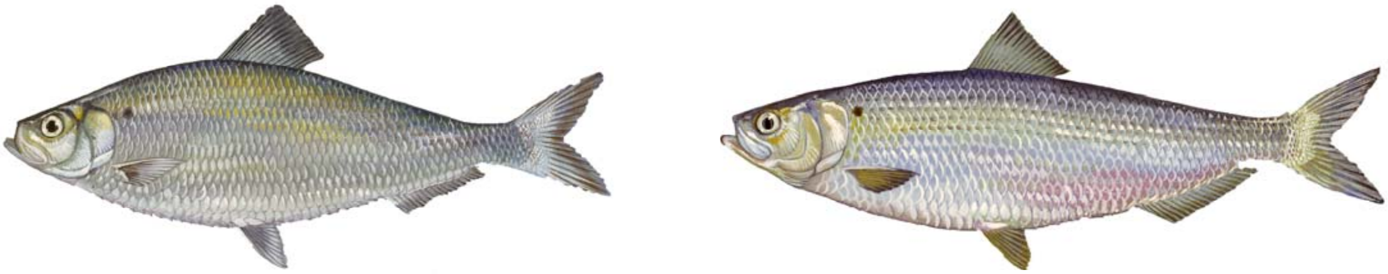
RIVER HERRING EXTINCTION RISK ANALYSIS WORKING GROUP REPORT

River Herring: Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*)



Alewife (left) and blueback herring (right) images courtesy U.S. Fish and Wildlife Service

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Working Group Members

John Sweka (USFWS), Michael Bailey (USFWS), Katie Drew (ASMFC), Matt Cieri (ME DMR), Gary Nelson (MA DMF), and Kiersten Curti (NEFSC)

NMFS Staff

Sarah Walsh Laporte (organizer), Kim Damon-Randall, Diane Borggaard, Tara Trinko Lake, Dan Kircheis, and Edith Carson (notetaker)

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Acronym List

AAL	Age at Length
ASMFC	Atlantic States Marine Fisheries Commission
CAA	Catch at Age
CAN	Canada
CAR	Carolina
ChesFIMS	Chesapeake Bay Fishery-Independent Multispecies Survey
ChesMMAP	Chesapeake Bay Multispecies Monitoring and Assessment Program
CI	Confidence Interval
CPUE	Catch Per Unit Effort
DBSRA	Depletion Based Stock Reduction Analysis
DFO	Division of Fisheries and Oceans Canada
DPS	Distinct Population Segment
ERA	Extinction Risk Analysis
ESA	Endangered Species Act
ft	feet
GSO	graduate school oceanography
km	kilometer
LIS	Long Island Sound
LIS/MAB	Long Island Sound/Mid-Atlantic Bight
MA DMF	Massachusetts Division of Marine Fisheries
MARSS	Multivariate Auto-Regressive State Space
MAB	Mid-Atlantic Bight
ME DMR	Maine Division of Marine Resources
NEAMAP	Northeast Area Monitoring and Assessment Program
NEFSC	Northeast Fisheries Science Center
NMFS	National Marine Fisheries Service
NNE	Northern New England
NRDC	Natural Resources Defense Council
P(E)	Probability of Extinction
PVA	Population Viability Analysis
SAT	Southern Atlantic
SCAA	Statistical Catch at Age
SNE	Southern New England
URI	University of Rhode Island
USFWS	U.S. Fish and Wildlife Service
YOY	young-of-year

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Introduction

On August 5, 2011, NOAA's National Marine Fisheries Service (NMFS), received a petition from the Natural Resources Defense Council (NRDC), requesting that we list alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) each as threatened throughout all or a significant portion of their range under the Endangered Species Act (ESA). In the alternative, they requested that NMFS designate distinct population segments (DPS) of alewife and blueback herring as specified in the petition (Central New England, Long Island Sound, Chesapeake Bay and Carolina for alewives, and Central New England, Long Island Sound, and Chesapeake Bay for blueback herring). The petition contained information on the two species, including taxonomy, historical and current distribution, physical and biological characteristics of its habitat and ecosystem relationships, population status and trends, and factors contributing to the species' decline. The petition also included information regarding the possible DPSs of alewife and blueback herring as described above. The petition also addressed the five factors identified in section 4(a)(1) of the ESA: (1) present or threatened destruction, modification, or curtailment of its habitat or range; (2) overutilization for commercial, recreational, scientific, or educational purposes; (3) disease or predation; (4) inadequacy of existing regulatory mechanisms; and (5) other natural or man-made factors affecting its continued existence.

NMFS reviewed the petition and the information in the Agency's files at the time the petition was received and published a positive 90-day finding on November 2, 2011. In the 90-day finding, NMFS indicated that it had determined that the information in the petition and readily available in the Agency's files indicated that the petitioned action may be warranted. As a result of the positive finding, NMFS is required to review the status of the species to determine if listing under the ESA is warranted.

The Atlantic States Marine Fisheries Commission (ASMFC) completed a stock assessment for river herring in May 2012, covering over 50 river specific stocks throughout the U.S. range of both species (ASMFC 2012). This represented a significant, multi-year effort on behalf of the ASMFC and the coastal states from Maine to Florida to gather all of the available information on river herring in the United States. NMFS recognized this extensive effort and, working cooperatively with the Commission, is utilizing this information in the review of the status of these two species. Because the stock assessment did not contain all elements necessary for making a listing determination under the ESA, NMFS identified the missing required elements and held public workshops and working group meetings of invited experts focusing on addressing this additional information. The three workshops/working group meetings addressed alewife and blueback herring stock structure, extinction risk analysis (ERA), and climate change. NMFS compiled reports from each workshop and working group meeting to determine which extinction risk method and stock structure analysis would best inform the listing determination. These reports do not contain any consensus advice regarding whether listing is warranted and do not include any ESA listing conclusions – such synthesis and analysis is solely within the Agency's purview. NMFS will use these reports along with the ASMFC river herring stock assessment to develop a listing determination.

Background

Alewife and blueback herring are collectively referred to as "river herring." Due to difficulties in distinguishing between the species, they are often harvested together in commercial and recreational fisheries and managed together by the ASMFC. Throughout this report, where there are similarities, they will be collectively referred to as river herring, and where there are distinctions they will be identified by species.

River herring are found along the Atlantic coast of North America, from the maritime provinces of Canada to the southeastern United States (Mullen *et al*., 1986; Shultz *et al*., 2009). The coastal ranges of the two species overlap, with blueback herring found in a greater and more southerly distribution ranging from Nova Scotia down to the St. John's River, Florida; and alewife found in a more northerly distribution, from Labrador and Newfoundland to as far south as South Carolina, though the extreme southern range is a less common occurrence (Collette and Klein-MacPhee, 2002; ASMFC, 2009a; Kocik *et al*., 2009). Adults are most often found at depths less than 100 m (328 ft) in waters along the continental shelf (Neves, 1981; ASMFC, 2009a; Shultz *et al*., 2009).

