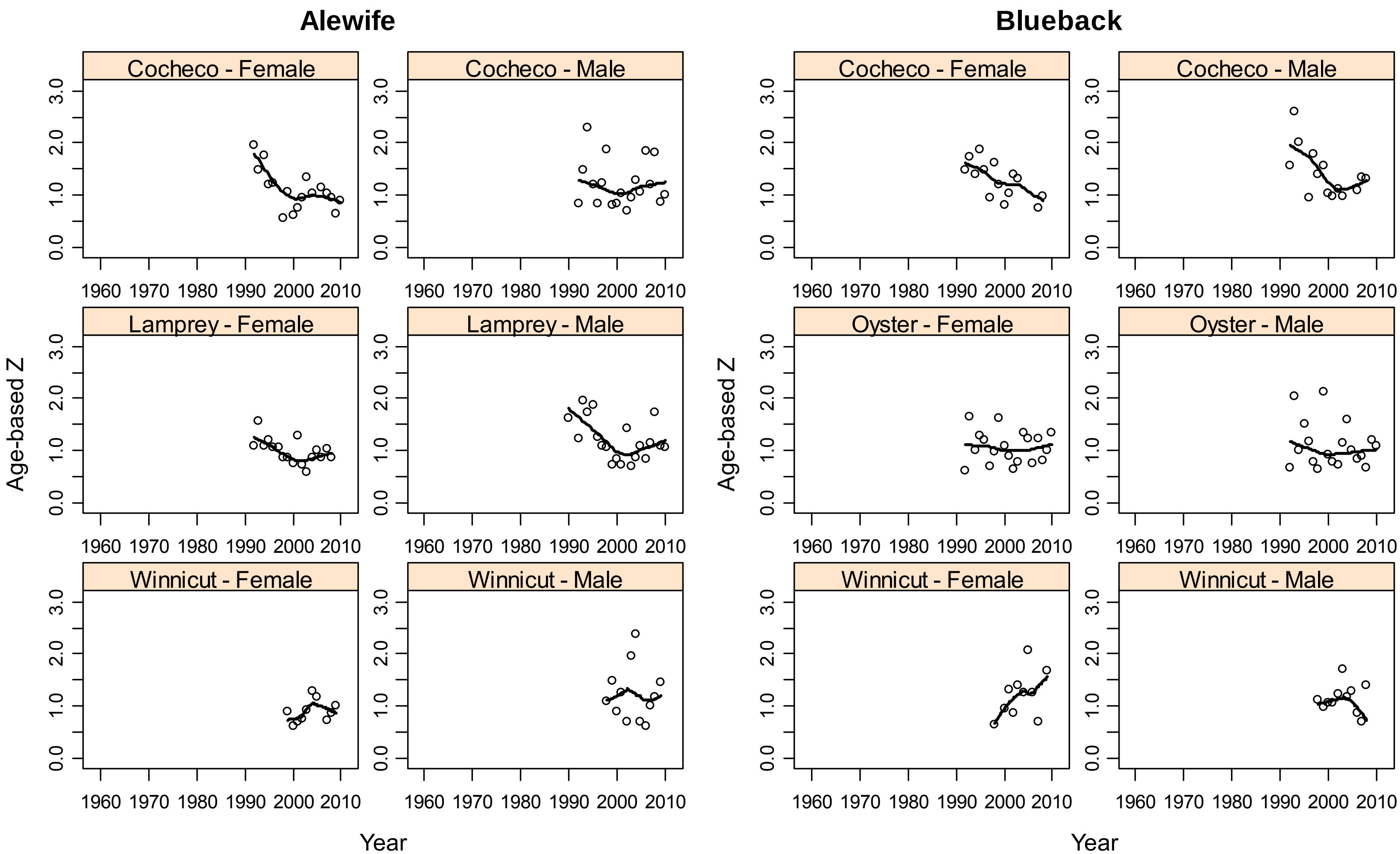



Figure 2.65 Age-based estimates of total instantaneous mortality (Z) for alewife and blueback herring from New Hampshire by river, sex, and year. Linear or loess smooths are drawn to indicate trend.

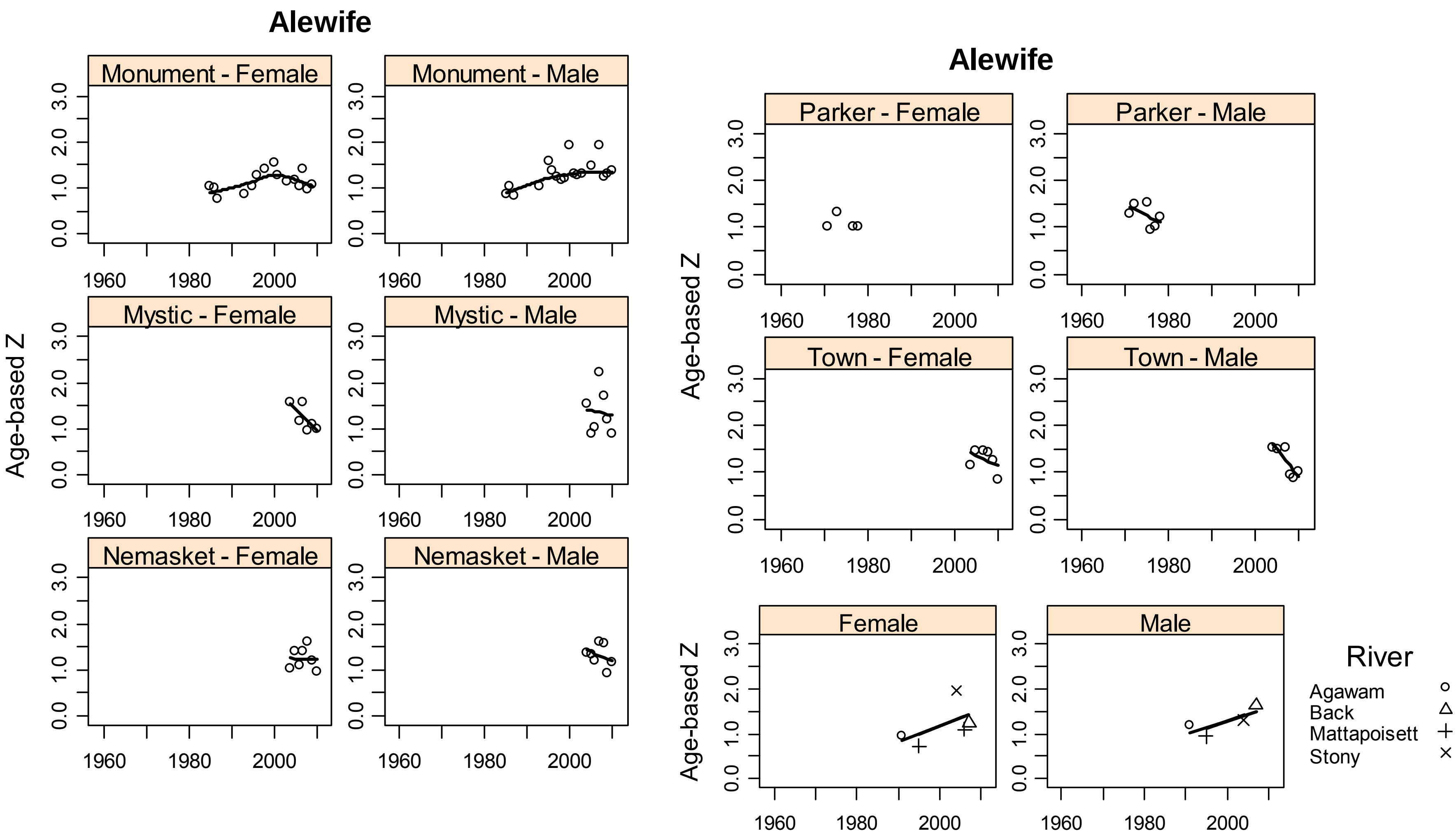



Figure 2.66. Age-based estimates of total instantaneous mortality (Z) for alewife from Massachusetts by river, sex, and year. Linear or loess smooths are drawn to indicate trend.

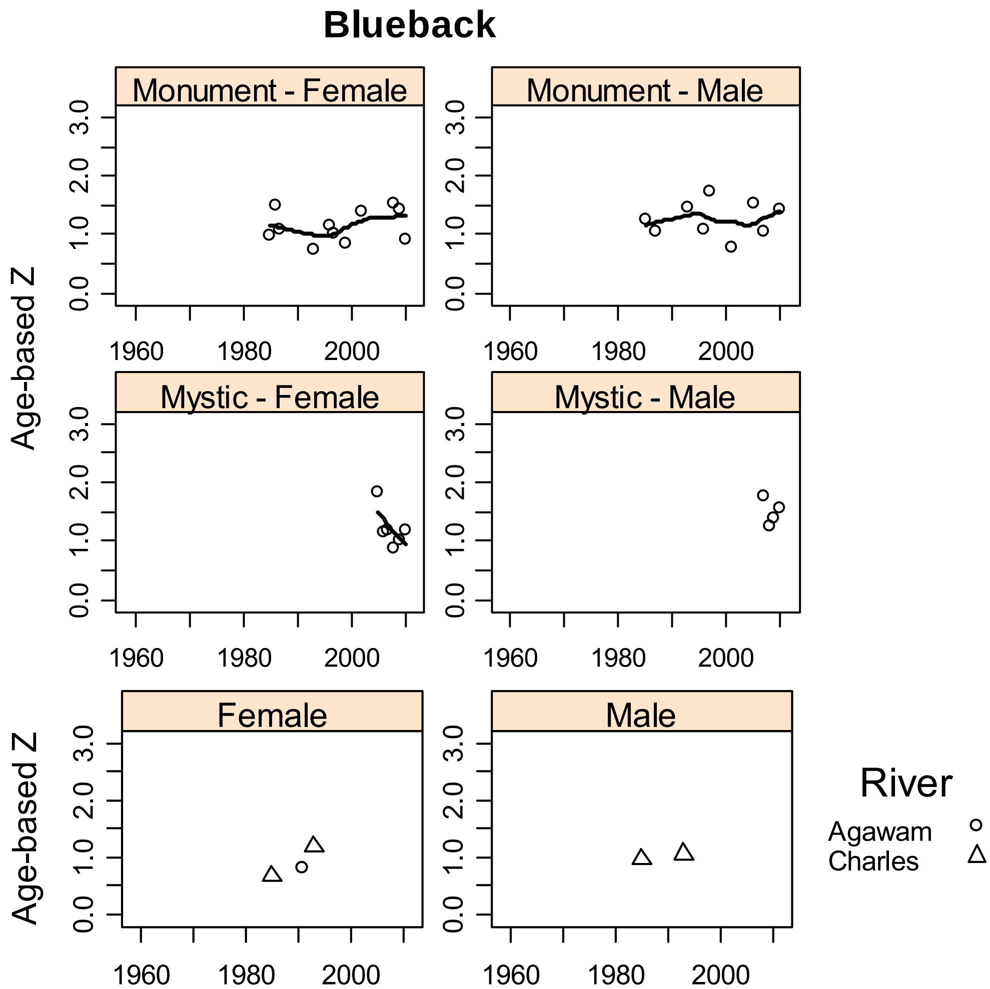



Figure 2.67. Age-based estimates of total instantaneous mortality (Z) for blueback herring from Massachusetts by river, sex, and year. Linear or loess smooths are drawn to indicate trend.


Figure 2.68 Age-based estimates of total instantaneous mortality (Z) for blueback herring from New York by river, sex, and year. Linear or loess smooths are drawn to indicate trend.

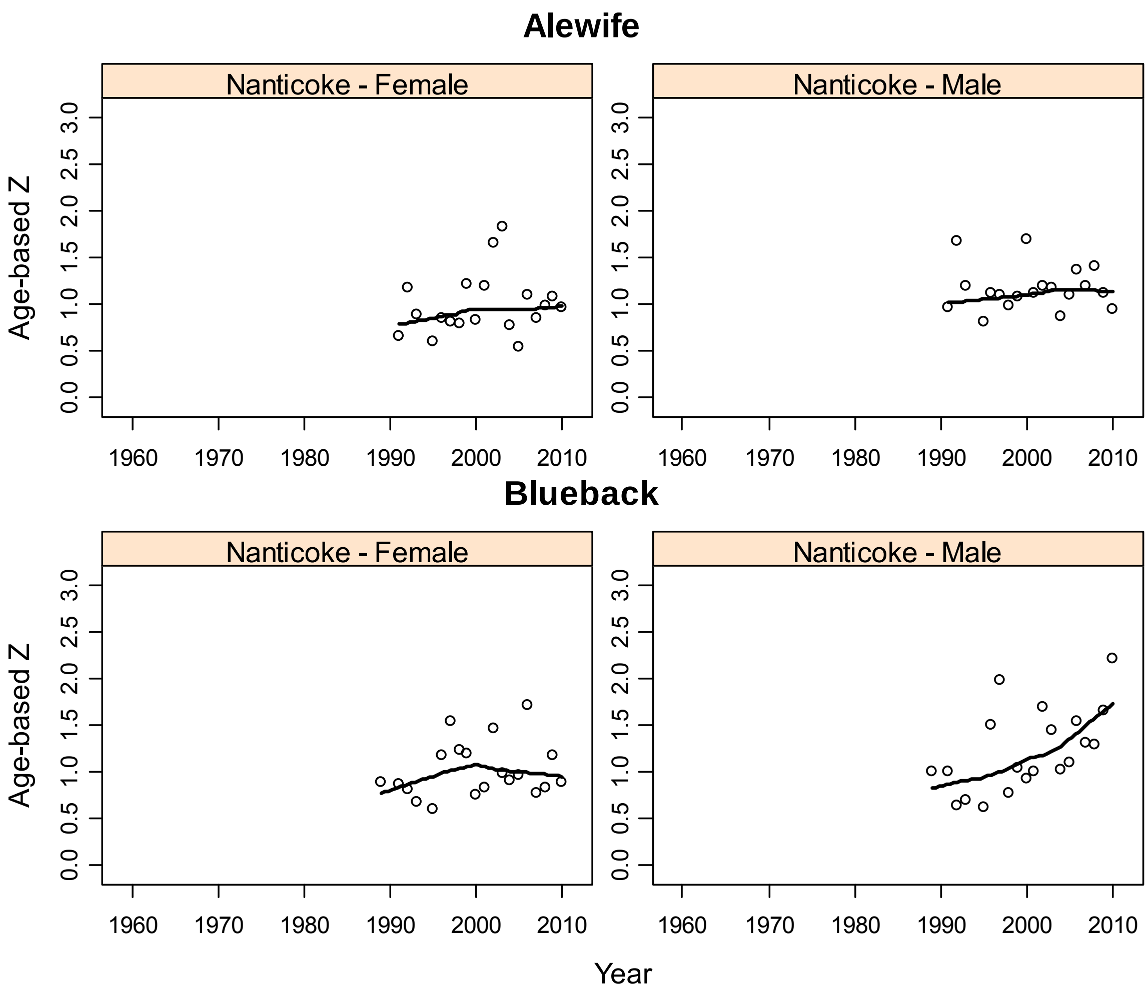



Figure 2.69. Age-based estimates of total instantaneous mortality (Z) for alewife and blueback herring from Maryland by river, sex, and year. Linear or loess smooths are drawn to indicate trend.

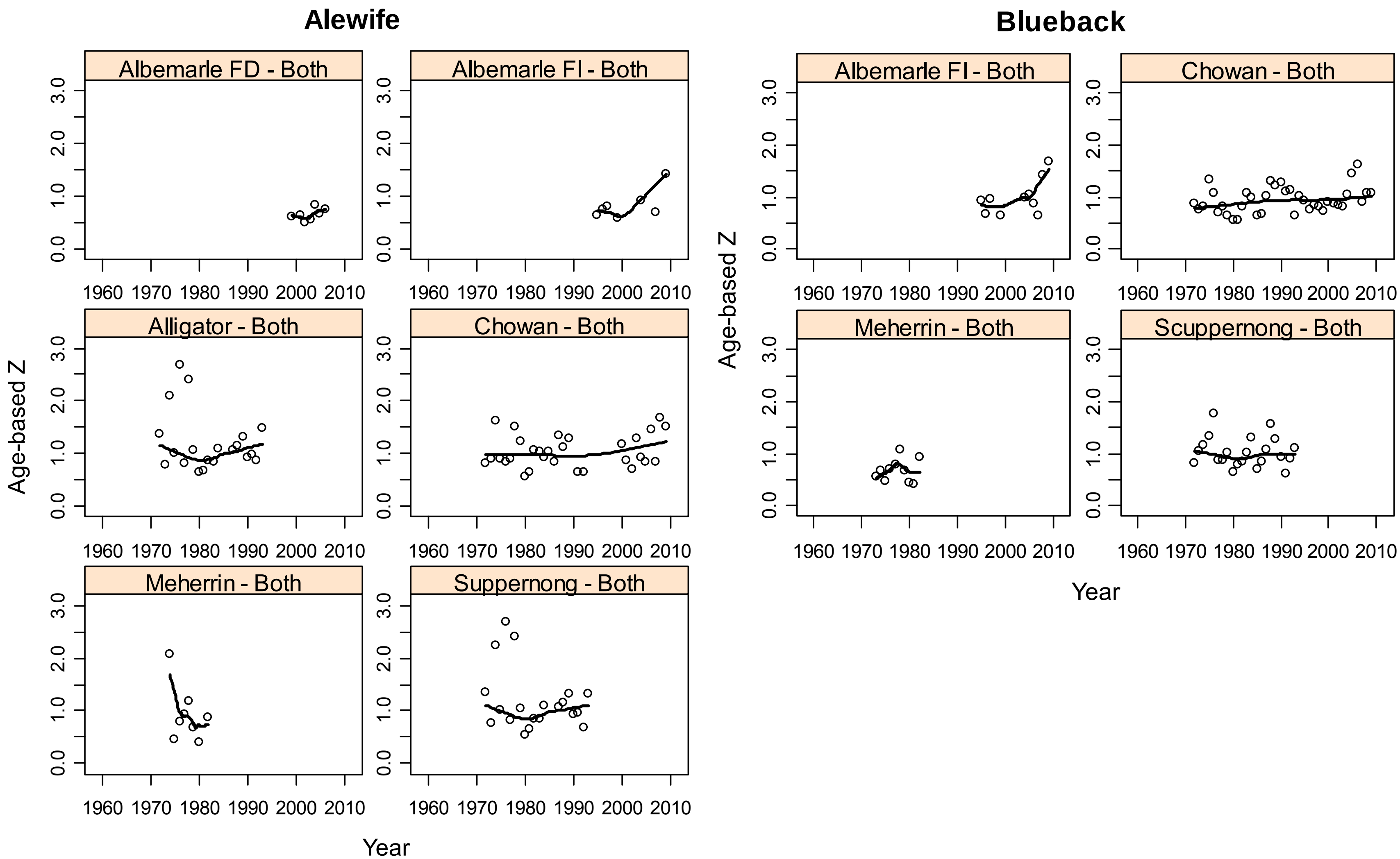



Figure 2.70. Age-based estimates of total instantaneous mortality (Z) for alewife and blueback herring (sexes combined) from North Carolina by river. Linear or loess smooths are drawn to indicate trend.

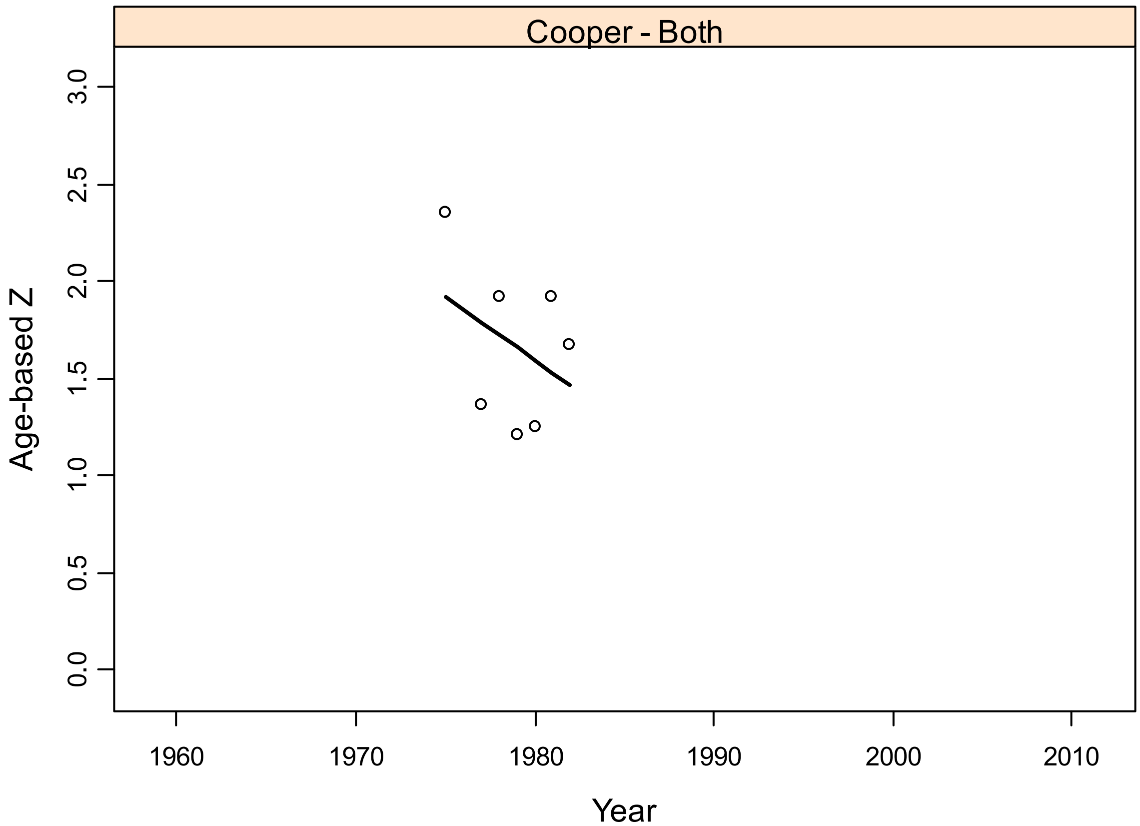



Figure 2.71. Age-based estimates of total instantaneous mortality (Z) for blueback herring (sexes combined) from South Carolina. Linear or loess smooths are drawn to indicate trend.

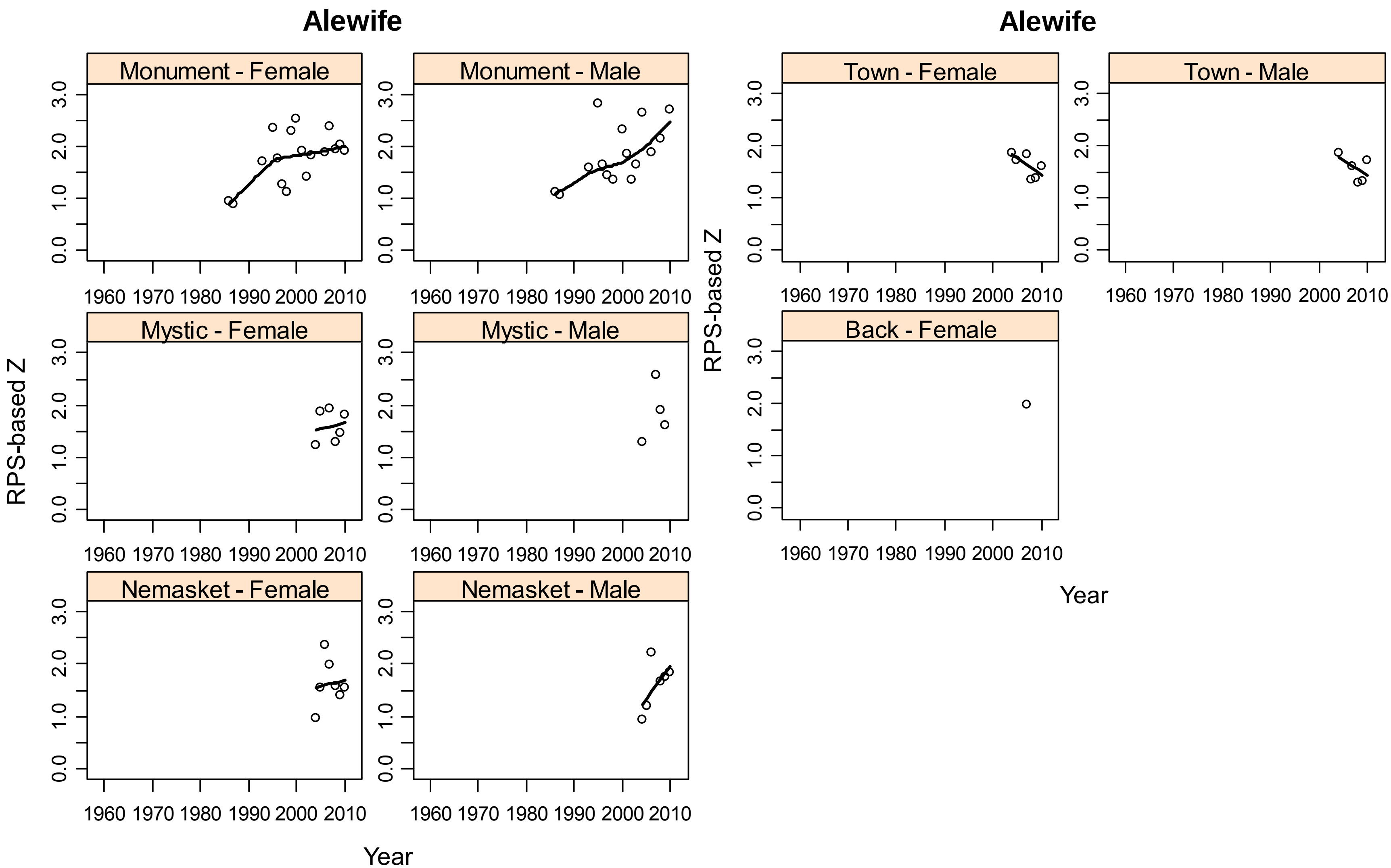



Figure 2.72 Repeat spawner-based estimates of total instantaneous mortality (Z) for alewife from Massachusetts by year, sex and river from Massachusetts. Linear or loess smooths are drawn to indicate trend.

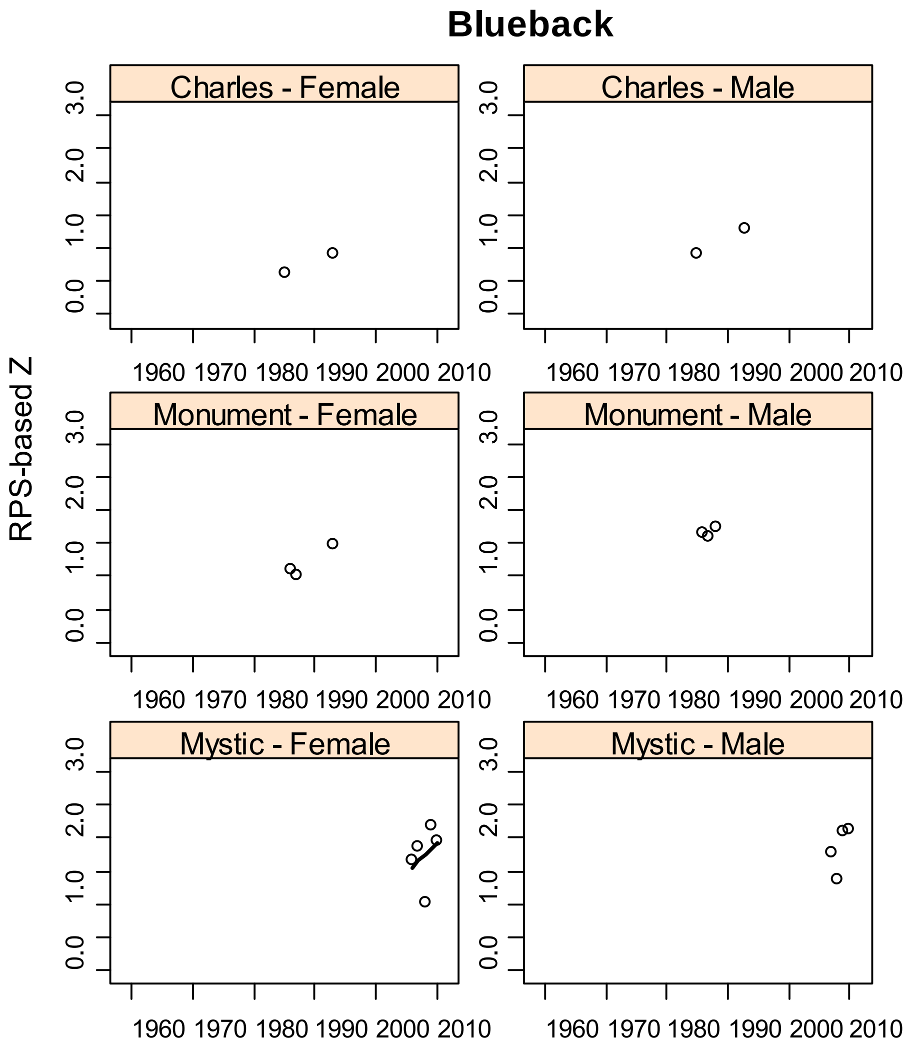



Figure 2.73. Repeat spawner-based estimates of total instantaneous mortality (Z) for blueback herring from Massachusetts by year, sex and river from Massachusetts. Linear or loess smooths are drawn to indicate trend.

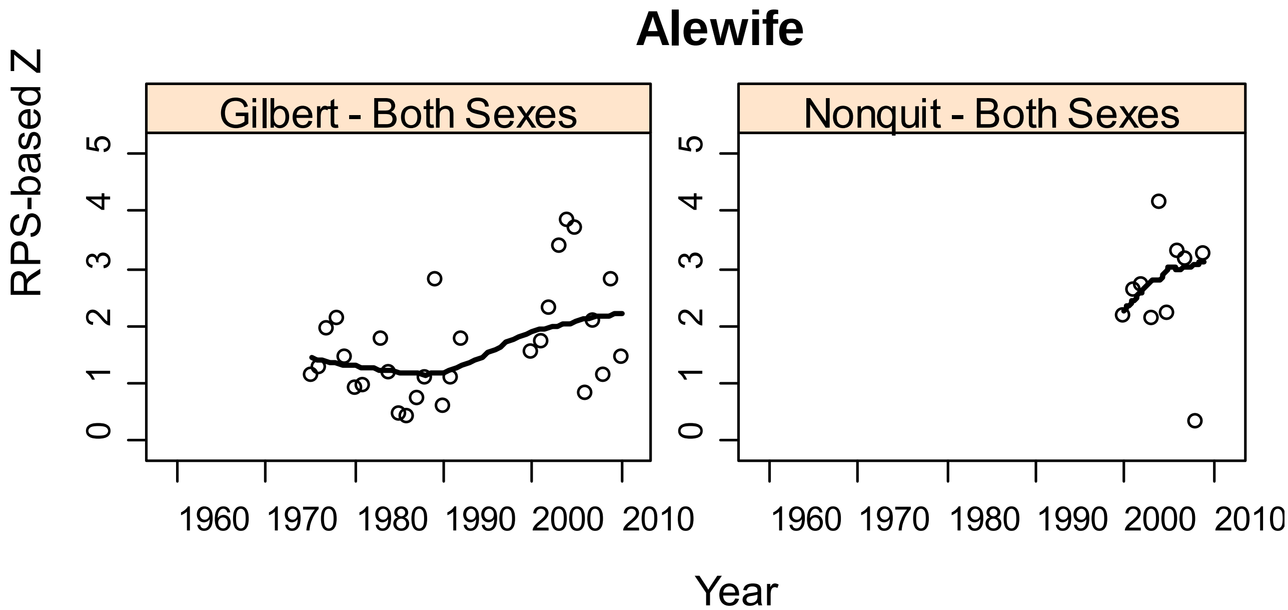



Figure 2.74. Repeat spawner-based estimates of total instantaneous mortality (Z) for alewife (sexes combined) from Rhode Island by river and year. Linear or loess smooths are drawn to indicate trend.

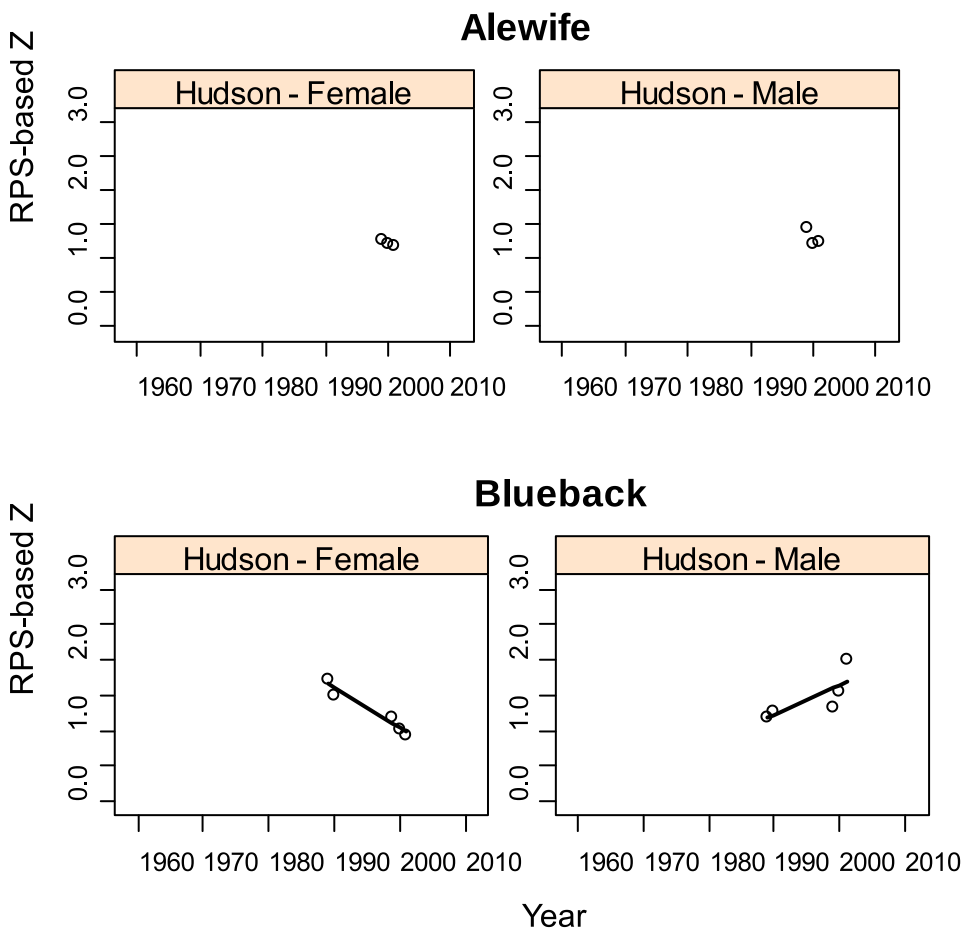



Figure 2.75. Repeat spawner-based estimates of total instantaneous mortality (Z) for male and female alewife and blueback herring by year, sex and river from New York. Linear or loess smooths are drawn to indicate trend.

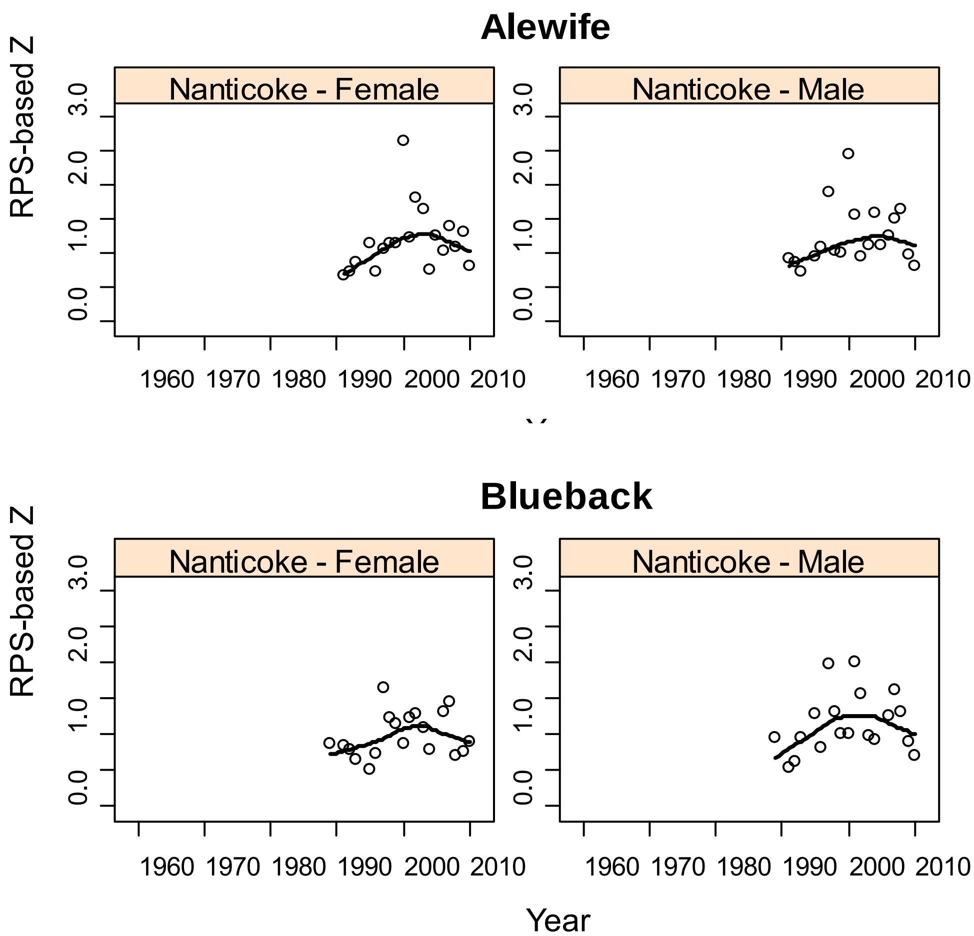



Figure 2.76 Repeat spawner-based estimates of total instantaneous mortality (Z) for alewife and blueback herring from Maryland by river, sex and year. Linear or loess smooths are drawn to indicate trend.

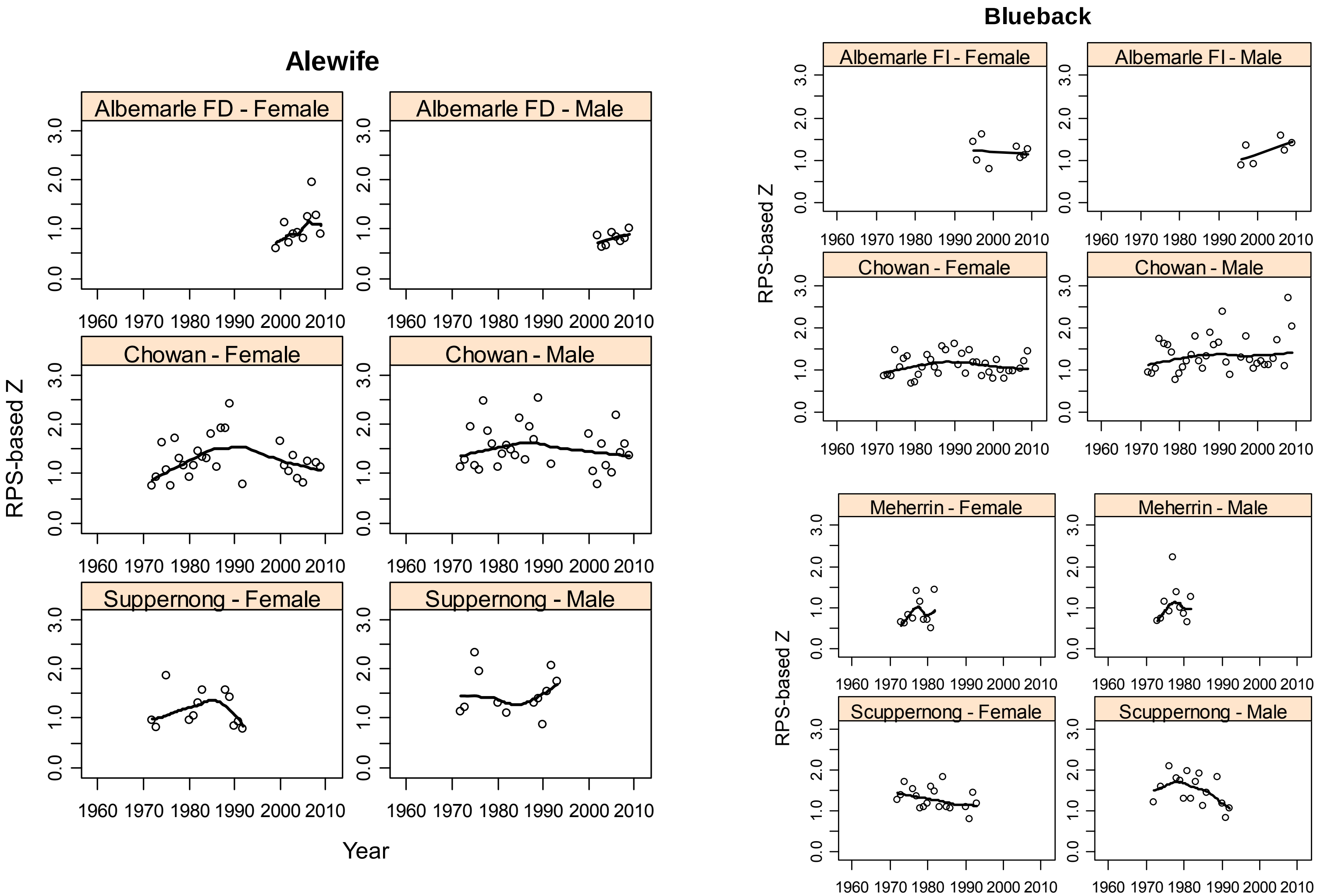



Figure 2.77. Repeat spawner-based estimates of total instantaneous mortality (Z) for alewife and blueback herring from North Carolina by river, sex and year. Linear or loess smooths are drawn to indicate trend.

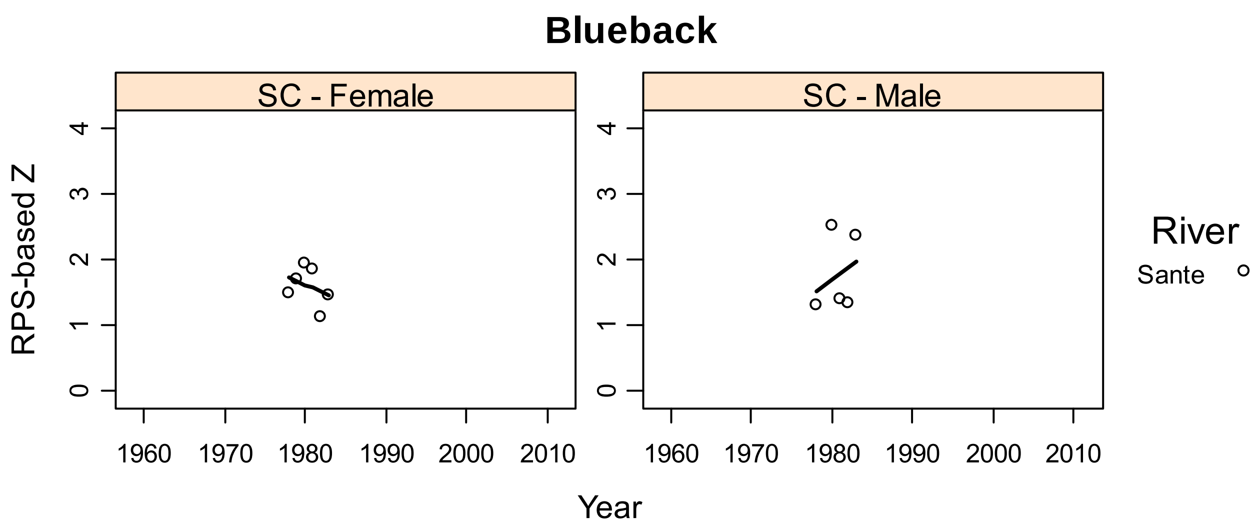



Figure 2.78 Repeat spawner-based estimates of total instantaneous mortality (Z) for blueback herring from South Carolina by river, sex and year. Linear or loess smooths are drawn to indicate trend.

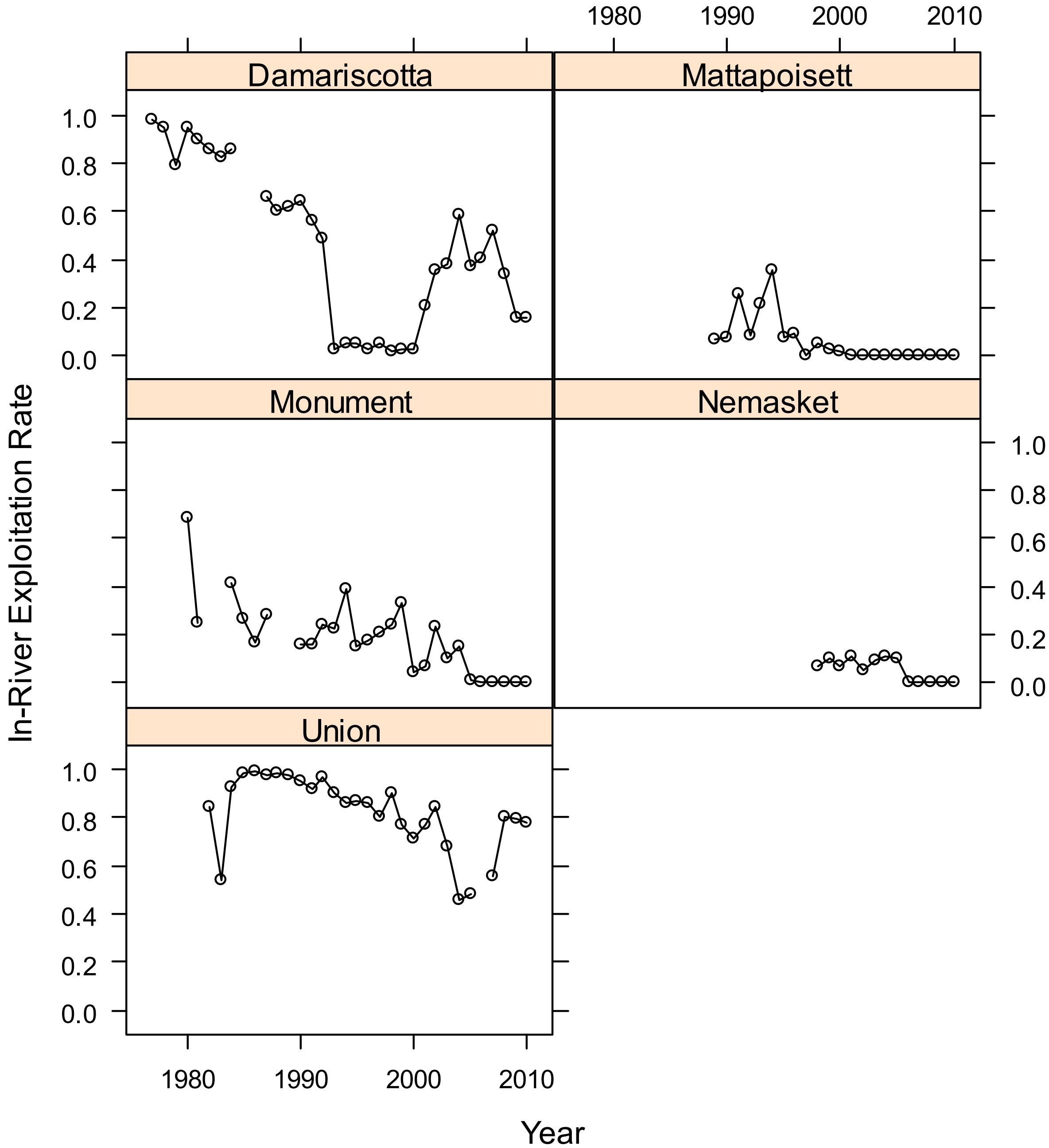



Figure 2.79. In-river exploitation rates for river herring from Massachusetts and Maine rivers, 1977-2010.

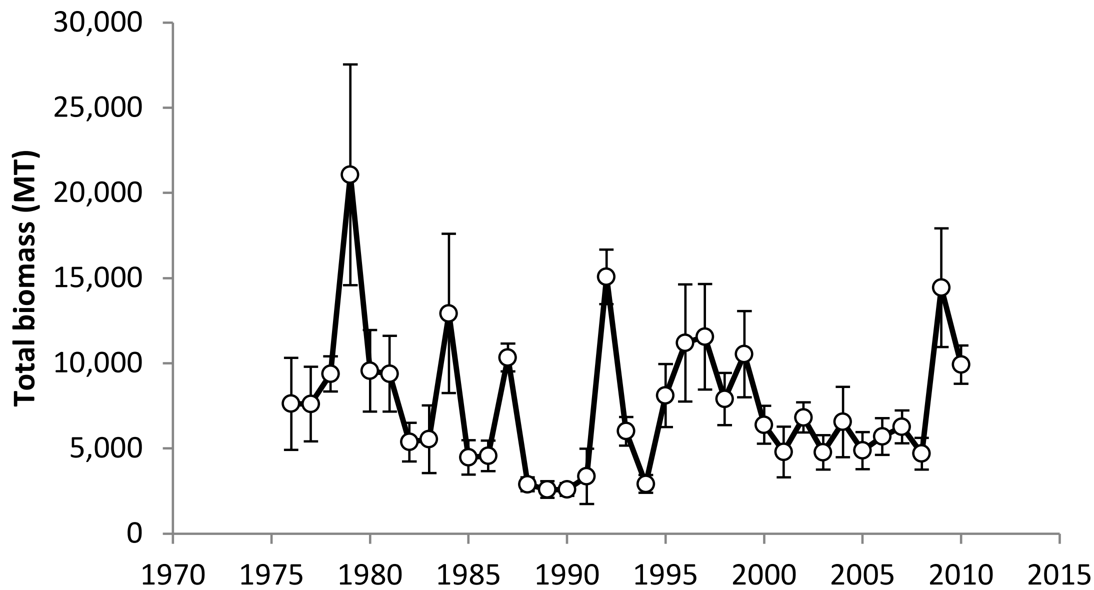



Figure 2.80. Minimum swept area estimates of total river herring biomass from NEFSC spring bottom trawl surveys (1976 – 2010).

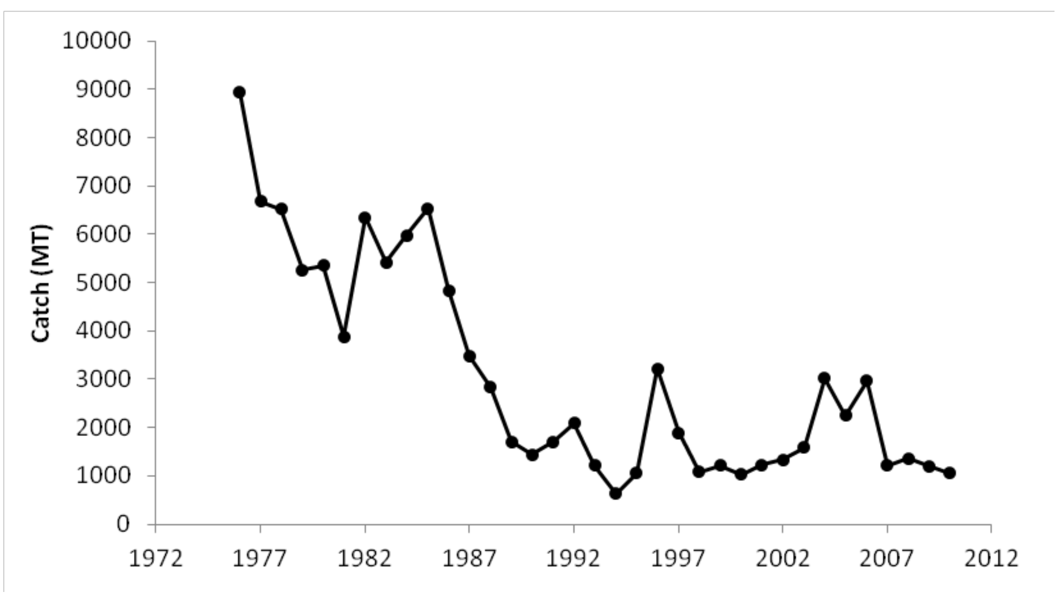



Figure 2.81 Total catch of river herring estimated from total reported landings plus total incidental catch using hindcasting methods.

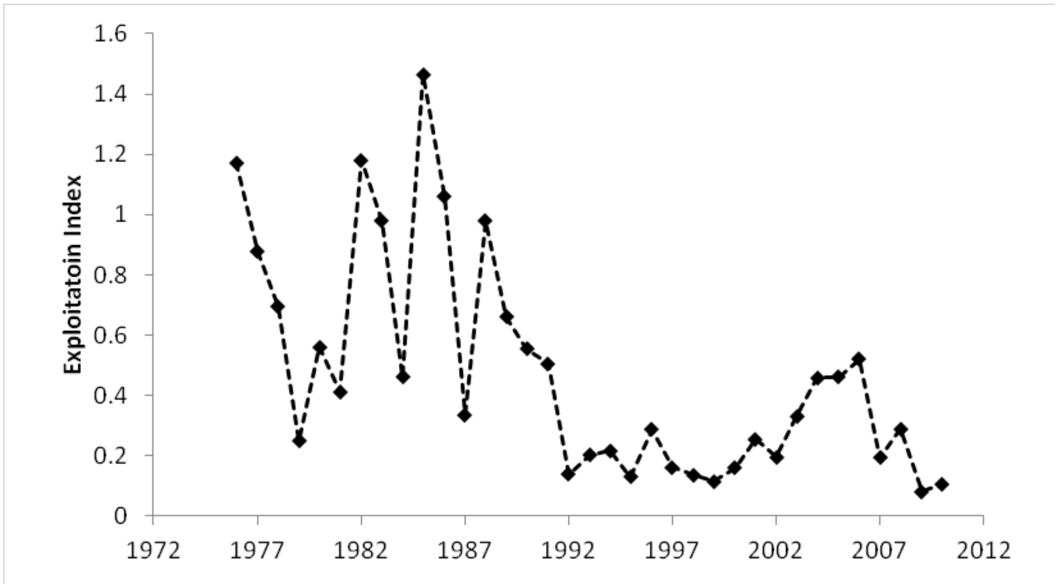



Figure 2.82 Relative exploitation of river herring (1976 – 2010).

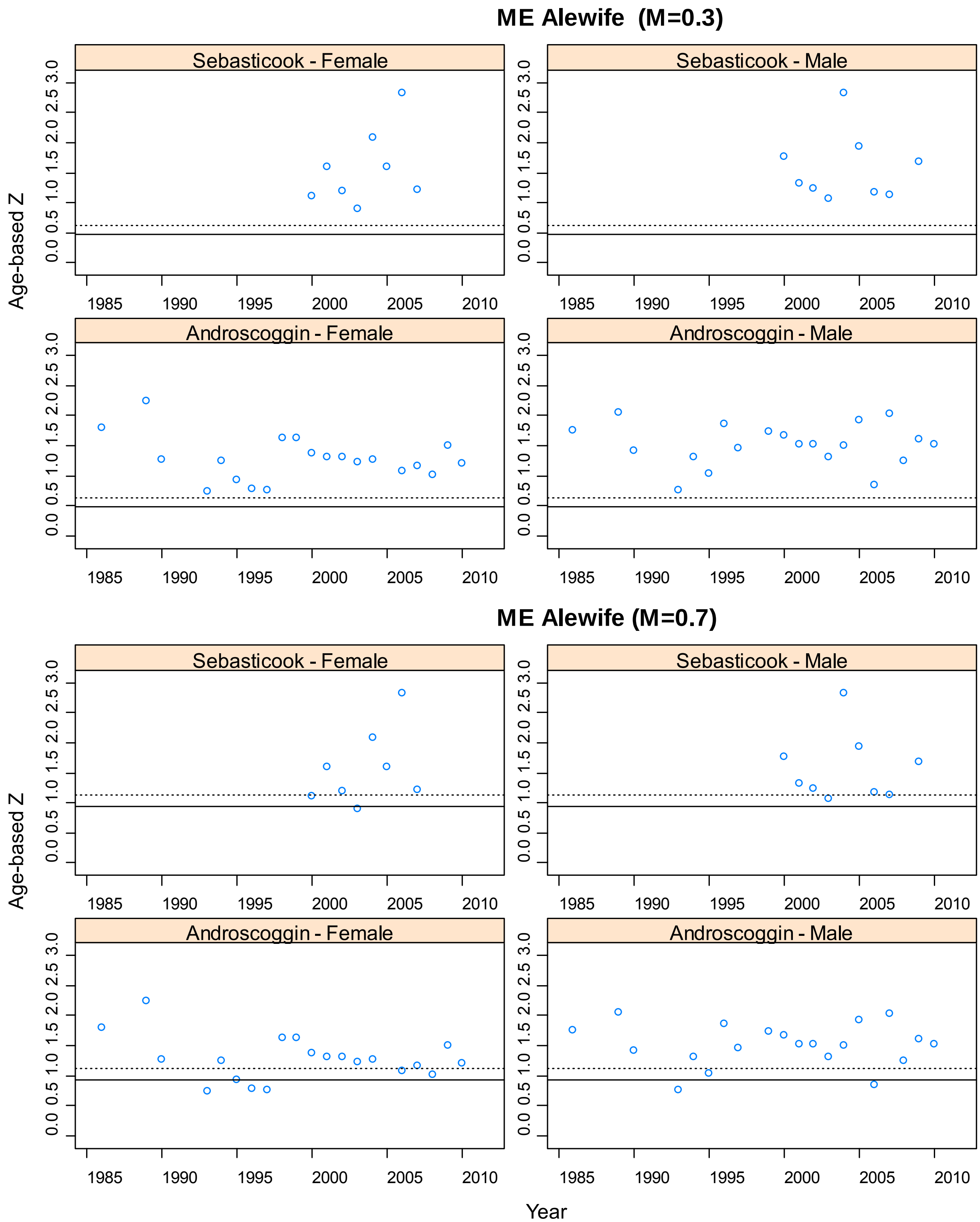



Figure 2.83. Empirical estimates of Z for ME alewife by river for different values of M. Dashed lines represent $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

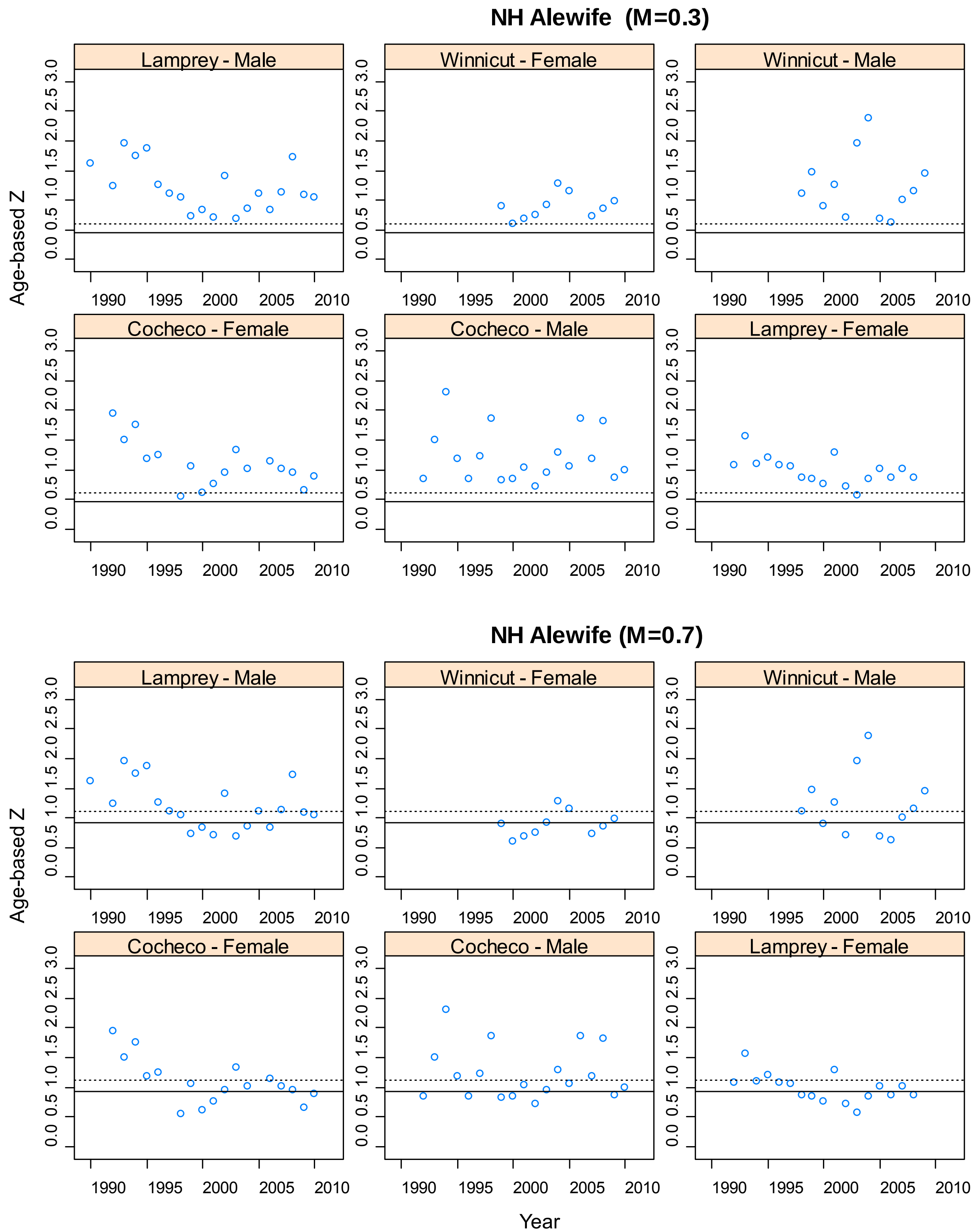



Figure 2.84. Empirical estimates of Z for NH alewife by river for different values of M. Dashed lines represent $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

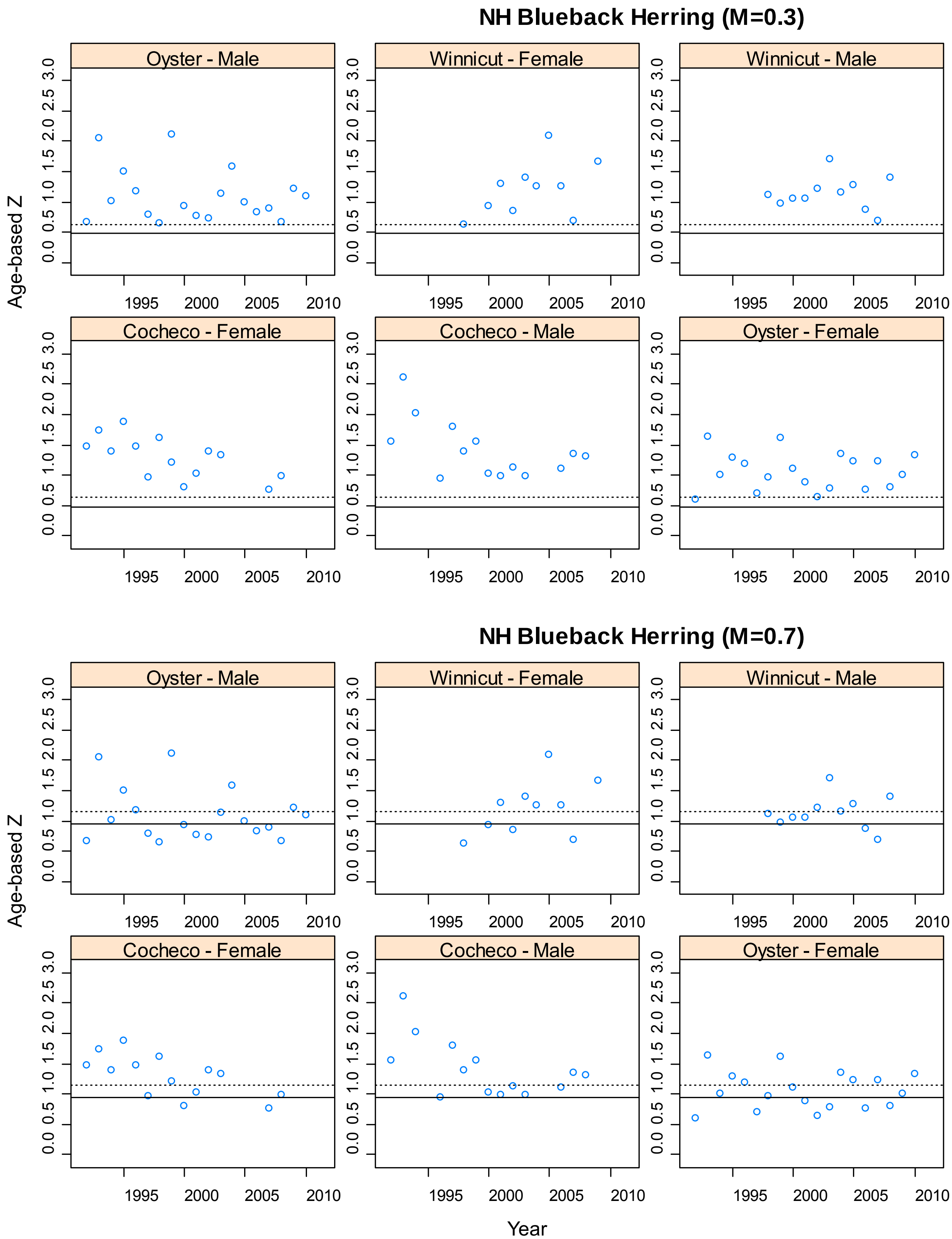



Figure 2.85. Empirical estimates of Z for NH blueback herring by river for different values of M. Dashed lines represent $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

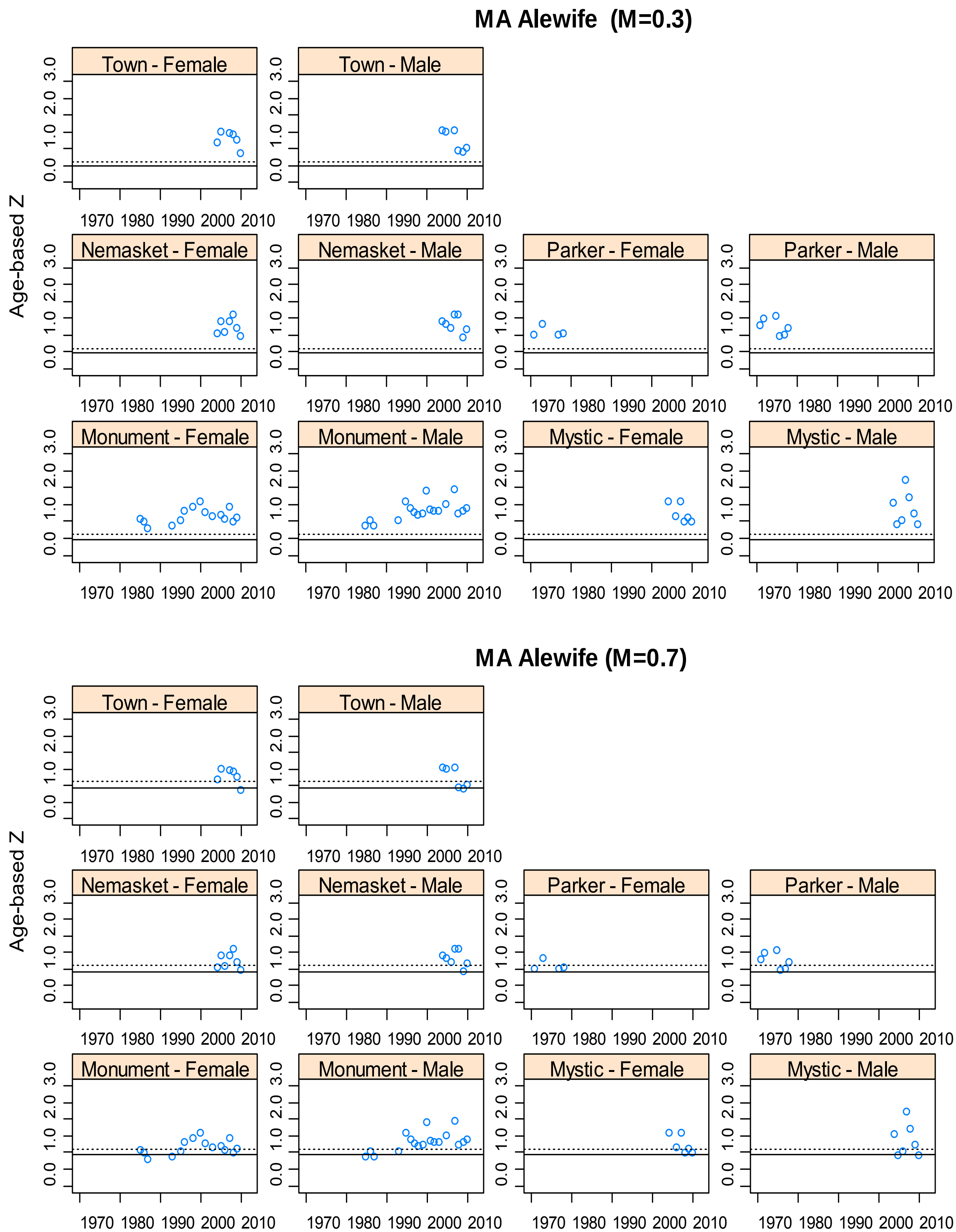



Figure 2.86. Empirical estimates of Z for MA alewife by river for different values of M. Dashed lines represent $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

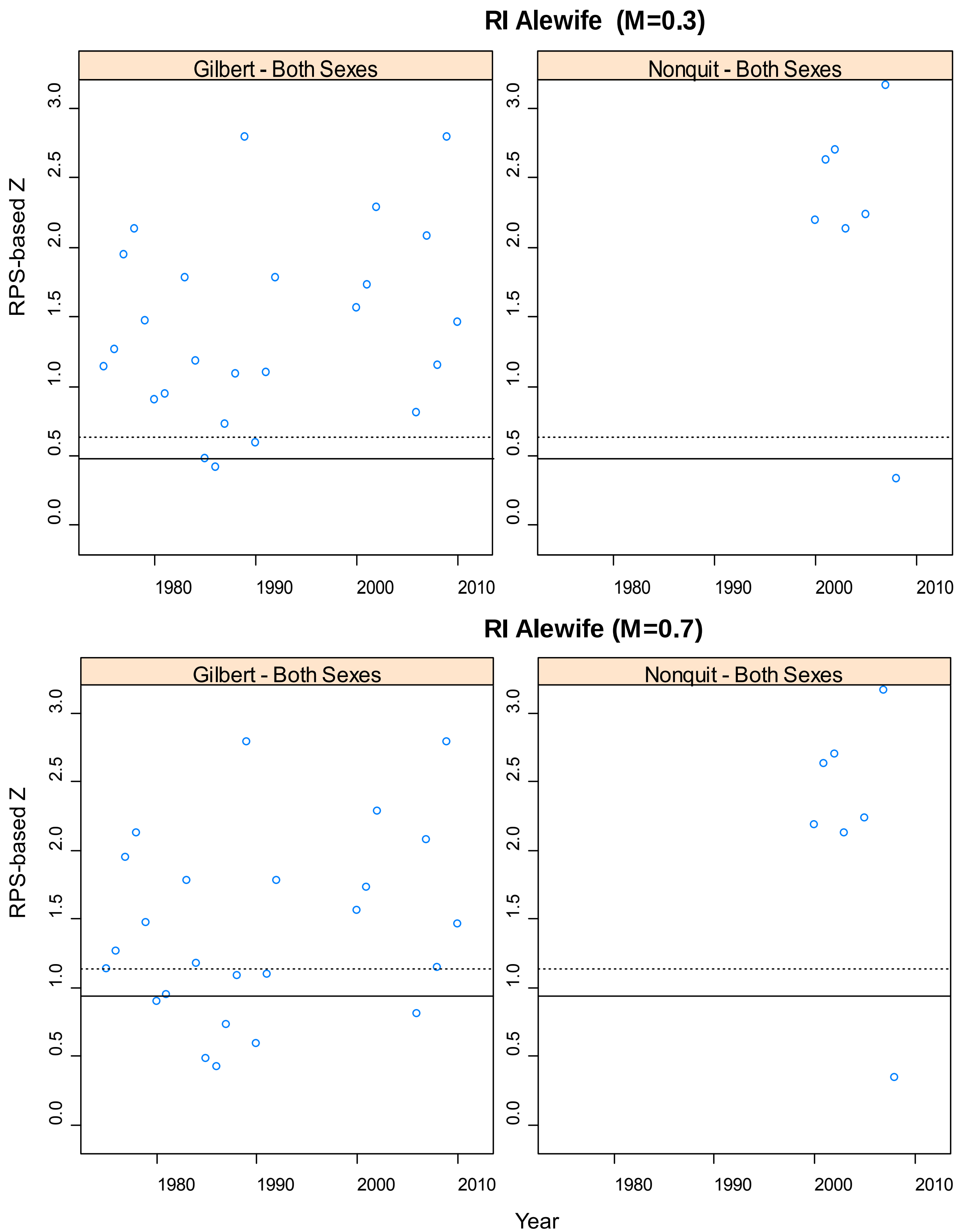



Figure 2.87. Empirical estimates of Z for RI alewife by river for different values of M. Dashed lines represent $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

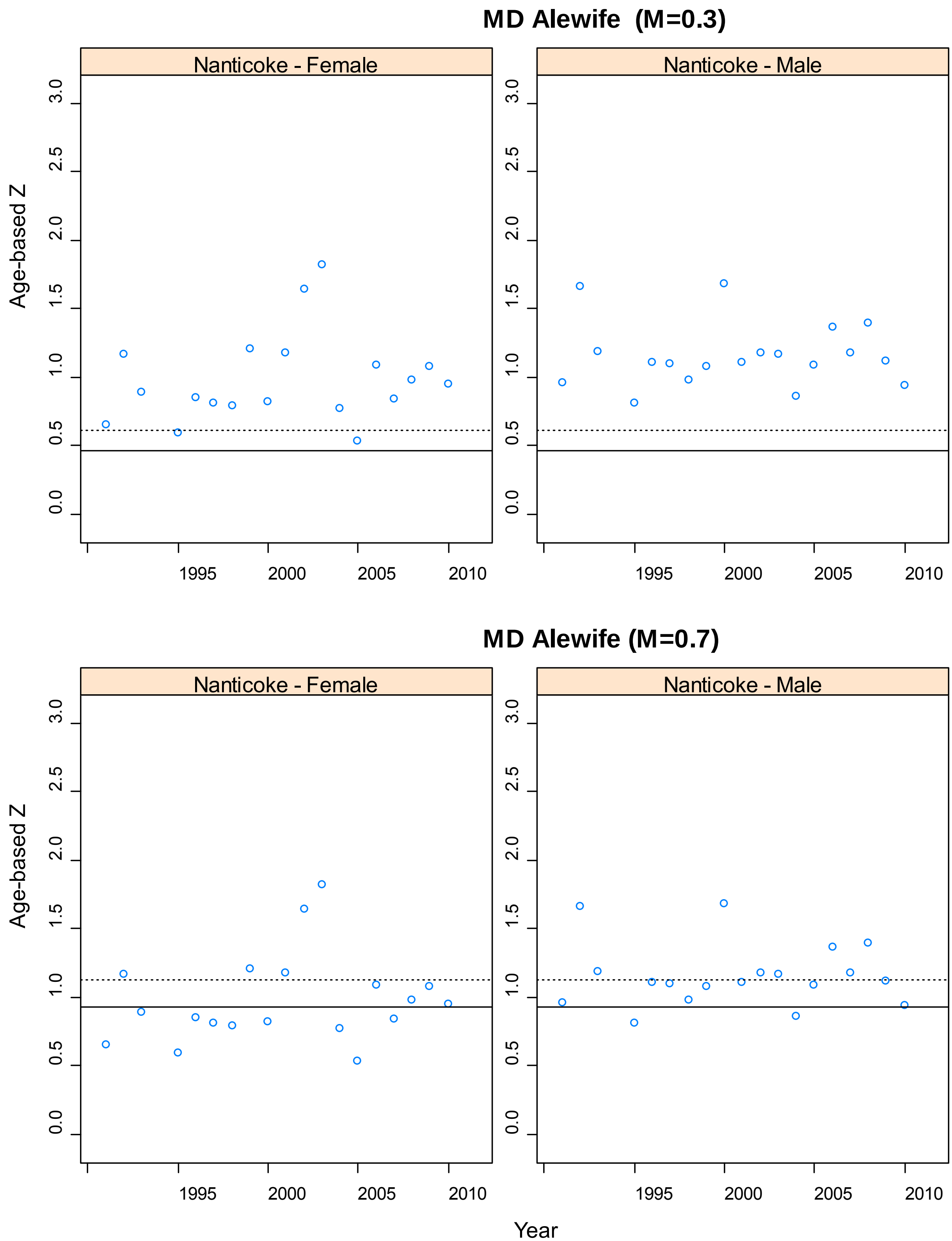



Figure 2.88. Empirical estimates of Z for MD alewife by river for different values of M. Dashed lines represent $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

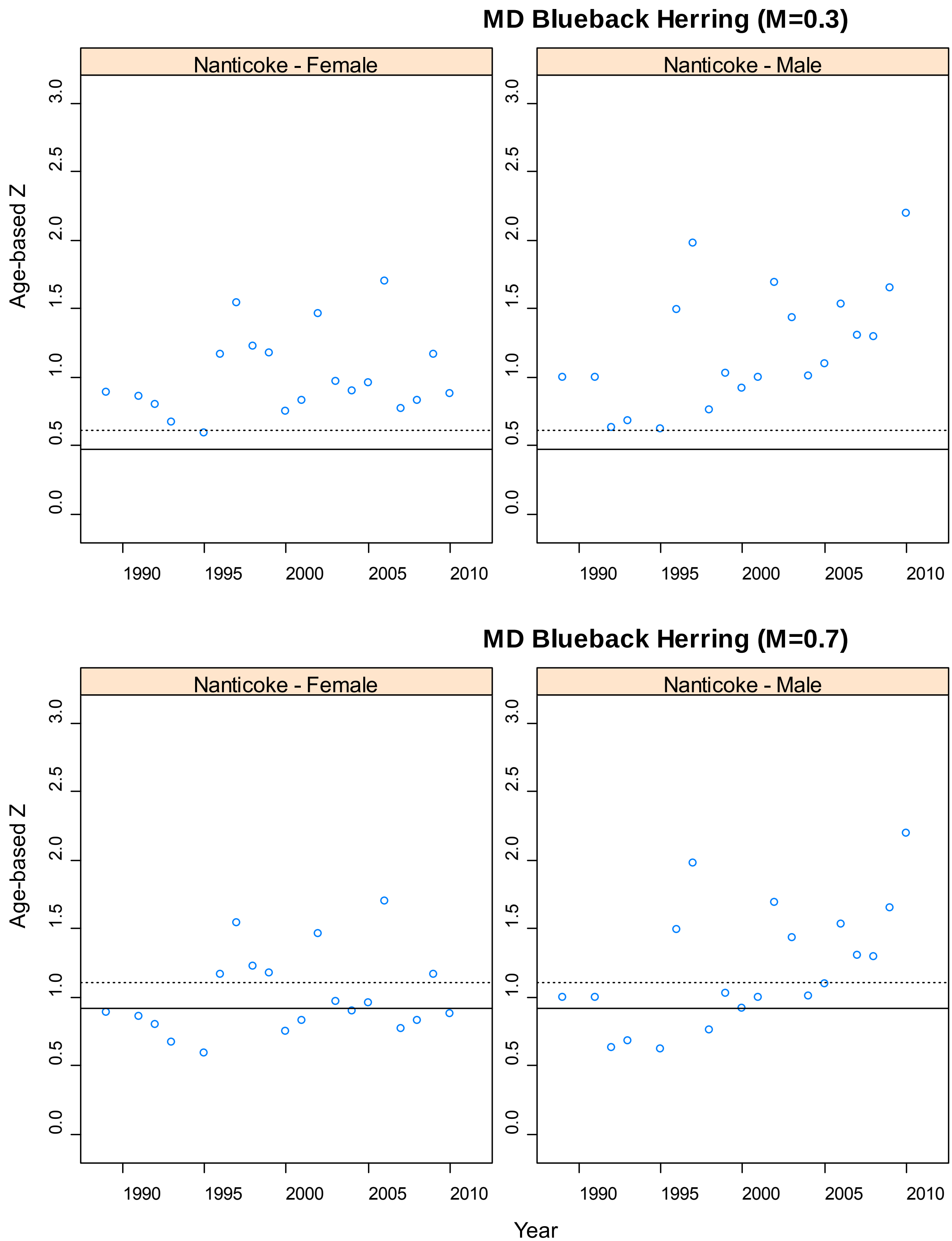



Figure 2.89. Empirical estimates of Z for MD blueback herring by river for different values of M. Dashed lines represent $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

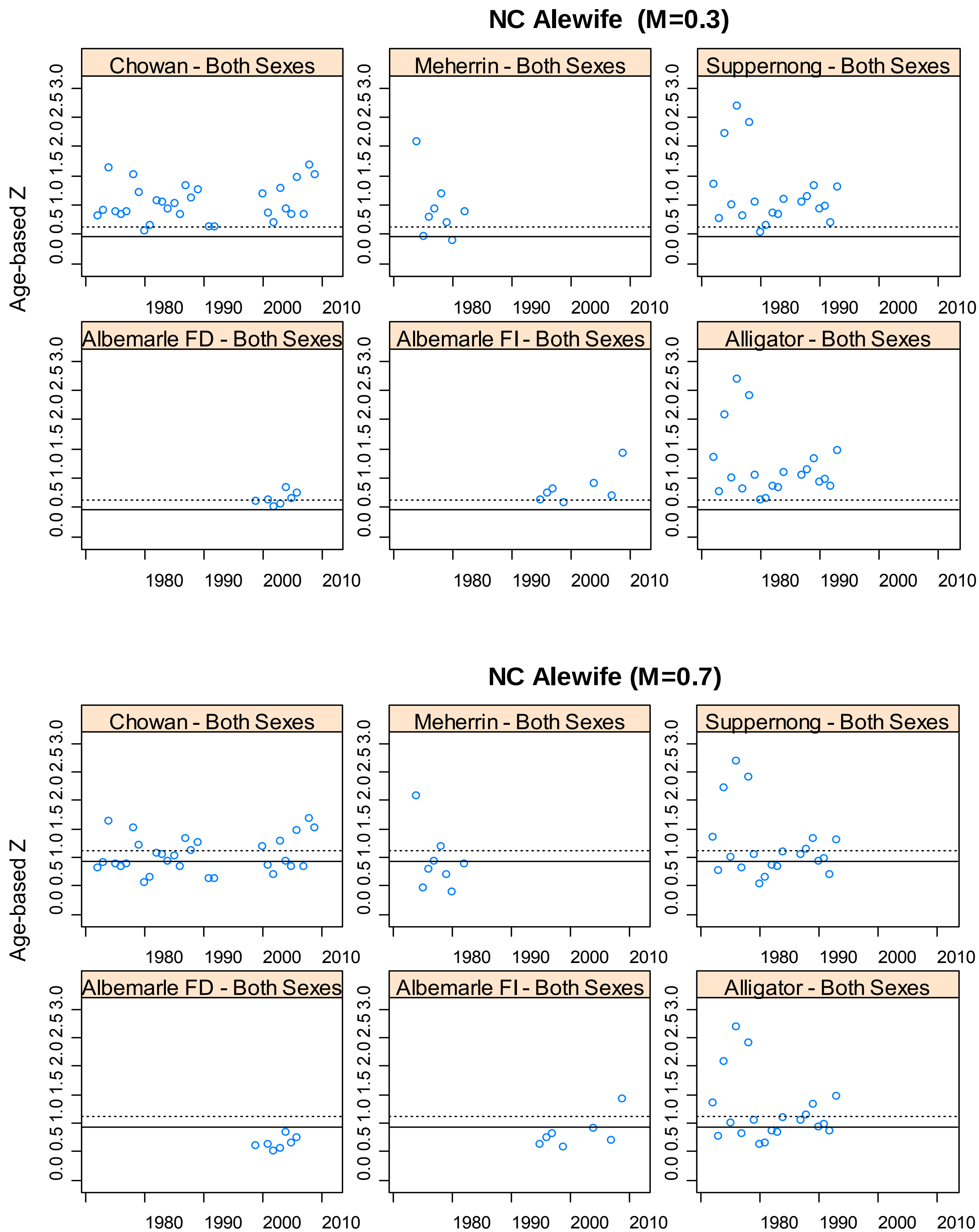



Figure 2.90 Empirical estimates of Z for NC alewife by river for different values of M. Dashed lines represent $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

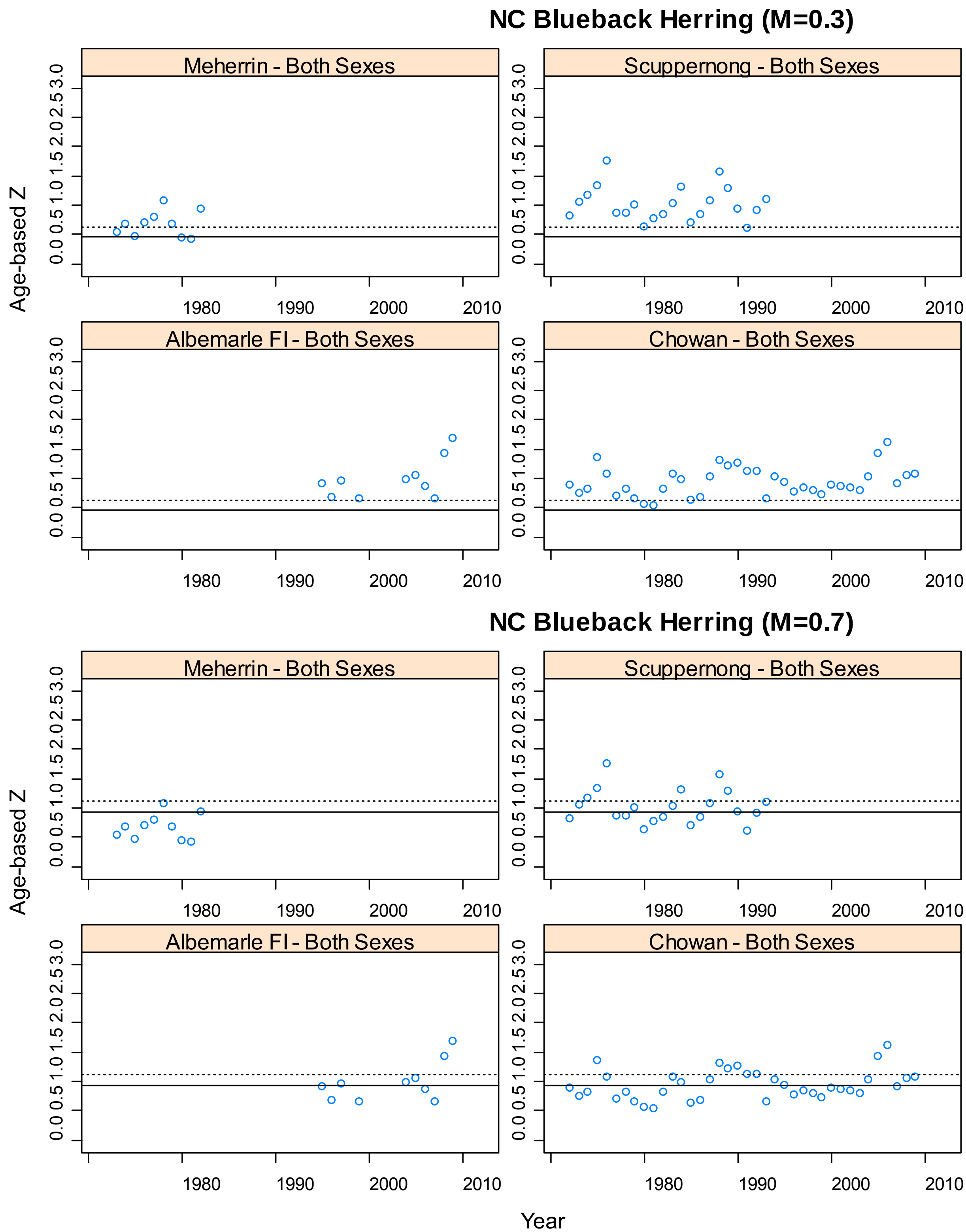



Figure 2.91 Empirical estimates of Z for NC blueback herring by river for different values of M. Dashed lines represent $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

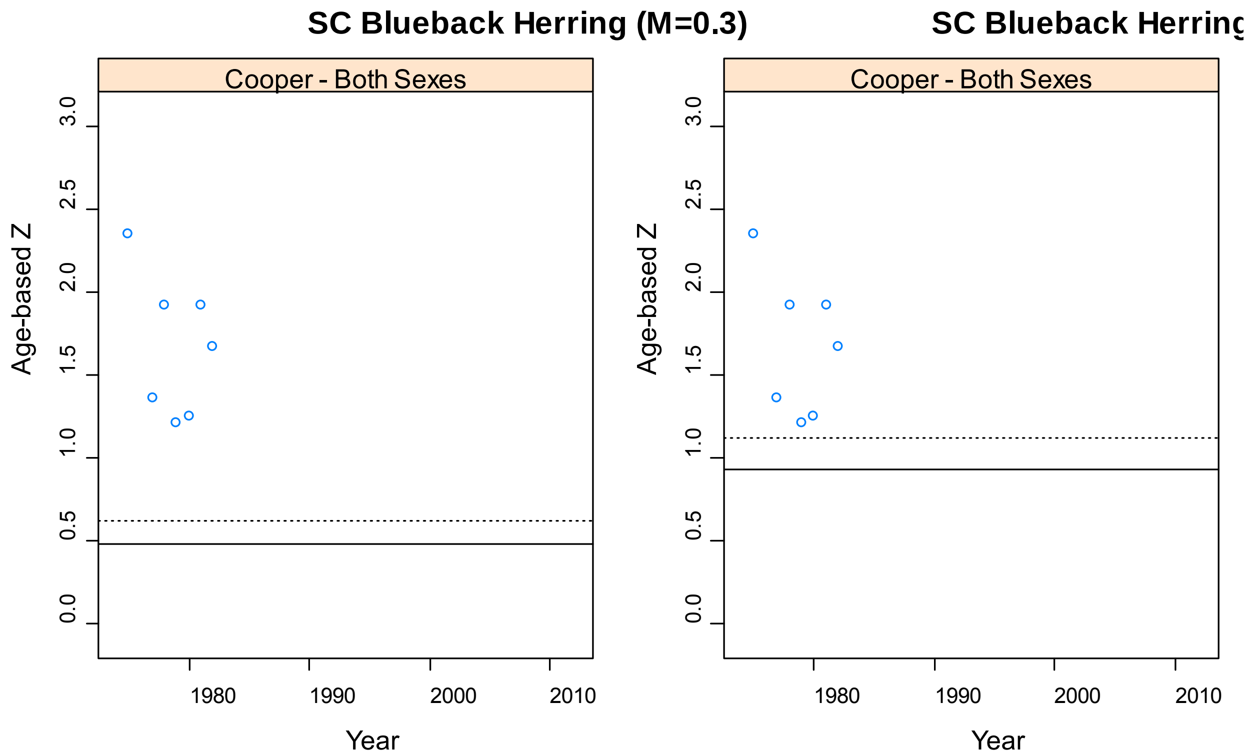



Figure 2.92. Empirical estimates of Z for NC blueback herring by river for different values of M. Dashed lines represent $Z_{20\%SPR}$ and $Z_{40\%SPR}$ benchmarks.

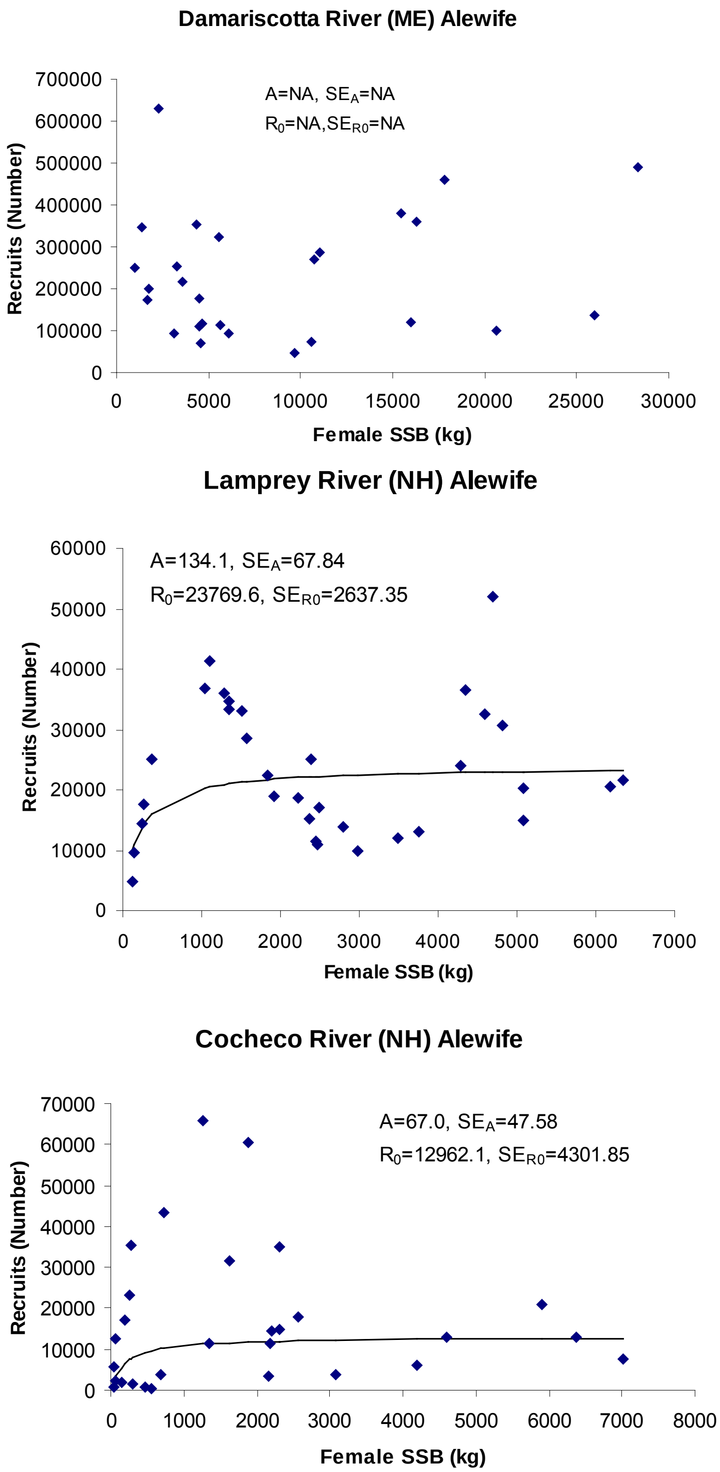



Figure 2.93 Updated stock-recruitment data for alewife from the Damariscotta River in Maine, and the Cocheco River and Lamprey River in New Hampshire generated using method M5. Also shown is the predicted relationship (solid line) from the Beverton-Holt S-R model and the estimated values of alpha (A) and R0. A solution could not be found for the Damariscotta River data.

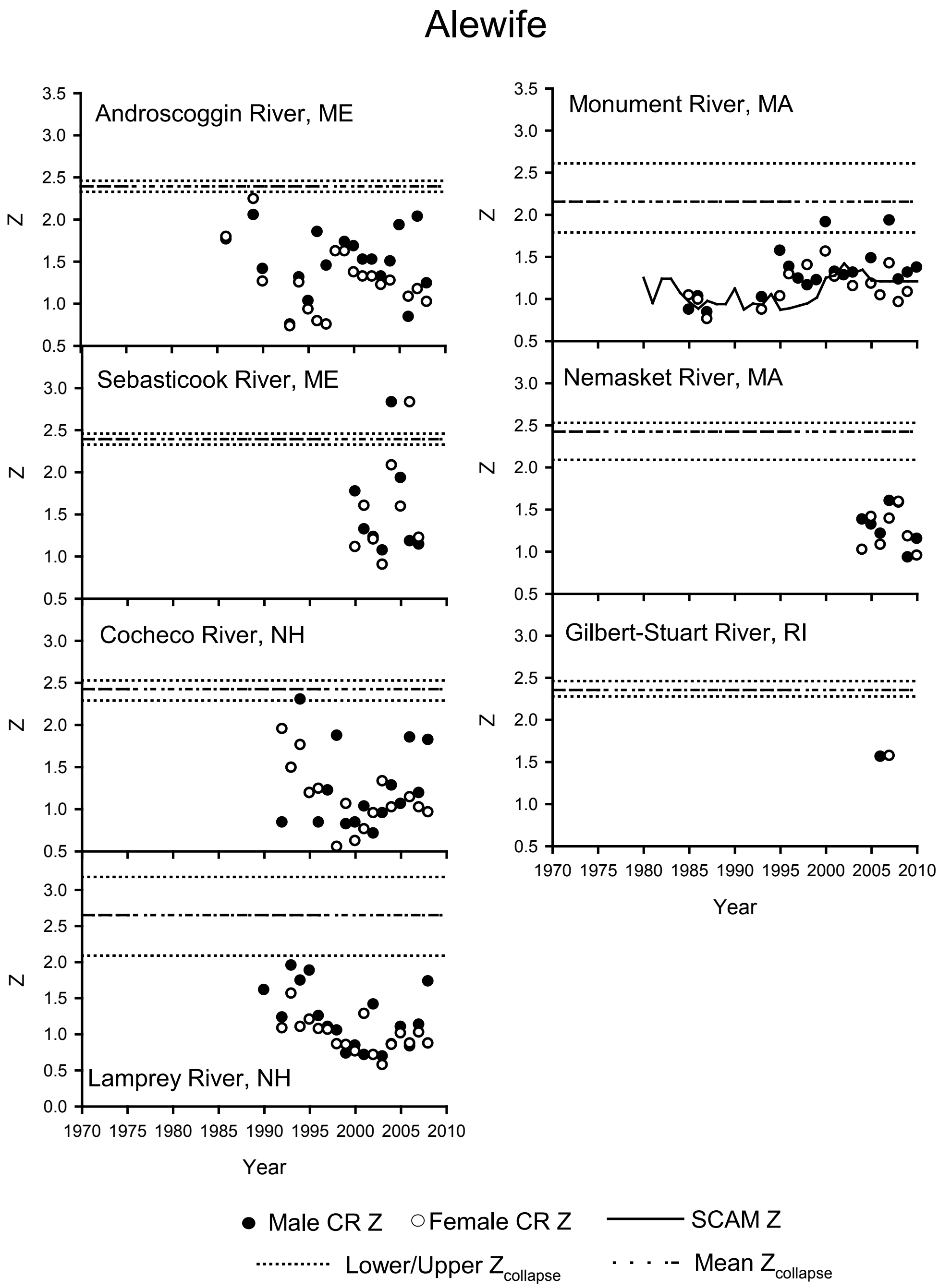



Figure 2.94 Plots of age-based Z estimates for male and female alewife derived by using the Chapman-Robson (CR) survival estimator or derived in stock assessment models (SCAM) compared to the minimum/maximum and average $Z_{collapse}$ values.

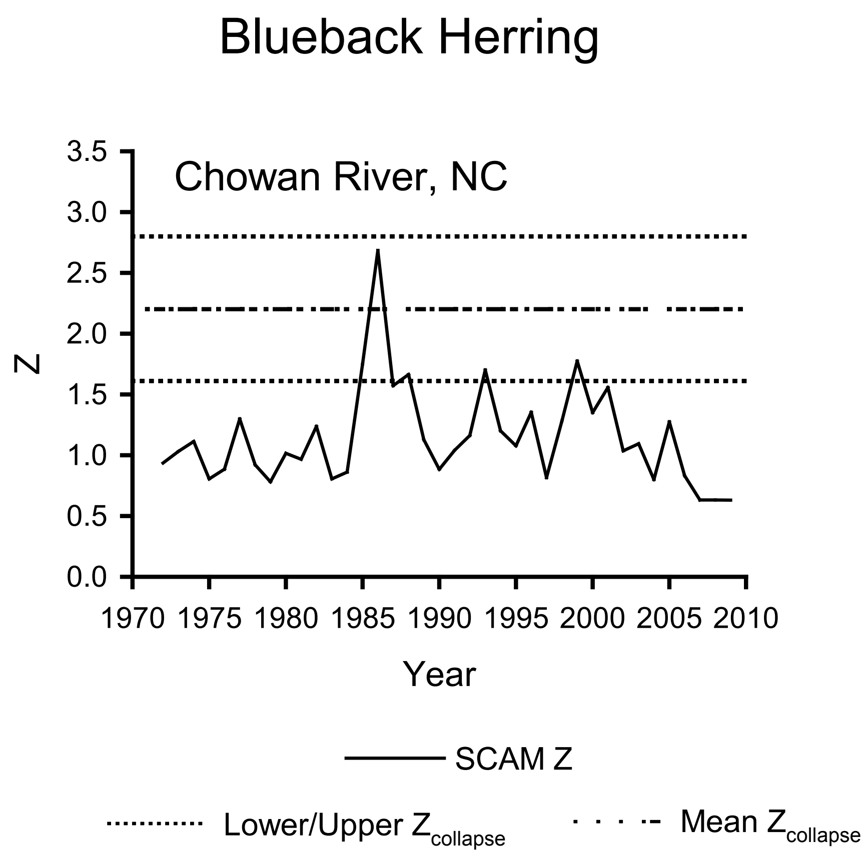



Figure 2.95 Plots of age-based Z estimates for blueback herring derived by using a stock assessment model (SCAM) compared to the minimum/maximum and average $Z_{collapse}$ values.

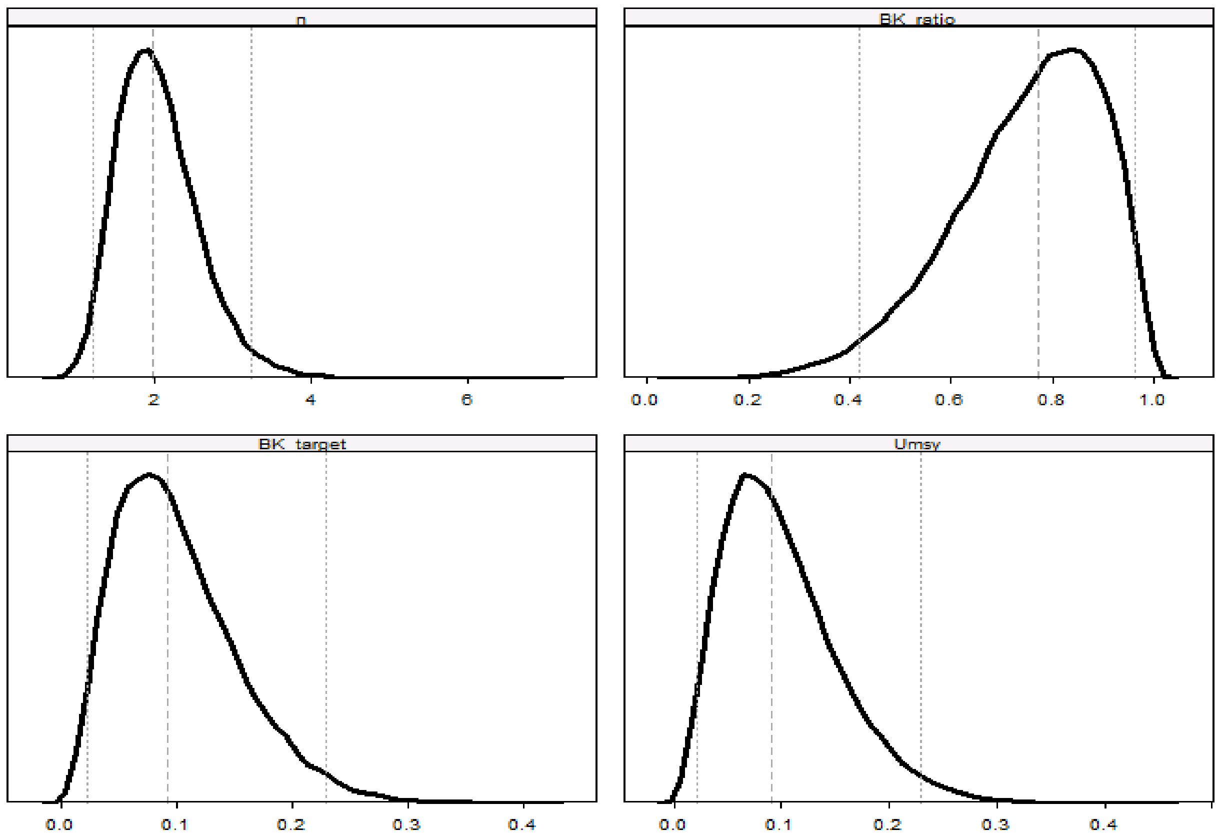



Figure 2.96 Distributions of population parameters drawn for DBSRA runs. Dashed lines represent the median and 5th and 95th percentiles of the distribution.