River herring are anadromous, meaning that they migrate up coastal rivers in the spring from the marine environment, to estuarine and freshwater rivers, ponds, and lake habitats to spawn (Collette and Klein-MacPhee, 2002; ASMFC, 2009a; Kocik *et al*., 2009). They are highly migratory, pelagic, schooling species, with seasonal spawning migrations that are cued by water temperature (Collette and Klein-MacPhee, 2002; Schultz, 2009). Depending upon temperature, blueback herring typically spawn from late March through mid-May. However, they have been documented spawning in the southern parts of their range as early as December or January, and as late as August in the northern range (ASMFC, 2009a). Alewives generally migrate earlier than other alosine fishes, but they have been documented spawning as early as February to June in the southern portion of their range, and as late as August in the northern portion of the range (ASMFC, 2009a). Alosines, including river herring, are believed to conform to a metapopulation paradigm with adults frequently returning to their natal rivers for spawning, with some limited straying occurring between rivers (Jones 2006, ASMFC, 2009a).

Throughout their life cycle, river herring use many different habitats ranging from the ocean, up through estuaries and rivers, to freshwater lakes and ponds. The substrate preferred for spawning varies greatly and can include substrates consisting of gravel, detritus, and submerged aquatic vegetation. Blueback herring prefer swifter moving waters than alewife (ASMFC, 2009a). Nursery areas can include freshwater and semi-brackish waters; however, little is known about their habitat preference in the marine environment (Meadows, 2008; ASMFC, 2009a).

Stock Structure Overview

To obtain expert opinions about anadromous alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) stock structure, NMFS convened a working group in Gloucester, MA, on June 20-21, 2012. This working group meeting brought together river herring experts from state and federal fisheries management agencies and academic institutions. Participants presented information to suggest the presence or absence of stock structure such as genetics, life history, and morphometrics. The discussion of the working group was presented at a public workshop on June 22, 2012, and information on stock structure was sought from the general public at this workshop.

While no consensus was sought or reached at the working group meeting, experts provided their individual opinions regarding stock structure of alewife and blueback herring based on the discussions from the meeting. All of the expert opinions received by NMFS suggested that evidence of regional stock structure (~100 km scale) exists for both alewife and blueback herring as shown by the recent genetics data (Palkovacs et al., unpublished data; Willis, unpublished data). However, the exact boundaries of the regional stocks differed from expert to expert. Whether alewives and blueback herring in the ocean migrate and mix with other regional stocks could not be determined; therefore, the ocean phase of alewives and blueback herring is considered a mixed stock until further tagging and genetic data are available.

NMFS has not yet determined if one or more DPSs exist for alewives and blueback herring. NMFS will use the information from these workshops to assess whether there are discrete and significant populations of alewives or blueback herring that might warrant separate protections under the joint US Fish and Wildlife Service and NMFS DPS policy (61 FR 4722). Upon applying the DPS policy, the evidence gathered at the stock structure workshop will help NMFS to make an informed decision on whether the stock structure can adequately be protected as a single unit or, whether one or more DPSs are necessary to best protect certain stock complexes of alewives or blueback herring that represent a discrete and significant unit to the taxon as a whole. In order to proceed with the extinction risk modeling effort, NMFS tasked the ERA team with assessing extinction risk for each species as detailed in Figure 1 for alewife and Figure 2 for blueback herring.

Figure 1. Hypotheses 1 and 2 for the extinction risk analysis working group to assess as potential stock structure of alewife in U.S. and Canadian waters.

Stock Structure of Alewife

Hypothesis 1:
One continuous stock complex throughout the entire range, from U.S. to Canada

Hypothesis 2:
Six stock complexes

- Carolina (all alewife rivers south of, and including the Chowan River)
- Mid-Atlantic (Rappahannock to Hudson River)
- Long Island Sound (Byram River to Pawcatuck River)
- Southern New England (Gilbert-Stewart to Mystic River)
- Northern New England (Lamprey to East Machias)
- Canada (all Canadian Rivers)

Figure 2. Hypotheses 1 and 2 for the extinction risk analysis working group to assess as potential stock structure of blueback herring in U.S. and Canadian waters.

Stock Structure of Blueback Herring

Hypothesis 1:
One continuous stock complex throughout the entire range from US to Canada

Hypothesis 2:
Five stock complexes

- Southern (St. John River to Cape Fear River)
- Mid-Atlantic (Neuse River to Connecticut River)
- Southern New England (Gilbert-Stewart to Mystic River)
- Northern New England (Exeter River to East Machias River)
- Canada (all Canadian Rivers)

NMFS may combine one or more stock complexes into a single DPS or multiple DPSs in the ESA listing determination. Therefore, NMFS asked, if possible, that the extinction risk analyses or projections calculated for Hypothesis 2 for both species allow for the possibility of combining results from stock complexes in the future.

Extinction Risk Analysis Workshop

To obtain expert opinions about anadromous alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) extinction risk, NMFS convened a workshop in Boston, MA, on July 10, 2012. This workshop was open to the public and brought together river herring experts from state and federal fisheries management agencies. Participants presented information on the river herring petition and ESA consideration process, an overview of the stock structure discussions, information on the ASMFC stock assessment, available data and models, as well as various ERA methodologies for other species that have been employed in the past. Panel presentations consisted of potential models that the panel would consider and discuss during the working group meeting. Information on river herring extinction risk was also sought from the public during this workshop through a public contribution session held at the end of the day. The contribution period was extended for a week after the workshop to allow for electronic submissions.

The first panel presentation was given by Dr. John Sweka of the U.S. Fish and Wildlife Service. He discussed the possibility of using a population viability analysis (PVA), more specifically, a diffusion approximation method of a PVA for river herring. PVAs can be used to predict the probability of a population persisting into the future or the probability of falling below some threshold (quasi-extinction), and there are many methods through which these models can be run, ranging from highly complex (i.e., Atlantic salmon in Legault, 2005) to more simple extrapolating trends (i.e., diffusion approximation as with Dennis *et al*., 1991). Working from the simpler method of diffusion approximation, improved methods were discussed which allowed for better estimates of population growth (µ) by accounting for life history and year class effects using a running sum method (Holmes, 2001 and 2004; Holmes and Fagan, 2002; McClure *et al*., 2003).

Detailing a running sum method (see Figure 3.), John Sweka described how this method takes the slope of the variance of running sums versus time lag. Given that it may take 3-5 years for a river herring to return to the river to spawn, the time series should, at minimum, be 5 years.

Figure 3. Formula for the running sum method (from Holmes, 2001).

$$R_t = \sum_{j=1}^{\tau} S_{t+j-1}$$

$$\hat{\mu} = mean[ln(R_{t+1}/R_t)]$$

$$\sigma^2{}_{\hat{\mu}} = slope\ of\ var\left[ln\left(\frac{R_{t+\tau}}{R_t}\right)\right]\ vs.\ \tau$$

$$\tau = 1, 2, 3, 4, 5, \ldots n$$

R_t = running sum in year t
S_t = adult returns in year t
$\hat{\mu}$ = mean growth rate
$\sigma^2{}_{\hat{\mu}}$ = variance
τ = time lag

In order to determine a probability of extinction (P(E)) analytically using the Dennis *et al*. (1991) method, a quasi-extinction threshold (TS_e) is input (see Figure 4). If the variance on the population growth rate is increased or the time period is extended out further, then the P(E) will likely be higher.