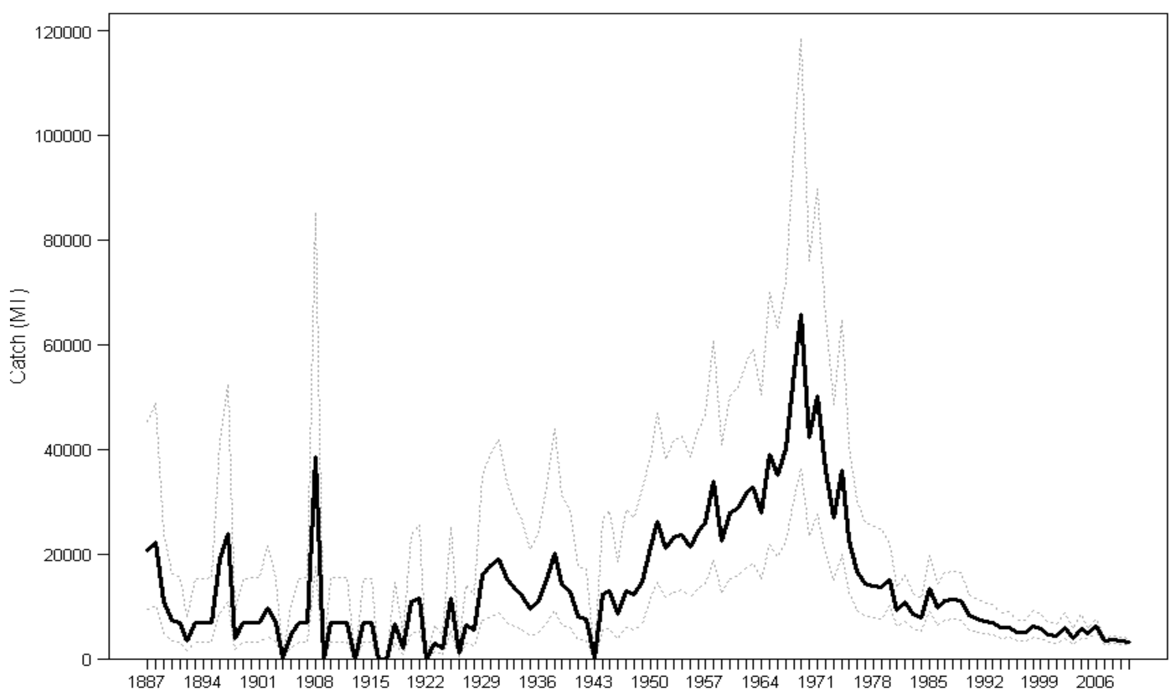



Figure 2.97 Median total catch and 95% confidence intervals

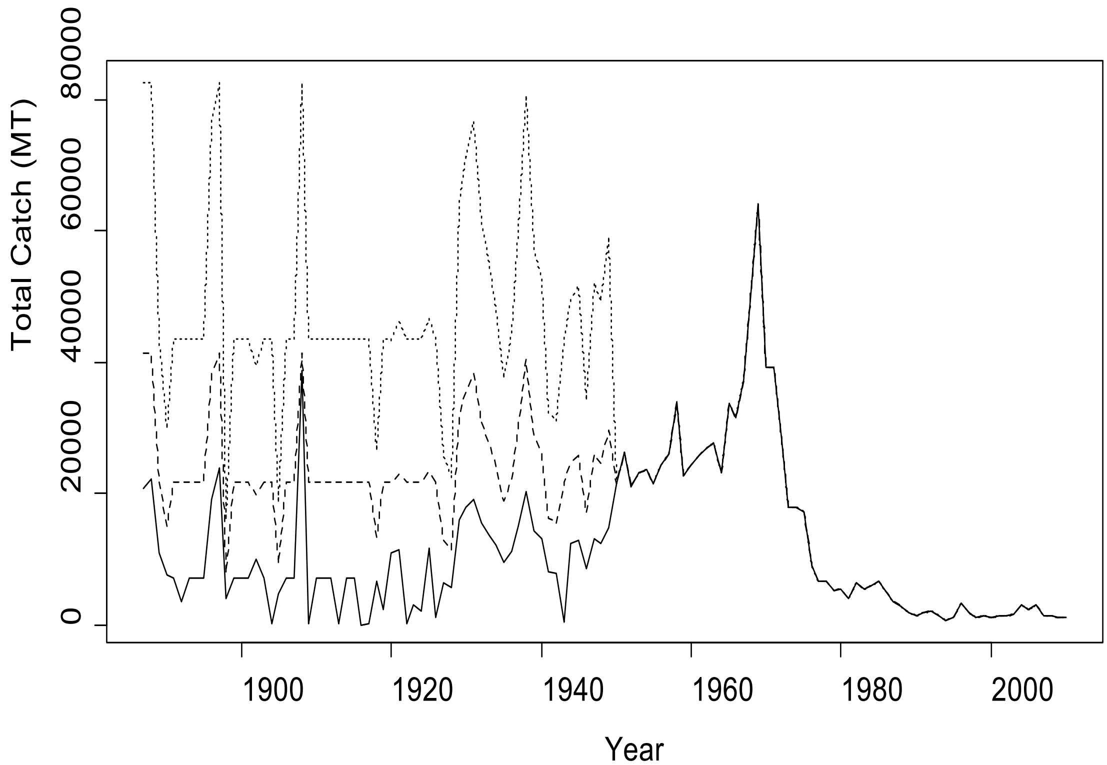



Figure 2.98 Base model time-series of catch (solid line) and inflated early time-series (dashed lines).

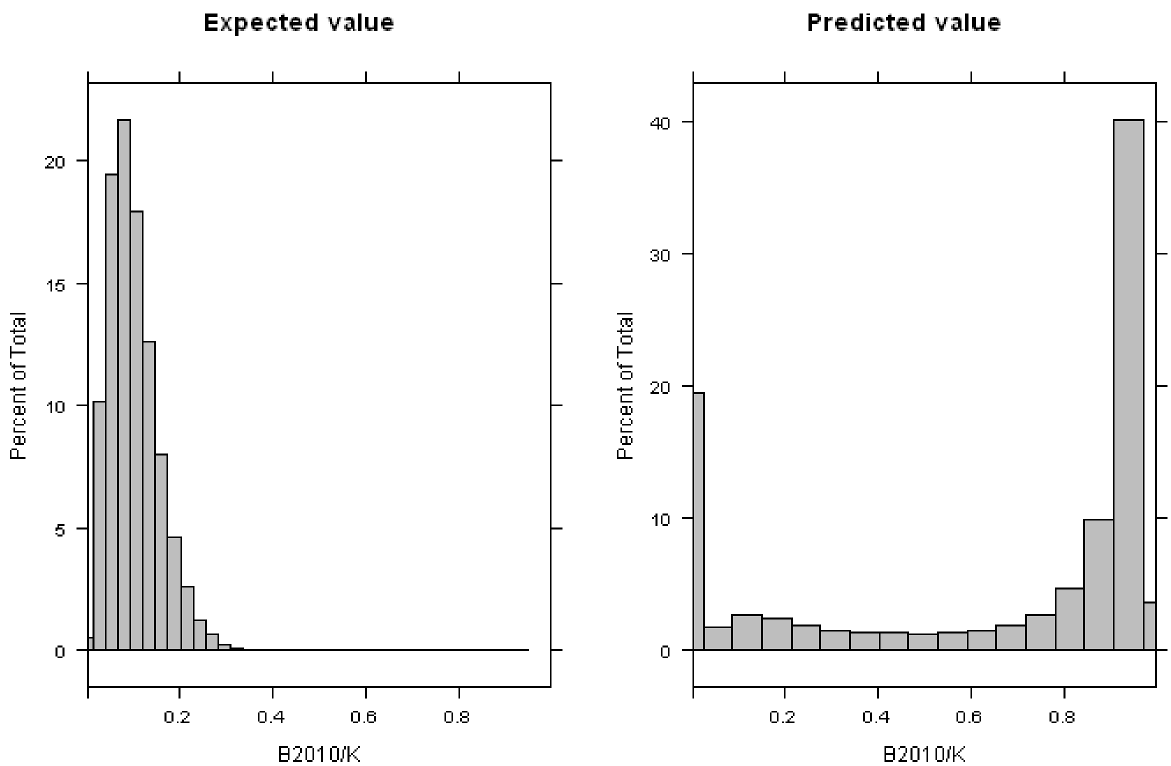



Figure 2.99	Distributions of expected $B_{2010}/K$ ratio (left) and model-predicted $B_{2010}/K$ ratio (right).

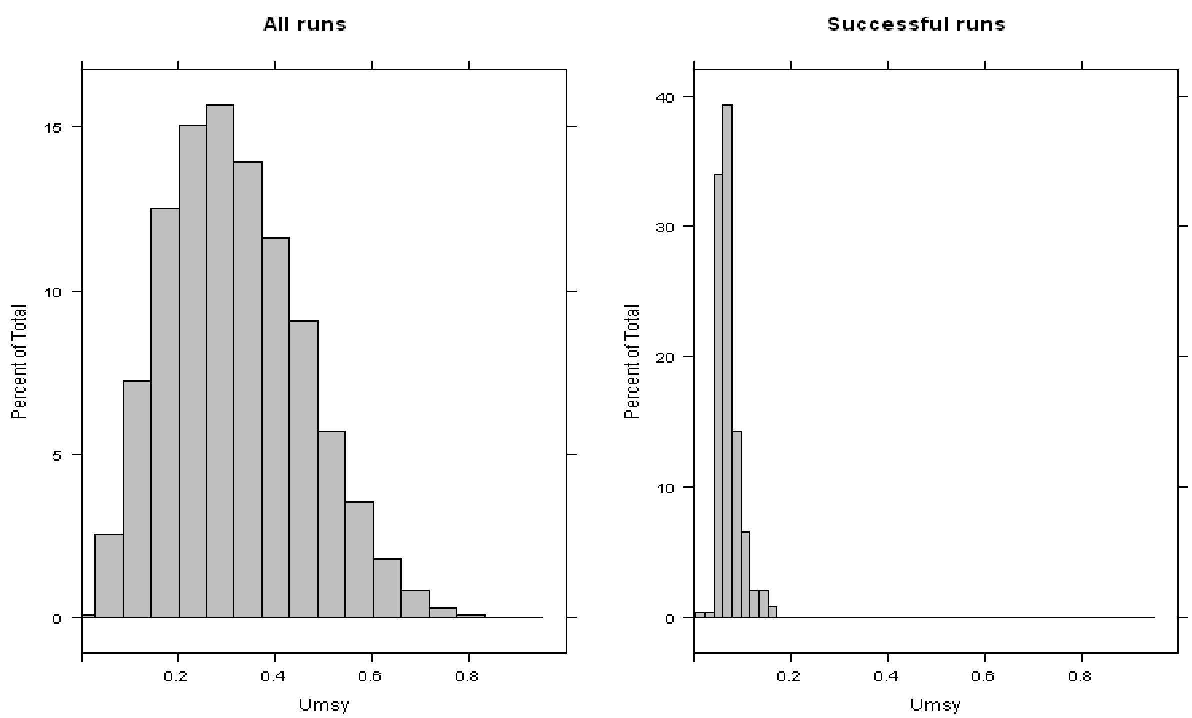



Figure 2.100	Initial distribution of $U_{MSY}$ values drawn (left) and distribution of $U_{MSY}$ values from successful runs (right).

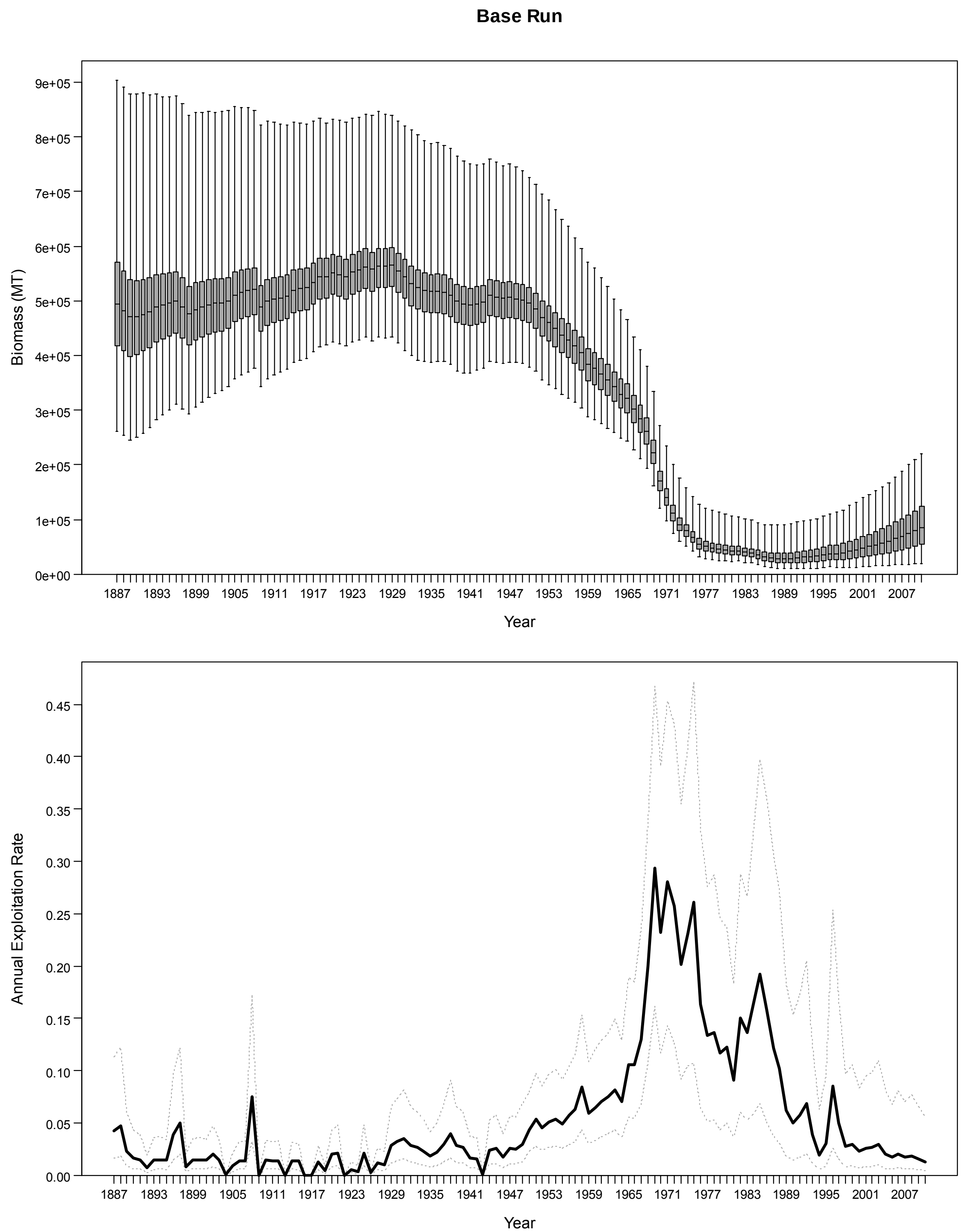



Figure 2.101 Biomass (top) and exploitation rate (bottom) time series with 95% confidence intervals for base model configuration.

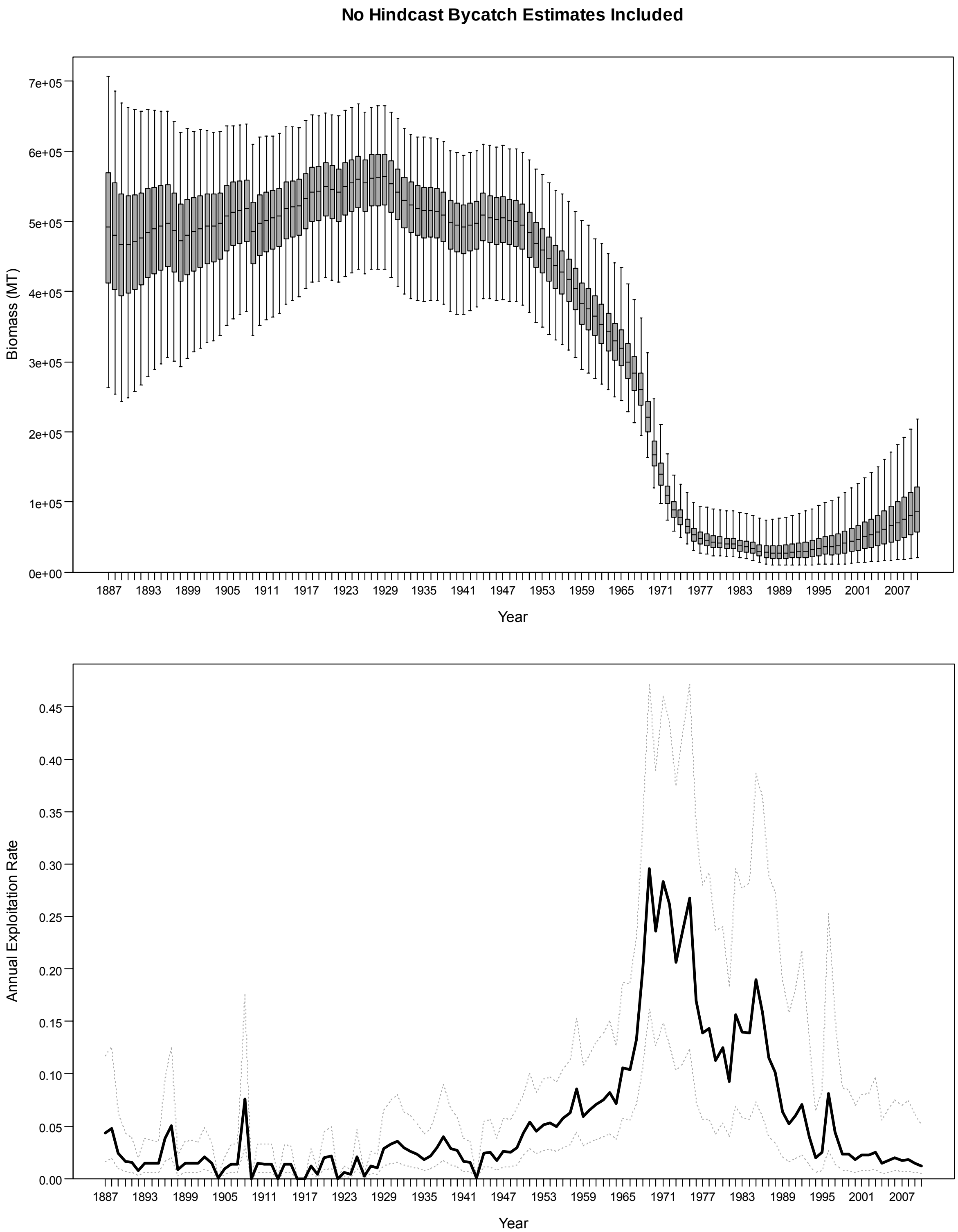



Figure 2.102 Biomass (top) and exploitation rate (bottom) time series with 95% confidence intervals for runs with no hindcast bycatch included in the catch time-series.

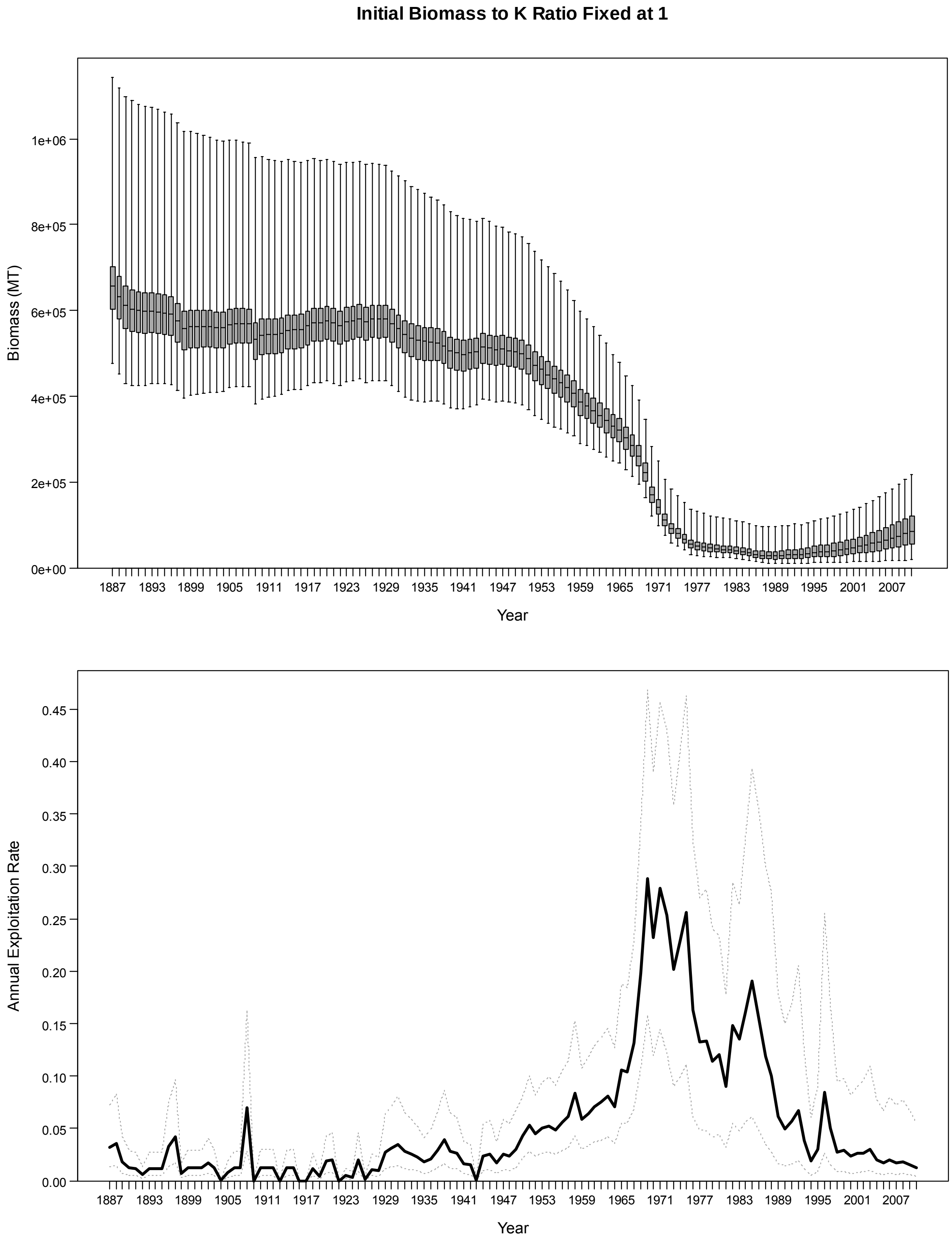



Figure 2.103 Biomass (top) and exploitation rate (bottom) time series with 95% confidence intervals for runs with the $B_0/K$ ratio fixed at 1.0.

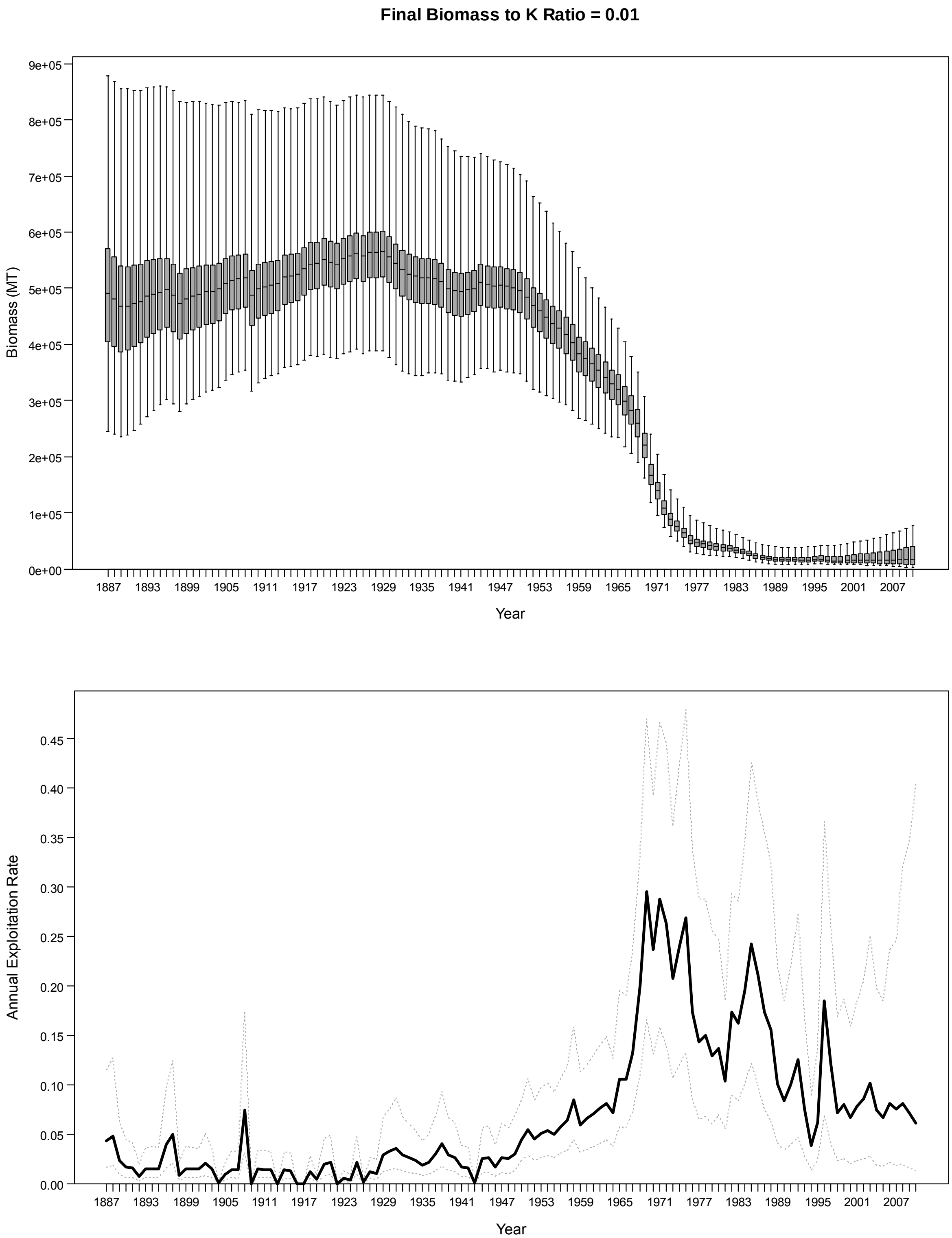



Figure 2.104 Biomass (top) and exploitation rate (bottom) time-series with 95% confidence intervals for runs with final B to K ratio of 1%.

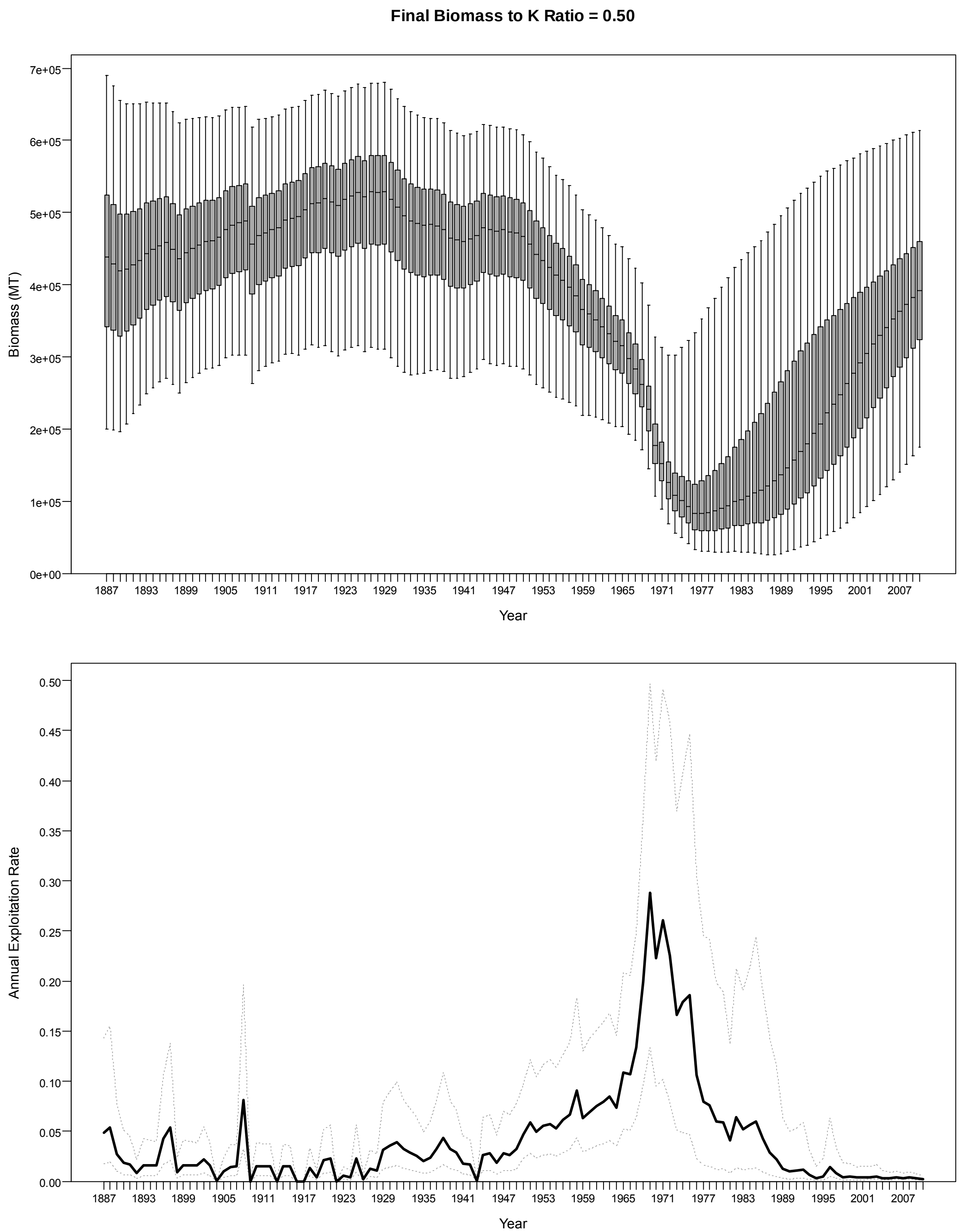



Figure 2.105 Biomass (top) and exploitation rate (bottom) time-series with 95% confidence intervals for runs with a mean final B to K ratio of 50%.

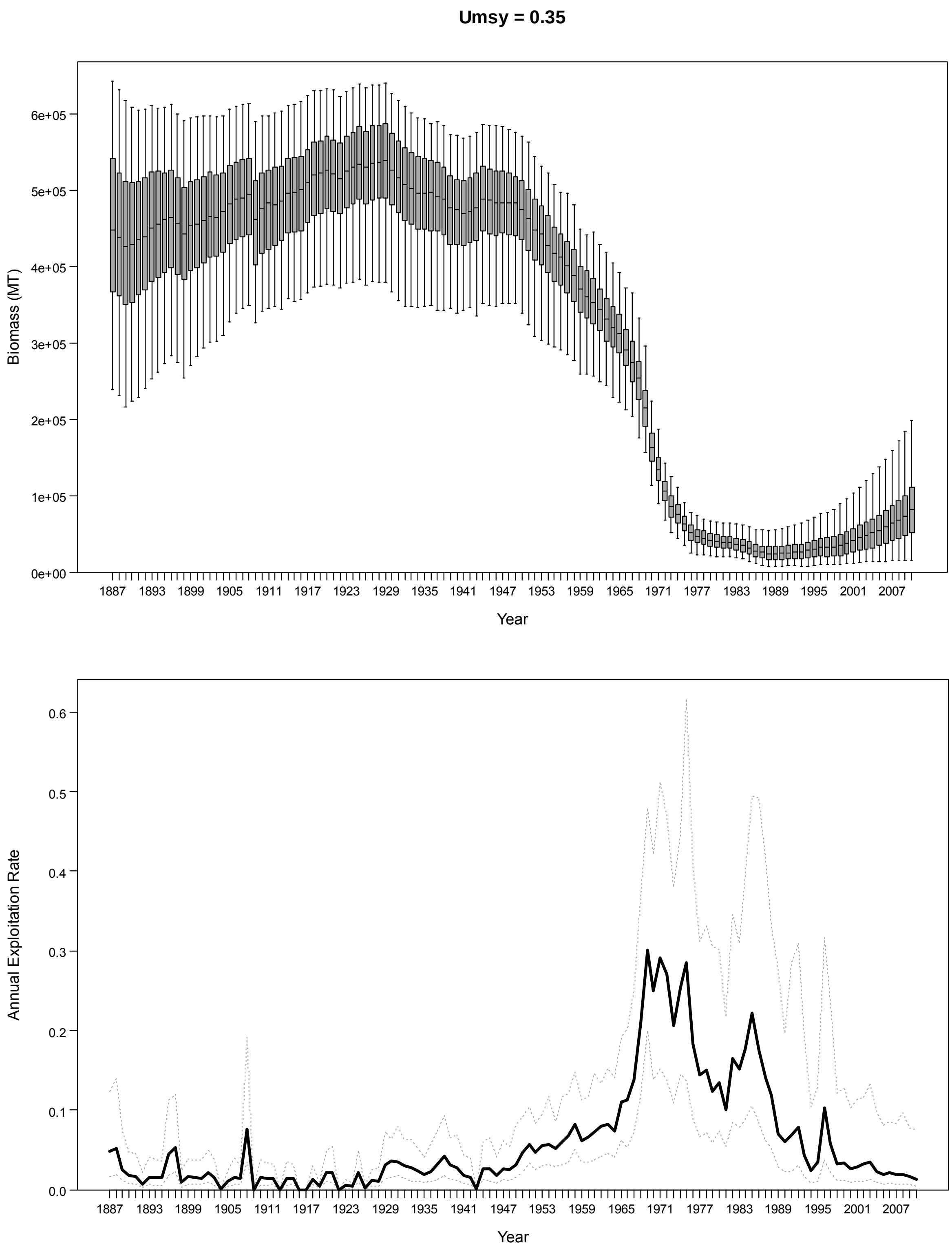



Figure 2.106 Biomass (top) and exploitation rate (bottom) time series with 95% confidence intervals for runs with mean $U_{MSY}$ = 0.35.

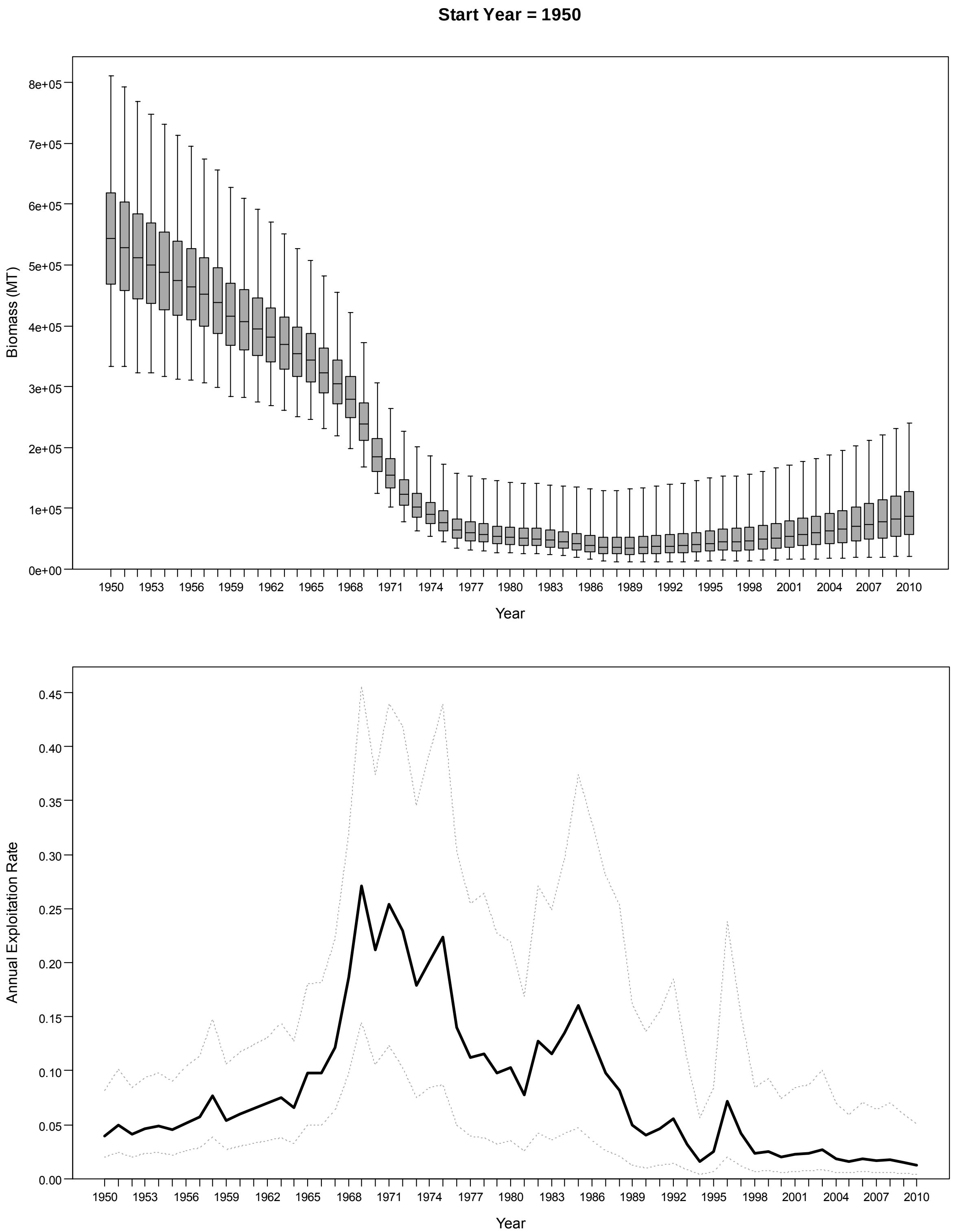
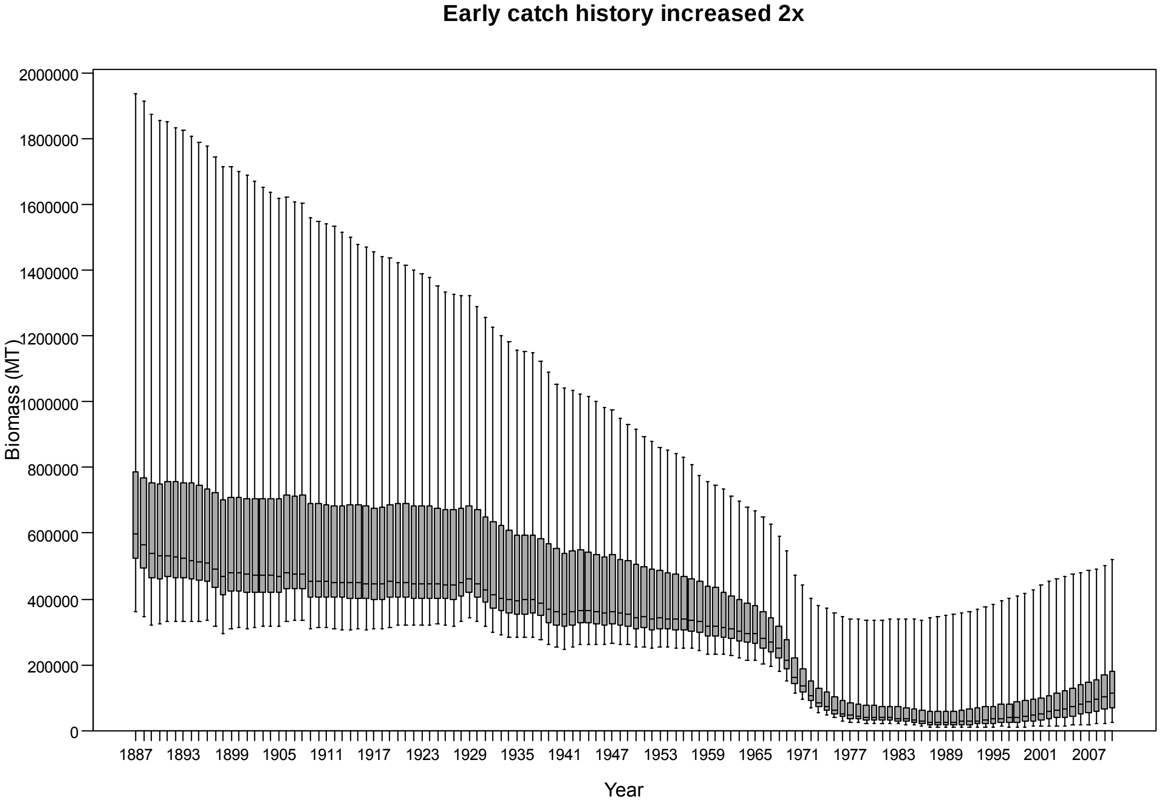



Figure 2.107 Biomass (top) and exploitation rate (bottom) time series with 95% confidence intervals for base model configuration with catch history starting in 1950.



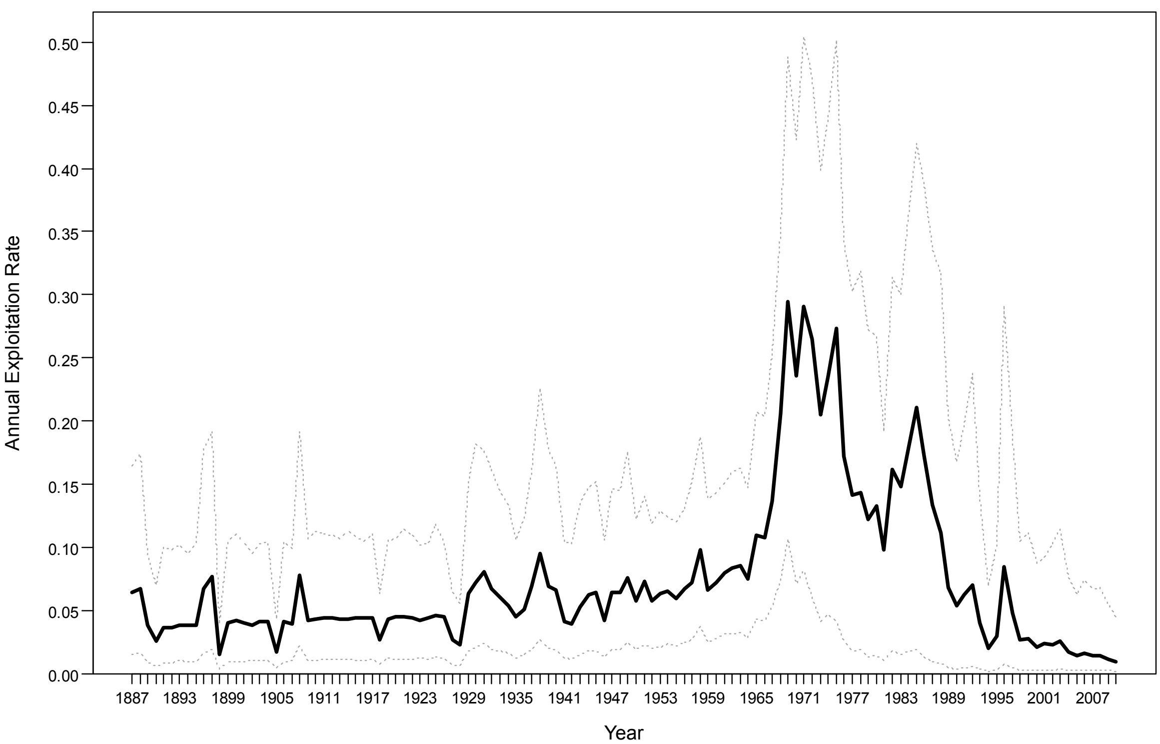




Figure 2.108 Biomass (top) and exploitation rate (bottom) time series with 95% confidence intervals for runs with pre-1950 catch increased by 200%.

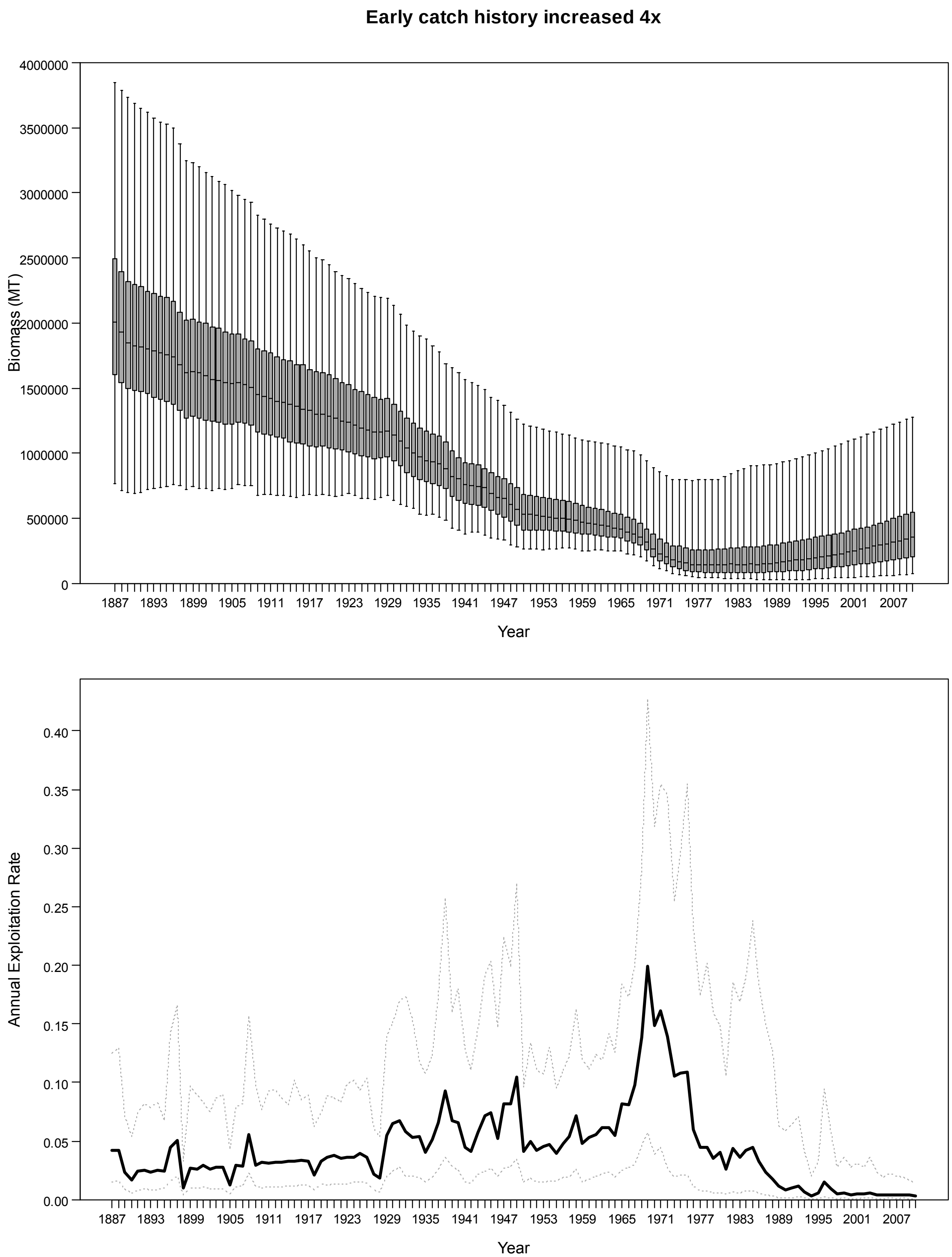



Figure 2.109 Biomass (top) and exploitation rate (bottom) time series with 95% confidence intervals for runs with pre-1950 catch increased by 400%.

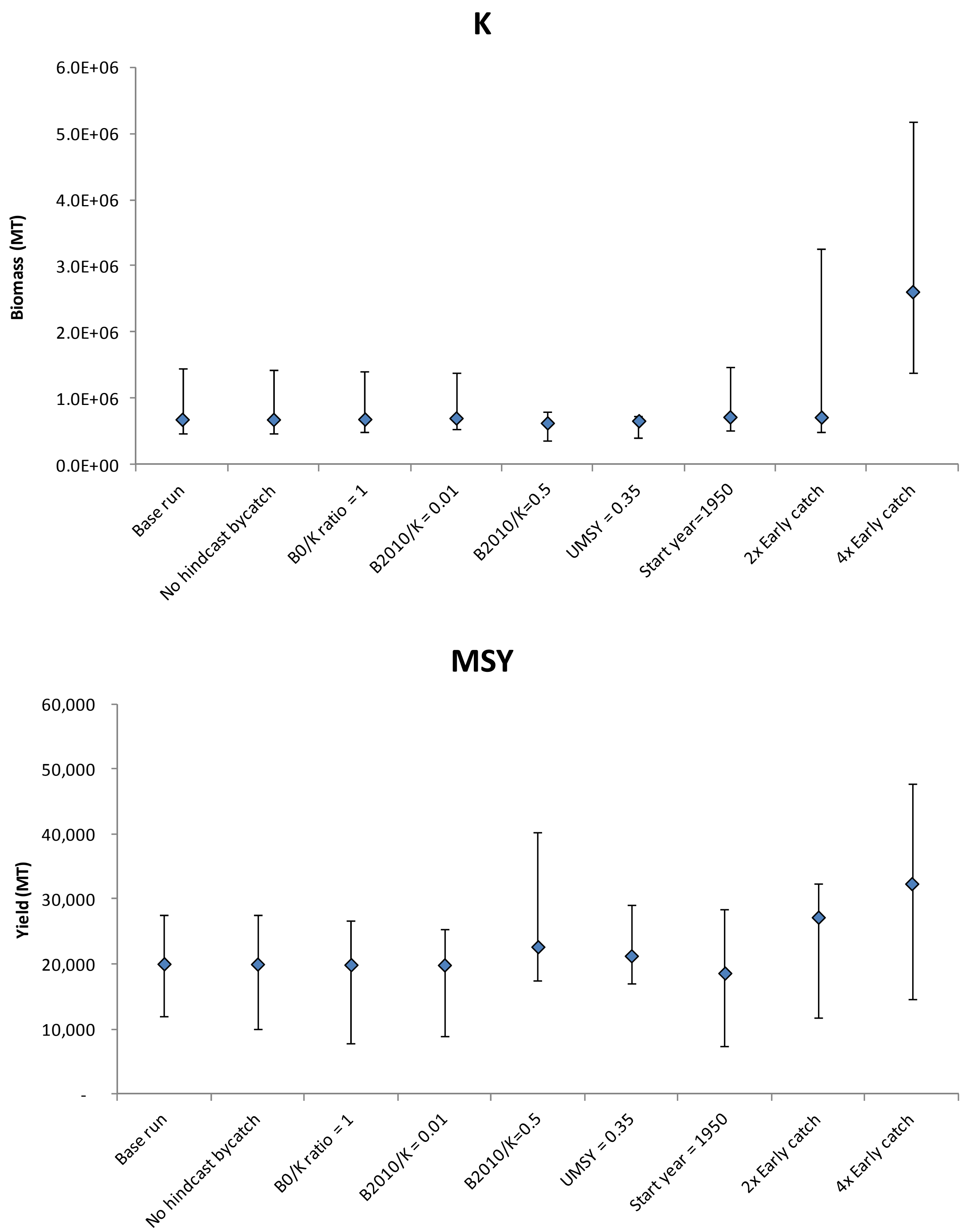



Figure 2.110 Estimates of K and MSY for different sensitivity runs. Error bars are 95% confidence intervals.

Appendix 1: Summary of available river herring fisheries independent and fisheries dependant data.

| State | River | Time series | By species | Harvest | Age | Length | Weight | Repeat Spawner | FI Adult | FI JAI | FD CPUE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ME | Damariscotta | 1943-2010 | | ● | | | | | | | |
| | St. George | 1943-2010 | | ● | | | | | | | |
| | Union | 1975-2010 | | ● | | | | | | | |
| | Orland | 1943-2010 | | ● | | | | | | | |
| | Androscoggin | 1983-2010 | ● | | ● | ● | | | | | |
| | Sebasticook | 2000-2010 | ● | | ● | ● | | | | | |
| | Merrymeeting Bay/Tribs | 1979-2009 | ● | | | ● | | | | ● | |
| | Gulf of Maine | 2000-2010 | ● | | | ● | | | ● | | |
| NH | Exeter/Squamscott | 1991-2010 | ● | ● | ● | ● | | ○ | ● | | |
| | Lamprey | 1991-2010 | ● | ● | ● | ● | | ○ | ● | | |
| | Winnicut | 1991-2010 | ● | ● | ● | ● | | ○ | ● | | |
| | Oyster | 1991-2010 | ● | ● | ● | ● | | ○ | ● | | |
| | Cocheco | 1991-2010 | ● | ● | ● | ● | | ○ | ● | | |
| | Taylor | 1991-2010 | ● | ● | ● | ● | | ○ | ● | | |
| | Great Bay Estuary | 1997-2010 | x | | | x | | | | x | |
| MA | Mattapoisett | 1988-2010 | ● | ● | ○ | ○ | ○ | | ● | | |
| | Monument | 1980-2010 | ● | ● | ○ | ○ | | ○ | ● | | |
| | Nemasket | 1996-2010 | ● | ● | ○ | ○ | ○ | | | | |
| | Parker | 1971-1978, 2000-2010 | ● | ● | ○ | ○ | | | ● | | |
| | Town | 2000-2010 | | ● | | | | | ● | | |
| | Agawam | 2006-2010 | | ● | ○ | ○ | | | | | |
| | Back | 2007-2010 | ● | ● | ● | ● | | | ● | | |
| | Charles | 2008-2009 | | ● | ● | ● | ● | ● | ● | | |
| | Mystic | 2004-2010 | ● | | ● | ● | ● | ● | | | |
| | Quashnet | 2004 | ● | | ● | ● | ● | ● | | | |
| | Stony Brook | 1978-2004 | ● | | ○ | ○ | ○ | ○ | ○ | | |
| RI | Gilbert Stuart | 1981-2010 | | | ● | ● | ● | ● | ● | ○ | |
| | Nonquit | 1999-2010 | | | ● | ● | ● | ● | ● | ○ | |
| | Buckeye Brook | 2003-2010 | | | | | | | ● | | |
| | Pawcatuck | 1988-2010 | | | x | x | x | x | ○ | ● | |
| | Ocean waters | 1979-2010 | | | | ● | | | ● | ● | |
| | Naragansett Bay | 1988-2010 | | | | ● | | | ● | ● | |
| | Coastal ponds | 1992-2010 | | | | ● | | | ● | ● | |
| CT | Bride Brook | 1966-1967, 2003-2011 | ● | | | ○ | | | ● | | |
| | Connecticut River | 1975-2011 | ● | | | ○ | | | ● | ○ | |
| | Farmington River | 1976-2011 | ● | | | | | | ● | | |
| | Thames River | 1996-2011 | ● | | | | | | ● | | |
| NY | Hudson | 1975-2010 | ● | ○ | ○ | ○ | | ○ | ○ | ○ | ○ |
| DE, NJ, PA | Delaware River | 1980-2010 | ○ | ○ | | ○ | | | ○ | ○ | ○ |
| | Delaware Bay | 1966-2010 | ○ | ○ | | ○ | | | ○ | ○ | ○ |
| MD | Nanticoke | 1959-2010 | ○ | | ○ | ○ | | ○ | | ○ | ○ |
| | Susquehanna | 1972-2010 | ○ | | | | | | x | | |
| | Chesapeake Bay | 1959-2010 | | | ○ | | | | | | ○ |
| MD, VA, DC | Potomac River | 1959-2010 | | ● | | ○ | | | ○ | ○ | ○ |
| VA | James | 1966-2010 | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| | Rappahannock | 1966-2010 | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| | York | 1966-2010 | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| NC | Albemarle Sound | 1972-2009 | | ○ | | | | ○ | ○ | ● | |
| | Chowan River | 1972-2009 | ● | ● | ● | ● | ● | ○ | | | ● |
| SC | Wynah Bay | | | | | | | | | x | |
| | Santee-Cooper | 1969-2010 | ○ | ● | ○ | ○ | ○ | ○ | ○ | x | ● |
| | Savannah River | | | | | | | | | x | |
| | Ashley-Combahee-Edisto Basin | | | | | | | | | x | |
| GA | Altamaha River | 2010 | | | | | | | | x | |
| | Ogeechee River | 2010 | | | | | | | | x | |
| | Savannah River | 2010 | | | | | | | | x | |
| FL | St. John's River | 2001 -2010 | ● | | | ● | | | ● | ○ | |

| | |
|---|---|
| ● | Data available for entire time-series |
| ○ | Data available for part of the time-series |
| x | Data available, but not reliable enough for assessment use |
| | Data not available |

Appendix 2. Commercial and Recreational River Herring Regulations as of January 1, 2012.

| State | River | Moratorium | Commercial Regs | Recreational Regs |
|---|---|---|---|---|
| ME | Damariscotta | | 3 day/week closure | 25 fish/day, gear restrictons |
| | St. George | | 2 day/week closure | 25 fish/day, gear restrictons |
| | Union | | | 25 fish/day, gear restrictons |
| | Orland | | 3 day/week closure | 25 fish/day, gear restrictons |
| | Androscoggin | Y | | |
| | Sebasticook | Y | | |
| | Merrymeeting Bay/Tribs | | | |
| | Gulf of Maine | | Gear restrictions | |
| NH | Exeter/Squamscott | | 5 day/week closure, 1 tote/person/day | |
| | Lamprey | | 1 day/week closure | |
| | Winnicut | | 1 day/week closure | |
| | Oyster | | 1 day/week closure | |
| | Cocheco | | 1 day/week closure | |
| | Taylor | | 1 day/week closure, closed area | |
| MA | Mattapoisett | 2005 | | |
| | Monument | 2005 | | |
| | Nemasket | 2005 | | |
| | Parker | 2005 | | |
| | Town | 2005 | | |
| | Agawam | 2005 | | |
| | Back | 2005 | | |
| | Charles | 2005 | | |
| | Mystic | 2005 | | |
| | Quashnet | 2005 | | |
| | Stony Brook | 2005 | | |
| RI | Gilbert Stuart | 2006 | | |
| | Nonquit | 2006 | | |
| | Buckeye Brook | 2006 | | |
| | Pawcatuck | 2006 | | |
| | Ocean waters | 2006 | | |
| | Naragansett Bay | 2006 | | |
| | Coastal ponds | 2006 | | |

| State | River | Moratorium | Commercial Regs | Recreational Regs |
|---|---|---|---|---|
| CT | Bride Brook | 2002 | | |
| | Connecticut River | 2002 | | |
| | Farmington River | 2002 | | |
| | Thames River | 2002 | | |
| NY | Hudson | | 1.5 days/week closure, gear restrictions | |
| DE, NJ, PA | Delaware River | 2012 | | |
| | Delaware Bay | 2012 | | |
| MD | Nanticoke | 2012 | | |
| | Susquehanna | 2012 | | |
| | Chesapeake Bay | 2012 | | |
| MD, VA, DC | Potomac River | 2010 | 50 lb bycatch allowance | |
| VA | James | 2012 | | |
| | Rappahannock | 2012 | | |
| | York | 2012 | | |
| NC | Albemarle Sound | 2007 | | |
| | Chowan River | 2007 | | |
| SC | Wynah Bay | 2012 | | |
| | Santee-Cooper | | 10 bushels/250 lbs/boat, gear restrictions | 1 bushel/day |
| | Savannah River | 2012 | | |
| | Ashley-Combahee-Edisto Basin | 2012 | | |
| GA | Altamaha River | 2012 | | |
| | Ogeechee River | 2012 | | |
| | Savannah River | 2012 | | |
| FL | St. Mary's River | 2012 | | |

*regulations as of January 1, 2012

Appendix 3: Estimates of incidental catch of alewife, blueback herring, hickory shad, and American shad.

A working paper prepared for the Fishery Management Action Team (FMAT) as part of a set of analyses for Amendment 14 to the Atlantic mackerel, squid and butterfish Fishery Management Plan.
September 15, 2011

**Part II. Analyses for Amendment 14 to the Atlantic mackerel, squid and butterfish Fishery Management Plan**

## 1.0 Estimates of incidental catch

### 1.1 Methods

Total incidental catch of river herring (alewife and blueback herring) and hickory and American shad (RHS) was quantified by fleet. Fleets included in the analyses were those sampled by the Northeast Fisheries Observer Program (NEFOP) and were stratified by region fished (Mid-Atlantic versus New England), time (year and quarter), gear group, and mesh size. Estimates that are restricted to a subset of trips identified as “targeted” trips for specific species were not used. These estimates are considered to be incomplete because the catches that occur on trips outside the trip subset are excluded. Furthermore, multiple species, such as Atlantic herring and mackerel, are often caught in a mixed fishery on the same trips during portions of the year. As such, defining targeted trips using a catch weight limit may lead to double counting of RHS incidental catch.

Region fished was defined using Statistical Areas for reporting commercial fishery data (Figure 1). The Mid-Atlantic region included Statistical Areas greater than 600, and New England included Statistical Areas 464 through 599. Gear groups included in the analyses were: bottom trawls, paired midwater trawls, single midwater trawls, gillnets, dredges, handlines, haul seines, longlines, pots/traps, purse seines, scallop trawl/dredge, seines and shrimp trawls. Bottom trawls and gillnets were further stratified into mesh groups. The estimated levels of precision when gillnet and bottom trawl incidental catches were quantified across all mesh sizes were very similar, and not consistently lower, than the precision estimates for these gears when estimated by mesh category. Since there was no gain in precision when we did not stratify by mesh, we split bottom trawl and gillnets into the following mesh categories:

| Mesh category | Bottom Trawl | Gillnet |
|---|---|---|
| small | mesh $\leq 3.5$ | mesh $< 5.5$ |
| medium | $3.5 <$ mesh $< 5.5$ | --- |
| large | mesh $\geq 5.5$ | $5.5 \leq$ mesh $< 8$ |
| x-large | --- | mesh $\geq 8$ |

Single and paired midwater trawls were split into separate fleets because the majority of both mackerel and herring landings during 2005-2010 were from paired midwater trawls, and the total catch-to-kept ratios varied between midwater trawl types.

The combined ratio method (Wigley et al 2007) is the standard discard estimation method implemented in NEFSC stock assessments. We used this method to quantify and estimate the precision (CV) of RHS total incidental catch for 1989 – 2010 across all fleets. Incidental catch estimates for the midwater trawl fleet are only provided for 2005-2010 because the estimates are most accurate as a result of improved sampling methodologies described below. Estimates of the precision are necessary in order to evaluate significant differences between incidental catch estimates by fleet and year.

Marked improvements to NEFOP sampling methodologies occurred in the high-volume midwater trawl (MWT) fisheries beginning in 2005, limiting the interpretability of estimates from these fleets in prior years. The NEFOP currently deploys specially-certified observers on paired and single midwater trawl vessels and purse seine vessels. NEFOP coverage of these high-volume fisheries that pump catch began in 2003 but the sampling focused on marine mammal interactions. In 2005, the focus of the sampling changed and the priorities became quantification of groundfish bycatch. At this time, the NEFOP implemented the catch composition log and observers began sampling the catches using a basket subsampling methodology in order to more accurately estimate catch weights over the course of pumping operations. At the same time, NEFOP protocols also required a more accurate quantification of the catches culled by the crew. Therefore, incidental catch estimates are provided beginning in 2005 because they are considered more accurate.

The NEFOP data used in this analysis were aggregated at the trip level. The sampling unit for the NEFOP database is a trip (Wigley et al. 2007) and observer sea days are allocated at the trip and fleet level, in contrast to the haul level. In addition, hauls within a trip are not independent of one another and are considered to be pseudo-replicates. The numbers of trips included in the analyses, for the Mid-Atlantic and New England regions, are presented in Tables 1 and 2, respectively.

For each trip, NEFOP data were used to calculate a total catch to kept (t/k) ratio, where t represents the total (retained+discarded) catch of an individual species (e.g., alewife, American shad) and k is the kept weight of all species. Annual estimates of total incidental catch were derived by quarter. Imputations were used for quarters with one or less observed trips.

The t/k ratios were expanded using a raising factor to quantify total incidental catch. With the exception of the midwater trawl fleets, total landed weight of all species (from the dealer database) was used as the raising factor. Total landings from the dealer database are considered to be more accurate than those of the VTR database because VTR landings represent a captain’s hail estimate. However, for the MWT fleets, we were unable to use the dealer data to estimate the kept weight of all species when stratifying by fishing area. When the area allocation (AA) tables were developed, MWT was not included in effort calculations because of difficulties determining effort for paired MWTs. Only those gears with effort information could be assigned to a Statistical Area. Given these limitations, VTR data were used as the expansion factor for the MWT fleet.

When quantifying incidental catch across multiple fleets, total kept weight of all species is an appropriate surrogate for effective fishing power because it is likely that all trips will not exhibit the same attributes (Wigley et al 2007). The use of effort without standardization makes the implicit assumption that effort is constant across all vessels, thereby resulting in a biased effort metric.

## 1.2 Results

### 1.2.1 Temporal distribution of incidental catches

The temporal distribution of incidental catches was summarized by quarter and fishing region (i.e., New England versus Mid-Atlantic), for the most recent six-year period (2005-2010), to take into account any effects that the most recent management changes may have had on the fleets included in the analyses. The gear types which exhibited the highest incidental catches of the combined four species consisted of bottom trawls, midwater trawls and gillnets. These gears comprised 92% of the total incidental catches in the Mid-Atlantic from all gear types and 97% in New England.

Incidental catches of the four species combined varied by region and quarter for each gear type. For the three predominant gear types, most of the catch of the four species combined was taken in midwater trawls (72%, of which 53% was from paired midwater trawls and the rest from single midwater trawls), followed by 24% in small mesh bottom trawls and 3% in large mesh gillnets (Table 3). Most of the catch (58%) occurred in the New England region where catches were higher for all three gear types; 36% taken in midwater trawls, followed by 18% in small mesh bottom trawls and 3% in large mesh gillnets. The highest quarterly catch (34%) occurred during Quarter 1 (Q1) in the Mid-Atlantic, of which the majority (32%) was taken in midwater trawls. The second and third highest quarterly catches of all four species occurred during Q4 (21%) and Q2 (14%) in New England. About 16% and 11% of the catches in New England during Q4 and Q2, respectively, were taken in midwater trawls.

Catches of all four species taken in midwater trawls during Q1 in the Mid-Atlantic and during all four quarters in New England comprised 69% of the total incidental catch during 2005-2010 (Table3). Small mesh bottom trawl catches in New England comprised an additional 19% of the total incidental catch and were highest during Q1 (7%) followed by Q3 (5%), Q4 (4%) and Q2 (3%). Catches in large mesh gillnets were highest in New England, comprising 3% of the total incidental catch, and were highest during Q3 and Q4 (both totaling 1%).

Given the similar migration patterns between the two shad species and between alewife and blueback herring, incidental catches were also summarized separately for river herring and shads. Shad catches occurred primarily in midwater trawls (42% of which 32% were from paired midwater trawls and the rest from single midwater trawls), followed by large mesh gillnets (27%) and small mesh bottom trawls (26%, Table 4). Shad catches were highest in the New England region (69%) and ranked from high to low were 29%, 23% and 13% for midwater trawls, large mesh gillnets and small mesh bottom trawls, respectively. Quarterly trends in shad catches were highly variable. The highest quarterly catches of shad occurred in midwater trawls during Q4 in New England (13%) and during Q1 in the Mid-Atlantic (12%), followed by catches taken during Q3 (9%) and Q4 (9%) in large mesh gillnets in New England.

River herring catches also occurred primarily in midwater trawls (76%, of which 56% were from paired midwater trawls and the rest from single midwater trawls), followed by small mesh bottom trawls (24%, Table 5). Catches of river herring in gillnets were negligible. Across gear types, catches of river herring were greater in New England (56%) than in the

Mid-Atlantic (44%). The percentages of midwater trawl catches of river herring were similar between New England (37%) and the Mid-Atlantic (38%). However, catches in New England small mesh bottom trawls were three times higher (18%) than those from the Mid-Atlantic (6%). Overall, the highest quarterly catches of river herring occurred in midwater trawls during Q1 in the Mid-Atlantic (35%), followed by catches in New England during Q4 (16%) and Q3 (11%). Quarterly catches in small mesh bottom trawls were highest in New England during Q1 (7%) and totaled 3-4% during each of the other three quarters.

### 1.2.2 Species-specific incidental catch estimates for 2005-2010

From 2005-2010, the total annual incidental catch of alewife ranged from 19.0-473.3 metric tons (mt) in New England and 8.9-256.2 mt in the mid-Atlantic. The dominant gear varied across years between paired midwater trawls and bottom trawls (Figure 2). Corresponding estimates of precision exhibited substantial interannual variation and ranged from 0.28-3.12 across gears and regions. In all years and regions, the small mesh category dominated alewife bottom trawl catches (Figure 3). With the exception of 2007, alewife catches in the mid-Atlantic were greatest in the first quarter and dominated by paired and single midwater trawls (Figure 4). In quarters 2-4, mid-Atlantic alewife catches were primarily from small mesh bottom trawls. In contrast, New England catches of Alewife generally increased with quarter, and with the exception of 2007, were consistently greatest in the fourth quarter. New England alewife catches represented a mixture of single midwater trawls, paired midwater trawls and small mesh bottom trawls.

Total annual blueback herring incidental catch from 2005-2010 ranged from 13.9–176.5 mt in New England and 1.2-382.6 mt in the mid-Atlantic. Across years paired and single midwater trawls exhibited the greatest blueback herring catches, with the exception of 2010 in the mid-Atlantic where bottom trawl was the most dominant gear (Figure 5). Corresponding precision estimates ranged from 0.27 – 3.65. The small mesh category dominated blueback herring bottom trawl catches (Figure 6). Similar to alewife, blueback herring catches were greatest in the 1$^{st}$ quarter in the Mid-Atlantic and, with the exception of 2007, in the fourth quarter in New England. In the mid-Atlantic, blueback herring catches were predominantly from midwater trawls. While small and medium mesh bottom trawls comprised approximately 60% of the total annual mid-Atlantic catch in 2007, the magnitude of this 2007 catch was small compared to other years. In New England, catches were largely from midwater trawls and to a lesser extent small mesh bottom trawls.

Total annual American shad incidental catches from 2005-2010 were generally less than that of the river herring species and ranged from 12.7–53.2 mt in New England and 5.9-36.6 mt in the mid-Atlantic. In contrast to both river herring species, the greatest annual American shad catches were due to gillnets as well as single MWTs, paired MWTs, and bottom trawls. Corresponding coefficients of variation ranged from 0.19 – 10.7. Within the bottom trawl fleet, the small mesh category generally exhibited the greatest catches; however, American shad were also caught in medium and large mesh bottom trawl fleets (Figure 9). Across regions and years, the large-mesh category generally dominated gillnet catches. Similar to the river herring species, American shad catches were greatest during the first quarter in the mid-Atlantic and the fourth quarter in New England. However, in contrast to the river herring species, the primary gears were more evenly distributed between midwater trawls, bottom trawls and large-mesh gillnets.

Total annual 2005-2010 hickory shad incidental catch was the smallest of all RHS species and ranged from 0.1–11.8 mt in New England and 1.0-8.7 mt in the mid-Atlantic. Across years, the dominant gear varied between bottom trawls, paired midwater trawls and gillnets (Figure 11). Precision estimates varied annually and ranged from 0.19–2.9 across gears and regions. Bottom trawl catches of hickory shad were predominantly comprised of the small mesh category, where gillnet catches were from both small and large mesh categories (Figure 12). Mid-Atlantic catches were more evenly distributed over quarter than for other RHS species, and were primarily comprised of small mesh bottom trawl and small and large mesh gillnets (Figure 13). The majority of New England quarterly catches was from midwater trawls, small-mesh bottom trawls and to a lesser extent large-mesh bottom trawls and gillnets.

Total annual incidental catch of unknown herring from 2005-2010 ranged from 5.2–228.2 mt in New England and 0.1 – 163.4 mt in the mid-Atlantic. The dominant gear by year and region varied between gillnet, paired MWT, single MWT, bottom trawl and the 'other' category (Figure 14). Corresponding coefficients of variation range from 0.2-0.8. Small- and large-mesh categories dominated unknown herring bottom trawl and gillnet catches, respectively (Figure 15). Mid-Atlantic catches were generally greatest in the first quarter and were from paired MWT, single MWT, small-mesh bottom trawl and large-mesh gillnets. New-England catches were approximately evenly distributed across quarter and largely from small-mesh bottom trawls and single MWTs (Figure 16).

Species-specific annual incidental catch estimates and the associated coefficients of variation are presented in Appendix 1.

#### 1.2.2.1 Validation of incidental catch estimates

Species-specific total catch and discard estimates can be used to quantify the amount kept by calculating the difference between the two estimates. These kept estimates can then be compared to species-specific landings obtained from the dealer or VTR databases to serve as validation. For both the river herring and shad species groups, kept estimates did not track the landings well (Figure 17). For Atlantic herring, however, landings and kept estimates were quite similar during the last 4-5 years of the time series. This consistency between kept and landed Atlantic herring estimates indicates that the employed methodology can be used to reconstruct landings. The discrepancy between landings and kept estimates of the RHS species suggests an inconsistency in the identification of these species at the ports of landing.

#### 1.2.2.2 Fisheries conducted by the fleets used in the incidental catch estimates

The incidental catch estimates are based on fleets (ex: gear, region, mesh) rather than fishery directivity. In order to identify the directivity of each of the fleets used in the incidental catch analysis, we analyzed trends in mackerel, herring, *Illex*, *Loligo*, and silver hake landings by month, area and mesh size. The analysis clearly indicated substantial fishery directivity overlap within fleets. For example, trends in mackerel and herring landings by gear indicate that both species are caught predominantly by paired midwater trawls (Figure 18).

Graphs of catch by codend mesh size recorded in the NEFOP database for observed hauls indicated an overlap in mesh sizes used on midwater trawl tows when the target species (i.e., targspec1 field in the NEFOP database) is either mackerel or Atlantic herring (Figure 19a). About 85% of mackerel midwater trawl catches and 96% of herring midwater trawl catches occurred with mesh sizes between 24 and 50 mm. Similar overlap in mesh size was apparent in bottom trawl tows targeting either mackerel or silver hake. Bottom trawl mesh sizes between 48 and 76 mm represented 99% of mackerel catches and 77% of silver hake catches (Figure 19b).

Some segregation in mackerel and herring 2005-2010 landings by Statistical Area was apparent (Figure 20a). The greatest proportions of herring midwater trawl landings occurred in New England (specifically Statistical Areas 512 through 522), whereas the greatest proportions of mackerel landings occurred in the Mid-Atlantic (Statistical Areas 612-622). However, there was some overlap in regional trends between the two species. For example, 20% of the total mackerel landings were from New England (Statistical Areas 525-537) and 19% of the total Atlantic herring landings were from the Mid-Atlantic. Similarly for bottom trawl landings, the greatest proportions of mackerel landings occurred in Mid-Atlantic statistical areas 612-622 and the greatest proportions of silver hake landings occurred in New England statistical areas 513-538 (Figure 20b). However, overlap was still apparent; 15% of total mackerel landings were caught in New England and 25% of total silver hake landings were from the Mid-Atlantic. Accordingly, Statistical Area alone does not appear to permit separation of fleets into fisheries.

Analysis of mackerel and herring landings by month and region indicated a mixed midwater trawl fishery from January-April in both the Mid-Atlantic and New England (Figure 21a). In the Mid-Atlantic, landings during January-April represented the vast majority (98%) of regional midwater trawl landings. Of the total January-April combined mackerel and herring landings from the Mid-Atlantic, between 24-39% were herring and 61–76% were mackerel. In New England, January-April landings only represented 21.7% of regional midwater trawl landings. Of the combined mackerel and herring landings, 32-41% were herring and 55-68% were mackerel. Analysis of mackerel, *Loligo* and silver hake bottom trawl landings by both region and month indicated a mixed fishery throughout the year (Figure 21b). While most mackerel landings occurred in January-April and most *Illex* landings occurred from June-October, silver hake and *Loligo* landings largely occurred throughout all months in both regions. Further examination of the distribution of January-April landings by Statistical Area indicated substantial overlap in both regions within both bottom trawl and midwater trawl fleets (Figure 22).

Based on trends in landings over time, region, gear and mesh category, and the strong evidence for mixed fisheries, it is not possible to clearly identify fishery directivity for each of the fleets used in the incidental catch analysis.

### 1.2.3 Spatial distribution of incidental catches

ArcGIS software (v. 10, ©ESRI) was used to produce maps of nominal fishing effort (days fished, from the Vessel Trip Reports), by ten-minute square (TNMS), for the gear types with the highest levels of incidental catch of each the four subject species during 2005-2010 (refer to Section 1.2.1). As previously noted, 2005-2010 was considered as the reference time period because it takes into account any effects that the most recent management changes may have had on the temporal and spatial distributions of the fleets included in the analyses. Gear types that were mapped included small mesh bottom trawls, single midwater trawls, paired midwater trawls and large mesh gillnets. Each TNMS was shaded according to the cumulative percentage of the total effort for the mapped time period. For each gear type, CPUE (kept+discarded weight of each of the four species / days fished) was computed from NEFOP data using observed tows. It should be noted that the days fished data from the Vessel Trip Reports (VTR) differ from the days fished data used to compute CPUE. The latter type of data is more accurate because it represents the sum of the actual tow durations within each TNMS, whereas days fished data from the VTRs represent the product of the average tow duration and the number of tows conducted during a subtrip as reported by each captain. Likewise, the data resolution of the geographic location data used to map VTR effort data differs from that used to map the NEFOP CPUE data. Mapping of the VTR data by TNMS represents a post-stratification of the effort data because captains are only asked to report a single fishing location (as a Statistical Area and a single latitude/longitude location within the Statistical Area) within each Statistical Area that is fished during a trip. The assignment of NEFOP CPUE data to each TNMS is more accurate because catch and effort data are recorded for each tow location.

For each map, CPUE data were mapped as the center point of a TNMS and overlain on the fishing effort layer to determine: 1.) where CPUE levels were highest; 2.) whether high incidental catch rates coincided with high levels of fishing effort; and 3.) to characterize the variability in temporal and spatial trends in effort and CPUE with respect to the potential for establishing closed areas or gear restriction areas to reduce bycatch of the four alosid species. Maps from the 2005-2010 reference period were compared to the 1999-2004 period to determine the degree of spatial consistency in broad-scale patterns of fishing effort for each gear type and incidental catch rates of each species. For comparative purposes, CPUE data classes used in the map legends for each of the two time periods were the same within each gear type. For midwater trawls, nominal effort and CPUE were not mapped for 1999-2004 because VTRs were not mandatory for the midwater trawl herring fleet until 2001 and, as previously explained in Section 1.1, the methods used by NEFOP fishery observers to quantify large-volume catches in the midwater trawl fleets were most accurate beginning in 2005 and the number of midwater trawl trips sampled by NEFOP was much higher.

#### 1.2.3.1 Maps of CPUE and effort, by fleet, for each species

As concluded in Section 1.2.1, most of the total incidental catch of river herring during 2005-2010, as well as the two shad species, occurred in midwater trawls (mainly in paired midwater trawls). Incidental catch rates of both alewife and blueback herring in paired midwater trawls during 2005-2010 were similar and were highest across broad areas in the western Gulf of Maine (SA 521 and 514 along and shoreward of the 100 m isobath), off the coast of central NJ (SA 612, 615 and 616), and scattered throughout southern New England (particularly off Rhode Island in Block Island Sound and along the southeast shore of Long Island, Figure 23). The highest catch rates of both species did not always coincide with the highest fleet effort. Catch rates of hickory shad in paired midwater trawls were much lower than those of American shad and occurred primarily in the western Gulf of Maine (Figure 24). American shad catch rates were highest in the same general areas as river herring, with the exception that American shad catch rates were lower in southern New England.

The second highest levels of incidental catches of each of the four alosid species occurred in small mesh bottom trawls. Fishing effort in the small mesh bottom trawl fleet varied between 2005-2010 and 1999-2004. During 1999-2004, effort occurred across a broader area, in the western Gulf of Maine and was much higher in southern New England (Figure 25). Incidental catch rates of blueback herring and alewife were also different between the two time periods, with the highest rates occurring in and around Block Island Sound during 2005-2010, but occurred offshore, for blueback herring, in scattered TNMS within SA 612, 613, 615 and 616 during 1999-2004 (Figures 25 and 26). Similar to the paired midwater trawl fleet, the highest incidental catch rates of both species did not always coincide with the highest levels of effort (e.g., Block Island Sound catch rates during 2005-2010). Catch rates of American shad in small mesh bottom trawls (Figure 27) were much higher than for hickory shad (Figure 28), similar to catch rates of the two shad species in paired midwater trawls. Catch rates of American shad in small mesh bottom trawls varied between the time periods and were highest in the vicinity of Long Island Sound during 2005-2010, followed by a broad range of mostly contiguous offshore areas in the Mid-Atlantic and southern New England (between the 100 and 400 m isobaths). During 1999-2004, catch rates of American shad and hickory shad were highest in the offshore areas, particularly in the southern portion of SA 537 between the 100 and 400 m isobaths (Figure 27 and 28).

Of the four bycatch species, most of the incidental catch in large-mesh gillnet fleet consists of the two shad species. Although fleet effort was highest off MA and NH (mainly inside of 100 m) during 2005-2010, catch rates of American shad were highest in areas where the fleet's effort was lowest; in the central Gulf of Maine in SA 515 (Figure 29). Incidental catches of hickory shad were extremely low (Figure 30).

Some of the maps included in the analysis showed CPUE data within ten-minute squares which lacked VTR effort data. Where this disconnect occurred in state waters, it may have been attributable to the fact that those vessels were not required to have federal permits, and thus, not required to submit VTRs. When this disconnect occurred seaward of the boundary for state territorial waters, it may have been due to incomplete submittals of VTR data for all trips, but more likely was due to differences between the spatial resolution of the VTR and NEFOP effort data.

#### 1.2.3.2 Maps of CPUE and effort, by fleet and quarter, for all four species combined

A second series of CPUE and effort maps was prepared for single and paired midwater trawls combined and small mesh bottom trawls, by quarter, during 2005-2010 because these two gear types comprised a majority of the incidental catches of all four species during this time period (Table 3). Incidental catches of all four species were mapped on a quarterly basis to provide a comprehensive summary of the data in time and space. Within each of the two gear types, the CPUE and effort data are comparable across quarters.

During 2005-2010, catch rates of all four species combined were highest in midwater trawls during Q1 and Q4 and were distributed across very large areas, but the areas were not always contiguous (Figures 31 and 32). During Q1, catch rates were very high in Block Island Sound and off eastern Long Island as well as in scattered areas of the Mid-Atlantic off New Jersey (Figure 31). During Q4, catch rates were highest in the western Gulf of Maine, along the 100 m isobath between Cape Cod, Massachusetts and New Hampshire and were also very high in an area of low effort by the fleet located south of Martha's Vineyard (Figure 32).

During 2005-2010, catch rates of all four species combined were highest in small mesh bottom trawls during Q1 and Q2 and were also distributed across very large areas, but which were generally contiguous (Figures 33 and 34). During Q1, the highest catch rates occurred in and around Block Island Sound, followed secondarily by the area of highest effort which was located near the shelf edge and north of a the Southern Gear Restricted Area (polygon denoted as a dashed line in the Mid-Atlantic). The high catch rates in Block Island Sound occurred primarily in Statistical Area 538, and also adjacent portions of SA 611 and SA 537, but effort by the small mesh bottom trawl fleet is unknown.

#### 1.2.3.3 Effectiveness of closed areas to reduce alosid bycatch

The establishment of year-round and/or seasonal closed areas (CAs) and/or gear restriction areas (GRAs) was evaluated as a potential management measure to reduce incidental catches of the subject alosid species. The degree of effectiveness of CAs and GRAs in accomplishing this objective is dependent on the degree of temporal and spatial overlap between the distribution of fishing effort for the fleets with the predominant bycatch and the distribution of the bycatch species, and more importantly, the interannual consistency of such overlap. If the highest incidental catches consistently occur across a reasonably small area each year, then CAs and/or GRAs may be effective. However, if the opposite situation is true, the size of the CA and/or GRA must be large in order to encompass the spatial extent of the interannual variability, and therefore, may not be practicable. In addition to these considerations, quantification of the effectiveness of CAs and GRAs is difficult for mobile species.

Maps of NEFSC spring and fall survey catches (presented in Part I) indicate that the seasonal and interannual distributions of all four species are highly variable in time and space. In addition, the analyses presented herein indicate that the incidental catches of all four bycatch species, as well as effort patterns in the predominant fleets which catch theses species are also highly variable in time and space. This is because of all four species undergo extensive coastwide migrations, which are largely influenced by water temperatures, and because the predominant gear types which incidentally catch these species (e.g., Atlantic herring and Atlantic mackerel in the MWT fleet and *Loligo*, *Illex*, hakes, and Atlantic mackerel in the small mesh BT fleet) are seeking target species which are also highly migratory. For example, the interannual variability in the spatial distribution of fishing effort in the midwater trawl fleet was quite variable during 2005-2010 (Figure 35). There was less variability in the annual effort distributions for the small mesh bottom trawl fleet, but during some years (e.g., 2005 and 2007) very little effort occurred inshore (Figure 36). Commercial catches of Atlantic mackerel also showed substantial interannual variability in the spatial distribution of monthly catches (Figures 37 and 38).

In conclusion, as a result of the high degree of interannual and seasonal variability in the spatial distributions of the four bycatch species as well as in the fishing effort of for the midwater trawl and small mesh bottom trawl fleets which incidentally catch these species, closed areas are not considered to be an effective management measure for the reduction of incidental catch of the four species addressed herein.

Table 1: Total number of trips recorded for each fleet in the observer, dealer and VTR databases for the Mid-Atlantic. Landings from the VTR database were used as the raising factor to estimate catch in the midwater trawl fleets. For all other fleets, the dealer database was used.

| | Number of trips | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bottom trawl | | | | | | Midwater trawl | | | |
| | Small mesh | | Medium mesh | | Large mesh | | Single | | Paired | |
| Year | Observer | Dealer | Observer | Dealer | Observer | Dealer | Observer | VTR | Observer | VTR |
| 1989 | 29 | 1,781 | 7 | 412 | 1 | 7 | | | | |
| 1990 | 31 | 1,363 | 19 | 386 | 0 | 11 | | | 0 | 0 |
| 1991 | 61 | 1,711 | 20 | 361 | 4 | 100 | 5 | 0 | 0 | 0 |
| 1992 | 39 | 1,294 | 12 | 283 | 14 | 284 | | | 9 | 0 |
| 1993 | 6 | 1,167 | 1 | 103 | 7 | 441 | | | 14 | 0 |
| 1994 | 6 | 2,170 | 6 | 156 | 14 | 1,998 | 1 | 64 | 30 | 44 |
| 1995 | 60 | 2,918 | 3 | 330 | 53 | 3,332 | 0 | 120 | 33 | 50 |
| 1996 | 68 | 3,143 | 10 | 652 | 16 | 3,344 | 0 | 264 | 0 | 14 |
| 1997 | 41 | 3,426 | 9 | 692 | 5 | 3,711 | 0 | 210 | 0 | 6 |
| 1998 | 24 | 3,693 | 3 | 784 | 13 | 3,647 | 0 | 239 | 0 | 34 |
| 1999 | 26 | 3,250 | 9 | 777 | 5 | 3,865 | 0 | 205 | 0 | 26 |
| 2000 | 25 | 3,230 | 10 | 806 | 28 | 3,250 | 5 | 194 | 1 | 74 |
| 2001 | 42 | 2,684 | 12 | 879 | 44 | 3,886 | 0 | 170 | 0 | 56 |
| 2002 | 15 | 2,408 | 18 | 998 | 38 | 4,172 | 0 | 72 | 1 | 107 |
| 2003 | 21 | 1,637 | 51 | 795 | 11 | 4,208 | 0 | 115 | 5 | 195 |
| 2004 | 108 | 1,836 | 151 | 692 | 96 | 4,874 | 2 | 99 | 8 | 249 |
| 2005 | 74 | 1,086 | 101 | 466 | 88 | 6,478 | 4 | 81 | 11 | 221 |
| 2006 | 100 | 1,810 | 47 | 736 | 62 | 5,051 | 8 | 74 | 6 | 184 |
| 2007 | 86 | 1,711 | 139 | 714 | 159 | 3,899 | 1 | 86 | 2 | 83 |
| 2008 | 66 | 1,776 | 84 | 701 | 129 | 4,391 | 10 | 17 | 8 | 143 |
| 2009 | 169 | 2,031 | 125 | 661 | 162 | 4,737 | 5 | 27 | 20 | 162 |
| 2010 | 182 | 1,895 | 187 | 420 | 276 | 3,944 | 4 | 15 | 13 | 85 |

| | Number of trips | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Gillnet | | | | | | Other | |
| | Small mesh | | Large mesh | | X-large mesh | | | |
| Year | Observer | Dealer | Observer | Dealer | Observer | Dealer | Observer | Dealer |
| 1989 | 0 | 67 | 0 | 27 | | | 0 | 15,494 |
| 1990 | 0 | 137 | 0 | 1 | 0 | 3 | 1 | 16,633 |
| 1991 | 0 | 121 | 0 | 1 | | | 8 | 17,948 |
| 1992 | 0 | 100 | 0 | 5 | | | 15 | 17,042 |
| 1993 | 0 | 80 | 0 | 33 | | | 42 | 17,467 |
| 1994 | 83 | 85 | 58 | 57 | 20 | 24 | 42 | 15,086 |
| 1995 | 126 | 185 | 202 | 516 | 73 | 294 | 44 | 13,440 |
| 1996 | 133 | 343 | 172 | 531 | 65 | 638 | 24 | 14,109 |
| 1997 | 90 | 422 | 133 | 400 | 111 | 1,021 | 27 | 18,541 |
| 1998 | 100 | 699 | 130 | 456 | 73 | 1,403 | 36 | 16,378 |
| 1999 | 42 | 848 | 23 | 566 | 19 | 1,443 | 57 | 15,424 |
| 2000 | 49 | 1,110 | 17 | 543 | 18 | 1,954 | 72 | 15,308 |
| 2001 | 54 | 1,280 | 17 | 441 | 17 | 2,193 | 97 | 15,747 |
| 2002 | 34 | 1,267 | 10 | 376 | 11 | 2,139 | 96 | 16,653 |
| 2003 | 25 | 750 | 4 | 294 | 13 | 2,104 | 115 | 17,997 |
| 2004 | 12 | 1,303 | 6 | 475 | 38 | 1,409 | 330 | 16,892 |
| 2005 | 19 | 1,270 | 4 | 335 | 82 | 1,739 | 400 | 23,185 |
| 2006 | 20 | 1,160 | 7 | 500 | 32 | 1,470 | 144 | 25,122 |
| 2007 | 19 | 1,231 | 13 | 516 | 32 | 2,045 | 245 | 27,634 |
| 2008 | 7 | 905 | 2 | 642 | 44 | 2,029 | 506 | 25,958 |
| 2009 | 9 | 1,252 | 8 | 1177 | 43 | 1,693 | 433 | 25,787 |
| 2010 | 12 | 851 | 52 | 1122 | 91 | 1,455 | 283 | 16,538 |

Table 2: Total number of trips recorded for each fleet in the observer, dealer and VTR databases for New England. Landings from the VTR database were used as the raising factor to estimate catch in the midwater trawl fleets. For all other fleets, the dealer database was used.

| | Number of trips | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bottom trawl | | | | | | Midwater trawl | | | |
| | Small mesh | | Medium mesh | | Large mesh | | Single | | Paired | |
| Year | Observer | Dealer | Observer | Dealer | Observer | Dealer | Observer | VTR | Observer | VTR |
| 1989 | 72 | 1,432 | 14 | 528 | 56 | 5,406 | | | 0 | 0 |
| 1990 | 33 | 1,665 | 4 | 355 | 54 | 5,851 | | | 0 | 0 |
| 1991 | 84 | 1,278 | 13 | 156 | 78 | 5,890 | 2 | 0 | 0 | 0 |
| 1992 | 56 | 1,348 | 1 | 120 | 68 | 5,531 | 0 | 0 | 0 | 0 |
| 1993 | 19 | 1,750 | 2 | 153 | 31 | 5,079 | 0 | 0 | 7 | 0 |
| 1994 | 9 | 3,426 | 2 | 239 | 27 | 8,341 | 0 | 306 | 4 | 53 |
| 1995 | 37 | 2,944 | 2 | 154 | 67 | 12,458 | 4 | 785 | 2 | 11 |
| 1996 | 47 | 2,665 | 2 | 51 | 39 | 12,475 | 0 | 902 | 0 | 18 |
| 1997 | 18 | 2,477 | 3 | 100 | 24 | 10,498 | 0 | 705 | 0 | 93 |
| 1998 | 5 | 2,979 | 0 | 94 | 11 | 11,095 | 0 | 508 | 0 | 170 |
| 1999 | 19 | 2,774 | 0 | 214 | 32 | 10,193 | 1 | 519 | 2 | 165 |
| 2000 | 8 | 2,297 | 9 | 124 | 99 | 11,064 | 7 | 463 | 0 | 367 |
| 2001 | 8 | 2,073 | 10 | 173 | 152 | 11,270 | 1 | 336 | 0 | 631 |
| 2002 | 35 | 1,625 | 29 | 221 | 214 | 11,138 | 0 | 371 | 0 | 651 |
| 2003 | 44 | 1,653 | 24 | 184 | 385 | 10,801 | 2 | 251 | 18 | 614 |
| 2004 | 86 | 1,283 | 83 | 152 | 525 | 9,343 | 23 | 254 | 60 | 581 |
| 2005 | 82 | 1,064 | 169 | 131 | 1341 | 8,388 | 43 | 265 | 91 | 463 |
| 2006 | 48 | 1,569 | 35 | 299 | 612 | 7,656 | 10 | 195 | 21 | 488 |
| 2007 | 57 | 1,745 | 18 | 213 | 618 | 7,461 | 10 | 84 | 11 | 235 |
| 2008 | 46 | 2,016 | 16 | 175 | 751 | 7,688 | 11 | 34 | 36 | 185 |
| 2009 | 195 | 1,895 | 23 | 270 | 877 | 7,373 | 10 | 48 | 67 | 223 |
| 2010 | 206 | 2,227 | 50 | 251 | 1049 | 6,043 | 29 | 57 | 106 | 213 |

| | Number of trips | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Gillnet | | | | | | Other | |
| | Small mesh | | Large mesh | | X-large mesh | | | |
| Year | Observer | Dealer | Observer | Dealer | Observer | Dealer | Observer | Dealer |
| 1989 | 0 | 10 | 0 | 497 | 0 | 1 | 40 | 28,527 |
| 1990 | 0 | 10 | 0 | 712 | | | 32 | 30,631 |
| 1991 | 0 | 50 | 0 | 1045 | 0 | 2 | 79 | 33,011 |
| 1992 | | | 0 | 1159 | 0 | 47 | 144 | 33,574 |
| 1993 | | | 0 | 1133 | 0 | 81 | 118 | 33,700 |
| 1994 | 0 | 3 | 61 | 2870 | 40 | 934 | 107 | 28,586 |
| 1995 | 0 | 8 | 105 | 6910 | 46 | 2,029 | 101 | 31,904 |
| 1996 | 0 | 21 | 55 | 6448 | 23 | 1,533 | 62 | 35,361 |
| 1997 | 0 | 12 | 51 | 5854 | 19 | 1,214 | 32 | 35,373 |
| 1998 | 3 | 14 | 115 | 5202 | 15 | 1,061 | 15 | 32,140 |
| 1999 | 1 | 6 | 98 | 3860 | 21 | 1,352 | 34 | 25,018 |
| 2000 | 0 | 17 | 107 | 4187 | 50 | 1,881 | 229 | 21,374 |
| 2001 | 1 | 17 | 69 | 4280 | 33 | 2,530 | 28 | 22,532 |
| 2002 | 0 | 14 | 91 | 3724 | 41 | 2,810 | 30 | 23,239 |
| 2003 | 0 | 20 | 326 | 4485 | 190 | 2,987 | 72 | 20,573 |
| 2004 | 1 | 16 | 699 | 3342 | 536 | 2,966 | 240 | 16,696 |
| 2005 | 0 | 39 | 587 | 3491 | 459 | 2,939 | 484 | 39,261 |
| 2006 | 0 | 67 | 142 | 3866 | 79 | 2,416 | 262 | 47,023 |
| 2007 | 2 | 78 | 132 | 5467 | 164 | 2,102 | 317 | 43,561 |
| 2008 | 3 | 27 | 170 | 6538 | 112 | 2,274 | 368 | 55,716 |
| 2009 | 2 | 12 | 313 | 6824 | 76 | 1,989 | 243 | 66,351 |
| 2010 | 0 | 22 | 1267 | 5374 | 771 | 2,653 | 383 | 150,268 |

Table 3: Proportion of 2005-2010 incidental catch of all river herring and shad species by region, fleet and quarter.

| | Bottom Trawl | | | Gillnet | | | Paired MWT | Single MWT | Total MWT | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | lg | med | sm | xlg | lg | sm | all | all | | |
| **Mid-Atlantic (SA >= 600)** | **0.001** | **0.002** | **0.062** | **0.000** | **0.005** | **0.001** | **0.270** | **0.083** | **0.353** | **0.424** |
| Q1 | 0.000 | 0.001 | 0.018 | 0.000 | 0.002 | 0.000 | 0.246 | 0.074 | 0.320 | 0.342 |
| Q2 | 0.000 | 0.000 | 0.012 | 0.000 | 0.001 | 0.000 | 0.016 | 0.007 | 0.023 | 0.037 |
| Q3 | 0.000 | 0.000 | 0.023 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.002 | 0.026 |
| Q4 | 0.000 | 0.001 | 0.010 | 0.000 | 0.001 | 0.000 | 0.007 | 0.000 | 0.008 | 0.020 |
| **New England (SA <= 500)** | **0.007** | **0.000** | **0.177** | **0.000** | **0.028** | **0.000** | **0.259** | **0.105** | **0.364** | **0.576** |
| Q1 | 0.002 | 0.000 | 0.065 | 0.000 | 0.003 | 0.000 | 0.025 | 0.015 | 0.040 | 0.111 |
| Q2 | 0.002 | 0.000 | 0.030 | 0.000 | 0.004 | 0.000 | 0.056 | 0.051 | 0.107 | 0.142 |
| Q3 | 0.002 | 0.000 | 0.046 | 0.000 | 0.011 | 0.000 | 0.050 | 0.007 | 0.057 | 0.115 |
| Q4 | 0.002 | 0.000 | 0.037 | 0.000 | 0.010 | 0.000 | 0.128 | 0.031 | 0.159 | 0.208 |
| **Grand Total** | **0.008** | **0.002** | **0.239** | **0.000** | **0.033** | **0.001** | **0.529** | **0.188** | **0.716** | **1.000** |

Table 4: Proportion of 2005-2010 incidental catch of American and hickory shad by region, fleet and quarter.

| | Bottom trawl | | | Gillnet | | | Paired MWT | Single MWT | Total MWT | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | lg | med | sm | xlg | lg | sm | all | all | | |
| **Mid-Atlantic (SA >= 600)** | **0.004** | **0.012** | **0.115** | **0.000** | **0.041** | **0.008** | **0.115** | **0.016** | **0.132** | **0.312** |
| Q1 | 0.001 | 0.006 | 0.030 | 0.000 | 0.014 | 0.003 | 0.103 | 0.014 | 0.117 | 0.172 |
| Q2 | 0.001 | 0.001 | 0.022 | 0.000 | 0.012 | 0.001 | 0.010 | 0.001 | 0.011 | 0.049 |
| Q3 | 0.001 | 0.001 | 0.045 | 0.000 | 0.004 | 0.002 | 0.000 | 0.000 | 0.001 | 0.054 |
| Q4 | 0.001 | 0.004 | 0.018 | 0.000 | 0.011 | 0.002 | 0.002 | 0.000 | 0.003 | 0.038 |
| **New England (SA <= 500)** | **0.027** | **0.000** | **0.140** | **0.001** | **0.233** | **0.000** | **0.208** | **0.078** | **0.286** | **0.688** |
| Q1 | 0.007 | 0.000 | 0.036 | 0.000 | 0.028 | 0.000 | 0.019 | 0.006 | 0.025 | 0.096 |
| Q2 | 0.007 | 0.000 | 0.030 | 0.000 | 0.032 | 0.000 | 0.043 | 0.013 | 0.056 | 0.125 |
| Q3 | 0.006 | 0.000 | 0.048 | 0.000 | 0.089 | 0.000 | 0.054 | 0.021 | 0.075 | 0.219 |
| Q4 | 0.006 | 0.000 | 0.027 | 0.000 | 0.085 | 0.000 | 0.092 | 0.038 | 0.130 | 0.248 |
| **Grand Total** | **0.030** | **0.013** | **0.256** | **0.001** | **0.274** | **0.008** | **0.324** | **0.094** | **0.418** | **1.000** |

Table 5: Proportion of 2005-2010 incidental catch of river herring by region, fleet and quarter.

| | Bottom trawl | | | | Gillnet | | Paired MWT | Single MWT | Total MWT | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | lg | med | sm | xlg | lg | sm | all | all | | |
| **Mid-Atlantic (SA >= 600)** | **0.001** | **0.001** | **0.055** | **0.000** | **0.000** | **0.000** | **0.291** | **0.092** | **0.383** | **0.439** |
| Q1 | 0.000 | 0.000 | 0.017 | 0.000 | 0.000 | 0.000 | 0.265 | 0.082 | 0.347 | 0.365 |
| Q2 | 0.000 | 0.000 | 0.010 | 0.000 | 0.000 | 0.000 | 0.017 | 0.008 | 0.025 | 0.036 |
| Q3 | 0.000 | 0.000 | 0.020 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.002 | 0.022 |
| Q4 | 0.000 | 0.000 | 0.009 | 0.000 | 0.000 | 0.000 | 0.008 | 0.000 | 0.008 | 0.017 |
| **New England (SA <= 500)** | **0.004** | **0.000** | **0.182** | **0.000** | **0.000** | **0.000** | **0.266** | **0.109** | **0.374** | **0.561** |
| Q1 | 0.001 | 0.000 | 0.069 | 0.000 | 0.000 | 0.000 | 0.026 | 0.016 | 0.043 | 0.113 |
| Q2 | 0.001 | 0.000 | 0.030 | 0.000 | 0.000 | 0.000 | 0.057 | 0.056 | 0.114 | 0.145 |
| Q3 | 0.001 | 0.000 | 0.045 | 0.000 | 0.000 | 0.000 | 0.049 | 0.006 | 0.055 | 0.101 |
| Q4 | 0.001 | 0.000 | 0.038 | 0.000 | 0.000 | 0.000 | 0.133 | 0.030 | 0.163 | 0.202 |
| **Grand Total** | **0.005** | **0.001** | **0.237** | **0.000** | **0.000** | **0.000** | **0.556** | **0.200** | **0.757** | **1.000** |

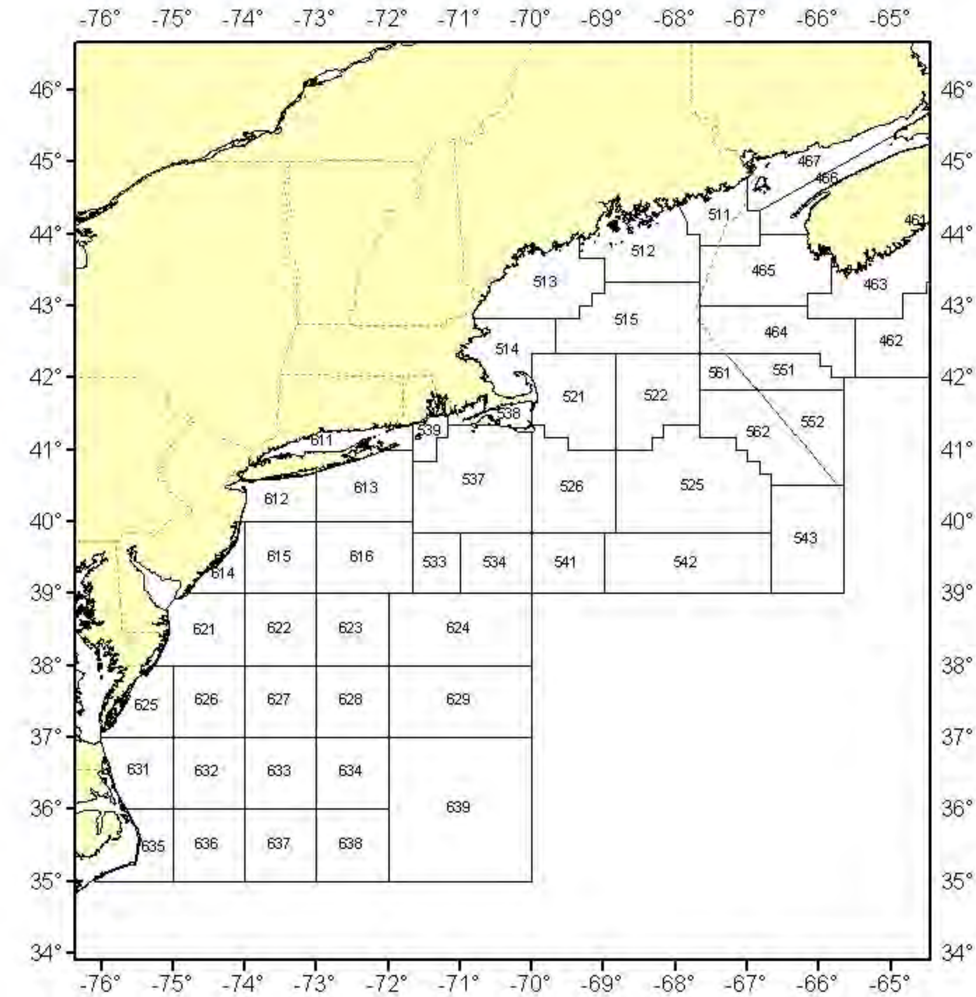



Figure 1: Statistical Areas used to define the fishing regions used in the incidental catch analysis. The Mid-Atlantic region included Statistical Areas greater than 600. The New England region included Statistical Areas 464 through 599.