Figure 4. Formula for determining the probability of extinction (from Dennis et al., 1991).

$$P(E) = \pi\Phi\left[\frac{-ln(TS_0/TS_e) + |\hat{\mu}|t_e}{\hat{\sigma}\sqrt{t_e}}\right]$$

$$+exp\left[\frac{2ln(TS_0/TS_e)|\hat{\mu}|}{\hat{\sigma}^2}\right]$$

$$\times\Phi\left[\frac{-ln(TS_0/TS_e) - |\hat{\mu}|t_e}{\hat{\sigma}\sqrt{t_e}}\right]$$

$$\pi = \begin{cases} 1, & \hat{\mu} \le 0 \\ exp[-2\mu\, ln\,(TS_0/TS_e)/\hat{\sigma}^2], & \hat{\mu} > 0 \end{cases}$$

$TS_0 = initial\ number\ of\ returns$

$TS_e = extinction\ treshold$

$t_e = time\ to\ extinction$

$\Phi = standard\ normal\ cdf$

Bootstrapping can be used to estimate the sampling distribution of a parameter, and construct confidence intervals (CI) to portray the precision of parameter estimates. Confidence intervals (CI) can be used to indicate the reliability of an estimate. Bootstrapping with a 90% CI for P(E) can be described by the formula in Figure 5.

Figure 5. Formula for determining the distribution used to calculate P(E) (from Dennis et al., 1991).

Distribution used to calculate P(E): $\hat{\mu} + \sqrt{\hat{\sigma}^2/(n-5)} \times t_{df}$

$n = number\ of\ years\ used\ in\ the\ calulation\ of\ \hat{\mu}$

$t_{df} = t\ distributed\ random\ variable\ with\ df\ degrees\ of\ freedom$

$\hat{\sigma}^2 = chi\ square\ distributed\ with\ df\ degrees\ of\ freedom\ \times \hat{\sigma}^2/df$

$df \approx 0.33 + 0.212n - 0.387T$

Given that absolute population estimates are not available for all species and stocks, index data can also be used to evaluate the probability of extinction. In particular, index data can be used to determine the probability that a population index will exhibit a specific percentage decline over a given timeframe, for example a 90% decline (Figure 6).

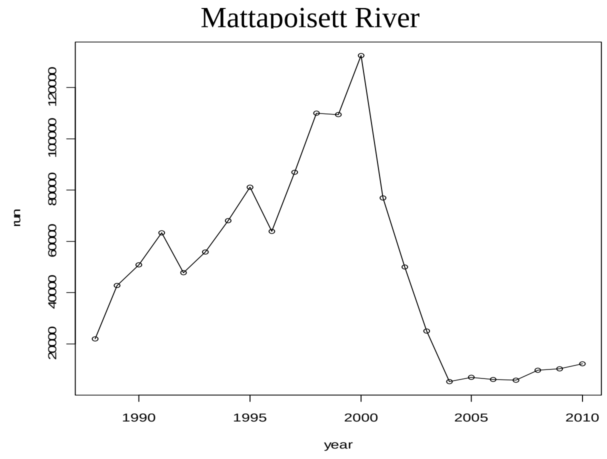
Figure 6. Formula for determining the probability of a specific percentage decline (90%) in the population over a given time period (from Dennis et al., 1991).

$$P\left(\frac{TS_{t_e}}{TS_0} < \frac{10}{1}\right) = 1 - \Phi\left[\frac{ln(10/1) + \hat{\mu}t_e}{\hat{\sigma}\sqrt{t_e}}\right]$$

$TS_0 = initial\ number\ of\ returns$
$TS_e = extinction\ treshold$
$t_e = time\ to\ extinction$
$\Phi = standard\ normal\ cdf$

In discussions on applying these methods to river herring, Dr. Sweka detailed available data, time series and areas covered, stating that run count time series could be used where available and that approximately 20 time series contained 10 years of data or more. However, he also noted that the majority of these run count data are only available for the New England region, and that few run counts are available south of the Connecticut River. Dr. Sweka also noted that the choice of which years to include in a diffusion approximation PVA can strongly affect model conclusions. The impact of year choice on model conclusions was illustrated using run counts from the Mattapoisett River (Figure 7). In this example, the estimated population trend is positive when the entire time series is utilized; however, the trend is negative when only the last 10 years of the time series is utilized.

Figure 7. Run count estimates from 1988 to 2010 for alewife in the Mattapoisett River showing a positive population trend across the entire series, but a negative population trend when only including data from 2000 to 2010.



Population Trend by Time Series

$\hat{\mu} = 0.032$ including $1988 - 2010$

$\hat{\mu} = -0.242$ including $2000 - 2010$

Following Dr. Sweka's presentation, Dr. Kiersten Curti of the Northeast Fisheries Science Center presented on the Multivariate Auto-Regressive State Space (MARSS) package in R. This package provides a method for fitting linear MARSS models to multivariate time-series data. This modeling package assumes density-independence and Gaussian errors; however, it can also account for both process and observation error. Process and observation error terms represent the uncertainty in model structure and observed measurements, respectively. The likelihood function used to estimate model parameters uses output from the Kalman filter, which assumes that the expected abundance at time (*t*) is conditioned on the abundances of all prior years. The MARSS package incorporates both state and observational models (Figure 8).

Figure 8. General form of the state and observation models comprising a MARSS model.

State Model:

$$\boldsymbol{x}_t = \boldsymbol{B}\boldsymbol{x}_{t-1} + \boldsymbol{u} + \boldsymbol{w}_t \text{ where } \boldsymbol{w}_t \sim \text{MVN}(0, \boldsymbol{Q})$$

$$\boldsymbol{x}_0 \sim \text{MVN}(\pi, \Lambda)$$

Observational Model:

$$\boldsymbol{y}_t = \boldsymbol{Z}\boldsymbol{x}_t + \boldsymbol{a} + \boldsymbol{v}_t \text{ where } \boldsymbol{v}_t \sim \text{MVN}(0, \boldsymbol{R})$$

The MARSS package has the ability to model multiple hidden states (e.g. different populations), and estimated parameters include the initial abundances for each hidden state as well as the interactions between the hidden states. Multiple abundance indices can be incorporated into the observation model; these time series can correspond to one or more hidden states. Using time series of population indices such as run counts and relative abundances from fishery-independent surveys, growth rates, process errors and observations errors can be estimated. Using the Dennis *et al*. (1991) method, the probability of extinction can also be estimated.

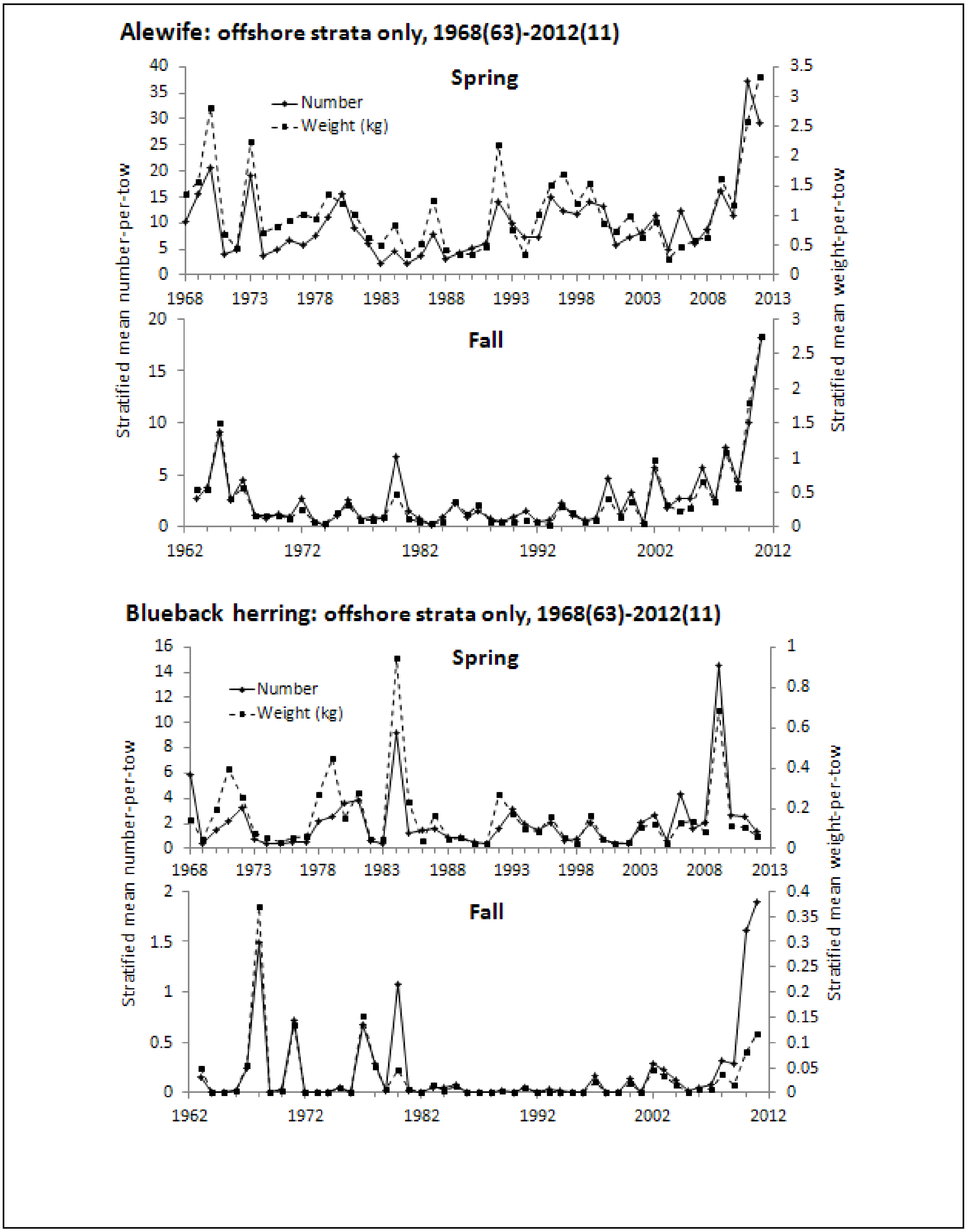
Dr. Curti also discussed potential data inputs, and recommended that the NMFS Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl survey indices should be used for coastwide applications. For the stock complex applications (hypothesis 2), run counts, where available, and regional fishery-independent surveys would be potentially useful data inputs.

The NEFSC bottom trawl survey is the only coastwide index available for river herring, has been consistently sampled for over 35 years, and has been used for many species stock assessments. Dr. Curti addressed the potential drawbacks of using the NEFSC trawl survey as a measure of relative abundance for river herring, and also detailed reasons why these drawbacks were not sufficient to omit the dataset from extinction risk analyses. In particular, the survey uses a bottom otter trawl, which may not be the best method for catching pelagic species like river herring. However, since river herring exhibit diel migrations, only those tows conducted during the day were used to quantify relative abundance because catchability is greatest during the day when river herring are distributed lower in the water column.

Another potential drawback is that the survey does not sample the entire range of both species, leaving out the southern portion of the coast south of North Carolina. However, the trawl survey is regularly used in peer-reviewed stock assessments for several other species whose ranges extend beyond the survey area, including Atlantic mackerel, spiny dogfish, butterfish, northern shortfin squid, and inshore longfin squid. The bottom trawl survey also did not show the decline in the 1990's that was seen in several run counts; however, during this time, run counts in some rivers were increasing while others were decreasing; thus, the coastwide trend is potentially depicting an average of river-specific run counts. Finally, NEFSC trawl survey data used in the river herring stock assessment began in 1975, which is after the time period of high landings and significant decline in abundance in the late 1960's and early 1970's (ASMFC 2012). The stock assessment used a time series beginning in 1975 because 1975 was the first year when the inshore strata were consistently sampled. However, the time series can be extended back to 1968 for the spring survey and 1963 for the fall survey by incorporating only offshore strata in the analysis. Extending the time series back to the 1960's captured a decline in relative abundance during the late 1960's and early 1970's (Figure 9).

The NEFSC bottom trawl survey indices for alewife in the 1970s and 1980s show that the population was in a low state; however, more recent trends (2008 through the present) have been increasing. Blueback herring are caught in lower abundances than alewife in the NEFSC bottom trawl survey, but this difference could be due to the timing of the survey in comparison to the timing of their seasonal migrations.

Figure 9. Spring and Fall stratified mean number and weight per tow for alewife and blueback herring from 1968(63) to 2012(11).



Dr. Gary Nelson of the Massachusetts Division of Marine Fisheries (MA DMF) concluded the panel presentations and discussed a few methods that are similar to the published approaches presented by the other panel members. He noted that the available data on run sizes are limited and not adequate for a full analysis; however, given that the population can potentially be projected into the future, the probability of the population falling below a certain threshold can be estimated.

Using a linear regression (see Figure 10), a line can be fit to the data comprising (*x*) years (e.g. a selected number of years from a time series). Based on this line fit, the population can be projected forward a specific number of years, applying error to the estimate. The probability that the population will fall below a certain threshold over a specific timeframe can then be calculated. The time series window is sequentially moved one year ahead, and with each new window, the equation is refitted to the new time series of data, the population is projected forward in time, and the probability of falling below a threshold value is calculated (see Figure 11).

Figure 10. Example of a linear regression showing line fit for run counts for the Monument River (MA) alewife population for 5 years over the time series.