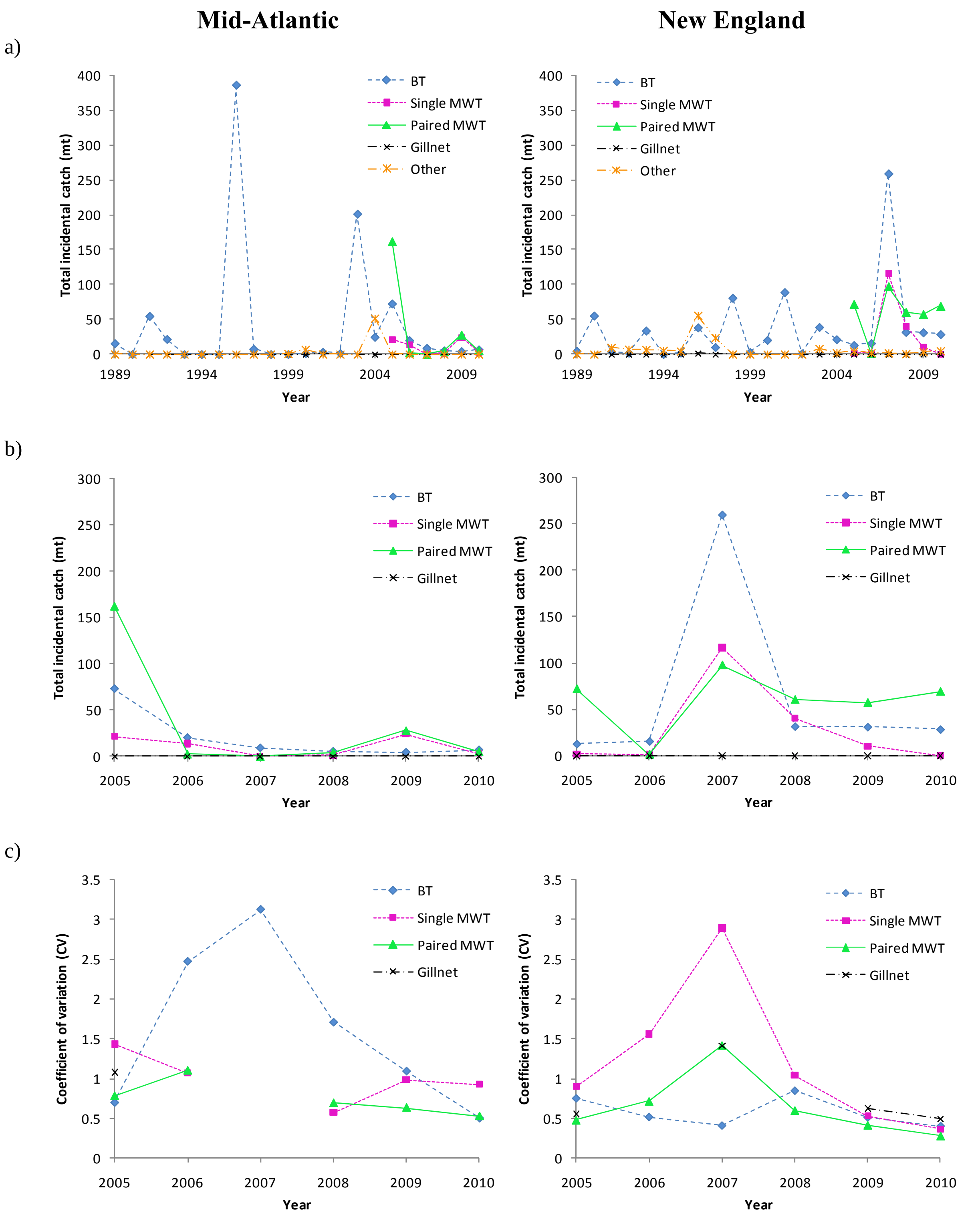



Figure 2: Alewife total annual incidental catch (mt) by region for the four gears with the largest catches from a) 1989 – 2010 and b) 2005 – 2010, and c) the corresponding estimates of precision. Midwater trawl estimates are only included beginning in 2005.

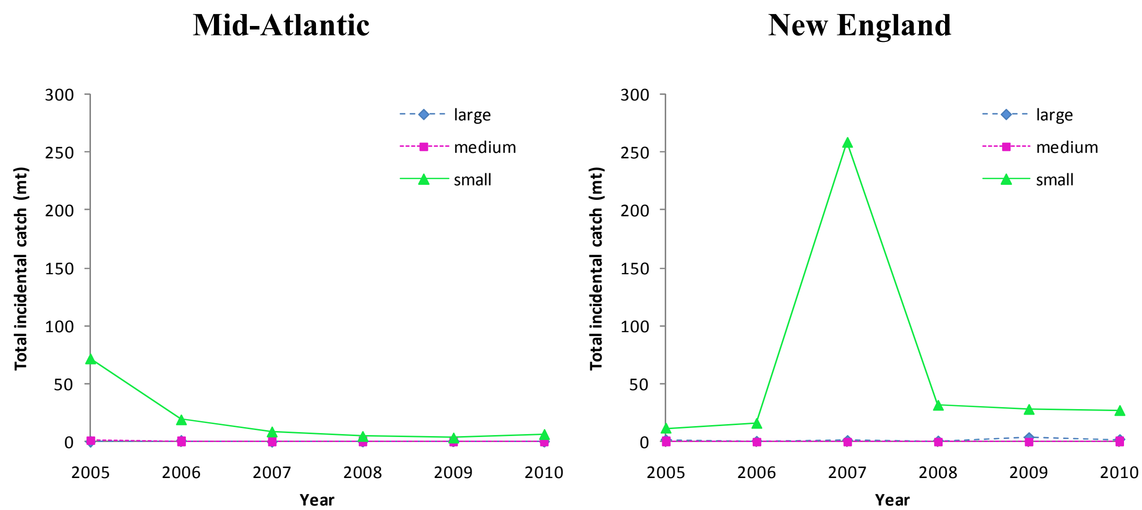
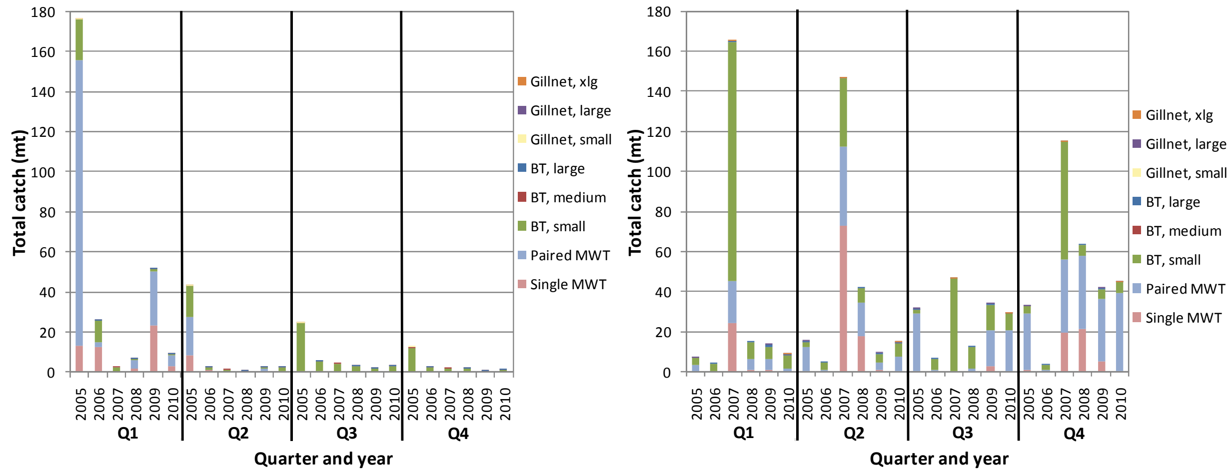



Figure 3: Alewife total incidental catch (mt) from 2005 – 2010 by region and bottom trawl mesh category.

**Mid-Atlantic** **New England**

**a)**




**b)**

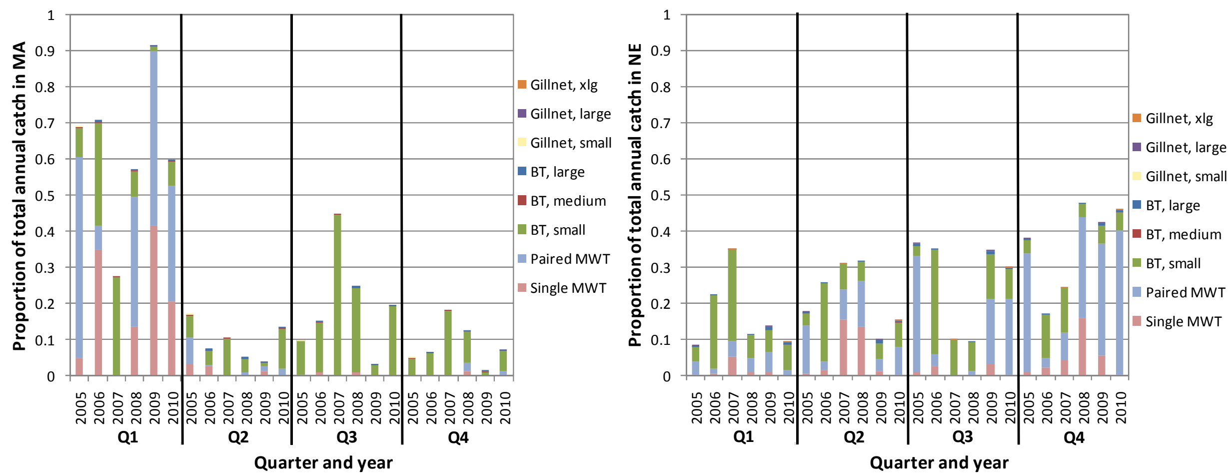



Figure 4: Alewife quarterly incidental catch (mt) by region and fleet (a) and the corresponding proportion of the total annual catch within each region and quarter (b).

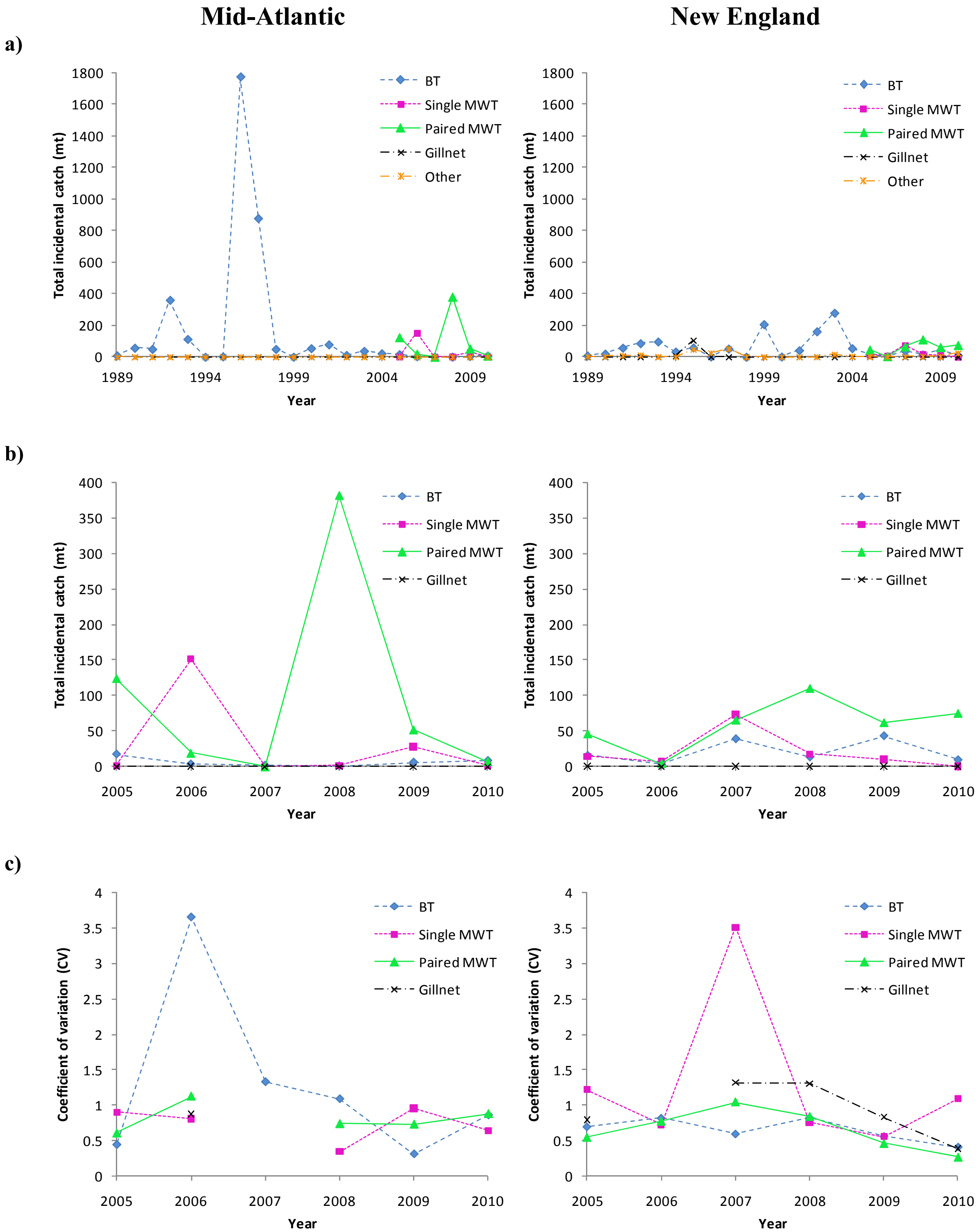



Figure 5: Blueback herring total annual incidental catch (mt) by region for the four gears with the largest catches from a) 1989 – 2010 and b) 2005 – 2010, and c) the corresponding estimates of precision. Midwater trawl estimates are only included beginning in 2005.

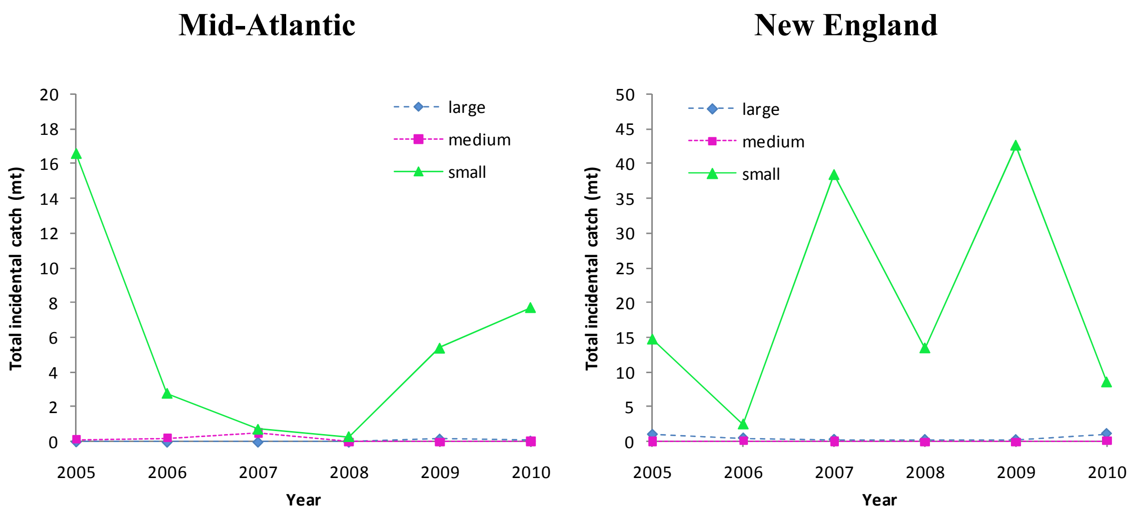



Figure 6: Blueback herring total incidental catch (mt) from 2005 – 2010 by region and bottom trawl mesh category.

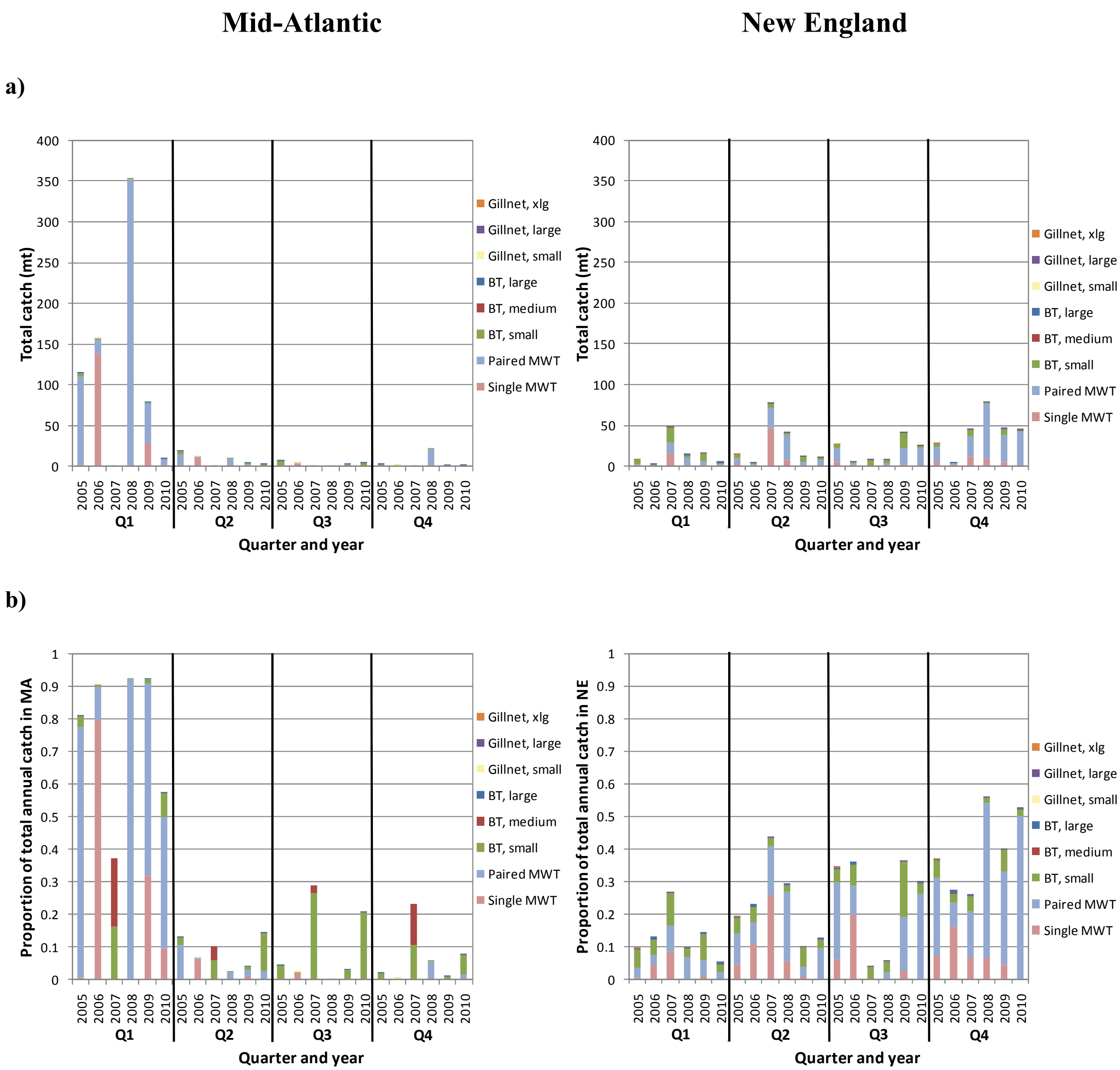



Figure 7: Blueback herring incidental catch (mt) by region and fleet (a) and the corresponding proportion of the total annual catch within each region and quarter (b).

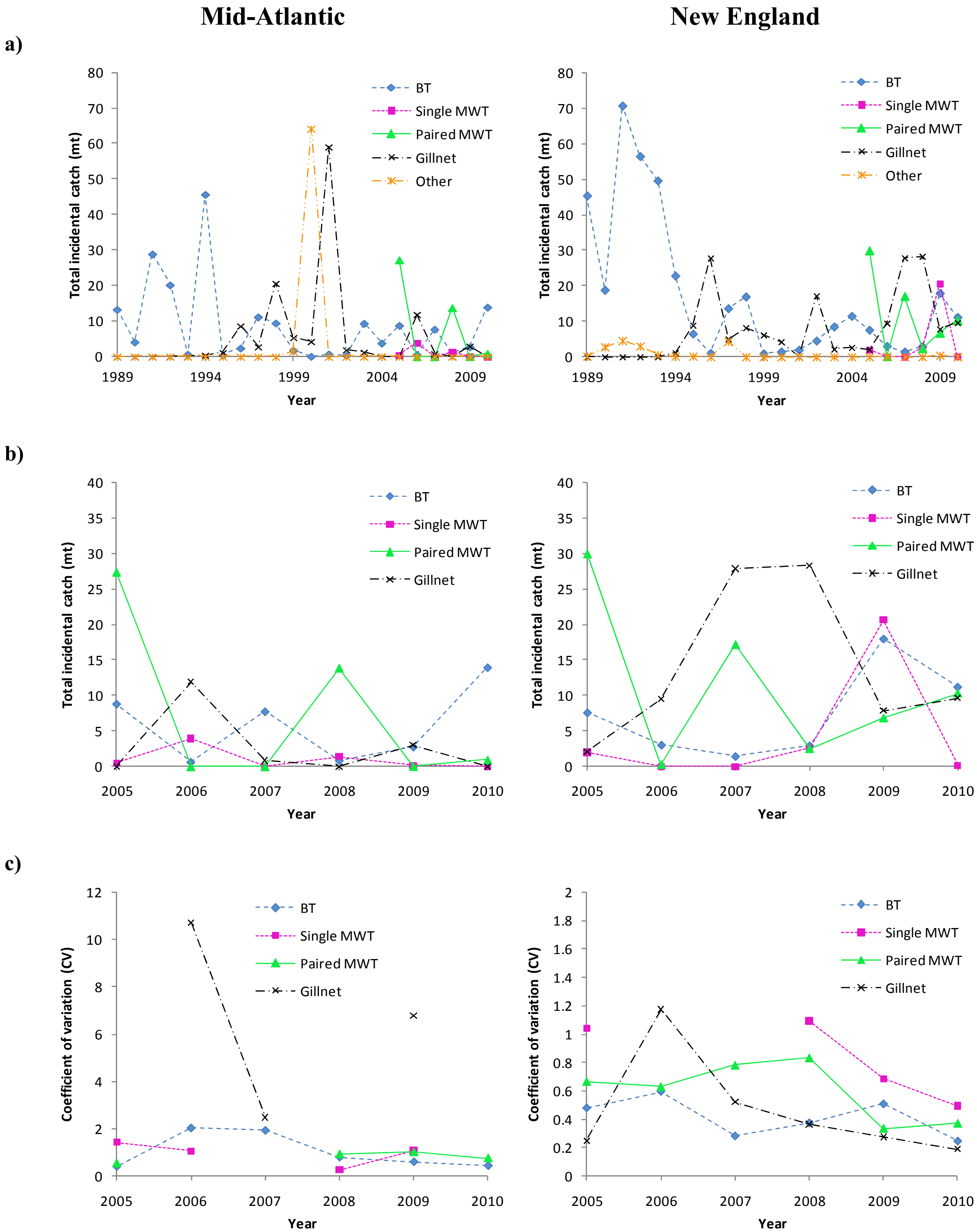



Figure 8: American shad total annual incidental catch (mt) by region for the four gears with the largest catches from a) 1989 – 2010 and b) 2005 – 2010, and c) the corresponding estimates of precision. Midwater trawl estimates are only included beginning in 2005.

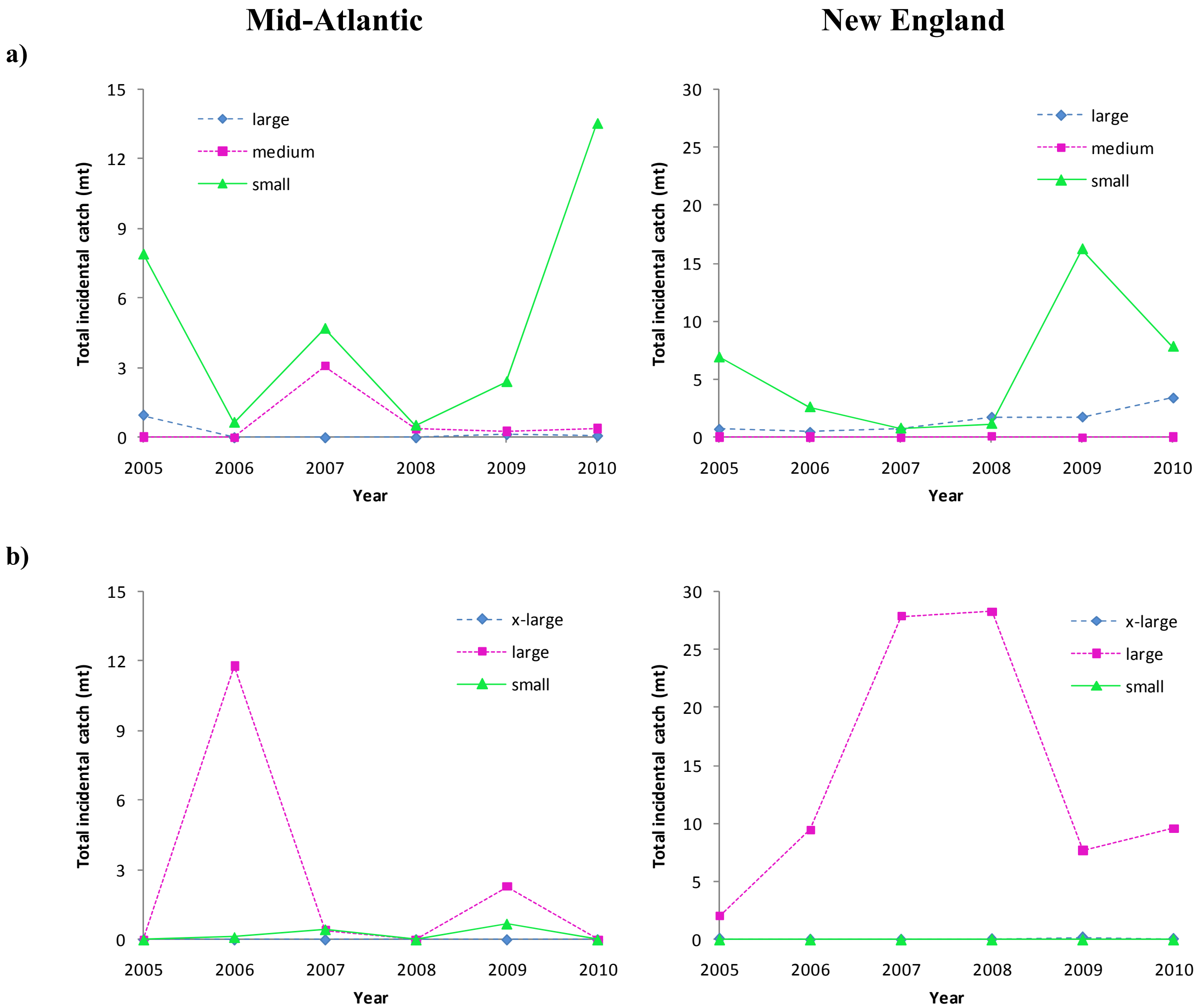



Figure 9: American shad total incidental catch (mt) from 2005 – 2010 by region and mesh category for a) bottom trawl and b) gillnet fleets.

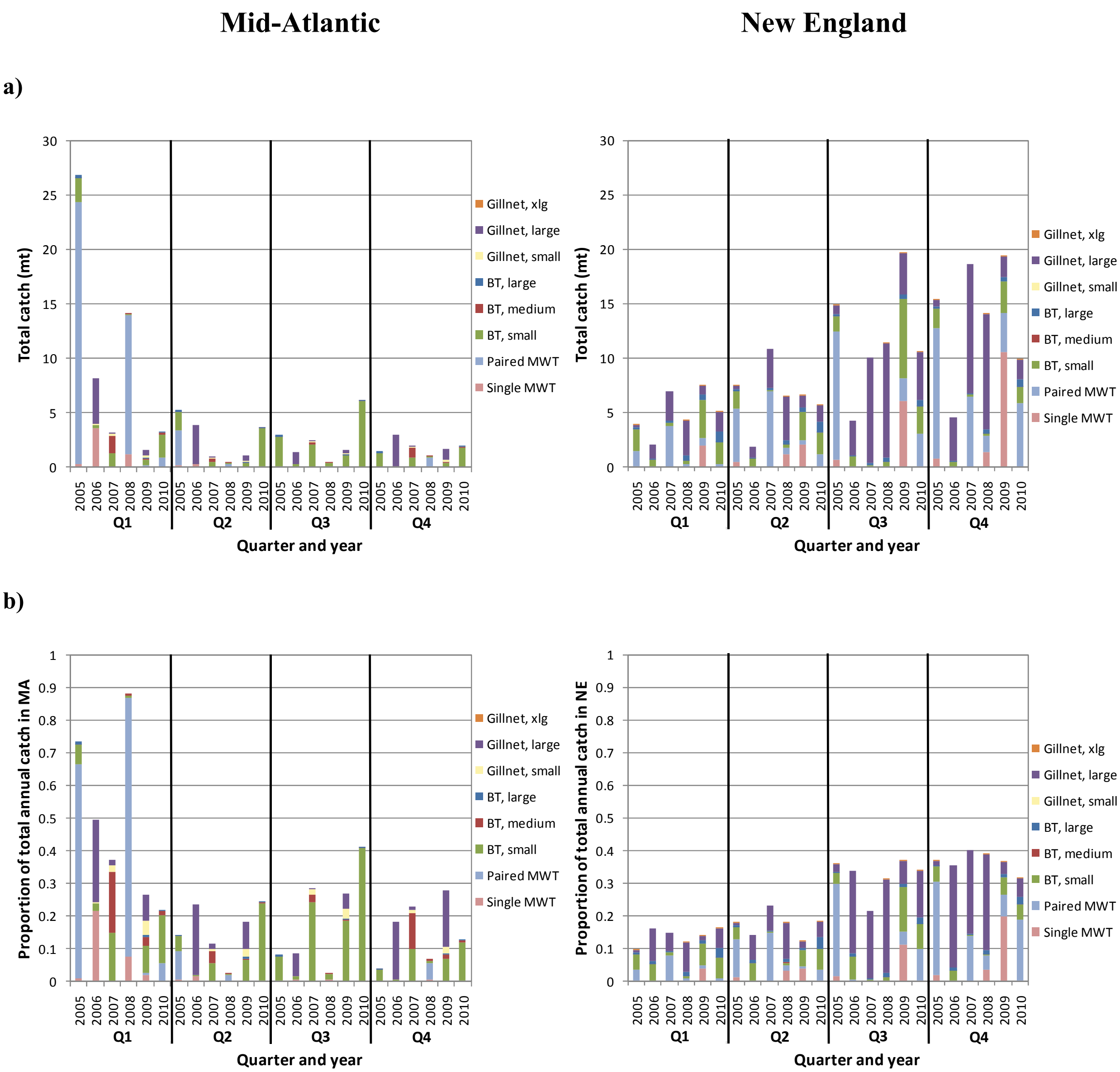



Figure 10: American shad quarterly incidental catch (mt) by region and fleet (a) and the corresponding proportion of the total annual catch within each region and quarter (b).

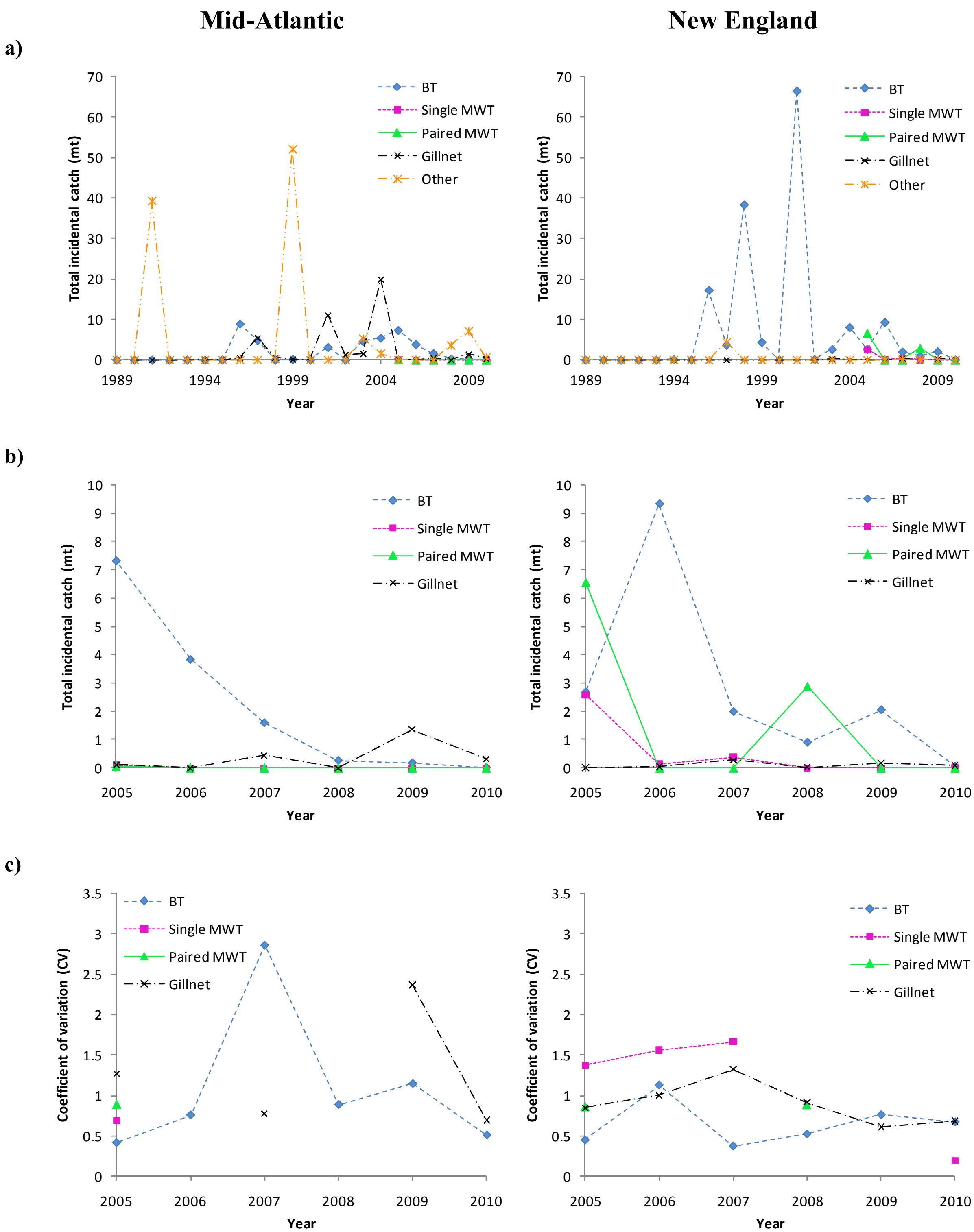



Figure 11: Hickory shad total annual incidental catch (mt) by region for the four gears with the largest catches from a) 1989 – 2010 and b) 2005 – 2010, and c) the corresponding estimates of precision. Midwater trawl estimates are only included beginning in 2005.

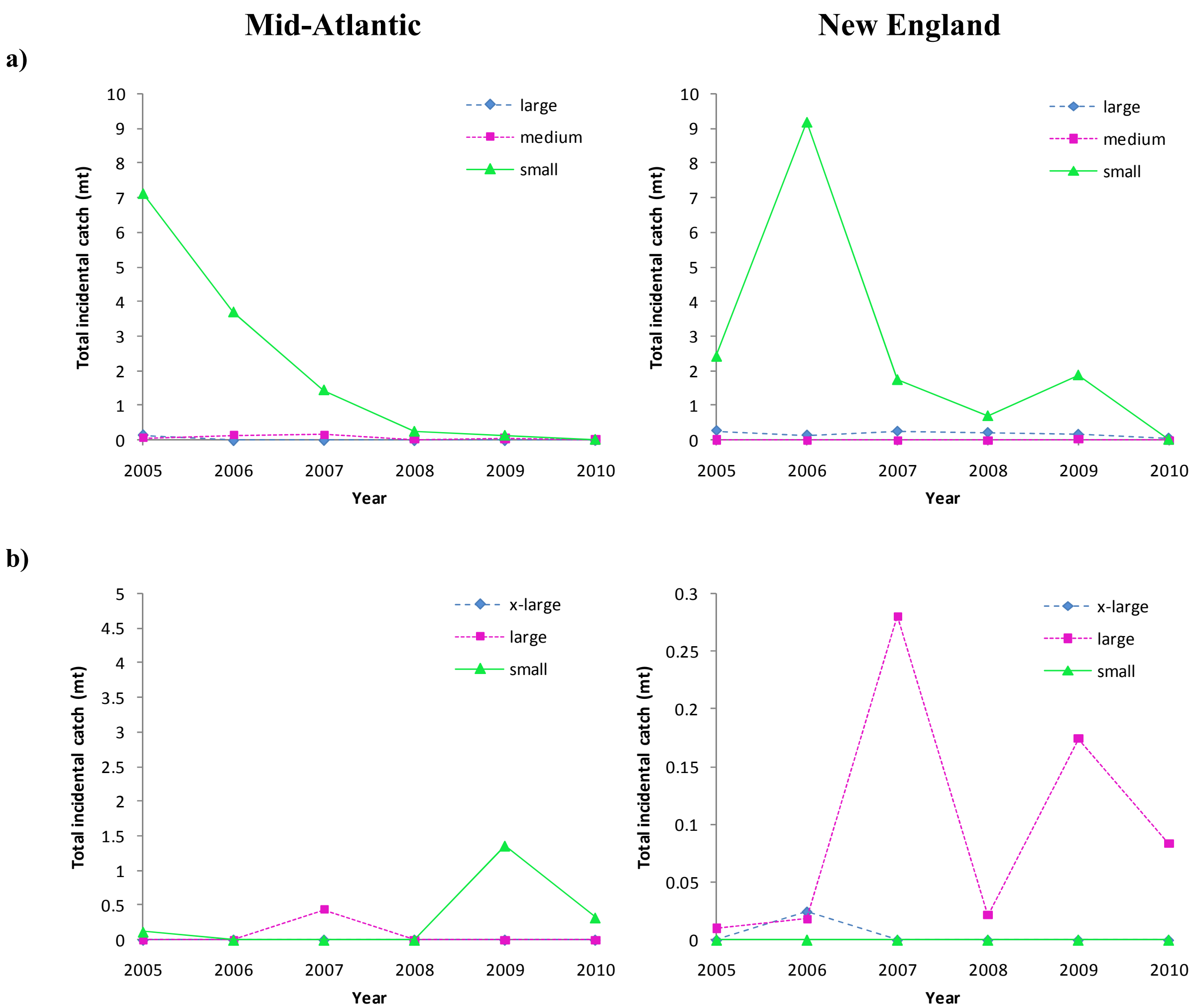



Figure 12: Hickory shad total incidental catch (mt) from 2005 – 2010 by region and mesh category for a) bottom trawl and b) gillnet fleets.

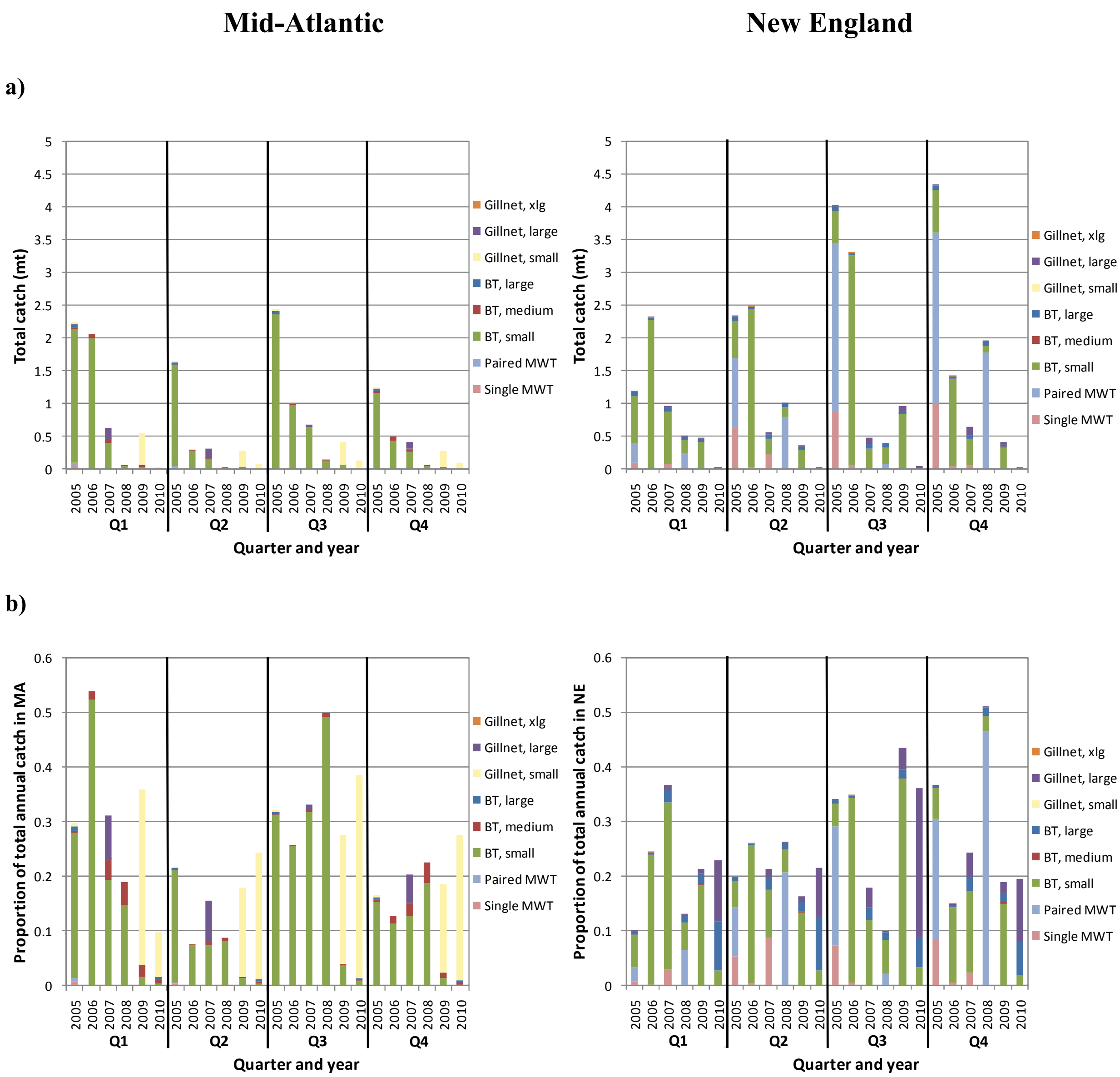



Figure 13: Hickory shad quarterly incidental catch (mt) by region and fleet (a) and the corresponding proportion of the total annual catch within each region and quarter (b).

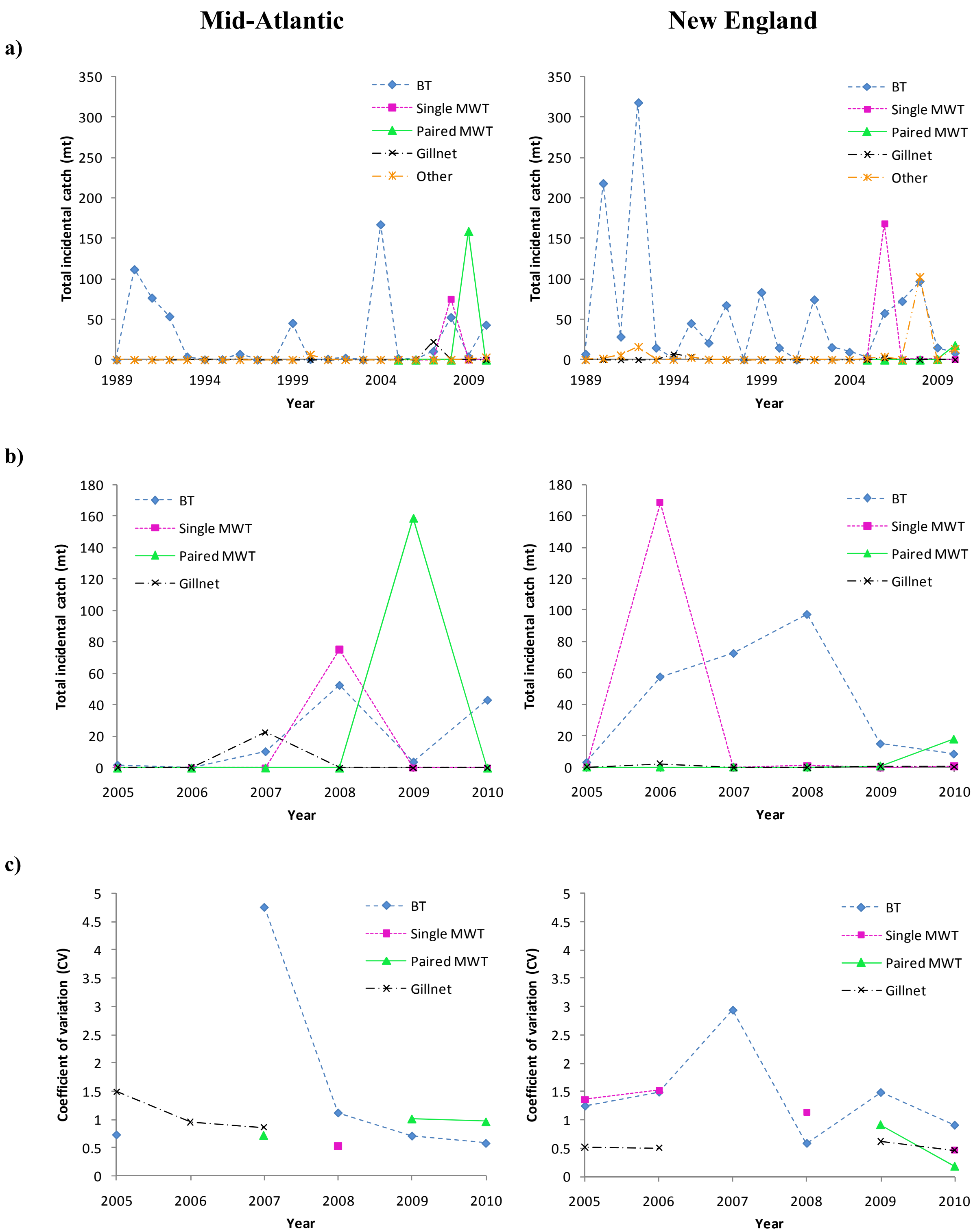



Figure 14: Unknown herring total annual incidental catch (mt) by region for the four gears with the largest catches from a) 1989 – 2010 and b) 2005 – 2010, and c) the corresponding estimates of precision.  Midwater trawl estimates are only included beginning in 2005.

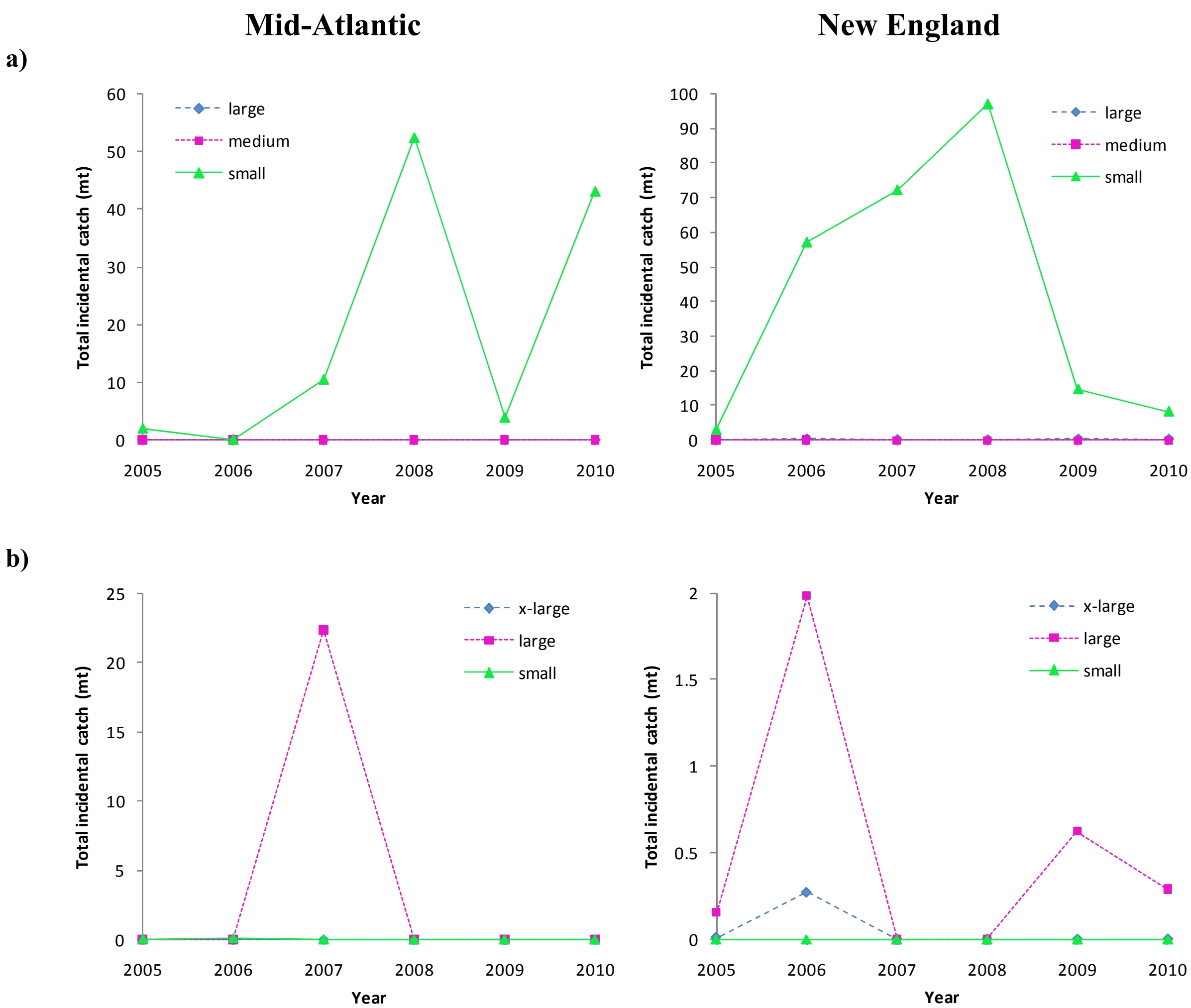
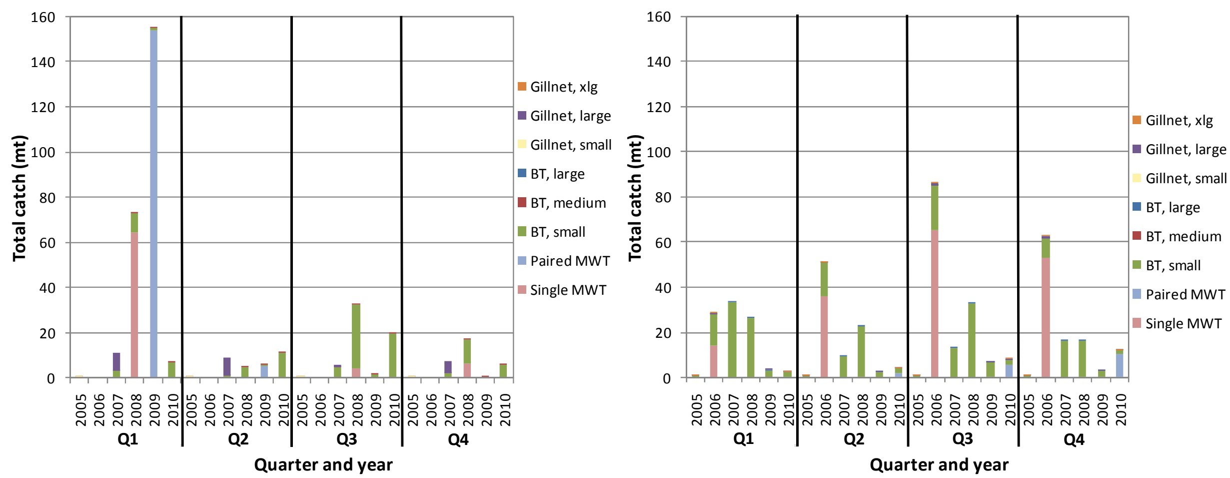



Figure 15: Unknown herring total incidental catch (mt) from 2005 – 2010 by region and mesh category for a) bottom trawl and b) gillnet fleets.