Fit Equation

($ln(Nt)=ln(N0)+ln(R)*t$) to data for 5 years

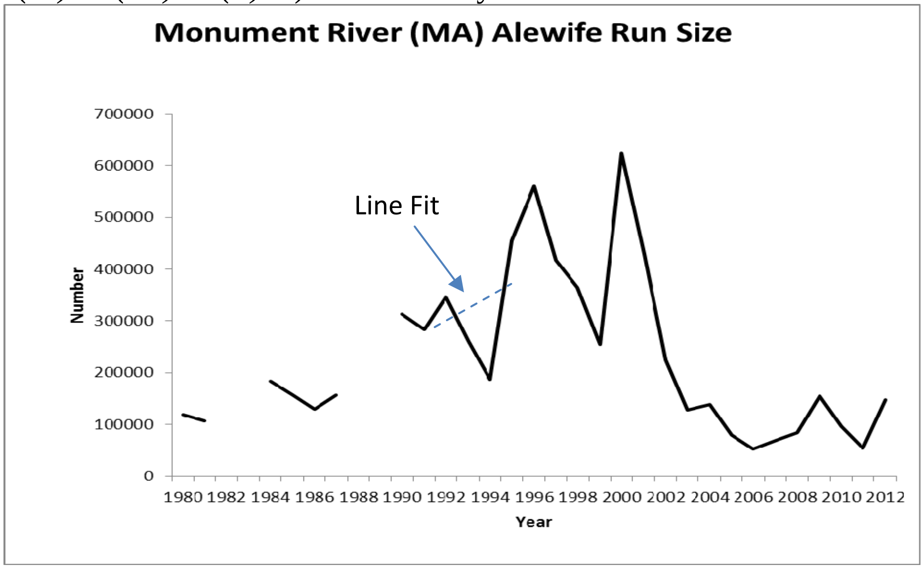
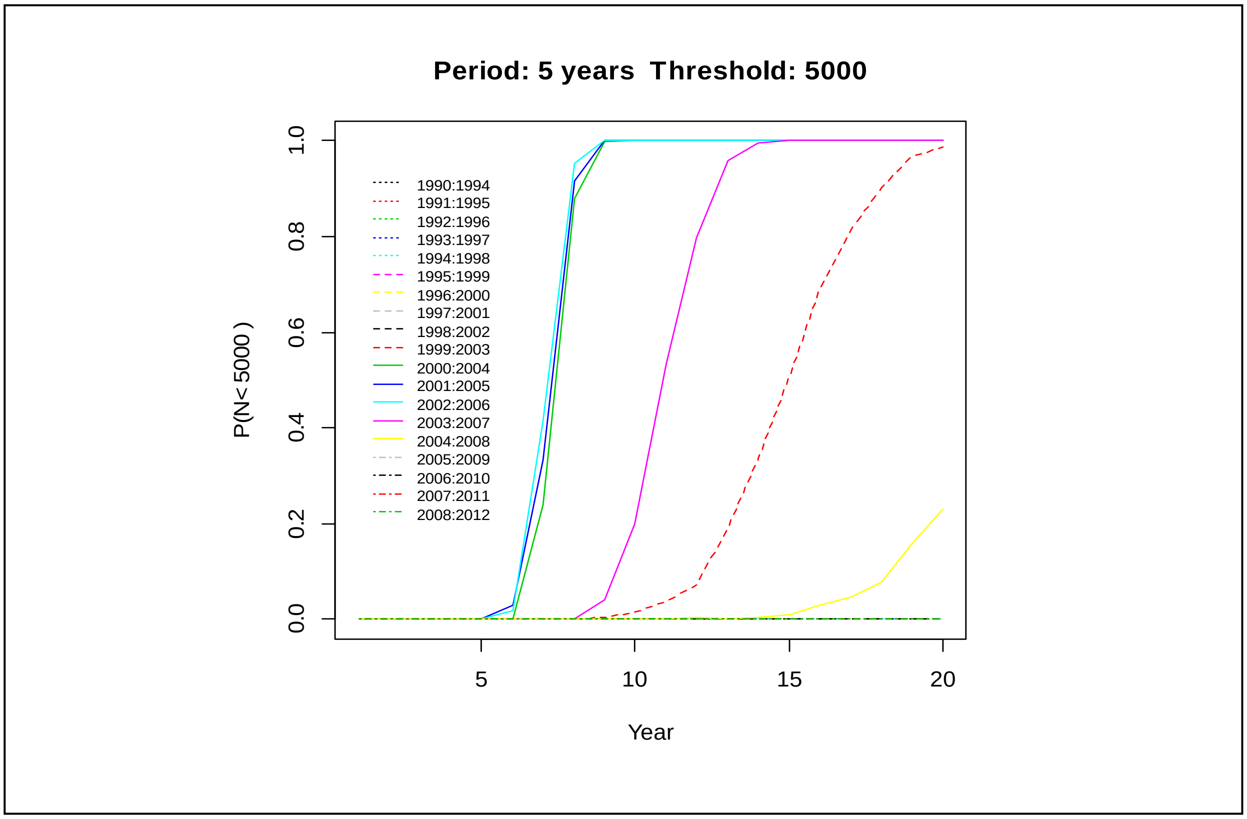
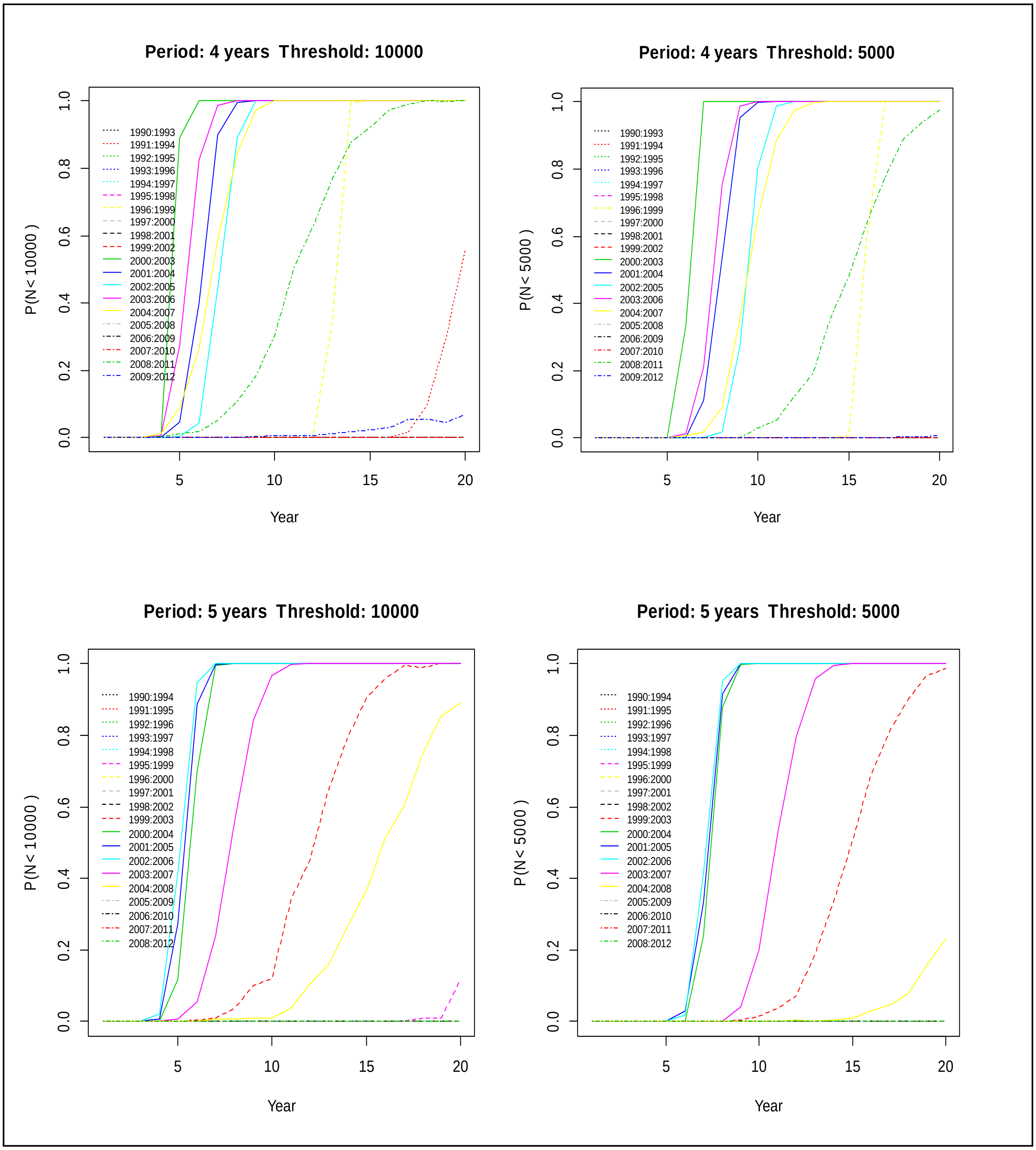


Figure 11. Example of 5-year forward projections estimating the probability that the Monument River (MA) alewife population will fall below a threshold of 5,000 fish..



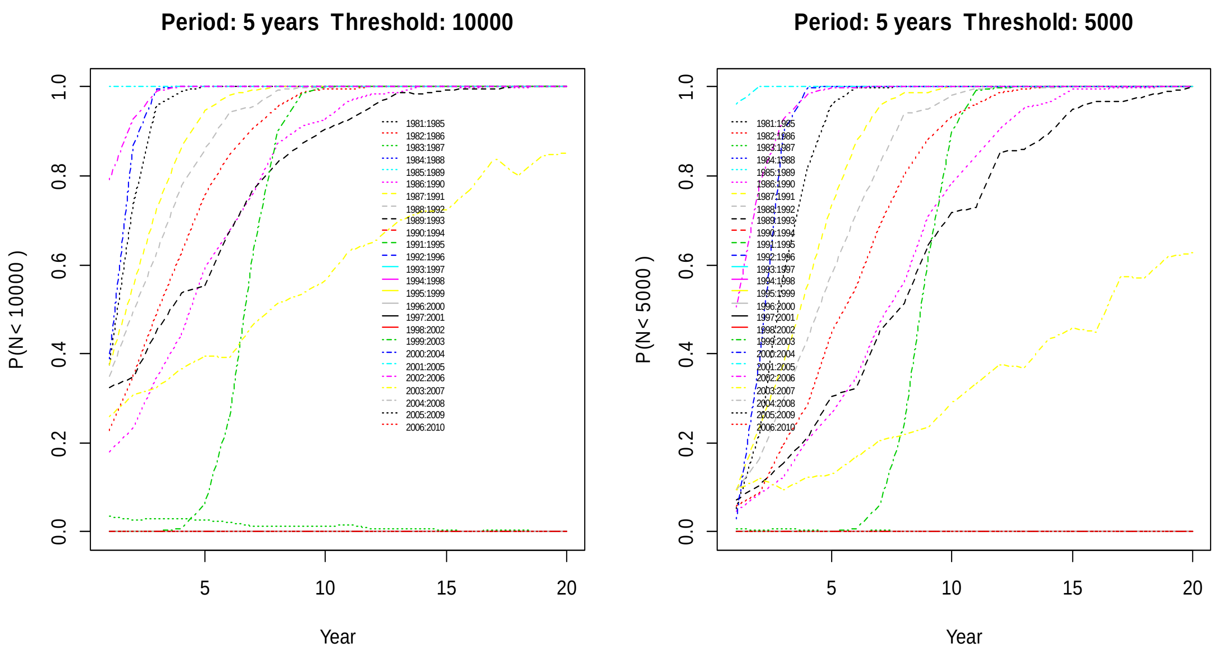
When this model was applied to the Monument River alewife run size data, the model showed a rapid decline in the population following the year 2000 (using a time window of 4 years); however, the model showed the trend flattening out with the 5 year time series, meaning that run would not likely go below 10,000 fish, indicating that there is less variation with the 5 year timeframe (Figure 12).

Figure 12. Example of a model using the line fit to project a population forward (4 years and 5 years) and calculate the probability of a population going below a certain threshold (10,000 or 5,000 fish) for the Monument River (MA) alewife population.



This same methodology was employed for the alewife run data in the Gilbert-Stuart River in RI and showed a similar pattern to the Monument River (see Figure 13). Following the same methodology, examples were run with the blueback herring populations from the Connecticut and Chowan Rivers, showing similar patterns of decline in the more recent years of the time series.

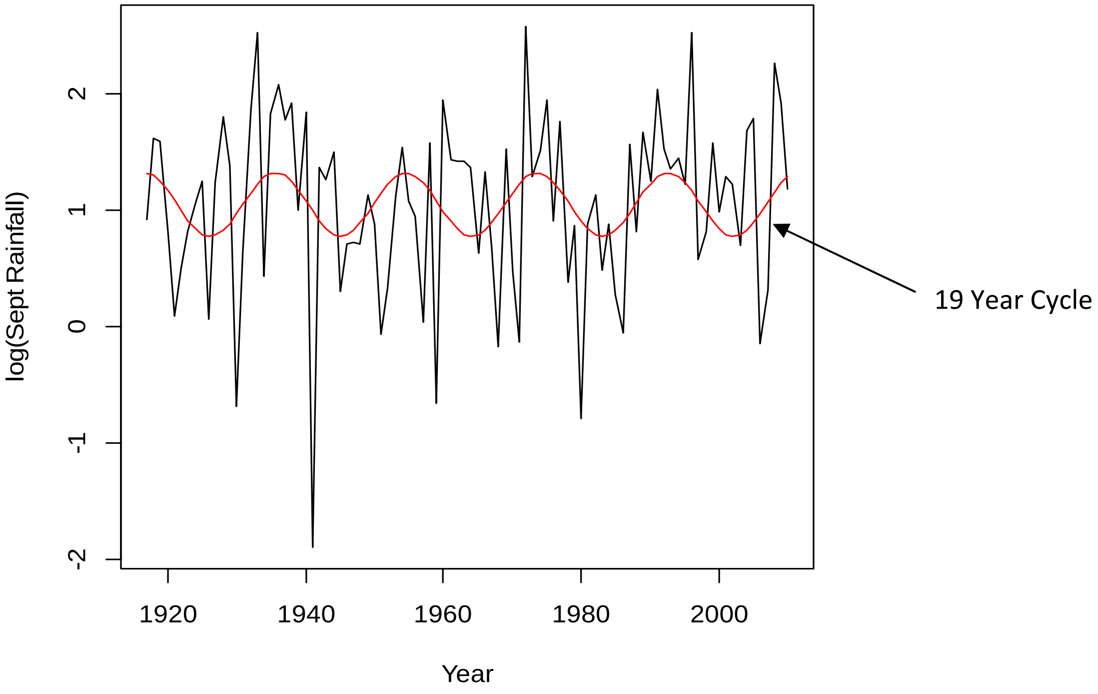
Figure 13. Example of a model using the line fit to project a population forward (5 years) and calculate the probability of a population going below a certain threshold (10,000 or 5,000 fish) for the Gilbert-Stuart River (RI) alewife population.