**Mid-Atlantic** **New England**

**a)**




**b)**

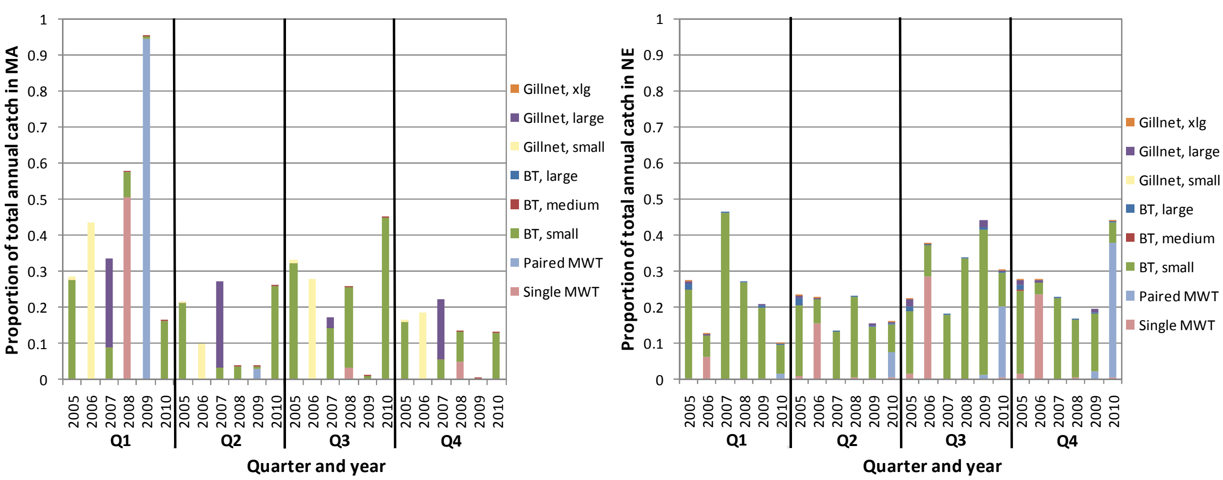



Figure 16: Unknown herring quarterly incidental catch (mt) by region and fleet (a) and the corresponding proportion of the total annual catch within each region and quarter (b).

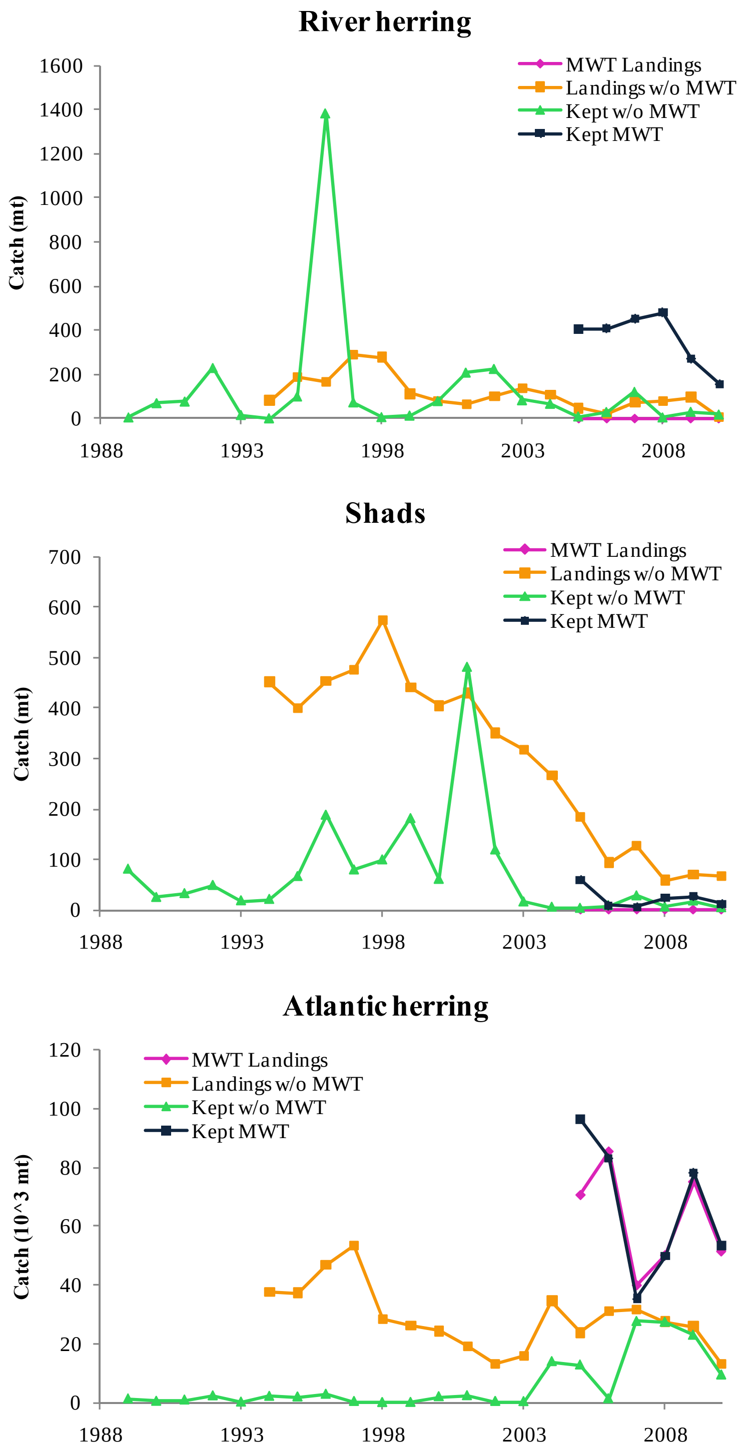
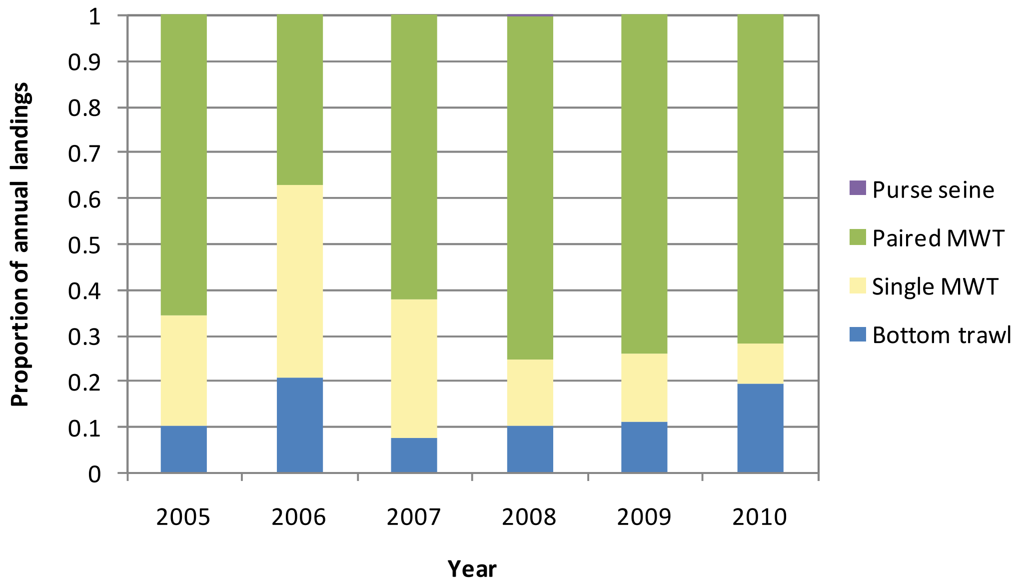



Figure 17: Comparison of landings obtained from the dealer database to the amount kept, quantified as the difference between total incidental catch and discards, for river herring (alewife and blueback herring), shad species (hickory and American shad) and Atlantic herring. Midwater trawl estimates are only included beginning in 2005. This validation exercise was conducted in a preliminary run where gear was not split into mesh categories.

a)




b)

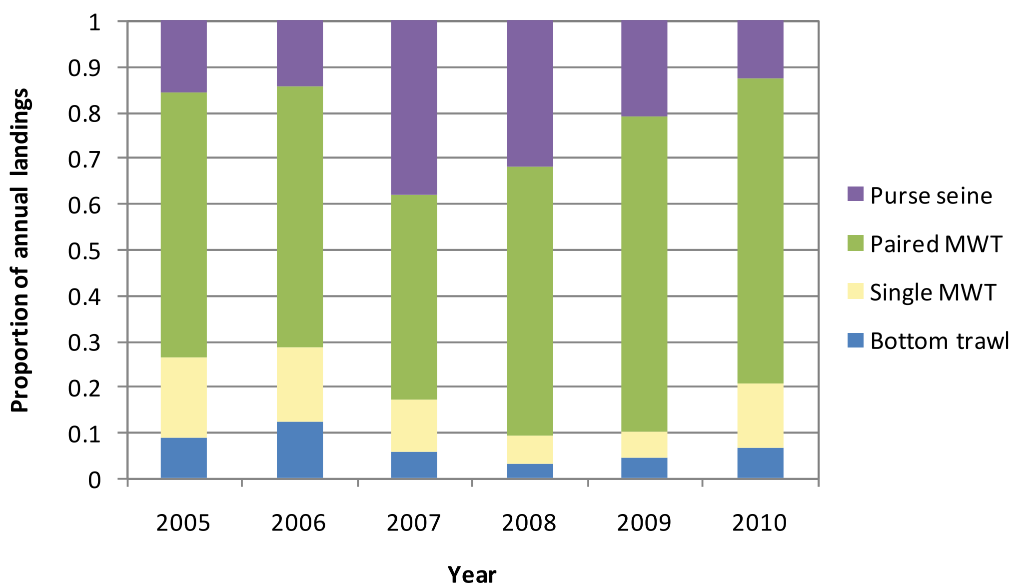
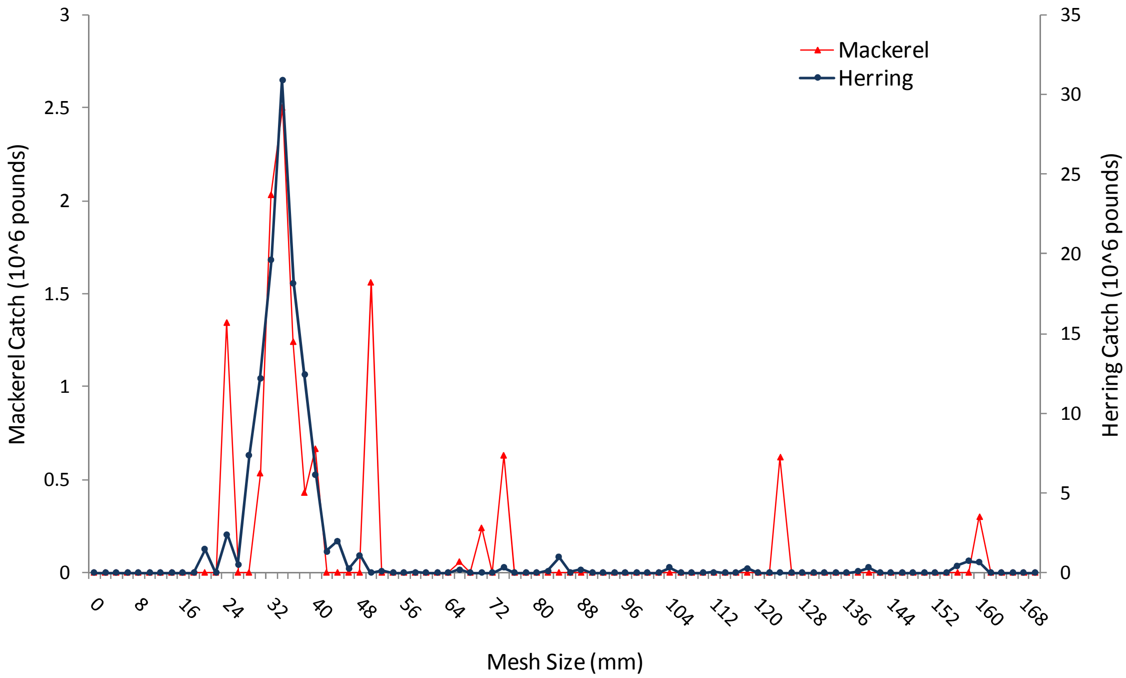



Figure 18: Distribution of a) mackerel and b) herring landings across gear from 2005 - 2010. Gears included in the analysis were purse seine, paired midwater trawls, single midwater trawls and bottom trawls. It was assumed that these gears represented the majority of both mackerel and herring landings.

**a)**




**b)**

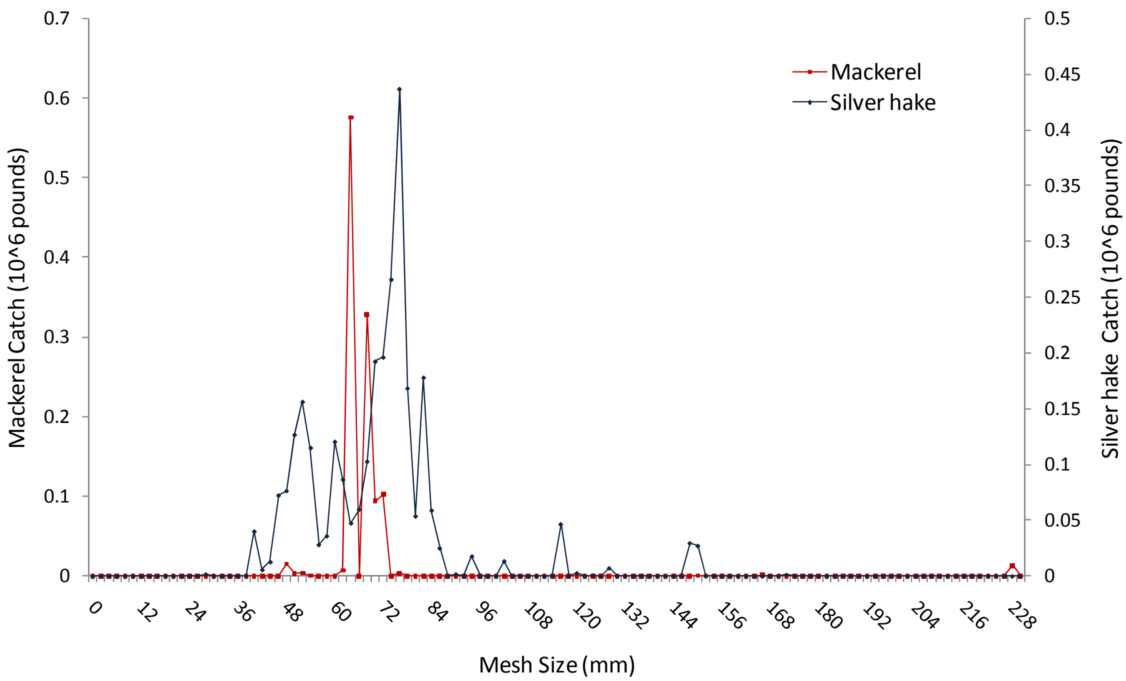
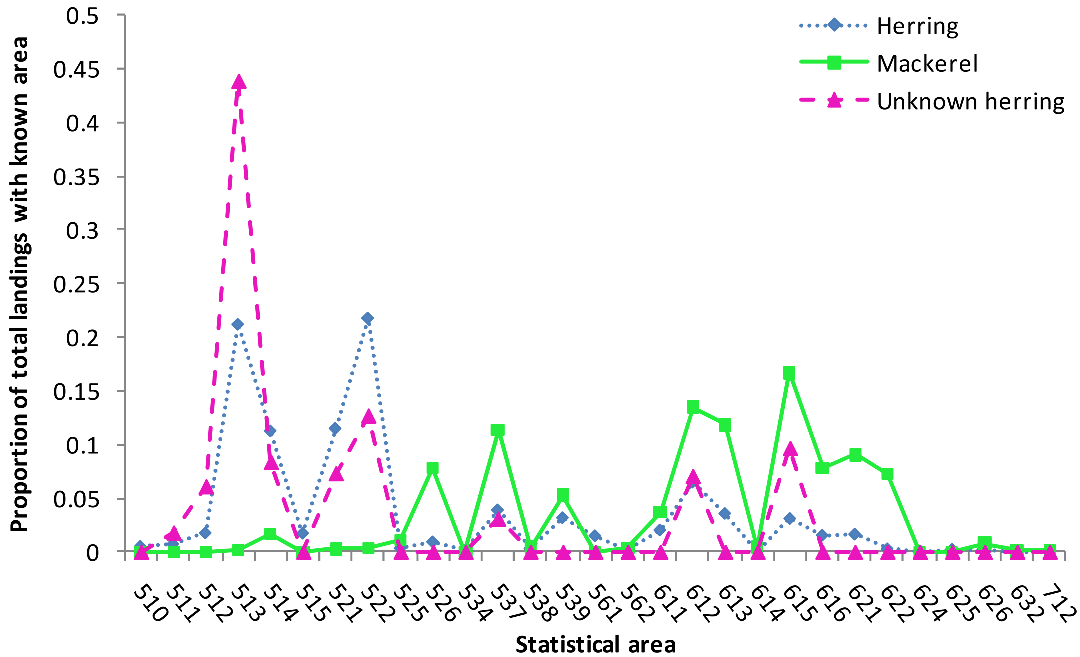



Figure 19: Mackerel and herring midwater trawl landings (a) and mackerel and silver hake bottom trawl landings (b) by mesh size from 2005 – 2010.

a)




b)

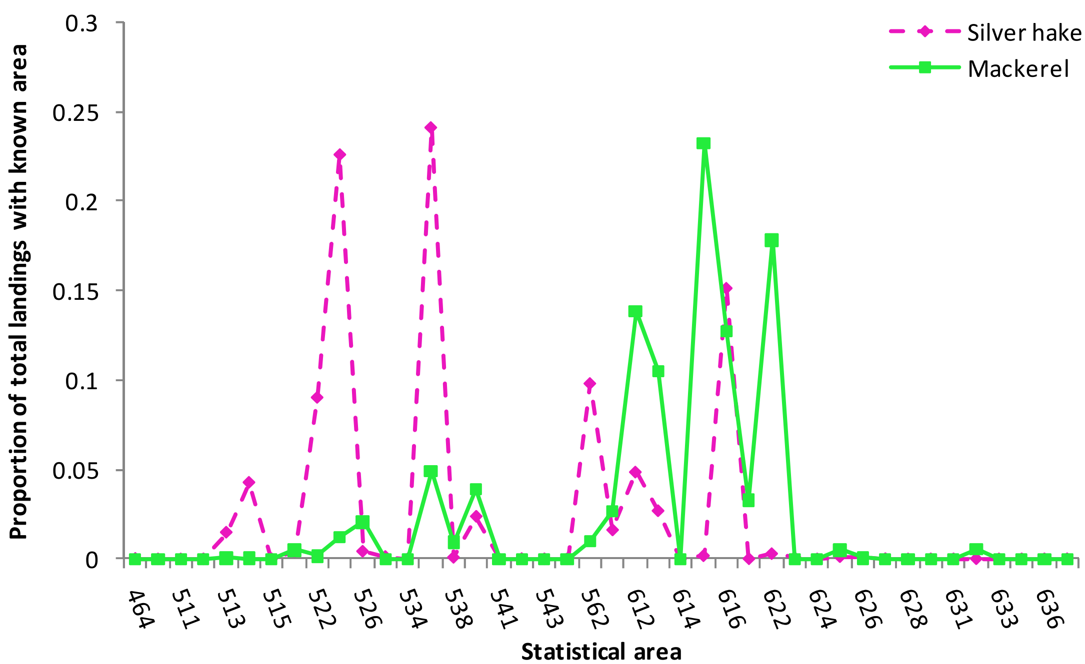



Figure 20: Proportion of species-specific midwater trawl (a) and bottom trawl (b) landings by statistical area from 2005 - 2010.

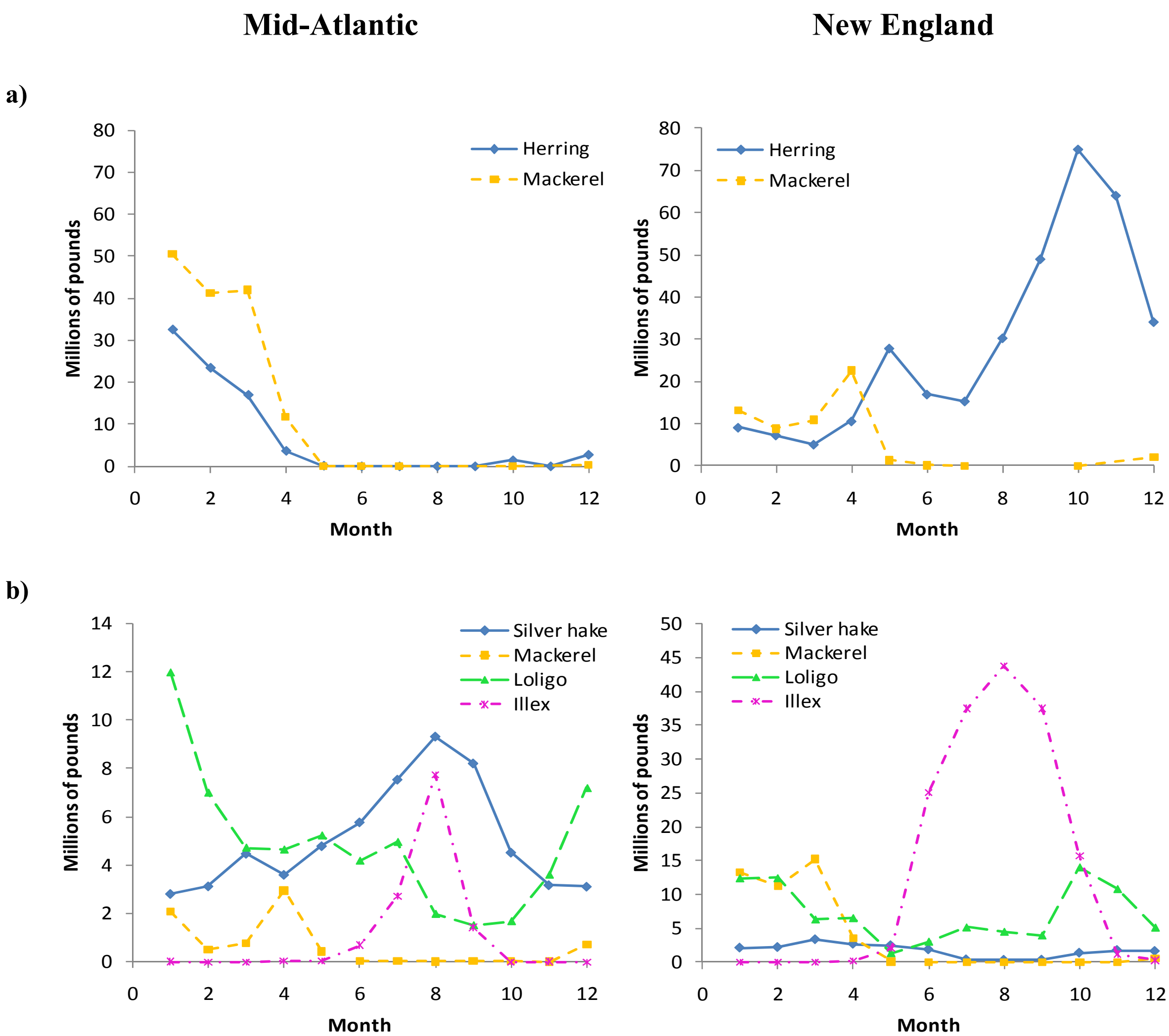
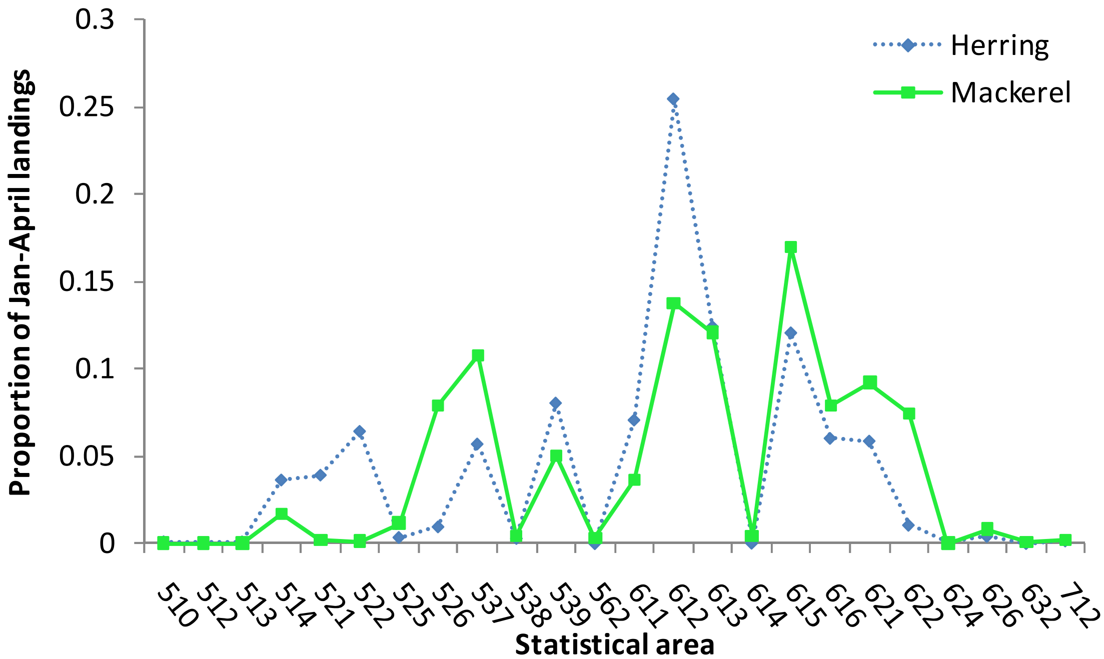



Figure 21: Species-specific midwater trawl (a) and bottom trawl (b) landings (millions of pounds) by month and region from 2005 - 2010.

a)




b)

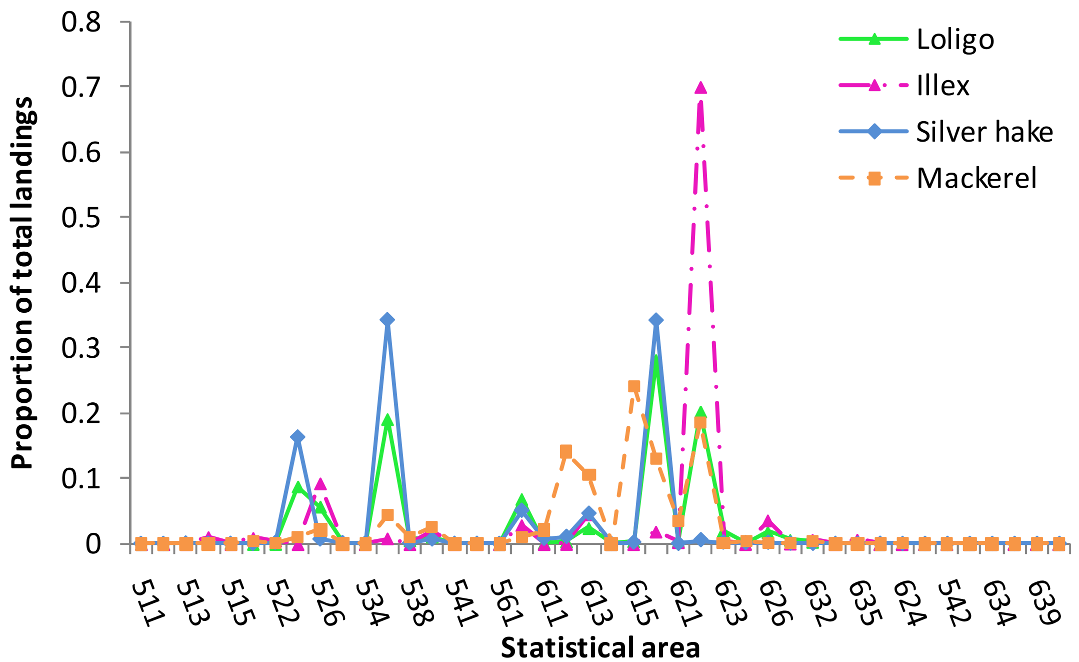
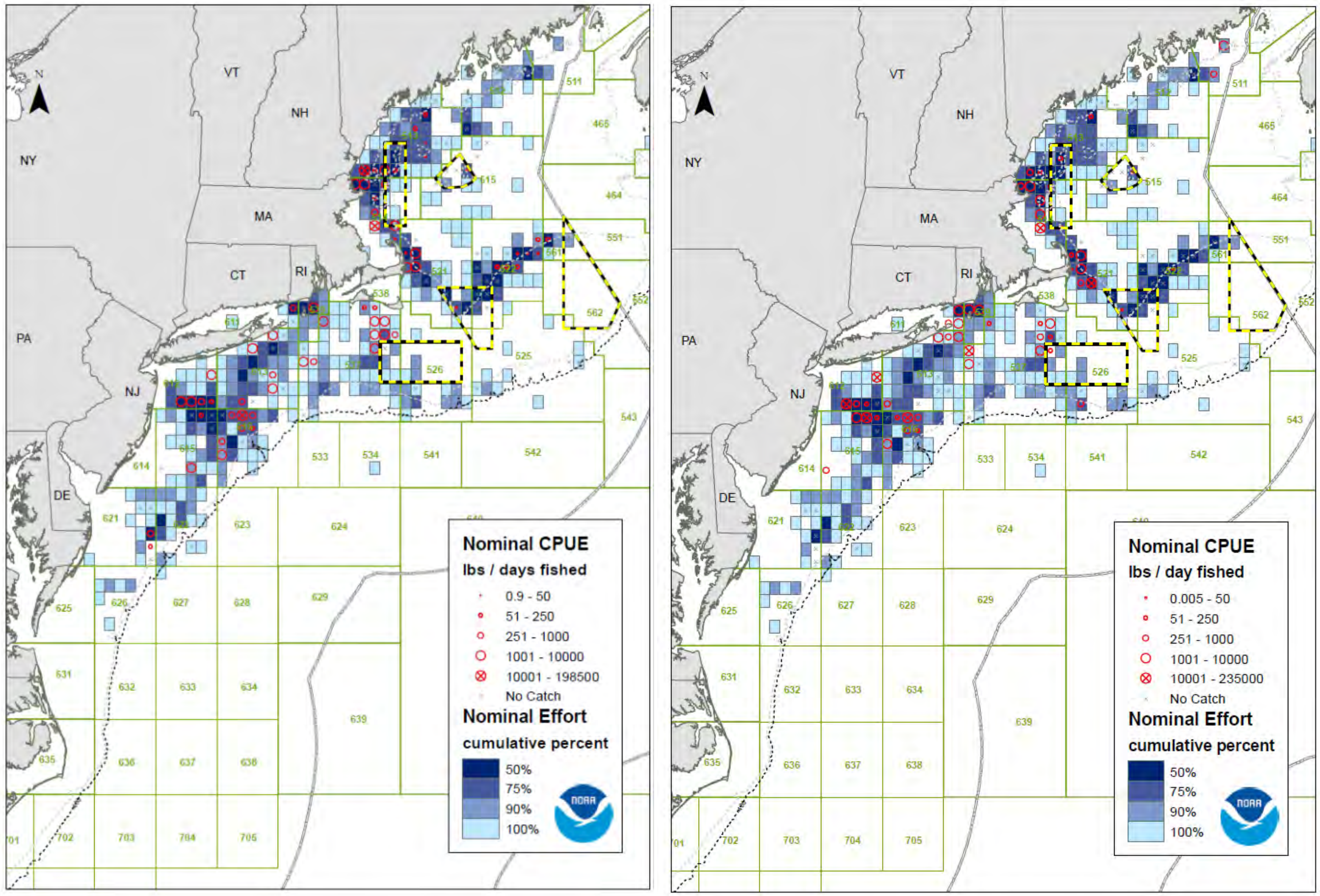



Figure 22: Proportion of January – April species-specific midwater trawl (a) and bottom trawl (b) landings by statistical area from 2005 - 2010.




Alewife - paired mid water trawl - 2005-2010

Date: 8/26/2011

Blueback herring - paired mid water trawl - 2005-2010

Date: 8/29/2011

Figure 23. Spatial distribution of nominal effort (days fished from Vessel Trip Reports) for the paired midwater trawl fleet and the fleet's incidental catch rates (kept+discarded weight/days fished from observed NEFOP trips) of alewife (left) and blueback (right), by ten-minute square, during 2005-2010.

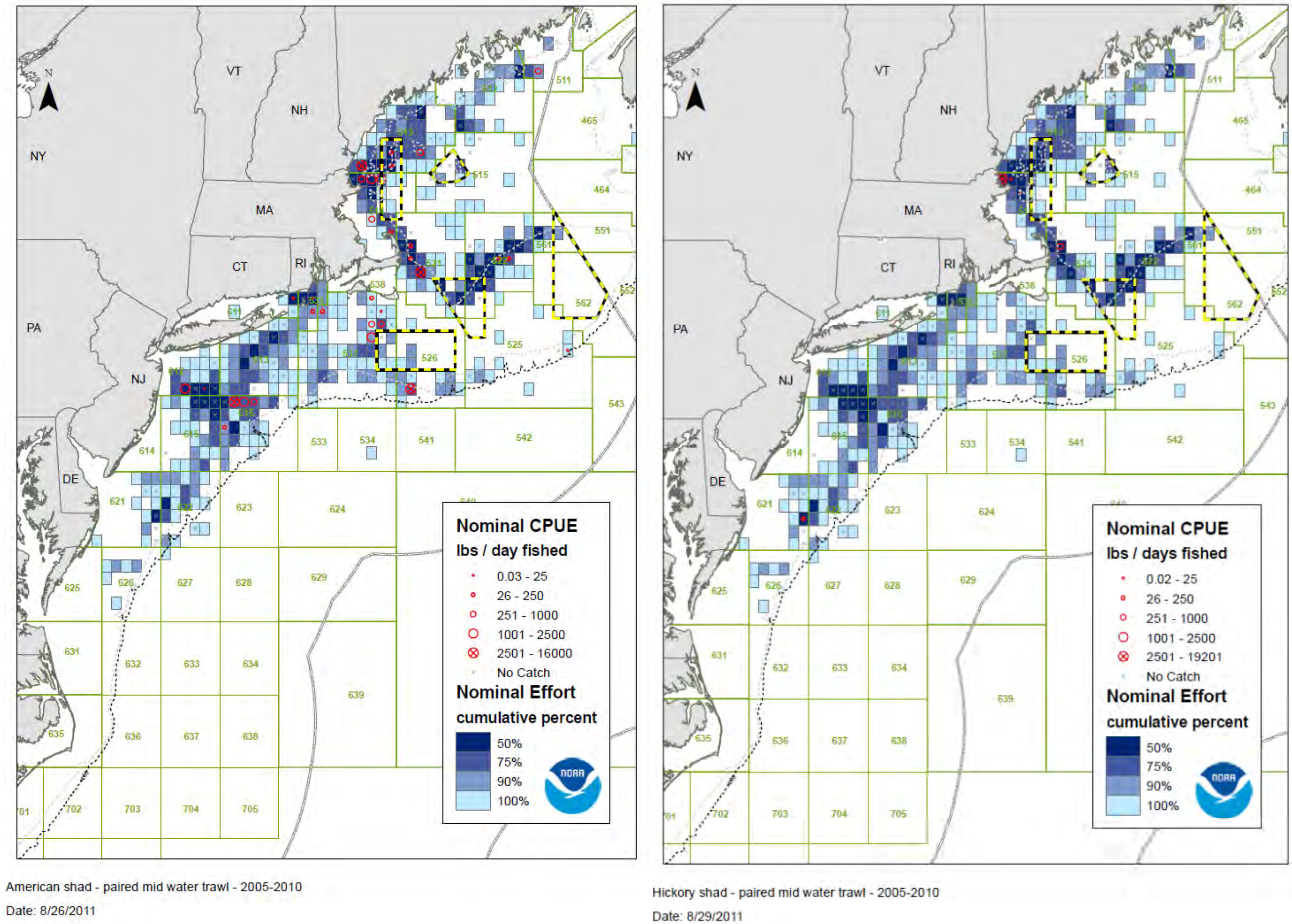



Figure 24. Spatial distribution of nominal effort (days fished from Vessel Trip Reports) for the paired midwater trawl fleet and the fleet's incidental catch rates (kept+discarded weight/days fished from observed NEFOP trips) of American shad (left) and hickory shad (right), by ten-minute square, during 2005-2010.

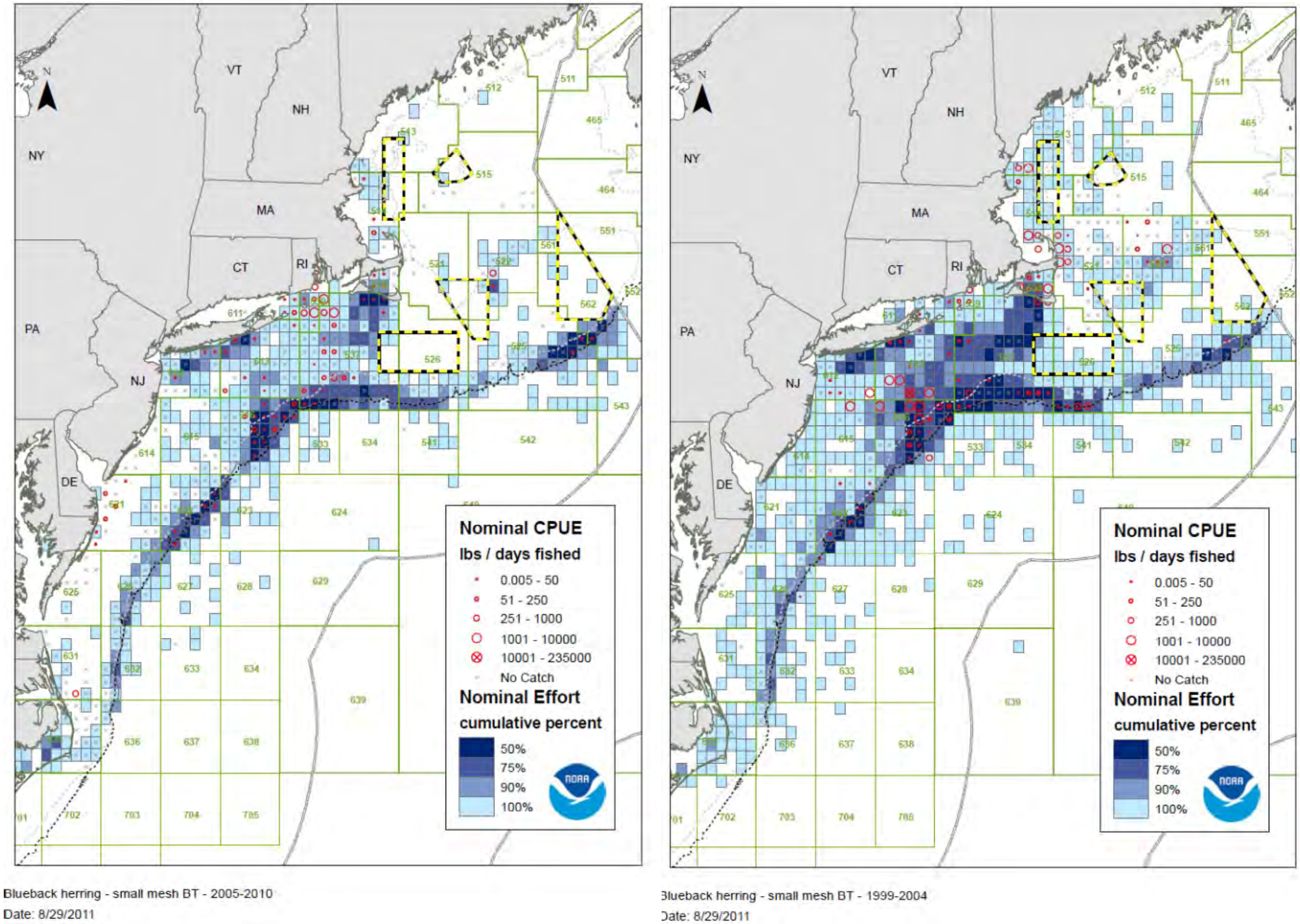
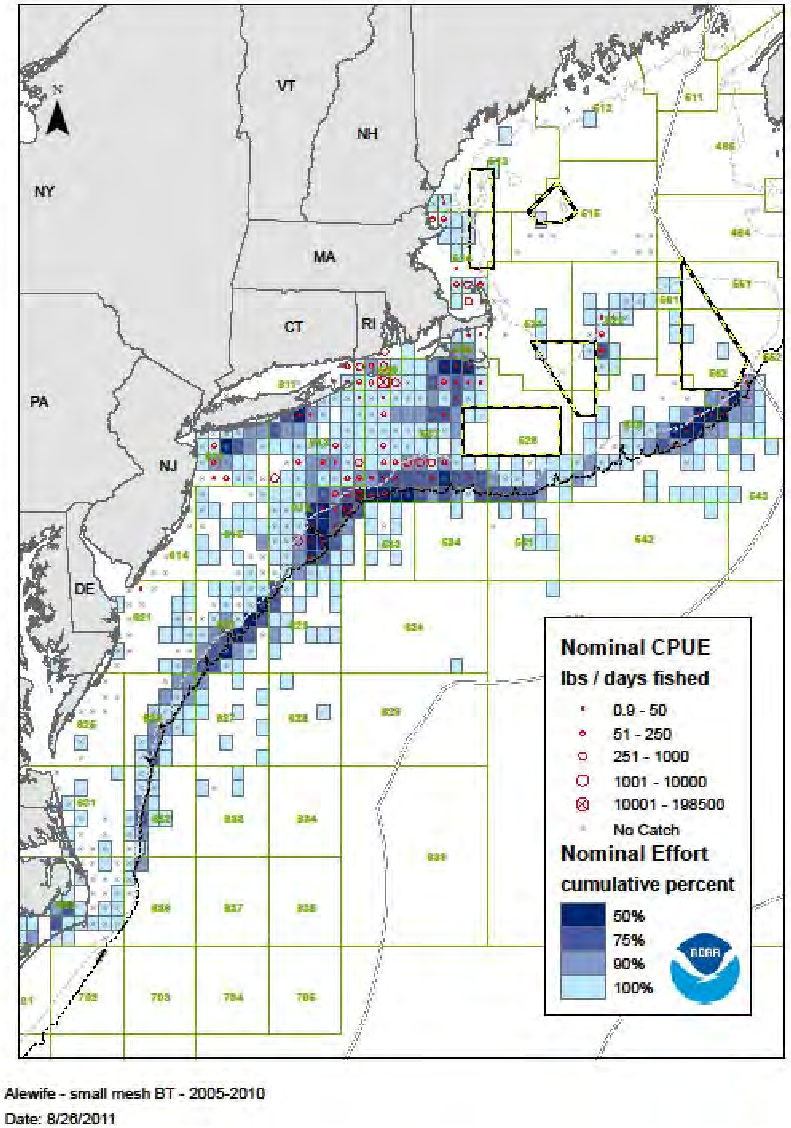



Figure 25. Spatial distribution of nominal effort (days fished from Vessel Trip Reports) for the small mesh (codend mesh ≤ 3.5 in.) bottom trawl fleet and the fleet's incidental catch rates (kept+discarded weight/days fished from observed NEFOP trips) of blueback herring, by ten-minute square, during 2005-2010 and 1999-2004.



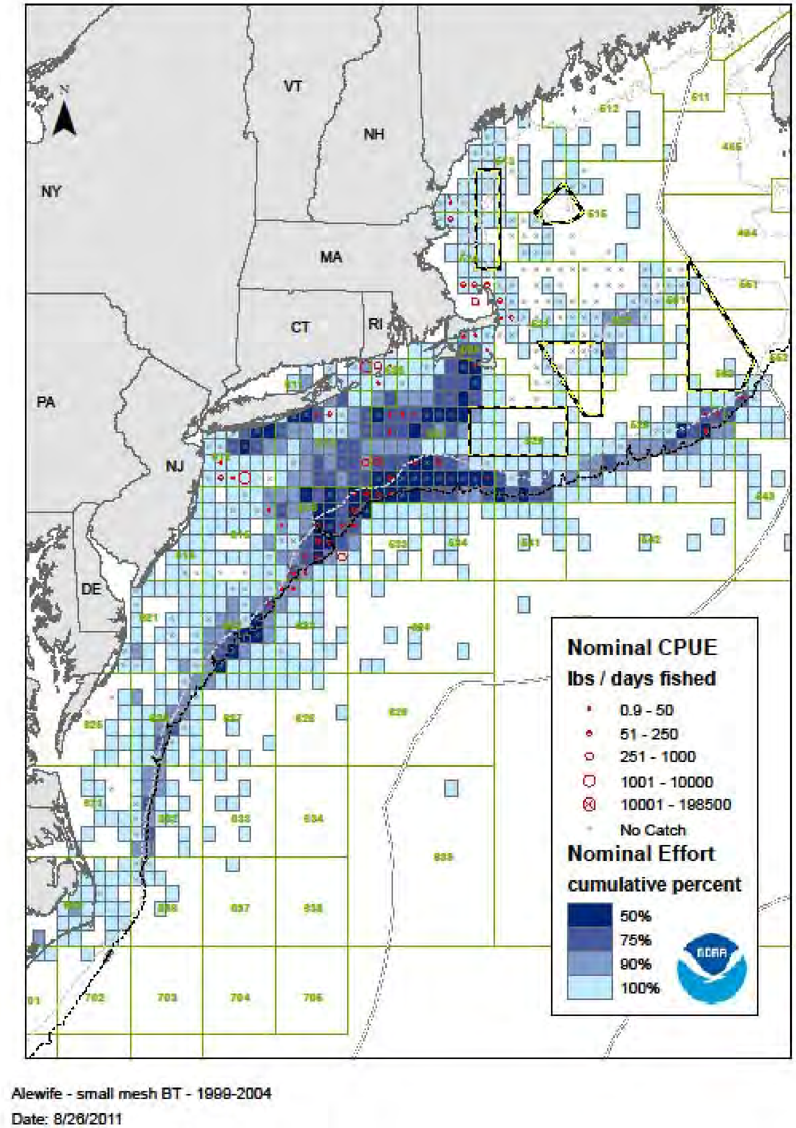




Figure 26. Spatial distribution of nominal effort (days fished from Vessel Trip Reports) for the small mesh (codend mesh ≤ 3.5 in.) bottom trawl fleet and the fleet's incidental catch rates (kept+discarded weight/days fished from observed NEFOP trips) of alewife, by ten-minute square, during 2005-2010 and 1999-2004.