In addition to this method, Dr. Nelson presented on a model from Deriso *et al*. (2008) which can determine if environmental variables may explain variation in recruitment in the stock assessment model. If it is determined that environmental variables are significant, then these variables may be analyzed for time trends and can potentially be projected forward to account for climate change estimations (see Figure 14).

Figure 14. Example of the Deriso et al. model and the temporal trend in September rainfall.

$$\hat{R}_y = \hat{R}_0 \cdot e^{\left(\sum_{i=1}^{n} \hat{\beta}_i X_{i,y} + \hat{\varepsilon}_y - 0.5\hat{\sigma}^2\right)}$$



This equation allows for estimating how many fish recruit to populate the species, and covariate terms can be incorporated into these models. Using this information, the population can be projected forward a specific number of years using error in starting abundance estimates, as well as incorporating error and projected environmental variation into the stock recruitment equation.

Extinction Risk Analysis Working Group Discussions

Following the Extinction Risk Analysis Workshop, NMFS held an Extinction Risk Analysis Working Group meeting on July 11-12, 2012. The working group consisted of the invited panel participants including Dr. John Sweka (USFWS), Dr, Michael Bailey (USFWS), Dr, Gary Nelson (MA DMF), Dr, Katie Drew (ASMFC), Dr. Matt Cieri (ME DMR), and Dr. Kiersten Curti (NEFSC), as well as NMFS Protected Resources Division representatives working on the ESA consideration process including Sarah Walsh Laporte (organizer), Kim Damon-Randall, Diane Borggaard, Tara Trinko Lake, Dan Kircheis, and Edith Carson (notetaker).

The basic goal of the working group meeting was to gather data and information from experts on population dynamics and population modeling to help NMFS make an informed decision on models and data to use for an extinction risk analysis for alewife and blueback herring. Each invited participant presented their individual expert opinion on the potential data inputs and models to be used for the river herring ERA. These expert opinions were collected by NMFS and summarized in this report. The decision on the data and models to be used for the ERA, as well as the status determination from those data, will be made by NMFS in the listing determination for both species.

As mentioned previously, NMFS has not made a determination as to whether DPSs of alewife and blueback herring exist; however, for the purpose of the ERA, NMFS requested that the ERA working group assess alewife and blueback herring under two potential stock structure hypotheses that were considered by the stock structure working group: 1) each as one stock complex throughout their range, and 2) six stock complexes for alewife and five stock complexes for blueback herring based on genetic differentiation.

Discussions on Available Data

The working group discussed all of the available data for each hypothesis for both species and the working group discussions are detailed in this section. The available data that was determined appropriate for use with different models and methods is detailed in the ‘Modeling Discussions’ and ‘Model Inputs and Assumptions’ sections further in the report.

It was determined that for alewife rangewide, available data included the NEFSC bottom trawl surveys, NMFS shrimp bottom trawl survey, several coastal fishery-independent surveys, and the Division of Fisheries and Oceans Canada (DFO) trawl surveys. For the NEFSC bottom trawl surveys, indices incorporating only offshore strata extend from 1968 to current for the spring, and 1963 to current for the fall; indices incorporating both inshore and offshore strata extend from 1975 to current for the fall, 1976 to current for the spring. The winter survey began in 1992 and was conducted through 2007. The NMFS shrimp bottom trawl survey began in 1983, samples the Gulf of Maine during the summer, and was considered to be an important component of the recent Atlantic herring stock assessment, which is a similar pelagic schooling species; therefore, may also provide useful information for river herring. Available coastal fishery-independent surveys included the Northeast Area Monitoring and Assessment Program (NEAMAP, 2007-2012), New Jersey ocean trawl survey (beginning in 1989), the Rhode Island combined coastal trawl survey (beginning in 1979), young-of-year (YOY) indices (from ME to NC seine surveys), and Z estimates (trends from ASMFC, 2012). DFO trawl survey data included the DFO summer research vessel series from the Scotian Shelf/Bay of Fundy from 1970 to 2011 and the DFO Georges Bank survey series from Georges Bank and the Northeast Peak to the Great South Channel from 1987 to 2012.

The working group discussed utility surveys (e.g., Hudson River utility surveys) and run data for the rangewide analysis, but indicated that the methodology of the utility surveys prevented their use and incorporation in the extinction risk models. Furthermore, the only run data available south of CT is in SC, and therefore, does not cover the coastwide range.

Discussions within the group indicated that the available data for blueback herring rangewide included the same data sets available for alewife rangewide.

The working group discussed the six individual stock complexes for alewives identified in Hypothesis 2, as well as available datasets. The working group further reviewed the genetic data to ensure that there were no gaps in the stock complex delineations for both species, and that the boundaries were clearly defined. The description of the six genetically unique stock complexes for alewives was refined to include: Canada – CAN (all Canadian waters combined), Northern New England – NNE (ME through NH waters, including the St. Croix River), Southern New England – SNE (MA through RI waters; note revised stock complex description below), Long Island Sound – LIS (all CT waters), Mid-Atlantic Bight – MAB (NY through VA waters; note revised stock complex description below), and Carolina – CAR (NC waters). However, on August 13, 2012, further genetic analysis became available (E. Palcovaks, Pers. comm.) suggesting that NY and CT waters should be included in the SNE stock complex, and that the MAB stock complex should include NJ through VA waters. The updated stock structure boundaries for alewives came from additional analyses that were conducted with the alewife dataset. Hybrids and misidentified samples were found and subsequently removed for this analysis, which found that, for alewife, the Connecticut and Hudson Rivers belong to the SNE stock complex. This new information decreases the number of alewife stock complexes from six to five. Therefore, hereafter in the report, SNE will represent the stock complex including MA through NY waters, and the MAB will represent the stock complex comprised of NJ through VA waters.

Available data for CAN alewife (also called gaspereau in Canada) were discussed and a few assessments were noted, including the Gaspereau River assessments (DFO, 2001 and 2007), Margaree River assessment (DFO, 1997 and 2001), Maritime province's assessments (DFO, 2001), technical report on the Mactaquac, Gaspereau, Margaree, and Miramichi Rivers (Gibson and Myers, 2003a), World Shad Symposium book (2003) and Prince Edward Island assessments (DFO, 1997). The working group discussed additional Canadian data, including a meta-analysis of habitat carrying capacity and maximum reproductive rate (Gibson and Myers, 2003b), as well as other survey data from DFO trawls (including the DFO summer RV series from the Scotian Shelf/Bay of Fundy from 1970 to 2011 and the DFO Georges Bank survey series from Georges Bank and the Northeast Peak to the Great South Channel from 1987 to 2012).

The group discussed available data for NNE alewife and determined that available data included run counts throughout ME and NH, and young-of-year (YOY) indices for ME. The near-shore trawl surveys were discussed for NNE alewife, but given that these trawls may be catching alewives from a different stock complex, these indices were not considered to be appropriate for use in the ERA. Additionally, the ASMFC river herring stock assessment sub-committee did not find any correlation between river run counts and near-shore trawl surveys (ASMFC 2012).