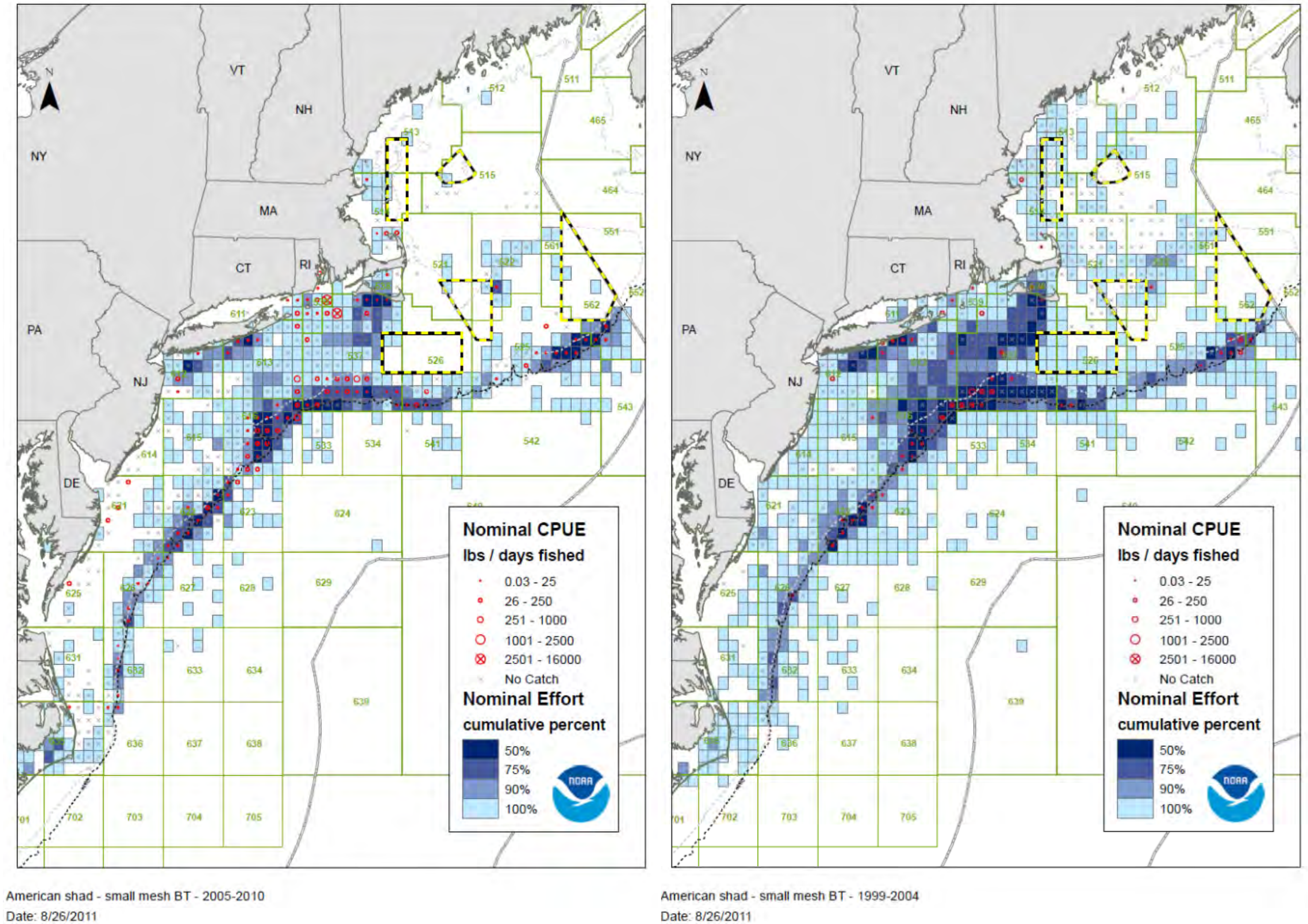
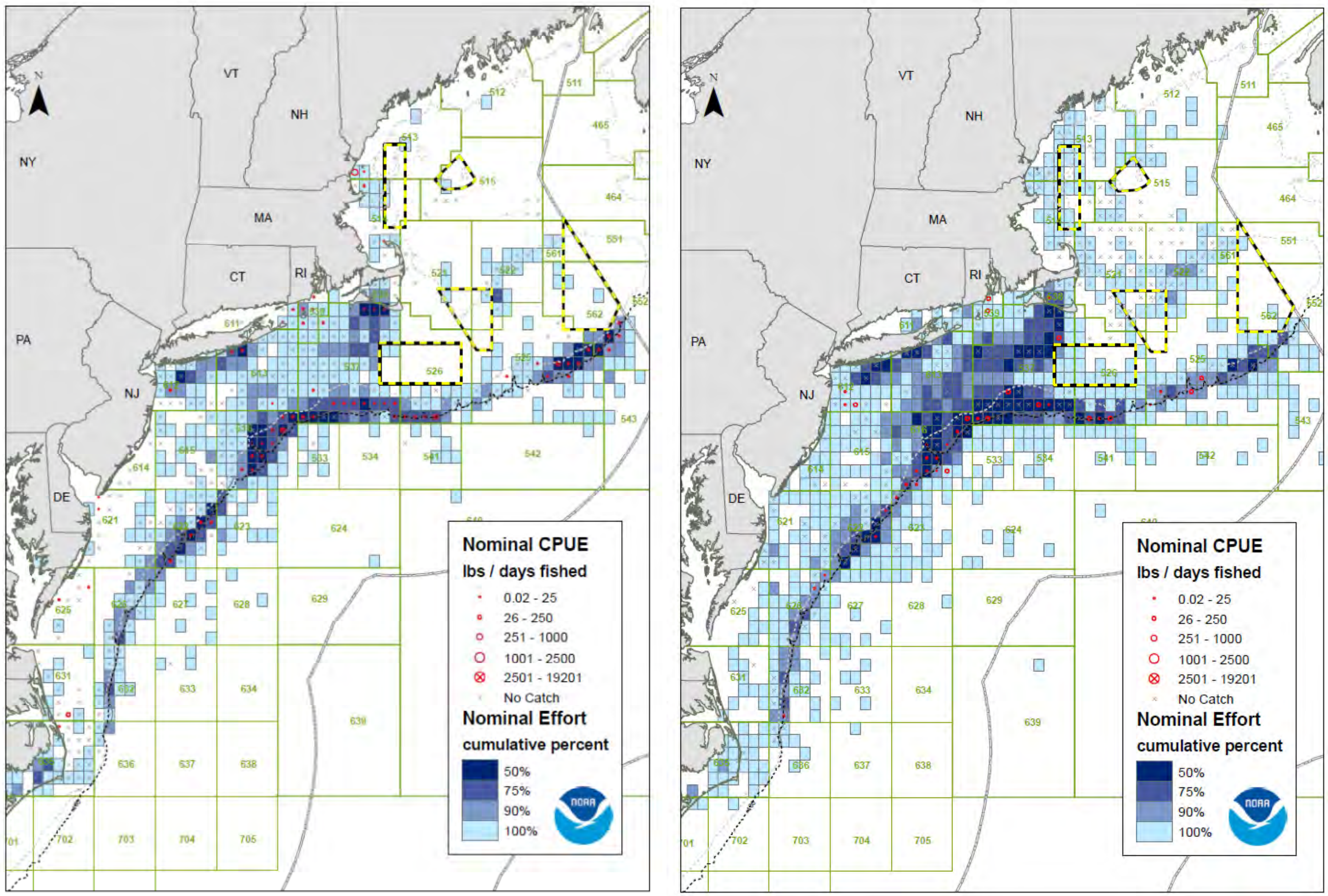



Figure 27. Spatial distribution of nominal effort (days fished from Vessel Trip Reports) for the small mesh (codend mesh ≤ 3.5 in.) bottom trawl fleet and the fleet's incidental catch rates (kept+discarded weight/days fished from observed NEFOP trips) of American shad, by ten-minute square, during 2005-2010 and 1999-2004.




Hickory shad - small mesh BT - 2005-2010
Date: 8/29/2011

Hickory shad - small mesh BT - 1999-2004
Date: 8/29/2011

Figure 28. Spatial distribution of nominal effort (days fished from Vessel Trip Reports) for the small mesh (codend mesh ≤ 3.5 in.) bottom trawl fleet and the fleet's incidental catch rates (kept+discarded weight/days fished from observed NEFOP trips) of hickory shad, by ten-minute square, during 2005-2010 and 1999-2004.

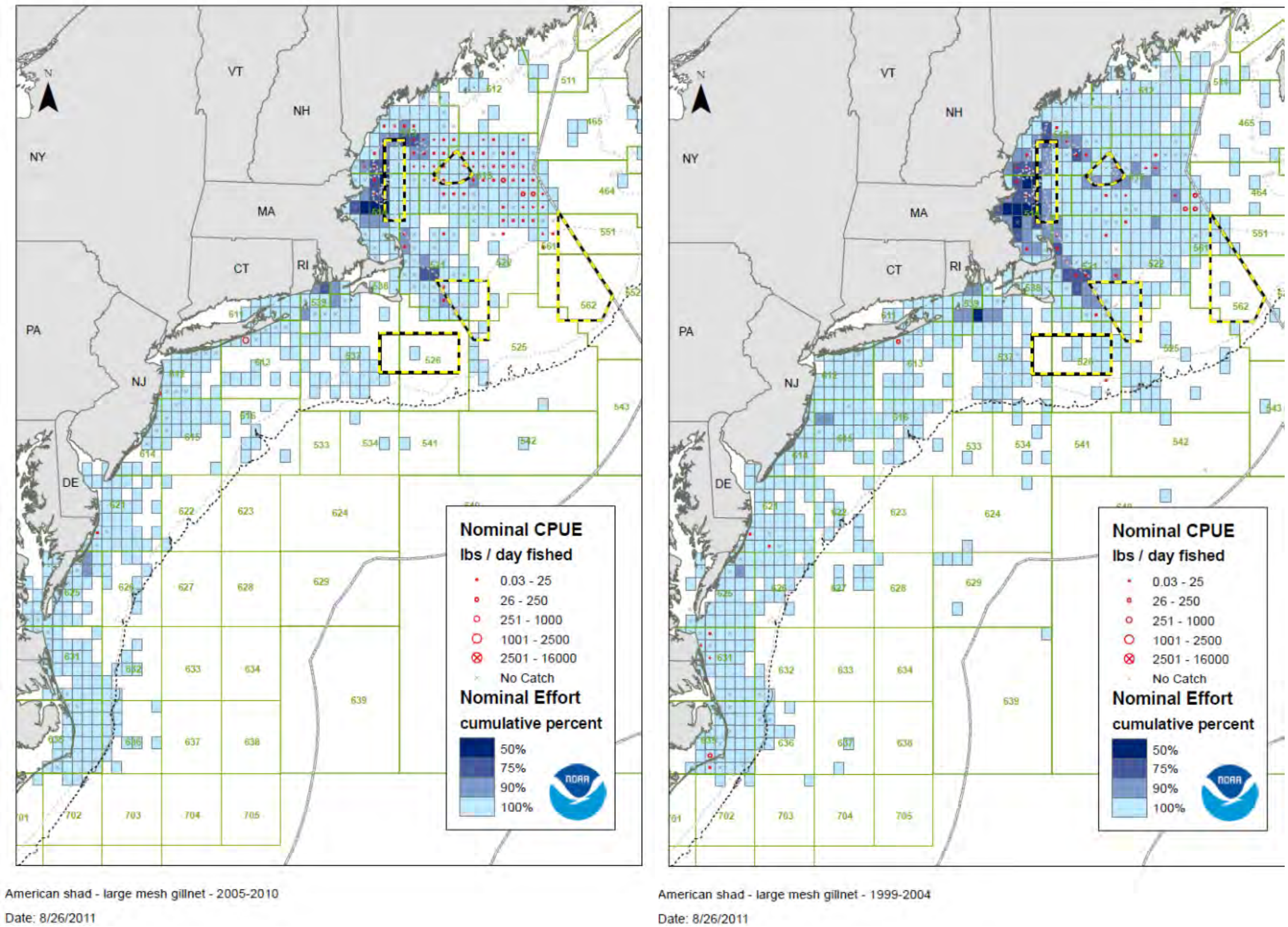
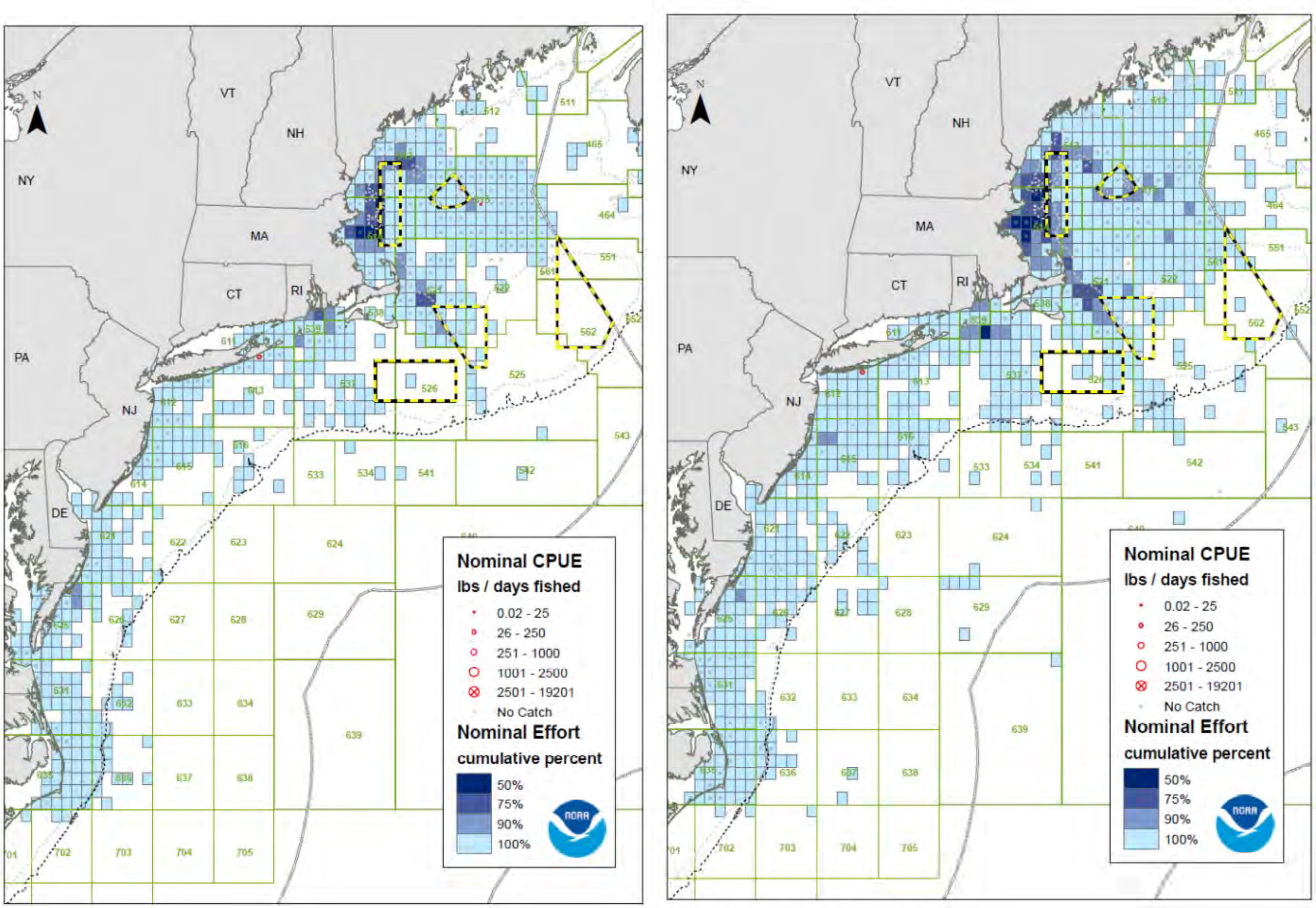



Figure 29. Spatial distribution of nominal effort (days fished from Vessel Trip Reports) for the large mesh (mesh 5.50-7.99 in.) gillnet fleet and the fleet's incidental catch rates (kept+discarded weight/days fished from observed NEFOP trips) of American shad, by ten-minute square, during 2005-2010 and 1999-2004.




Hickory shad - large mesh gillnet - 2005-2010

Date: 8/29/2011

Hickory shad - large mesh gillnet - 1999-2004

Date: 8/29/2011

Figure 30. Spatial distribution of nominal effort (days fished from Vessel Trip Reports) for the large mesh (mesh 5.50-7.99 in.) gillnet fleet and the fleet's incidental catch rates (kept+discarded weight/days fished from observed NEFOP trips) of hickory shad, by ten-minute square, during 2005-2010 and 1999-2004.

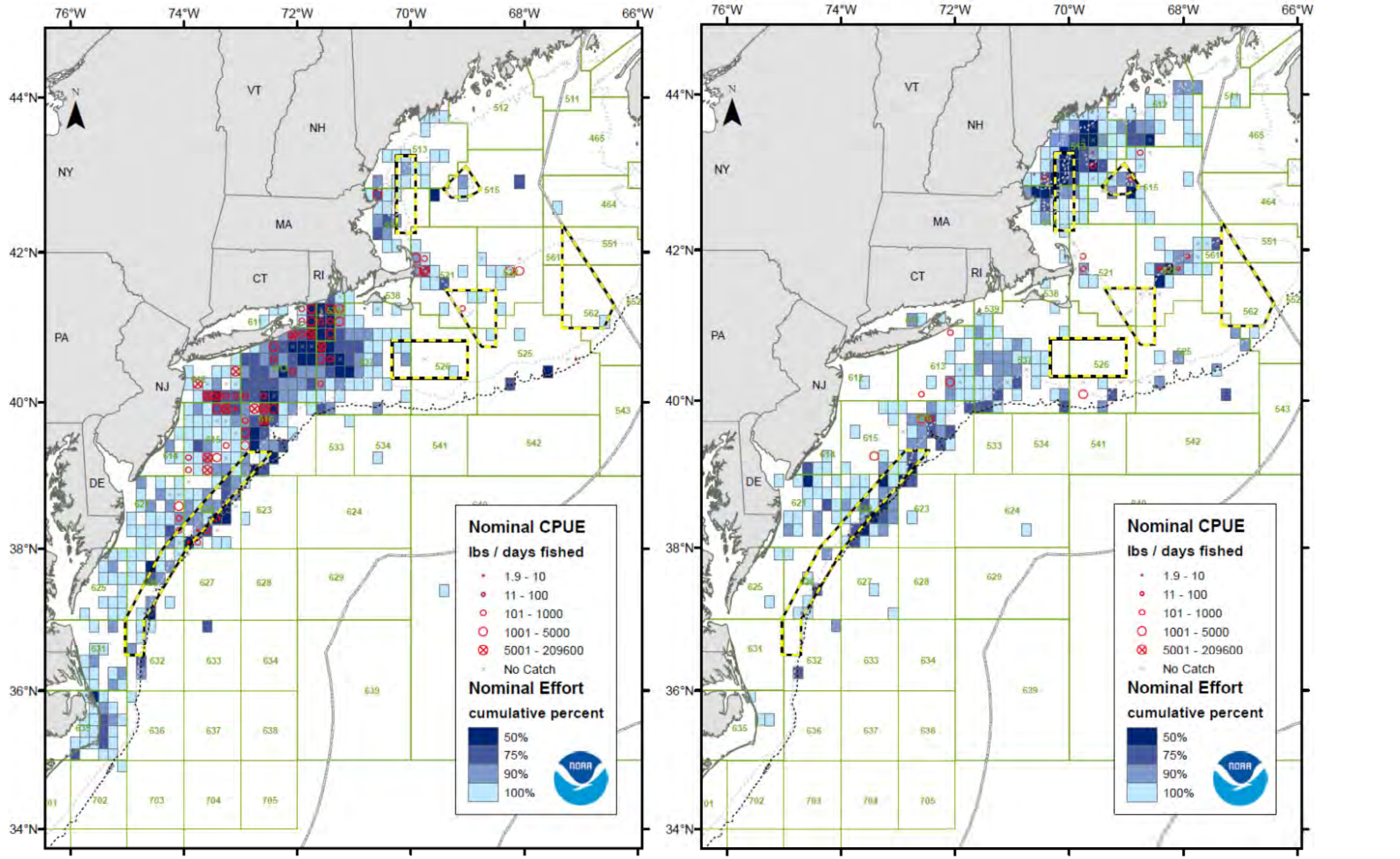



Figure 31. Spatial distribution of nominal effort (days fished from Vessel Trip Reports) for the paired and single midwater trawl fleet and the fleet's incidental catch rates (kept+discarded weight/days fished from observed NEFOP trips) of alewife, blueback herring, hickory shad, and American shad combined, by ten-minute square, during Quarter 1 (left) and 2 (right) for 2005-2010.

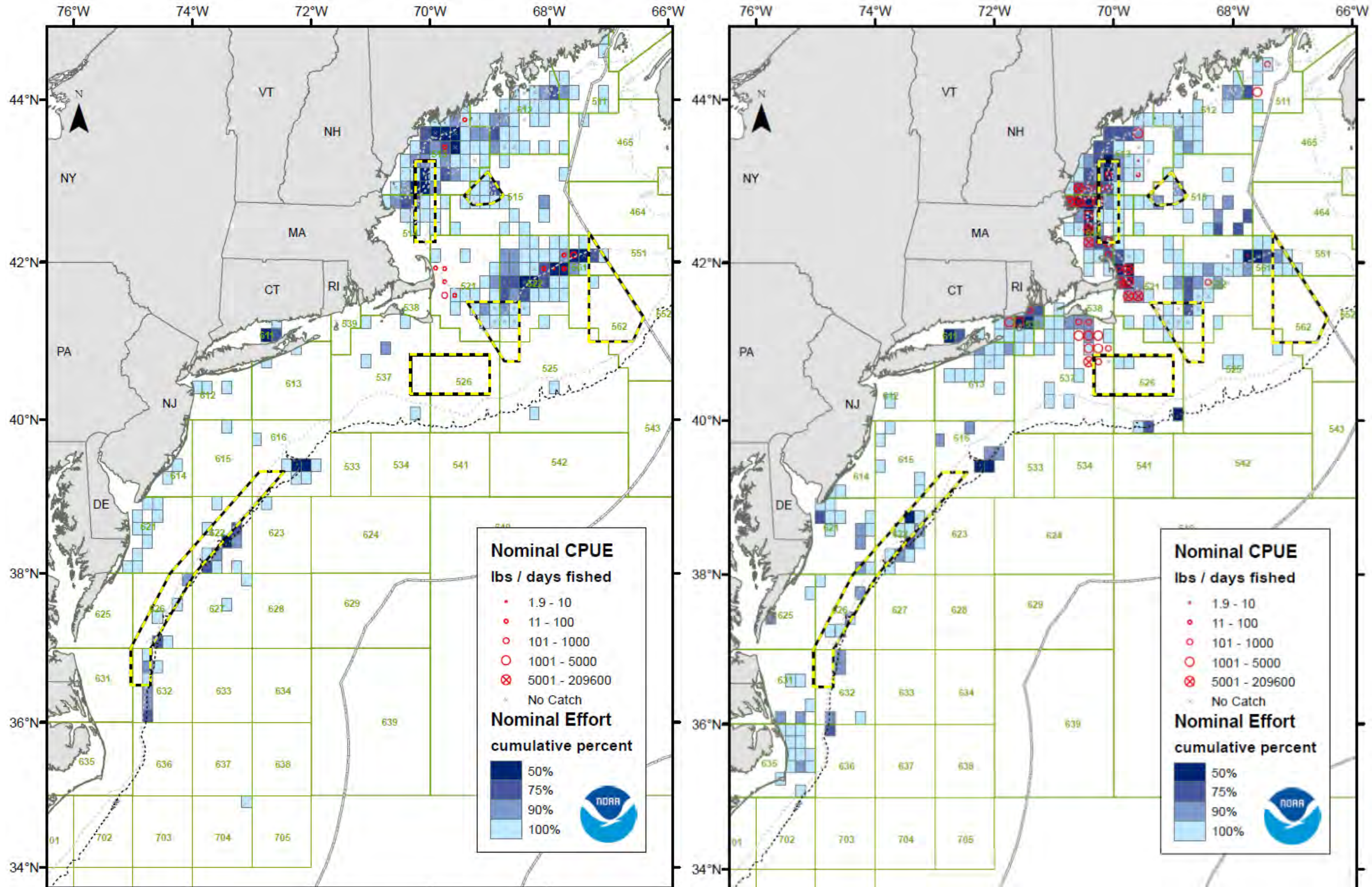



Figure 32. Spatial distribution of nominal effort (days fished from Vessel Trip Reports) for the paired and single midwater trawl fleet and the fleet's incidental catch rates (kept+discarded weight/days fished from observed NEFOP trips) of alewife, blueback herring, hickory shad, and American shad combined, by ten-minute square, during Quarter 3 (left) and 4 (right) for 2005-2010.

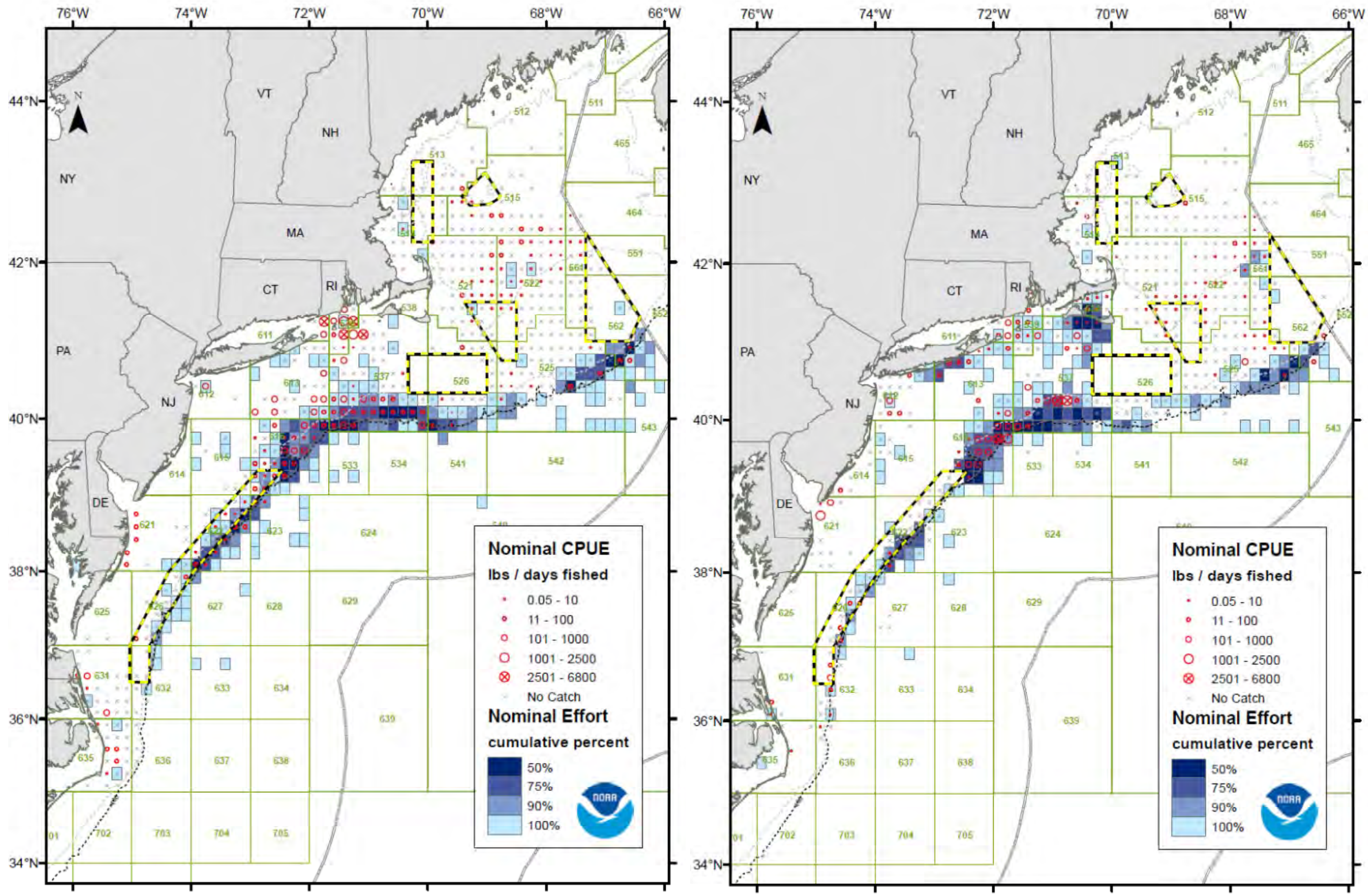



Figure 33. Spatial distribution of nominal effort (days fished from Vessel Trip Reports) for the small mesh (codend mesh ≤ 3.5 in.) bottom trawl fleet and the fleet's incidental catch rates (kept+discarded weight/days fished from observed NEFOP trips) of alewife, blueback herring, hickory shad, and American shad combined, by ten-minute square, during Quarter 1 (left) and 2 (right) for 2005-2010.

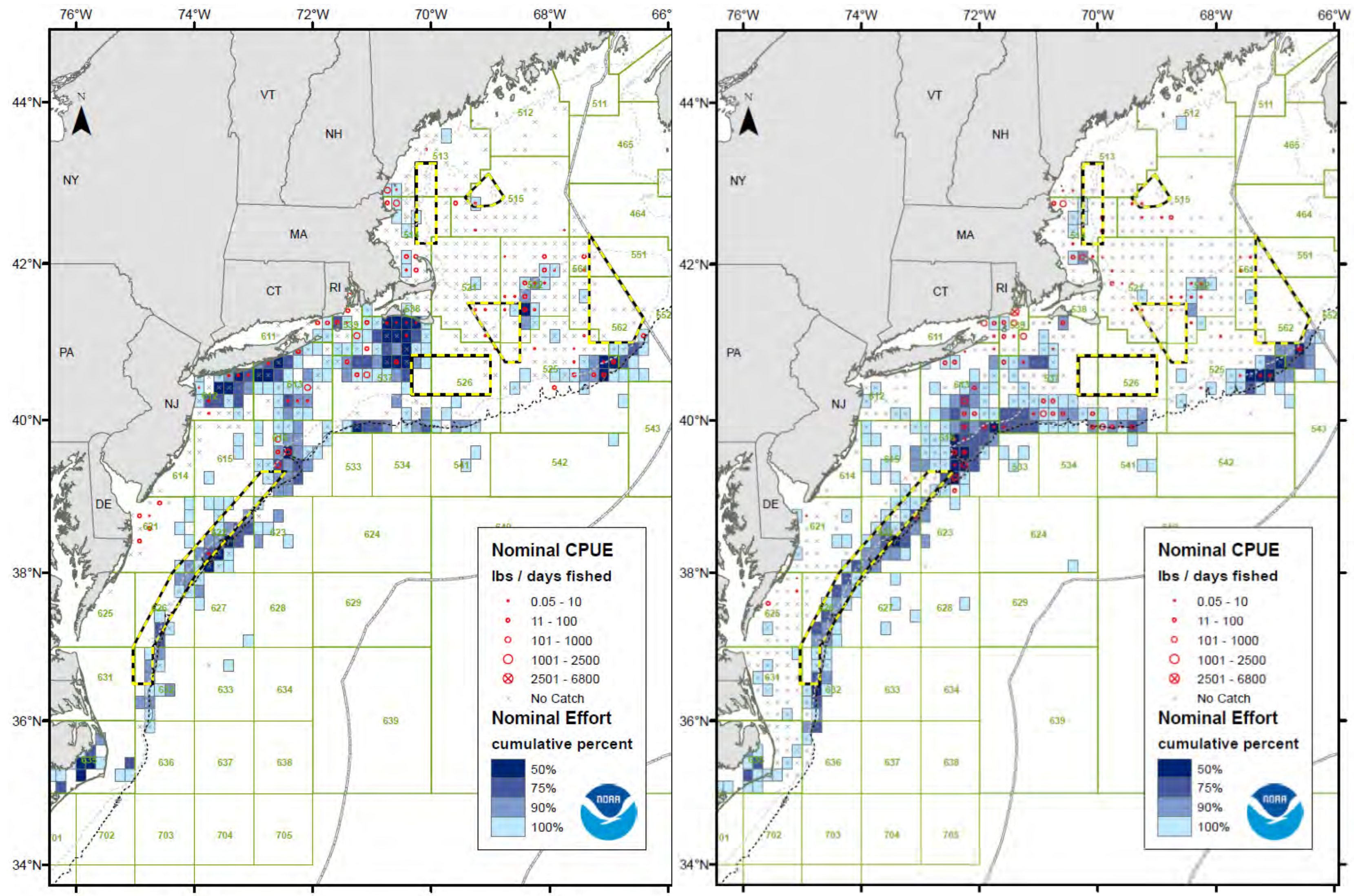



Figure 34. Spatial distribution of nominal effort (days fished from Vessel Trip Reports) for the small mesh (codend mesh ≤ 3.5 in.) bottom trawl fleet and the fleet's incidental catch rates (kept+discarded weight/days fished from observed NEFOP trips) of alewife, blueback herring, hickory shad, and American shad combined, by ten-minute square, during Quarter 3 (left) and 4 (right) for 2005-2010.

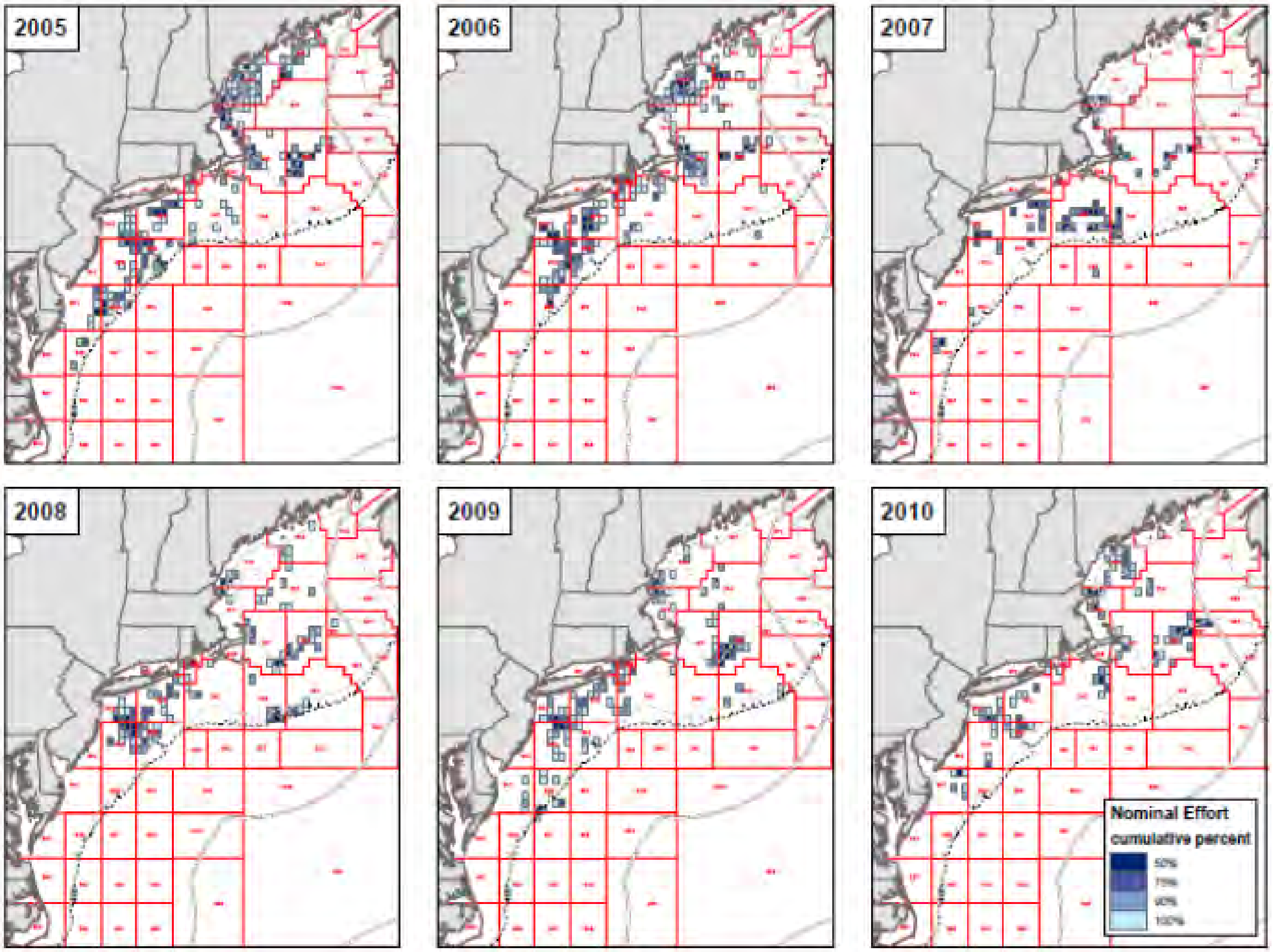



Figure 35. Variability in the spatial distribution of fishing effort (days fished from the Vessel Trip Reports), by the paired midwater trawl fleet, during 2005-2010.

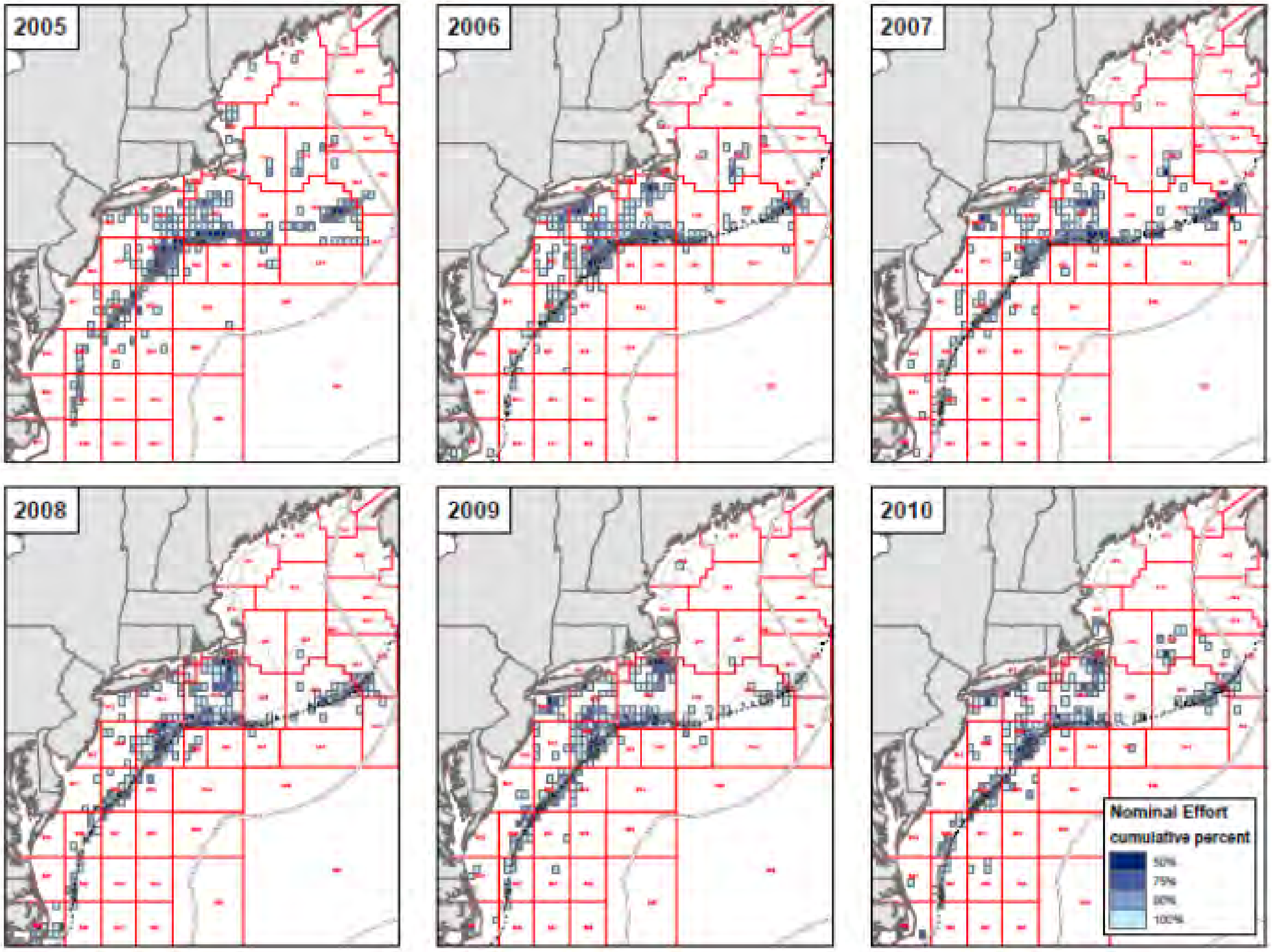



Figure 36. Variability in the spatial distribution of fishing effort (days fished from the Vessel Trip Reports), by the small mesh (codend mesh ≤ 3.5 in.) trawl fleet, during 2005-2010.

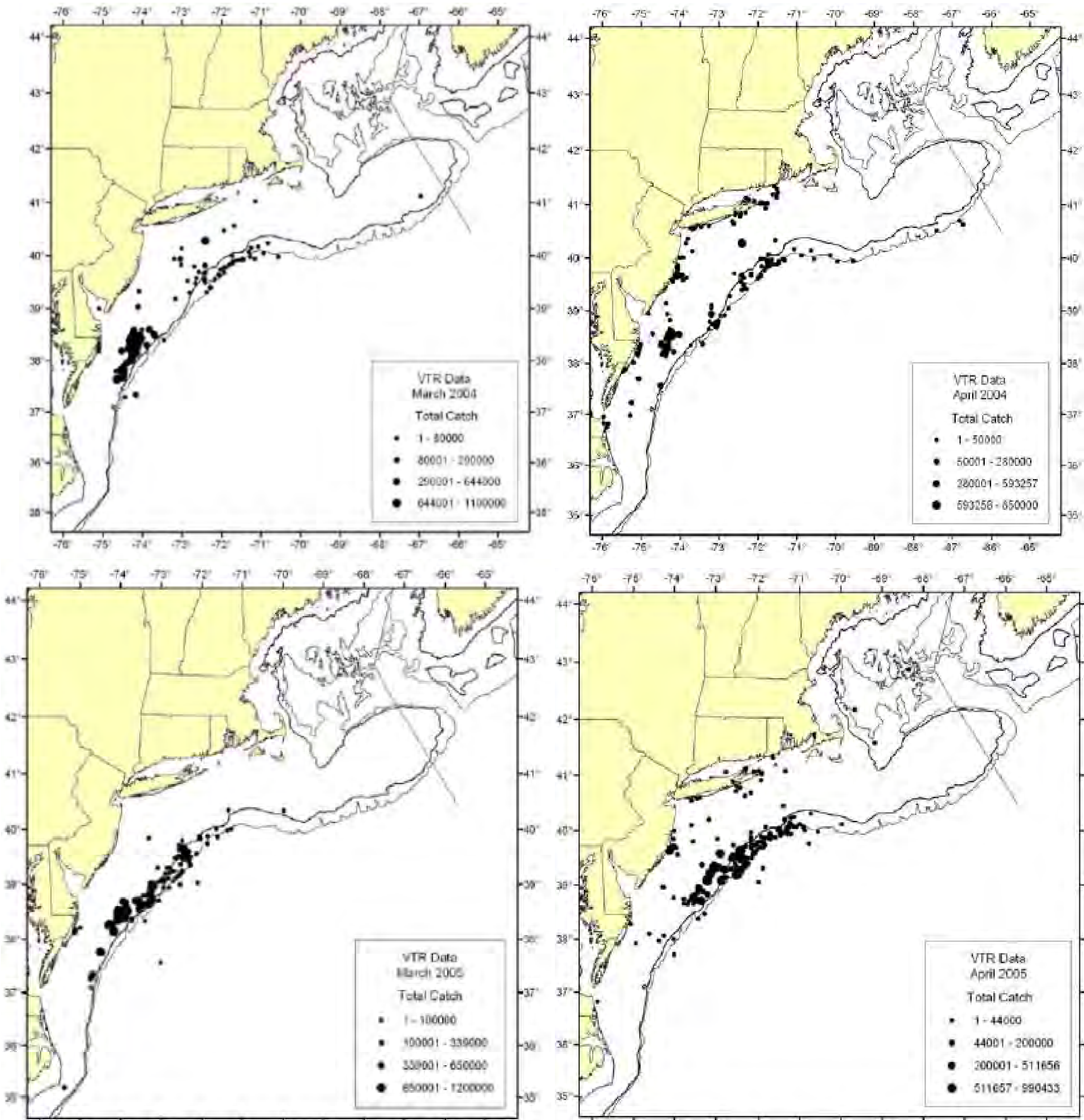



Figure 37. Differences in the spatial distributions of Atlantic mackerel catches during March and April of 2004 (top) versus 2005 (bottom). Each circle may represent a portion of a trip if the trip occurred in different statistical areas. Source: 2009 Working Paper for TRAC assessment of mackerel.

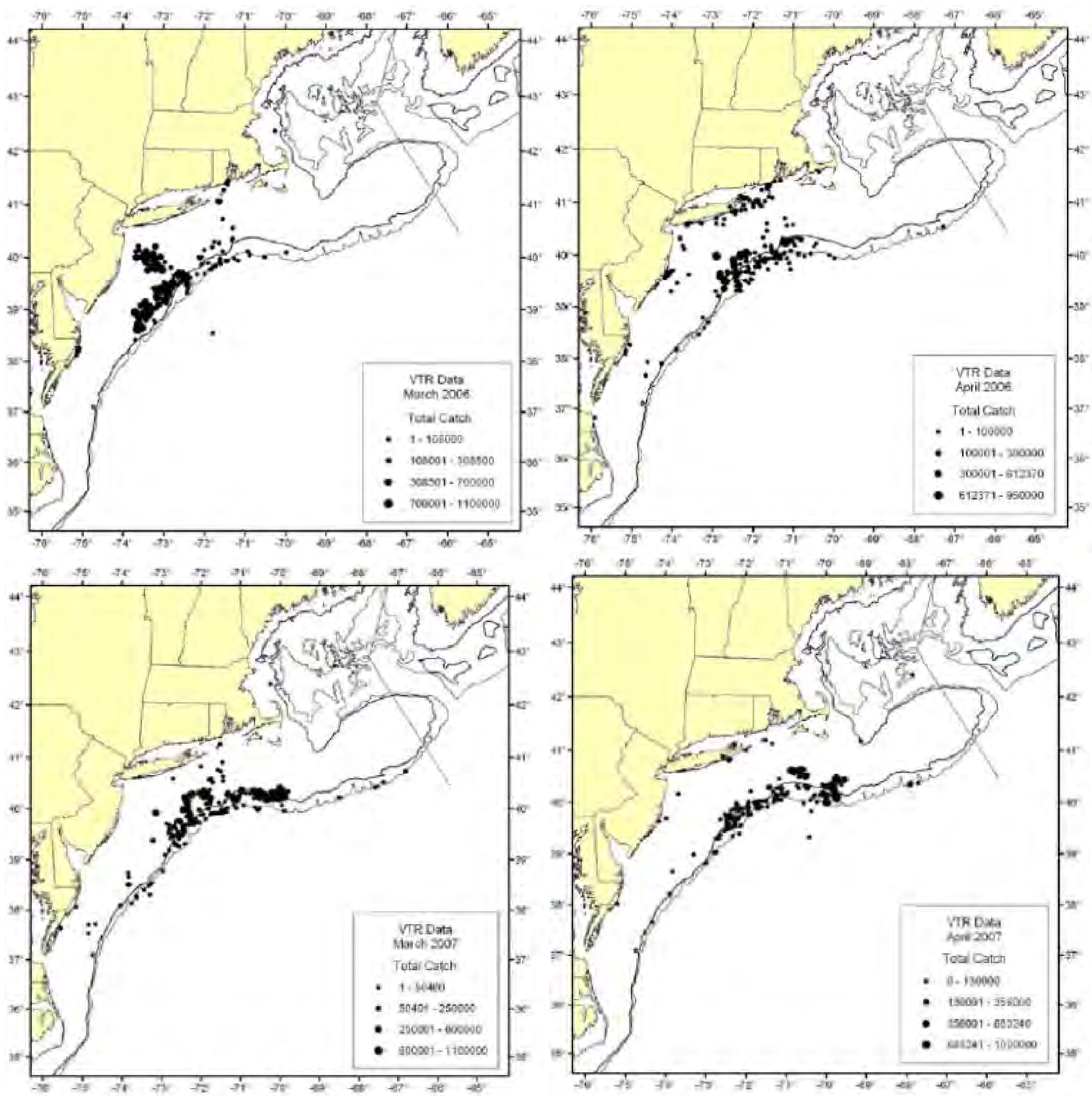



Figure 38. Differences in the spatial distributions of Atlantic mackerel catches during March and April of 2006 (top) versus 2007 (bottom). Each circle may represent a portion of a trip if the trip occurred in different statistical areas. Source: 2009 Working Paper for TRAC assessment of mackerel.

**Appendix 1**

Table A1: Species-specific total annual incidental catch (mt) and the associated coefficient of variation across all fleets and regions. Midwater trawl estimates were only included beginning in 2005.

| | Alewife | | American shad | | Blueback herring | | Herring NK | | Hickory Shad | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Catch | CV | Catch | CV | Catch | CV | Catch | CV | Catch | CV |
| 1989 | 20.35 | 0.49 | 58.92 | 0.60 | 19.60 | 0.39 | 7.08 | 1.03 | 0.00 | |
| 1990 | 55.31 | 0.68 | 25.81 | 0.34 | 78.94 | 0.44 | 331.34 | 0.72 | 0.00 | |
| 1991 | 68.24 | 0.48 | 104.27 | 0.25 | 115.41 | 0.37 | 110.46 | 0.48 | 39.35 | 0.00 |
| 1992 | 30.56 | 0.36 | 79.80 | 0.29 | 458.17 | 0.44 | 387.54 | 0.39 | 0.00 | |
| 1993 | 40.47 | 0.51 | 50.96 | 0.52 | 210.56 | 0.40 | 18.60 | 0.46 | 0.00 | |
| 1994 | 5.45 | 0.30 | 70.31 | 0.67 | 40.16 | 0.33 | 9.79 | 0.59 | 0.24 | 0.31 |
| 1995 | 6.36 | 0.48 | 17.17 | 0.41 | 213.50 | 0.43 | 51.89 | 1.44 | 0.02 | 1.42 |
| 1996 | 482.01 | 1.07 | 39.99 | 0.38 | 1803.43 | 2.10 | 28.68 | 0.43 | 26.64 | 0.82 |
| 1997 | 41.25 | 1.01 | 37.00 | 0.67 | 982.04 | 0.65 | 67.60 | 4.25 | 18.27 | 0.90 |
| 1998 | 80.88 | 1.47 | 55.31 | 0.43 | 49.32 | 1.27 | 0.42 | 0.65 | 39.19 | 1.45 |
| 1999 | 3.86 | 0.96 | 15.72 | 0.41 | 206.66 | 0.59 | 128.81 | 1.26 | 56.79 | 0.58 |
| 2000 | 28.37 | 0.67 | 74.39 | 1.82 | 55.46 | 0.37 | 21.96 | 0.53 | 0.06 | 0.80 |
| 2001 | 93.02 | 1.05 | 61.92 | 0.42 | 120.13 | 0.47 | 2.10 | 0.42 | 80.62 | 0.38 |
| 2002 | 2.72 | 3.86 | 24.07 | 0.41 | 173.23 | 0.31 | 76.51 | 1.85 | 1.41 | 1.05 |
| 2003 | 248.43 | 1.46 | 21.37 | 0.91 | 332.48 | 0.56 | 15.31 | 1.21 | 14.30 | 0.89 |
| 2004 | 99.74 | 0.93 | 18.16 | 0.35 | 81.54 | 0.47 | 176.74 | 0.74 | 35.03 | 0.78 |
| 2005 | 347.43 | 0.42 | 78.24 | 0.32 | 220.04 | 0.38 | 7.18 | 0.60 | 19.41 | 0.38 |
| 2006 | 57.61 | 0.91 | 29.29 | 4.37 | 187.48 | 0.67 | 232.02 | 1.16 | 13.35 | 0.81 |
| 2007 | 484.02 | 0.79 | 55.08 | 0.45 | 180.13 | 1.47 | 105.31 | 2.08 | 4.77 | 0.98 |
| 2008 | 145.03 | 0.43 | 52.38 | 0.32 | 526.59 | 0.57 | 327.99 | 0.40 | 7.83 | 0.65 |
| 2009 | 158.66 | 0.26 | 59.54 | 0.45 | 202.02 | 0.30 | 180.05 | 0.91 | 10.89 | 0.83 |
| 2010 | 118.50 | 0.20 | 46.12 | 0.17 | 125.02 | 0.20 | 86.50 | 0.32 | 1.12 | 0.65 |

Table A2: Mid-Atlantic total annual incidental catch (mt) and the associated coefficient of variation for bottom trawl, single and paired midwater trawls, gillnet, and all other fleets for each individual species. Herring NK represents unknown herring. Midwater trawl estimates are only included beginning in 2005.

| | | Bottom Trawl | | Single MWT | | Paired MWT | | Gillnet | | Other | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Year** | **Catch** | **CV** | **Catch** | **CV** | **Catch** | **CV** | **Catch** | **CV** | **Catch** | **CV** |
| Alewife | 1989 | 15.55 | 0.61 | | | | | 0.00 | | 0.00 | |
| | 1990 | 0.04 | 1.07 | | | | | 0.00 | | 0.00 | |
| | 1991 | 54.78 | 0.59 | | | | | 0.00 | | 0.00 | |
| | 1992 | 21.74 | 0.51 | | | | | 0.00 | | 0.00 | |
| | 1993 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1994 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1995 | 0.00 | 3.28 | | | | | 0.00 | | 0.00 | |
| | 1996 | 386.70 | 1.33 | | | | | 0.03 | 0.13 | 0.00 | |
| | 1997 | 7.63 | 3.31 | | | | | 0.00 | | 0.00 | |
| | 1998 | 0.00 | | | | | | 0.01 | 0.30 | 0.00 | |
| | 1999 | 0.13 | 2.03 | | | | | 0.00 | | 0.76 | 0.26 |
| | 2000 | 1.38 | 1.28 | | | | | 0.00 | | 6.70 | 0.88 |
| | 2001 | 3.24 | 0.59 | | | | | 0.83 | 1.49 | 0.00 | |
| | 2002 | 1.52 | 6.90 | | | | | 0.00 | | 0.00 | |
| | 2003 | 201.52 | 1.80 | | | | | 0.00 | | 0.00 | |
| | 2004 | 24.83 | 1.57 | | | | | 0.00 | | 51.49 | 1.61 |
| | 2005 | 72.68 | 0.70 | 21.35 | 1.43 | 162.03 | 0.78 | 0.14 | 1.08 | 0.00 | |
| | 2006 | 19.97 | 2.47 | 13.96 | 1.07 | 2.61 | 1.11 | 0.00 | | 0.00 | |
| | 2007 | 8.87 | 3.12 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2008 | 5.20 | 1.71 | 1.81 | 0.57 | 4.51 | 0.69 | 0.00 | | 0.00 | |
| | 2009 | 4.24 | 1.10 | 24.06 | 0.98 | 27.90 | 0.63 | 0.00 | | 0.00 | |
| | 2010 | 6.85 | 0.51 | 3.16 | 0.92 | 5.40 | 0.52 | 0.00 | | 0.01 | 0.97 |
| American Shad | 1989 | 13.32 | 0.41 | | | | | 0.00 | | 0.00 | |
| | 1990 | 4.15 | 0.46 | | | | | 0.00 | | 0.00 | |
| | 1991 | 28.95 | 0.50 | | | | | 0.00 | | 0.00 | |
| | 1992 | 20.25 | 0.42 | | | | | 0.00 | | 0.00 | |
| | 1993 | 0.71 | 1.29 | | | | | 0.00 | | 0.00 | |
| | 1994 | 45.73 | 1.00 | | | | | 0.43 | 0.11 | 0.00 | |
| | 1995 | 0.46 | 3.63 | | | | | 1.14 | 0.55 | 0.00 | |
| | 1996 | 2.44 | 0.51 | | | | | 8.66 | 0.57 | 0.00 | |
| | 1997 | 11.21 | 1.92 | | | | | 2.78 | 0.20 | 0.00 | |
| | 1998 | 9.49 | 1.05 | | | | | 20.64 | 0.34 | 0.00 | |
| | 1999 | 1.77 | 1.89 | | | | | 5.40 | 0.49 | 1.48 | 1.33 |
| | 2000 | 0.11 | 0.52 | | | | | 4.27 | 0.87 | 64.25 | 2.11 |
| | 2001 | 0.78 | 0.77 | | | | | 59.09 | 0.44 | 0.00 | |

| Species | Year | Bottom Trawl | | Single MWT | | Paired MWT | | Gillnet | | Other | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Catch | CV | Catch | CV | Catch | CV | Catch | CV | Catch | CV |
| | 2002 | 0.40 | 0.73 | | | | | 1.93 | 0.41 | 0.00 | |
| | 2003 | 9.41 | 2.03 | | | | | 1.25 | 0.59 | 0.01 | 1.06 |
| | 2004 | 3.85 | 0.62 | | | | | 0.13 | 0.39 | 0.04 | 0.86 |
| | 2005 | 8.83 | 0.40 | 0.48 | 1.43 | 27.30 | 0.53 | 0.00 | | 0.00 | |
| | 2006 | 0.63 | 2.03 | 3.92 | 1.07 | 0.00 | | 11.89 | 10.70 | 0.00 | |
| | 2007 | 7.75 | 1.93 | 0.00 | | 0.00 | | 0.83 | 2.49 | 0.00 | |
| | 2008 | 0.85 | 0.79 | 1.40 | 0.27 | 13.84 | 0.94 | 0.00 | | 0.00 | |
| | 2009 | 2.78 | 0.60 | 0.12 | 1.07 | 0.05 | 1.02 | 2.97 | 6.78 | 0.00 | |
| | 2010 | 13.97 | 0.43 | 0.00 | | 0.93 | 0.76 | 0.00 | | 0.00 | |
| Blueback Herring | 1989 | 8.93 | 0.65 | | | | | 0.00 | | 0.00 | |
| | 1990 | 56.86 | 0.48 | | | | | 0.00 | | 0.00 | |
| | 1991 | 49.54 | 0.53 | | | | | 0.00 | | 0.00 | |
| | 1992 | 360.88 | 0.44 | | | | | 0.00 | | 0.00 | |
| | 1993 | 112.69 | 0.53 | | | | | 0.00 | | 0.12 | 1.15 |
| | 1994 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1995 | 2.24 | 3.33 | | | | | 0.17 | 1.55 | 0.00 | |
| | 1996 | 1777.32 | 2.13 | | | | | 0.03 | 0.87 | 0.00 | |
| | 1997 | 878.61 | 0.67 | | | | | 0.09 | 0.48 | 0.00 | |
| | 1998 | 49.05 | 1.28 | | | | | 0.11 | 0.23 | 0.00 | |
| | 1999 | 0.10 | 0.52 | | | | | 0.01 | 1.34 | 0.00 | |
| | 2000 | 54.02 | 0.38 | | | | | 0.00 | | 0.00 | |
| | 2001 | 78.34 | 0.49 | | | | | 0.19 | 0.78 | 0.02 | 2.11 |
| | 2002 | 11.52 | 0.76 | | | | | 0.00 | | 0.00 | |
| | 2003 | 37.41 | 1.91 | | | | | 0.15 | 0.47 | 0.00 | |
| | 2004 | 22.23 | 1.11 | | | | | 0.03 | 1.04 | 0.00 | |
| | 2005 | 16.76 | 0.45 | 1.31 | 0.91 | 123.94 | 0.61 | 0.00 | | 0.00 | |
| | 2006 | 2.99 | 3.65 | 151.37 | 0.81 | 19.07 | 1.13 | 0.01 | 0.88 | 0.00 | |
| | 2007 | 1.21 | 1.33 | 0.00 | | 0.00 | | 0.00 | | 0.02 | 0.94 |
| | 2008 | 0.30 | 1.09 | 1.58 | 0.35 | 380.77 | 0.75 | 0.00 | | 0.00 | |
| | 2009 | 5.57 | 0.32 | 27.99 | 0.96 | 51.90 | 0.74 | 0.00 | | 0.01 | 0.88 |
| | 2010 | 7.81 | 0.86 | 1.66 | 0.65 | 7.51 | 0.88 | 0.00 | | 0.01 | 1.03 |
| Herring NK | 1989 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1990 | 111.73 | 0.69 | | | | | 0.00 | | 0.00 | |
| | 1991 | 76.60 | 0.56 | | | | | 0.00 | | 0.00 | |
| | 1992 | 53.54 | 0.65 | | | | | 0.00 | | 0.00 | |
| | 1993 | 3.65 | 0.00 | | | | | 0.00 | | 0.00 | |
| | 1994 | 0.08 | 1.00 | | | | | 0.38 | 0.10 | 0.00 | |
| | 1995 | 0.36 | 2.82 | | | | | 0.03 | 0.49 | 0.07 | 1.13 |
| | 1996 | 7.01 | 0.79 | | | | | 0.32 | 0.84 | 0.00 | |

| Species | Year | Bottom Trawl Catch | Bottom Trawl CV | Single MWT Catch | Single MWT CV | Paired MWT Catch | Paired MWT CV | Gillnet Catch | Gillnet CV | Other Catch | Other CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1997 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1998 | 0.07 | 1.85 | | | | | 0.16 | 0.25 | 0.00 | |
| | 1999 | 45.35 | 2.06 | | | | | 0.14 | 1.09 | 0.00 | |
| | 2000 | 0.64 | 0.98 | | | | | 0.23 | 0.63 | 6.34 | 0.94 |
| | 2001 | 0.93 | 0.80 | | | | | 0.12 | 0.62 | 0.00 | |
| | 2002 | 2.21 | 0.73 | | | | | 0.00 | | 0.00 | |
| | 2003 | 0.00 | | | | | | 0.02 | 1.68 | 0.01 | 1.29 |
| | 2004 | 167.25 | 0.78 | | | | | 0.00 | | 0.00 | |
| | 2005 | 1.89 | 0.73 | 0.00 | | 0.00 | | 0.06 | 1.50 | 0.07 | 0.19 |
| | 2006 | 0.00 | | 0.00 | | 0.00 | | 0.09 | 0.96 | 0.00 | |
| | 2007 | 10.41 | 4.76 | 0.00 | | 0.10 | 0.73 | 22.37 | 0.86 | 0.00 | |
| | 2008 | 52.40 | 1.12 | 75.02 | 0.53 | 0.00 | | 0.00 | | 0.00 | |
| | 2009 | 3.84 | 0.71 | 0.00 | | 158.78 | 1.02 | 0.00 | | 0.79 | 0.82 |
| | 2010 | 43.02 | 0.58 | 0.00 | | 0.03 | 0.97 | 0.00 | | 2.96 | 0.95 |
| Hickory Shad | 1989 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1990 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1991 | 0.00 | | | | | | 0.00 | | 39.35 | 0.00 |
| | 1992 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1993 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1994 | 0.00 | | | | | | 0.11 | 0.17 | 0.00 | |
| | 1995 | 0.02 | 2.09 | | | | | 0.01 | 0.11 | 0.00 | |
| | 1996 | 8.92 | 0.57 | | | | | 0.47 | 0.32 | 0.00 | |
| | 1997 | 4.82 | 2.18 | | | | | 5.41 | 0.80 | 0.00 | |
| | 1998 | 0.00 | | | | | | 0.47 | 0.39 | 0.31 | 0.98 |
| | 1999 | 0.11 | 2.47 | | | | | 0.14 | 0.71 | 52.14 | 0.63 |
| | 2000 | 0.00 | | | | | | 0.05 | 0.87 | 0.00 | |
| | 2001 | 3.10 | 1.04 | | | | | 10.99 | 0.53 | 0.00 | |
| | 2002 | 0.00 | | | | | | 1.28 | 1.15 | 0.00 | |
| | 2003 | 4.58 | 2.61 | | | | | 1.52 | 1.73 | 5.35 | 0.40 |
| | 2004 | 5.44 | 1.60 | | | | | 19.91 | 1.25 | 1.60 | 2.28 |
| | 2005 | 7.32 | 0.41 | 0.08 | 0.69 | 0.06 | 0.89 | 0.12 | 1.27 | 0.00 | |
| | 2006 | 3.83 | 0.75 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2007 | 1.59 | 2.86 | 0.00 | | 0.00 | | 0.44 | 0.77 | 0.00 | |
| | 2008 | 0.26 | 0.88 | 0.00 | | 0.00 | | 0.00 | | 3.63 | 1.20 |
| | 2009 | 0.18 | 1.14 | 0.00 | | 0.00 | | 1.35 | 2.36 | 7.14 | 1.17 |
| | 2010 | 0.02 | 0.51 | 0.00 | | 0.00 | | 0.32 | 0.70 | 0.64 | 1.08 |

Table A3: New England total annual incidental catch (mt) and the associated coefficient of variation for bottom trawl, single and paired midwater trawls, gillnet, and all other fleets for each individual species. Herring NK represents unknown herring. Midwater trawl estimates are only included beginning in 2005.

| | | Bottom Trawl | | Single MWT | | Paired MWT | | Gillnet | | Other | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Year | Catch | CV | Catch | CV | Catch | CV | Catch | CV | Catch | CV |
| Alewife | 1989 | 4.66 | 0.63 | | | | | 0.00 | | 0.13 | 0.95 |
| | 1990 | 55.27 | 0.68 | | | | | 0.00 | | 0.00 | |
| | 1991 | 4.02 | 0.62 | | | | | 0.00 | | 9.44 | 0.44 |
| | 1992 | 1.92 | 0.45 | | | | | 0.00 | | 6.90 | 0.25 |
| | 1993 | 33.80 | 0.61 | | | | | 0.00 | | 6.67 | 0.28 |
| | 1994 | 0.08 | 1.56 | | | | | 0.00 | | 5.36 | 0.31 |
| | 1995 | 2.10 | 1.37 | | | | | 0.09 | 1.07 | 4.17 | 0.25 |
| | 1996 | 38.37 | 0.39 | | | | | 1.31 | 1.02 | 55.60 | 0.47 |
| | 1997 | 10.08 | 3.16 | | | | | 0.00 | | 23.54 | 0.40 |
| | 1998 | 80.88 | 1.47 | | | | | 0.00 | | 0.00 | |
| | 1999 | 2.96 | 1.24 | | | | | 0.00 | | 0.00 | |
| | 2000 | 20.30 | 0.88 | | | | | 0.00 | | 0.00 | |
| | 2001 | 88.94 | 1.10 | | | | | 0.00 | | 0.00 | |
| | 2002 | 1.20 | 0.78 | | | | | 0.00 | | 0.00 | |
| | 2003 | 38.87 | 0.57 | | | | | 0.03 | 0.66 | 8.02 | 0.46 |
| | 2004 | 21.31 | 0.59 | | | | | 0.04 | 0.55 | 2.08 | 0.74 |
| | 2005 | 12.98 | 0.75 | 1.92 | 0.90 | 71.99 | 0.48 | 0.02 | 0.56 | 4.32 | 0.52 |
| | 2006 | 15.86 | 0.52 | 1.34 | 1.56 | 1.81 | 0.72 | 0.00 | | 2.05 | 0.43 |
| | 2007 | 259.38 | 0.41 | 116.52 | 2.89 | 97.42 | 1.42 | 0.02 | 1.41 | 1.82 | 0.80 |
| | 2008 | 31.84 | 0.85 | 40.49 | 1.04 | 60.46 | 0.60 | 0.00 | | 0.71 | 0.38 |
| | 2009 | 31.26 | 0.51 | 10.60 | 0.53 | 57.29 | 0.42 | 0.01 | 0.63 | 3.30 | 0.41 |
| | 2010 | 28.62 | 0.40 | 0.58 | 0.36 | 69.08 | 0.28 | 0.02 | 0.49 | 4.79 | 0.34 |
| American Shad | 1989 | 45.43 | 0.77 | | | | | 0.00 | | 0.18 | 1.02 |
| | 1990 | 18.86 | 0.44 | | | | | 0.00 | | 2.79 | 0.56 |
| | 1991 | 70.77 | 0.30 | | | | | 0.00 | | 4.54 | 1.11 |
| | 1992 | 56.54 | 0.38 | | | | | 0.00 | | 3.01 | 0.41 |
| | 1993 | 49.68 | 0.53 | | | | | 0.00 | | 0.57 | 0.97 |
| | 1994 | 22.86 | 0.55 | | | | | 1.12 | 0.88 | 0.16 | 0.76 |
| | 1995 | 6.52 | 0.96 | | | | | 8.89 | 0.29 | 0.16 | 1.05 |
| | 1996 | 1.05 | 4.45 | | | | | 27.82 | 0.48 | 0.03 | 1.10 |
| | 1997 | 13.68 | 0.87 | | | | | 5.01 | 0.44 | 4.31 | 0.60 |
| | 1998 | 16.98 | 1.20 | | | | | 8.19 | 0.44 | 0.00 | |
| | 1999 | 0.93 | 0.64 | | | | | 6.15 | 0.71 | 0.00 | |
| | 2000 | 1.50 | 1.20 | | | | | 4.25 | 0.51 | 0.00 | |
| | 2001 | 1.98 | 0.62 | | | | | 0.07 | 1.66 | 0.00 | |

| Species | Year | Bottom Trawl Catch | Bottom Trawl CV | Single MWT Catch | Single MWT CV | Paired MWT Catch | Paired MWT CV | Gillnet Catch | Gillnet CV | Other Catch | Other CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2002 | 4.56 | 1.41 | | | | | 17.17 | 0.44 | 0.00 | |
| | 2003 | 8.52 | 0.41 | | | | | 2.18 | 0.78 | 0.02 | 1.07 |
| | 2004 | 11.52 | 0.52 | | | | | 2.63 | 0.26 | 0.00 | 1.29 |
| | 2005 | 7.59 | 0.48 | 1.98 | 1.04 | 29.97 | 0.67 | 2.09 | 0.25 | 0.00 | |
| | 2006 | 3.04 | 0.60 | 0.00 | | 0.18 | 0.63 | 9.46 | 1.18 | 0.15 | 1.06 |
| | 2007 | 1.45 | 0.28 | 0.00 | | 17.15 | 0.78 | 27.86 | 0.52 | 0.03 | 0.95 |
| | 2008 | 2.95 | 0.38 | 2.57 | 1.09 | 2.43 | 0.84 | 28.30 | 0.37 | 0.04 | 0.99 |
| | 2009 | 17.98 | 0.51 | 20.64 | 0.69 | 6.76 | 0.34 | 7.83 | 0.28 | 0.42 | 0.83 |
| | 2010 | 11.22 | 0.25 | 0.11 | 0.49 | 10.28 | 0.37 | 9.61 | 0.19 | 0.00 | |
| Blueback Herring | 1989 | 8.20 | 0.56 | | | | | 0.00 | | 2.48 | 0.69 |
| | 1990 | 19.64 | 1.11 | | | | | 0.00 | | 2.44 | 0.60 |
| | 1991 | 57.25 | 0.58 | | | | | 0.00 | | 8.62 | 0.83 |
| | 1992 | 85.85 | 1.45 | | | | | 0.00 | | 11.44 | 0.50 |
| | 1993 | 96.72 | 0.61 | | | | | 0.00 | | 1.02 | 0.55 |
| | 1994 | 32.99 | 0.37 | | | | | 6.64 | 0.84 | 0.53 | 0.71 |
| | 1995 | 59.07 | 0.83 | | | | | 104.57 | 0.71 | 47.44 | 0.48 |
| | 1996 | 1.53 | 1.35 | | | | | 0.23 | 0.73 | 24.33 | 0.36 |
| | 1997 | 51.56 | 4.66 | | | | | 0.00 | | 51.79 | 0.51 |
| | 1998 | 0.00 | | | | | | 0.17 | 0.72 | 0.00 | |
| | 1999 | 206.56 | 0.59 | | | | | 0.00 | | 0.00 | |
| | 2000 | 1.43 | 0.87 | | | | | 0.00 | | 0.01 | 0.67 |
| | 2001 | 41.50 | 1.00 | | | | | 0.00 | | 0.08 | 0.96 |
| | 2002 | 161.07 | 0.33 | | | | | 0.64 | 1.23 | 0.00 | |
| | 2003 | 279.00 | 0.61 | | | | | 0.02 | 0.79 | 15.90 | 0.41 |
| | 2004 | 54.11 | 0.55 | | | | | 1.83 | 0.69 | 3.34 | 0.61 |
| | 2005 | 15.75 | 0.70 | 14.03 | 1.22 | 45.50 | 0.55 | 0.23 | 0.80 | 2.53 | 0.75 |
| | 2006 | 3.14 | 0.82 | 7.06 | 0.73 | 3.65 | 0.77 | 0.00 | | 0.17 | 0.76 |
| | 2007 | 38.65 | 0.60 | 72.91 | 3.51 | 64.97 | 1.05 | 0.01 | 1.32 | 2.37 | 0.83 |
| | 2008 | 13.73 | 0.83 | 17.46 | 0.76 | 109.73 | 0.84 | 0.02 | 1.31 | 3.01 | 0.77 |
| | 2009 | 42.84 | 0.56 | 9.85 | 0.56 | 61.42 | 0.46 | 0.03 | 0.84 | 2.40 | 0.47 |
| | 2010 | 9.79 | 0.41 | 0.39 | 1.09 | 74.45 | 0.27 | 0.07 | 0.39 | 23.34 | 0.45 |
| Herring NK | 1989 | 7.08 | 1.03 | | | | | 0.00 | | 0.00 | |
| | 1990 | 218.18 | 1.04 | | | | | 0.00 | | 1.43 | 0.82 |
| | 1991 | 28.44 | 1.04 | | | | | 0.00 | | 5.43 | 1.35 |
| | 1992 | 318.11 | 0.46 | | | | | 0.00 | | 15.88 | 0.37 |
| | 1993 | 14.75 | 0.58 | | | | | 0.00 | | 0.20 | 0.51 |
| | 1994 | 2.26 | 0.53 | | | | | 6.73 | 0.84 | 0.35 | 0.56 |
| | 1995 | 44.96 | 1.66 | | | | | 3.69 | 0.59 | 2.79 | 0.91 |
| | 1996 | 20.80 | 0.53 | | | | | 0.30 | 0.99 | 0.25 | 1.08 |

| Species | Year | Bottom Trawl Catch | Bottom Trawl CV | Single MWT Catch | Single MWT CV | Paired MWT Catch | Paired MWT CV | Gillnet Catch | Gillnet CV | Other Catch | Other CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1997 | 67.48 | 4.26 | | | | | 0.08 | 1.28 | 0.04 | 0.64 |
| | 1998 | 0.18 | 1.27 | | | | | 0.00 | | 0.00 | |
| | 1999 | 83.28 | 1.59 | | | | | 0.03 | 1.15 | 0.00 | |
| | 2000 | 14.75 | 0.68 | | | | | 0.00 | | 0.01 | 1.03 |
| | 2001 | 0.00 | | | | | | 0.05 | 1.54 | 1.00 | 0.46 |
| | 2002 | 74.30 | 1.91 | | | | | 0.00 | | 0.00 | |
| | 2003 | 15.25 | 1.21 | | | | | 0.03 | 0.59 | 0.00 | |
| | 2004 | 9.47 | 0.63 | | | | | 0.02 | 0.57 | 0.00 | |
| | 2005 | 3.20 | 1.24 | 0.15 | 1.36 | 0.00 | | 0.17 | 0.52 | 1.64 | 0.55 |
| | 2006 | 57.53 | 1.49 | 168.41 | 1.52 | 0.00 | | 2.25 | 0.50 | 3.75 | 0.58 |
| | 2007 | 72.42 | 2.93 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2008 | 97.17 | 0.58 | 0.98 | 1.13 | 0.00 | | 0.00 | | 102.41 | 0.93 |
| | 2009 | 15.01 | 1.48 | 0.00 | | 0.67 | 0.91 | 0.63 | 0.62 | 0.35 | 0.78 |
| | 2010 | 8.52 | 0.90 | 0.49 | 0.46 | 17.84 | 0.18 | 0.29 | 0.46 | 13.34 | 0.55 |
| | 1989 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1990 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1991 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1992 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1993 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1994 | 0.10 | 0.63 | | | | | 0.00 | | 0.03 | 1.05 |
| | 1995 | 0.00 | | | | | | 0.00 | | 0.00 | |
| | 1996 | 17.26 | 1.24 | | | | | 0.00 | | 0.00 | |
| | 1997 | 3.68 | 3.16 | | | | | 0.00 | | 4.37 | 0.63 |
| | 1998 | 38.40 | 1.48 | | | | | 0.00 | | 0.00 | |
| Hickory Shad | 1999 | 4.40 | 0.70 | | | | | 0.00 | | 0.00 | |
| | 2000 | 0.00 | 0.83 | | | | | 0.00 | | 0.00 | |
| | 2001 | 66.53 | 0.45 | | | | | 0.00 | | 0.00 | |
| | 2002 | 0.12 | 1.00 | | | | | 0.00 | | 0.00 | |
| | 2003 | 2.59 | 1.02 | | | | | 0.27 | 0.46 | 0.00 | |
| | 2004 | 8.04 | 0.78 | | | | | 0.04 | 0.84 | 0.00 | |
| | 2005 | 2.68 | 0.45 | 2.58 | 1.37 | 6.56 | 0.86 | 0.01 | 0.85 | 0.00 | |
| | 2006 | 9.32 | 1.12 | 0.15 | 1.56 | 0.00 | | 0.04 | 1.00 | 0.01 | 1.06 |
| | 2007 | 1.99 | 0.38 | 0.37 | 1.66 | 0.00 | | 0.28 | 1.33 | 0.11 | 0.98 |
| | 2008 | 0.90 | 0.52 | 0.00 | | 2.89 | 0.88 | 0.02 | 0.91 | 0.12 | 1.01 |
| | 2009 | 2.05 | 0.76 | 0.00 | | 0.00 | | 0.17 | 0.61 | 0.00 | |
| | 2010 | 0.06 | 0.67 | 0.00 | 0.19 | 0.00 | | 0.08 | 0.68 | 0.00 | |

Table A4: Mid-Atlantic total annual incidental catch (mt) and the associated coefficient of variation by mesh category for bottom trawl and gillnet for each individual species. Herring NK represents unknown herring. Midwater trawl estimates are only included beginning in 2005.

| | | Bottom Trawl | | | | | | Gillnet | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Small mesh | | Med. mesh | | Large mesh | | Small mesh | | Large mesh | | X-large mesh | |
| Species | Year | Catch | CV | Catch | CV | Catch | CV | Catch | CV | Catch | CV | Catch | CV |
| Alewife | 1989 | 15.55 | 0.61 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1990 | 0.04 | 1.07 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1991 | 54.78 | 0.59 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1992 | 21.72 | 0.51 | 0.00 | | 0.02 | 1.10 | 0.00 | | 0.00 | | | |
| | 1993 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1994 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1995 | 0.00 | 3.28 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1996 | 386.66 | 1.33 | 0.04 | 0.53 | 0.00 | | 0.03 | 0.12 | 0.00 | 0.81 | 0.00 | |
| | 1997 | 6.74 | 3.75 | 0.89 | 0.44 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1998 | 0.00 | | 0.00 | | 0.00 | | 0.01 | 0.30 | 0.00 | | 0.00 | |
| | 1999 | 0.13 | 2.03 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2000 | 1.38 | 1.28 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2001 | 3.24 | 0.59 | 0.00 | | 0.00 | | 0.83 | 1.49 | 0.00 | | 0.00 | |
| | 2002 | 1.52 | 6.90 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2003 | 201.52 | 1.80 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2004 | 24.29 | 1.61 | 0.54 | 0.50 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2005 | 71.58 | 0.71 | 1.11 | 3.34 | 0.00 | | 0.14 | 1.08 | 0.00 | | 0.00 | |
| | 2006 | 19.20 | 2.57 | 0.10 | 2.74 | 0.67 | 1.95 | 0.00 | | 0.00 | | 0.00 | |
| | 2007 | 8.86 | 3.12 | 0.01 | 0.58 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2008 | 4.95 | 1.80 | 0.02 | 1.38 | 0.24 | 0.74 | 0.00 | | 0.00 | | 0.00 | |
| | 2009 | 3.62 | 1.28 | 0.09 | 1.04 | 0.53 | 0.82 | 0.00 | | 0.00 | | 0.00 | |
| | 2010 | 6.63 | 0.53 | 0.06 | 0.45 | 0.16 | 0.95 | 0.00 | | 0.00 | | 0.00 | |
| American Shad | 1989 | 11.34 | 0.48 | 0.00 | | 1.98 | 0.00 | 0.00 | | 0.00 | | | |
| | 1990 | 4.15 | 0.46 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1991 | 16.27 | 0.49 | 12.67 | 0.94 | 0.00 | | 0.00 | | 0.00 | | | |
| | 1992 | 20.13 | 0.42 | 0.00 | | 0.12 | 0.51 | 0.00 | | 0.00 | | | |
| | 1993 | 0.71 | 1.29 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1994 | 45.69 | 1.00 | 0.00 | | 0.04 | 0.75 | 0.42 | 0.11 | 0.01 | 0.27 | 0.00 | |
| | 1995 | 0.43 | 3.92 | 0.03 | 0.90 | 0.00 | | 0.36 | 1.56 | 0.78 | 0.35 | 0.00 | |
| | 1996 | 2.42 | 0.51 | 0.02 | 7.54 | 0.00 | | 7.27 | 0.68 | 1.39 | 0.28 | 0.00 | |
| | 1997 | 6.17 | 3.48 | 5.04 | 0.40 | 0.00 | | 0.53 | 0.54 | 2.23 | 0.22 | 0.02 | 0.86 |
| | 1998 | 9.49 | 1.05 | 0.00 | | 0.00 | | 13.36 | 0.51 | 6.49 | 0.23 | 0.79 | 0.87 |
| | 1999 | 1.57 | 2.12 | 0.19 | 0.91 | 0.00 | | 1.75 | 0.77 | 3.64 | 0.62 | 0.00 | |
| | 2000 | 0.11 | 0.52 | 0.00 | | 0.00 | | 0.00 | 1.08 | 4.27 | 0.87 | 0.00 | |
| | 2001 | 0.61 | 0.68 | 0.18 | 2.48 | 0.00 | | 58.84 | 0.44 | 0.25 | 0.65 | 0.00 | |

| Species | Year | Bottom Trawl | | | | | | Gillnet | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Small mesh | | Med. mesh | | Large mesh | | Small mesh | | Large mesh | | X-large mesh | |
| | | Catch | CV | Catch | CV | Catch | CV | Catch | CV | Catch | CV | Catch | CV |
| | 2002 | 0.40 | 0.73 | 0.00 | | 0.00 | | 1.65 | 0.48 | 0.29 | 0.19 | 0.00 | |
| | 2003 | 9.41 | 2.03 | 0.00 | | 0.00 | | 0.12 | 0.70 | 1.12 | 0.65 | 0.00 | |
| | 2004 | 3.23 | 0.73 | 0.25 | 0.83 | 0.38 | 0.70 | 0.13 | 0.39 | 0.00 | | 0.00 | |
| | 2005 | 7.88 | 0.44 | 0.01 | 3.34 | 0.94 | 0.59 | 0.00 | | 0.00 | | 0.00 | |
| | 2006 | 0.63 | 2.03 | 0.00 | | 0.00 | | 0.11 | 0.34 | 11.79 | 10.80 | 0.00 | |
| | 2007 | 4.68 | 3.16 | 3.07 | 0.76 | 0.00 | | 0.44 | 1.06 | 0.39 | 5.17 | 0.00 | |
| | 2008 | 0.51 | 1.27 | 0.35 | 0.60 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2009 | 2.39 | 0.69 | 0.26 | 0.69 | 0.13 | 0.85 | 0.69 | 2.17 | 2.28 | 8.80 | 0.00 | |
| | 2010 | 13.51 | 0.45 | 0.38 | 0.51 | 0.08 | 1.11 | 0.00 | | 0.00 | | 0.00 | |
| | 1989 | 8.93 | 0.65 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1990 | 49.94 | 0.52 | 6.93 | 1.22 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1991 | 49.53 | 0.53 | 0.01 | 1.06 | 0.00 | | 0.00 | | 0.00 | | | |
| | 1992 | 360.88 | 0.44 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1993 | 112.69 | 0.53 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1994 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1995 | 2.18 | 3.43 | 0.00 | | 0.06 | 1.21 | 0.10 | 2.56 | 0.07 | 0.40 | 0.00 | |
| | 1996 | 1777.32 | 2.13 | 0.00 | | 0.00 | | 0.03 | 0.93 | 0.00 | 0.86 | 0.00 | |
| | 1997 | 877.27 | 0.68 | 1.34 | 1.30 | 0.00 | | 0.00 | | 0.02 | 0.52 | 0.07 | 0.60 |
| | 1998 | 49.05 | 1.28 | 0.00 | | 0.00 | | 0.04 | 0.30 | 0.07 | 0.33 | 0.00 | 0.91 |
| Blueback Herring | 1999 | 0.10 | 0.52 | 0.00 | | 0.00 | | 0.01 | 1.34 | 0.00 | | 0.00 | |
| | 2000 | 54.02 | 0.38 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2001 | 78.34 | 0.49 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.19 | 0.78 |
| | 2002 | 11.52 | 0.76 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2003 | 37.41 | 1.91 | 0.00 | | 0.00 | | 0.15 | 0.47 | 0.00 | | 0.00 | |
| | 2004 | 18.21 | 1.35 | 3.90 | 0.56 | 0.13 | 1.06 | 0.00 | | 0.00 | | 0.03 | 1.04 |
| | 2005 | 16.61 | 0.45 | 0.13 | 0.52 | 0.02 | 0.91 | 0.00 | | 0.00 | | 0.00 | |
| | 2006 | 2.79 | 3.91 | 0.20 | 0.60 | 0.00 | | 0.01 | 0.88 | 0.00 | | 0.00 | |
| | 2007 | 0.72 | 2.20 | 0.49 | 0.58 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2008 | 0.30 | 1.09 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2009 | 5.40 | 0.32 | 0.00 | | 0.17 | 0.75 | 0.00 | | 0.00 | | 0.00 | |
| | 2010 | 7.74 | 0.87 | 0.01 | 0.47 | 0.06 | 1.09 | 0.00 | | 0.00 | | 0.00 | |
| | 1989 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1990 | 111.73 | 0.69 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1991 | 76.60 | 0.56 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| Herring NK | 1992 | 51.48 | 0.67 | 2.07 | 1.56 | 0.00 | | 0.00 | | 0.00 | | | |
| | 1993 | 0.00 | | 3.65 | 0.00 | 0.00 | | 0.00 | | 0.00 | | | |
| | 1994 | 0.08 | 1.00 | 0.00 | | 0.00 | | 0.38 | 0.10 | 0.00 | 0.63 | 0.00 | |
| | 1995 | 0.31 | 3.25 | 0.00 | | 0.05 | 1.09 | 0.00 | 0.18 | 0.03 | 0.51 | 0.00 | |
| | 1996 | 7.01 | 0.79 | 0.00 | | 0.00 | | 0.29 | 0.93 | 0.03 | 0.81 | 0.00 | |

| Species | Year | Bottom Trawl | | | | | | Gillnet | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Small mesh | | Med. mesh | | Large mesh | | Small mesh | | Large mesh | | X-large mesh | |
| | | Catch | CV | Catch | CV | Catch | CV | Catch | CV | Catch | CV | Catch | CV |
| | 1997 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1998 | 0.07 | 1.85 | 0.00 | | 0.00 | | 0.01 | 0.30 | 0.13 | 0.28 | 0.02 | 0.91 |
| | 1999 | 45.35 | 2.06 | 0.00 | | 0.00 | | 0.07 | 0.81 | 0.07 | 1.96 | 0.00 | |
| | 2000 | 0.60 | 1.03 | 0.00 | | 0.04 | 2.67 | 0.21 | 0.67 | 0.02 | 1.03 | 0.00 | |
| | 2001 | 0.93 | 0.80 | 0.00 | | 0.00 | | 0.12 | 0.62 | 0.00 | | 0.00 | |
| | 2002 | 2.21 | 0.73 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2003 | 0.00 | | 0.00 | | 0.00 | | 0.02 | 1.68 | 0.00 | | 0.00 | |
| | 2004 | 167.25 | 0.78 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2005 | 1.89 | 0.73 | 0.00 | 0.83 | 0.00 | | 0.06 | 1.50 | 0.00 | | 0.00 | |
| | 2006 | 0.00 | | 0.00 | | 0.00 | | 0.09 | 0.96 | 0.00 | | 0.00 | |
| | 2007 | 10.41 | 4.76 | 0.00 | 2.55 | 0.00 | | 0.00 | | 22.37 | 0.86 | 0.00 | |
| | 2008 | 52.35 | 1.12 | 0.05 | 0.61 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2009 | 3.79 | 0.72 | 0.05 | 0.87 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2010 | 43.01 | 0.58 | 0.01 | 1.12 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1989 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1990 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1991 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1992 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1993 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1994 | 0.00 | | 0.00 | | 0.00 | | 0.11 | 0.17 | 0.00 | 0.63 | 0.00 | |
| | 1995 | 0.00 | | 0.00 | | 0.02 | 2.09 | 0.01 | 0.11 | 0.00 | | 0.00 | |
| | 1996 | 8.92 | 0.57 | 0.00 | | 0.00 | | 0.16 | 0.16 | 0.30 | 0.49 | 0.00 | |
| | 1997 | 3.01 | 3.40 | 1.81 | 1.24 | 0.00 | | 5.40 | 0.80 | 0.00 | 0.91 | 0.00 | |
| | 1998 | 0.00 | | 0.00 | | 0.00 | | 0.47 | 0.39 | 0.00 | | 0.00 | |
| Hickory Shad | 1999 | 0.11 | 2.47 | 0.00 | | 0.00 | | 0.14 | 0.71 | 0.00 | | 0.00 | |
| | 2000 | 0.00 | | 0.00 | | 0.00 | | 0.02 | 1.07 | 0.03 | 1.28 | 0.00 | |
| | 2001 | 0.44 | 0.53 | 2.66 | 1.21 | 0.00 | | 10.94 | 0.54 | 0.05 | 0.87 | 0.00 | |
| | 2002 | 0.00 | | 0.00 | | 0.00 | | 1.28 | 1.15 | 0.00 | | 0.00 | |
| | 2003 | 4.44 | 2.70 | 0.14 | 0.71 | 0.00 | | 1.52 | 1.73 | 0.00 | | 0.00 | |
| | 2004 | 5.44 | 1.60 | 0.00 | | 0.00 | | 0.00 | | 19.91 | 1.25 | 0.00 | |
| | 2005 | 7.11 | 0.42 | 0.07 | 2.60 | 0.15 | 0.62 | 0.12 | 1.27 | 0.00 | | 0.00 | |
| | 2006 | 3.69 | 0.74 | 0.14 | 6.42 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2007 | 1.44 | 3.17 | 0.15 | 0.43 | 0.00 | 0.53 | 0.00 | | 0.44 | 0.77 | 0.00 | |
| | 2008 | 0.24 | 0.97 | 0.02 | 0.78 | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2009 | 0.12 | 1.58 | 0.05 | 0.99 | 0.00 | | 1.35 | 2.36 | 0.00 | | 0.00 | |
| | 2010 | 0.01 | 1.04 | 0.00 | 1.08 | 0.01 | 0.44 | 0.32 | 0.70 | 0.00 | | 0.00 | |

Table A5: New England total annual incidental catch (mt) and the associated coefficient of variation by mesh category for bottom trawl and gillnet for each individual species. Herring NK represents unknown herring. Midwater trawl estimates are only included beginning in 2005.

| | | Bottom Trawl | | | | | | Gillnet | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Small mesh | | Med. mesh | | Large mesh | | Small mesh | | Large mesh | | X-large mesh | |
| Species | Year | Catch | CV | Catch | CV | Catch | CV | Catch | CV | Catch | CV | Catch | CV |
| Alewife | 1989 | 4.22 | 0.69 | 0.32 | 1.64 | 0.12 | 0.98 | 0.00 | | 0.00 | | 0 | |
| | 1990 | 11.91 | 1.91 | 0.00 | | 43.36 | 0.69 | 0.00 | | 0.00 | | | |
| | 1991 | 3.21 | 0.74 | 0.57 | 1.28 | 0.24 | 1.17 | 0.00 | | 0.00 | | 0.00 | |
| | 1992 | 1.16 | 0.62 | 0.00 | | 0.76 | 0.64 | | | 0.00 | | 0.00 | |
| | 1993 | 33.75 | 0.61 | 0.00 | | 0.06 | 1.89 | | | 0.00 | | 0.00 | |
| | 1994 | 0.00 | | 0.00 | | 0.08 | 1.56 | 0.00 | | 0.00 | | 0.00 | |
| | 1995 | 2.10 | 1.37 | 0.00 | | 0.00 | | 0.00 | | 0.09 | 1.07 | 0.00 | |
| | 1996 | 38.37 | 0.39 | 0.00 | | 0.00 | | 0.00 | | 1.31 | 1.02 | 0.00 | |
| | 1997 | 10.05 | 3.17 | 0.00 | | 0.03 | 1.39 | 0.00 | | 0.00 | | 0.00 | |
| | 1998 | 80.88 | 1.47 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1999 | 2.96 | 1.24 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2000 | 20.30 | 0.88 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2001 | 88.28 | 1.10 | 0.00 | | 0.66 | 1.22 | 0.00 | | 0.00 | | 0.00 | |
| | 2002 | 1.16 | 0.80 | 0.00 | 2.33 | 0.04 | 0.88 | 0.00 | | 0.00 | | 0.00 | |
| | 2003 | 38.21 | 0.58 | 0.00 | | 0.65 | 0.40 | 0.00 | | 0.03 | 0.66 | 0.00 | |
| | 2004 | 21.02 | 0.60 | 0.00 | 0.88 | 0.28 | 0.35 | 0.00 | | 0.04 | 0.55 | 0.00 | |
| | 2005 | 11.53 | 0.84 | 0.00 | 0.13 | 1.45 | 0.94 | 0.00 | | 0.02 | 0.56 | 0.00 | |
| | 2006 | 15.68 | 0.52 | 0.00 | | 0.18 | 0.50 | 0.00 | | 0.00 | | 0.00 | |
| | 2007 | 258.45 | 0.41 | 0.00 | | 0.93 | 0.65 | 0.00 | | 0.00 | | 0.02 | 1.41 |
| | 2008 | 31.31 | 0.87 | 0.00 | | 0.53 | 0.28 | 0.00 | | 0.00 | | 0.00 | |
| | 2009 | 27.75 | 0.57 | 0.00 | | 3.52 | 0.65 | 0.00 | | 0.01 | 0.63 | 0.00 | |
| | 2010 | 26.81 | 0.43 | 0.10 | 1.81 | 1.71 | 0.18 | 0.00 | | 0.02 | 0.51 | 0.00 | 0.84 |
| American Shad | 1989 | 38.90 | 0.89 | 0.00 | | 6.53 | 0.33 | 0.00 | | 0.00 | | 0.00 | |
| | 1990 | 2.95 | 0.56 | 0.00 | | 15.91 | 0.51 | 0.00 | | 0.00 | | | |
| | 1991 | 6.87 | 0.50 | 0.28 | 1.31 | 63.63 | 0.33 | 0.00 | | 0.00 | | 0.00 | |
| | 1992 | 6.87 | 0.58 | 0.00 | | 49.67 | 0.42 | | | 0.00 | | 0.00 | |
| | 1993 | 38.25 | 0.68 | 0.00 | | 11.42 | 0.41 | | | 0.00 | | 0.00 | |
| | 1994 | 18.89 | 0.66 | 0.12 | 0.69 | 3.86 | 0.43 | 0.00 | | 1.12 | 0.88 | 0.00 | |
| | 1995 | 1.24 | 0.83 | 0.03 | 0.99 | 5.25 | 1.18 | 0.00 | | 8.85 | 0.29 | 0.04 | 0.84 |
| | 1996 | 0.36 | 12.72 | 0.04 | 0.00 | 0.64 | 1.07 | 0.00 | | 27.82 | 0.48 | 0.00 | |
| | 1997 | 2.10 | 4.25 | 0.00 | | 11.58 | 0.68 | 0.00 | | 4.86 | 0.46 | 0.15 | 1.04 |
| | 1998 | 12.95 | 0.32 | 0.00 | | 4.03 | 4.93 | 0.00 | | 7.21 | 0.49 | 0.98 | 0.91 |
| | 1999 | 0.10 | 1.24 | 0.00 | | 0.83 | 0.70 | 0.00 | | 4.75 | 0.86 | 1.40 | 1.15 |
| | 2000 | 0.00 | | 0.00 | | 1.50 | 1.20 | 0.00 | | 4.13 | 0.52 | 0.12 | 0.95 |
| | 2001 | 0.84 | 1.27 | 0.05 | 0.66 | 1.08 | 0.54 | 0.00 | | 0.07 | 1.66 | 0.00 | |

| | | Bottom Trawl | | | | | | Gillnet | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Small mesh | | Med. mesh | | Large mesh | | Small mesh | | Large mesh | | X-large mesh | |
| **Species** | **Year** | **Catch** | **CV** | **Catch** | **CV** | **Catch** | **CV** | **Catch** | **CV** | **Catch** | **CV** | **Catch** | **CV** |
| | 2002 | 4.39 | 1.47 | 0.00 | | 0.17 | 0.71 | 0.00 | | 17.10 | 0.44 | 0.08 | 1.08 |
| | 2003 | 7.35 | 0.47 | 0.00 | 0.85 | 1.17 | 0.31 | 0.00 | | 1.62 | 1.00 | 0.56 | 0.88 |
| | 2004 | 10.90 | 0.55 | 0.00 | 1.37 | 0.61 | 0.30 | 0.00 | | 2.49 | 0.27 | 0.14 | 0.73 |
| | 2005 | 6.88 | 0.53 | 0.00 | 0.12 | 0.72 | 0.20 | 0.00 | | 2.02 | 0.26 | 0.07 | 0.37 |
| | 2006 | 2.58 | 0.70 | 0.00 | 0.62 | 0.46 | 0.24 | 0.00 | | 9.46 | 1.18 | 0.00 | |
| | 2007 | 0.75 | 0.49 | 0.00 | | 0.70 | 0.26 | 0.00 | | 27.86 | 0.52 | 0.00 | |
| | 2008 | 1.15 | 0.86 | 0.05 | 0.61 | 1.75 | 0.29 | 0.00 | | 28.27 | 0.37 | 0.03 | 1.10 |
| | 2009 | 16.21 | 0.56 | 0.00 | | 1.77 | 0.23 | 0.00 | | 7.65 | 0.28 | 0.18 | 0.79 |
| | 2010 | 7.80 | 0.35 | 0.02 | 1.64 | 3.40 | 0.12 | 0.00 | | 9.55 | 0.19 | 0.06 | 0.43 |
| Blueback Herring | 1989 | 4.58 | 0.72 | 0.00 | | 3.62 | 0.89 | 0.00 | | 0.00 | | 0.00 | |
| | 1990 | 5.79 | 1.66 | 0.00 | | 13.85 | 1.42 | 0.00 | | 0.00 | | | |
| | 1991 | 57.20 | 0.58 | 0.01 | 0.93 | 0.05 | 0.75 | 0.00 | | 0.00 | | 0.00 | |
| | 1992 | 85.38 | 1.46 | 0.00 | | 0.47 | 0.72 | | | 0.00 | | 0.00 | |
| | 1993 | 96.08 | 0.61 | 0.00 | | 0.64 | 0.59 | | | 0.00 | | 0.00 | |
| | 1994 | 32.94 | 0.37 | 0.00 | | 0.05 | 0.63 | 0.00 | | 6.64 | 0.84 | 0.00 | |
| | 1995 | 58.98 | 0.83 | 0.00 | | 0.09 | 0.48 | 0.00 | | 104.57 | 0.71 | 0.00 | |
| | 1996 | 1.53 | 1.35 | 0.00 | | 0.00 | | 0.00 | | 0.23 | 0.73 | 0.00 | |
| | 1997 | 51.49 | 4.66 | 0.00 | | 0.07 | 1.41 | 0.00 | | 0.00 | | 0.00 | |
| | 1998 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.17 | 0.72 | 0.00 | |
| | 1999 | 199.81 | 0.61 | 0.00 | | 6.74 | 1.83 | 0.00 | | 0.00 | | 0.00 | |
| | 2000 | 1.41 | 0.88 | 0.00 | | 0.02 | 1.49 | 0.00 | | 0.00 | | 0.00 | |
| | 2001 | 41.48 | 1.00 | 0.00 | | 0.03 | 0.97 | 0.00 | | 0.00 | | 0.00 | |
| | 2002 | 159.90 | 0.33 | 0.02 | 1.31 | 1.15 | 0.56 | 0.00 | | 0.64 | 1.23 | 0.00 | |
| | 2003 | 272.92 | 0.62 | 0.12 | 0.46 | 5.97 | 0.35 | 0.00 | | 0.01 | 0.96 | 0.00 | 1.36 |
| | 2004 | 49.61 | 0.60 | 0.02 | 0.80 | 4.47 | 0.53 | 0.00 | | 1.77 | 0.71 | 0.06 | 0.54 |
| | 2005 | 14.73 | 0.75 | 0.02 | 0.16 | 1.01 | 0.38 | 0.00 | | 0.23 | 0.80 | 0.00 | 0.90 |
| | 2006 | 2.55 | 1.01 | 0.12 | 0.77 | 0.48 | 0.40 | 0.00 | | 0.00 | | 0.00 | |
| | 2007 | 38.36 | 0.60 | 0.01 | 8.19 | 0.28 | 0.45 | 0.00 | | 0.01 | 1.32 | 0.00 | |
| | 2008 | 13.47 | 0.85 | 0.00 | | 0.26 | 0.41 | 0.00 | | 0.02 | 1.31 | 0.00 | |
| | 2009 | 42.59 | 0.57 | 0.00 | | 0.25 | 0.60 | 0.00 | | 0.03 | 0.84 | 0.00 | |
| | 2010 | 8.59 | 0.46 | 0.07 | 0.48 | 1.13 | 0.41 | 0.00 | | 0.07 | 0.39 | 0.00 | |
| Herring NK | 1989 | 6.83 | 1.07 | 0.00 | | 0.25 | 1.00 | 0.00 | | 0.00 | | 0.00 | |
| | 1990 | 10.95 | 1.90 | 0.00 | | 207.24 | 1.09 | 0.00 | | 0.00 | | | |
| | 1991 | 21.44 | 1.35 | 6.35 | 0.87 | 0.64 | 1.07 | 0.00 | | 0.00 | | 0.00 | |
| | 1992 | 313.19 | 0.47 | 0.00 | | 4.92 | 0.55 | | | 0.00 | | 0.00 | |
| | 1993 | 9.70 | 0.81 | 0.00 | | 5.05 | 0.66 | | | 0.00 | | 0.00 | |
| | 1994 | 0.35 | 0.99 | 0.00 | | 1.91 | 0.60 | 0.00 | | 6.73 | 0.84 | 0.00 | |
| | 1995 | 44.36 | 1.69 | 0.00 | | 0.60 | 0.40 | 0.00 | | 3.69 | 0.59 | 0.00 | |
| | 1996 | 20.46 | 0.54 | 0.07 | 0.00 | 0.27 | 0.68 | 0.00 | | 0.00 | | 0.30 | 0.99 |

| | | Bottom Trawl | | | | | | Gillnet | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Small mesh | | Med. mesh | | Large mesh | | Small mesh | | Large mesh | | X-large mesh | |
| **Species** | **Year** | **Catch** | **CV** | **Catch** | **CV** | **Catch** | **CV** | **Catch** | **CV** | **Catch** | **CV** | **Catch** | **CV** |
| | 1997 | 61.89 | 4.64 | 5.20 | 0.62 | 0.38 | 0.77 | 0.00 | | 0.04 | 1.02 | 0.04 | 2.28 |
| | 1998 | 0.00 | | 0.00 | | 0.18 | 1.27 | 0.00 | | 0.00 | | 0.00 | |
| | 1999 | 83.28 | 1.59 | 0.00 | | 0.00 | | 0.00 | | 0.03 | 1.15 | 0.00 | |
| | 2000 | 14.31 | 0.70 | 0.00 | | 0.44 | 1.48 | 0.00 | | 0.00 | | 0.00 | |
| | 2001 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.05 | 1.54 | 0.00 | |
| | 2002 | 73.95 | 1.91 | 0.00 | 0.77 | 0.35 | 0.73 | 0.00 | | 0.00 | | 0.00 | |
| | 2003 | 14.49 | 1.28 | 0.00 | | 0.76 | 0.58 | 0.00 | | 0.03 | 0.59 | 0.00 | |
| | 2004 | 9.24 | 0.64 | 0.00 | | 0.22 | 0.59 | 0.00 | | 0.02 | 0.60 | 0.00 | 1.16 |
| | 2005 | 2.97 | 1.34 | 0.01 | 0.12 | 0.23 | 0.29 | 0.00 | | 0.16 | 0.55 | 0.01 | 0.90 |
| | 2006 | 57.15 | 1.50 | 0.05 | 0.63 | 0.33 | 0.57 | 0.00 | | 1.98 | 0.56 | 0.27 | 0.99 |
| | 2007 | 72.27 | 2.94 | 0.00 | | 0.15 | 0.51 | 0.00 | | 0.00 | | 0.00 | |
| | 2008 | 97.08 | 0.58 | 0.00 | | 0.09 | 0.62 | 0.00 | | 0.00 | | 0.00 | |
| | 2009 | 14.70 | 1.51 | 0.00 | | 0.30 | 0.39 | 0.00 | | 0.63 | 0.62 | 0.00 | |
| | 2010 | 8.27 | 0.93 | 0.00 | | 0.26 | 0.68 | 0.00 | | 0.29 | 0.46 | 0.00 | 0.84 |
| | 1989 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1990 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | | |
| | 1991 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1992 | 0.00 | | 0.00 | | 0.00 | | | | 0.00 | | 0.00 | |
| | 1993 | 0.00 | | 0.00 | | 0.00 | | | | 0.00 | | 0.00 | |
| | 1994 | 0.00 | | 0.00 | | 0.10 | 0.63 | 0.00 | | 0.00 | | 0.00 | |
| | 1995 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1996 | 17.26 | 1.24 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 1997 | 3.43 | 3.40 | 0.00 | | 0.25 | 0.81 | 0.00 | | 0.00 | | 0.00 | |
| | 1998 | 38.40 | 1.48 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| Hickory Shad | 1999 | 4.40 | 0.70 | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.00 | |
| | 2000 | 0.00 | | 0.00 | | 0.00 | 0.83 | 0.00 | | 0.00 | | 0.00 | |
| | 2001 | 66.32 | 0.45 | 0.00 | | 0.20 | 0.76 | 0.00 | | 0.00 | | 0.00 | |
| | 2002 | 0.00 | | 0.00 | | 0.12 | 1.00 | 0.00 | | 0.00 | | 0.00 | |
| | 2003 | 2.53 | 1.05 | 0.00 | | 0.06 | 0.93 | 0.00 | | 0.25 | 0.48 | 0.01 | 0.84 |
| | 2004 | 7.98 | 0.79 | 0.00 | | 0.06 | 0.39 | 0.00 | | 0.04 | 0.84 | 0.00 | |
| | 2005 | 2.41 | 0.49 | 0.00 | 0.92 | 0.26 | 0.56 | 0.00 | | 0.01 | 0.85 | 0.00 | |
| | 2006 | 9.19 | 1.14 | 0.00 | | 0.13 | 0.32 | 0.00 | | 0.02 | 1.88 | 0.02 | 1.05 |
| | 2007 | 1.74 | 0.43 | 0.00 | | 0.24 | 0.36 | 0.00 | | 0.28 | 1.33 | 0.00 | |
| | 2008 | 0.70 | 0.66 | 0.00 | | 0.21 | 0.45 | 0.00 | | 0.02 | 0.91 | 0.00 | |
| | 2009 | 1.88 | 0.83 | 0.02 | 0.30 | 0.15 | 0.35 | 0.00 | | 0.17 | 0.61 | 0.00 | |
| | 2010 | 0.02 | 1.24 | 0.00 | | 0.04 | 0.80 | 0.00 | | 0.08 | 0.68 | 0.00 | |

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