For SNE alewife, available datasets include run counts throughout MA and RI, a YOY index for RI, the Narragansett Bay seine survey as well as a University of Rhode Island Graduate School of Oceanography (GSO) trawl survey. In addition, statistical catch at age (SCAA) models used in the ASMFC stock assessment (e.g., SCAA for the Monument River, MA) were suggested as a possibility to include for outputs for projections (ASMFC, 2012). YOY indices for CT as well as run counts for the area (e.g., the Holyoke Dam run count) were also identified; however, caveats should be noted with these run counts as the available time series is short, and some series are not species specific. Using the Holyoke Dam run count was considered to be questionable given its location far up the river and that spawning could occur below the dam. Additionally, this run primarily consists of blueback herring and was not considered to be a reliable data set for alewife. In addition, YOY surveys for NY were also identified.

For MAB alewife, datasets include YOY surveys for NJ, MD, D.C., and VA, adult and juvenile trawl surveys in the Delaware River/Bay, SCAA for the Nanticoke River in Maryland, as well as the Virginia Institute of Marine Science (VIMS) trawl survey, and the bridge tow work performed by Dr. Ken Able with zooplankton nets catching outmigrating juveniles. In addition, the Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) and the Chesapeake Bay Fishery-Independent Multispecies Survey (ChesFIMS) were identified as additional sources of data; however, it was noted that ChesFIMS is a short time series.

The CAR alewife available data included bridge tow work, the Albemarle Sound YOY seine survey, NC independent gillnet surveys and electrofishing surveys, the SCAA for the Chowan River in NC and abundance estimates from a North Carolina stock assessment model. The bridge tow work was discussed further, and given that YOY indices are abundant and this data set would primarily consist of YOY indices, it was determined that the data set would be duplicative.

The working group discussed the five individual stock complexes of blueback herring identified in Hypothesis 2 as well as available datasets. The five stock complexes include: Canada – CAN (all Canadian waters), Northern New England – NNE (ME through NH waters, including the St. Croix River), Southern New England – SNE (MA through RI waters), Long Island Sound/Mid-Atlantic – LIS/MAB (CT waters to the Neuse-Pamlico System, NC), and Southern Atlantic– SAT (Cape Fear River, NC to St. Johns River, FL). Discussions on the delineations for the individual stock complexes were discussed and detailed above.

Available data for CAN blueback herring included survey data from DFO trawls (including the DFO summer RV series from the Scotian Shelf/Bay of Fundy from 1970 to 2011 and the DFO Georges Bank survey series from Georges Bank and the Northeast Peak to the Great South Channel from 1987 to 2012), as well as other DFO river assessments; however, the assessments have caveats surrounding them, given that the survey is only conducted through June 15th, when blueback herring would not be thought to be present in the rivers systems, due to a later spawning period. Blueback herring in Canada are less abundant than alewives, occurring in fewer CAN rivers. However, in some rivers, blueback herring may account for greater than 25% of the river herring in a specific river, with some rivers showing blueback herring in greater numbers than alewives (DFO, 2001a). As mentioned above, the observed lower abundance of blueback herring in CAN rivers is thought to be directly related to the fishery closure in mid-June which causes a lower rate of blueback herring catch due to the later timing of the blueback herring spawning migrations (DFO, 2001a). For NNE blueback herring, available datasets include run counts, YOY seine survey (in ME only), the ME/NH trawl survey, and ME harvesters and ME Division of Marine Resources (DMR) samples. For run counts, discussions included the caveats that run counts could only be used from rivers where blueback herring are dominant and/or a few river counts in NH, given that blueback herring do not account for much of the river herring run counts in ME. The ME harvester and ME DMR sample information can be used to show species spawning and presence, but given the short time series, these data are not adequate to provide for a trend analysis. The ME/NH trawl survey is considered to include inshore and offshore strata, but the uncertainty regarding the origination of the sampled fish was also noted.

For SNE blueback herring, available datasets include run counts throughout MA and RI, YOY index (for RI only), the URI Graduate School of Oceanography (GSO) trawl survey, and the Narragansett Bay/Salt Pond seine survey. It was noted that the GSO trawl survey contains two stations, one at Fox Island and one at Whale Rock which is at the mouth of the Narragansett Bay. The working group discussed this survey as well as the other surveys in other regions (i.e., ChesFIMS, ChesMMAP) that may not be located entirely within the rivers or bays comprising a stock complex, and it was determined that a survey should only be used if stations are within a river or in close proximity to the mouth of the river. These criteria for using trawl surveys will be applied to both alewife and blueback herring datasets used for modeling the ERA of each stock complex. It was additionally suggested that if the station or location yields data that are consistent with the river or stock complex that it would be associated with, then this could help to reinforce the use of a survey from a location not within a river.

For LIS/MAB blueback herring, datasets include YOY surveys (for CT, NY, NJ, MD, D.C., and VA), run counts from CT rivers, trawl surveys in the Delaware River/Bay as well as the VIMS trawl surveys, the bridge tow work by Dr. Able, electrofishing surveys, the Albemarle Sound YOY survey, and model estimates of abundance for the Chowan River. In addition, ChesMMAP and ChesFIMS were identified as additional sources of data; however, it was noted that ChesFIMS is a short time series. It was also noted that the VIMS trawl survey was not used in the last assessment for eels because the raw data were not available; however, while the raw data were also not available for river herring, the index was considered to be valid and was used in the ASMFC stock assessment. The New Jersey ocean trawl survey was also discussed, and it was determined that as the sampling stations are located perpendicular to the coast, they would yield coastal mixed stock complex data, rather than data necessarily specific to the LIS/MAB blueback herring stock complex. As noted above, the working group discussed the bridge tow work and, given that YOY indices are abundant and this data set would primarily consist of YOY indices, determined that the data set would be duplicative.

For SAT blueback herring, the working group indicated that data are sparse for that area; however, the following data sets were considered: tagging data from 1980-1990, catch-per-unit-effort (CPUE) data from the Santee River, and minimum population size estimates based on run counts and harvest. Commercial CPUE could be analyzed to determine if there is any relationship with the tagging trends for SC, and though the tagging time series is 10 years, it is not very recent data. It was also noted that the minimum population size estimates for the Santee River were affected by fish passage efficiency. In years of heavy rainfall, the lift on the river passes a greater number of blueback herring than in dry years when the blueback herring tend to go up rivers without fish counters, indicating that year to year changes in population estimates are strongly affected by rainfall. In addition, the lift has not been maintained adequately and passage efficiency has most likely degraded over time. The commercial CPUE is less affected by fish passage issues, and fishing effort will switch between rivers to follow the river herring.

Modeling Discussions

Given the available data for both species rangewide as well as for the individual stock complexes, the working group discussed potential models for performing an ERA. Depletion-based stock reduction analysis (DBSRA), age-structured projection models, CPUE, MARSS models, and diffusion approximation were the main methods discussed as potential models to be used for the river herring ERA.

A DBSRA has been widely used on the west coast and was used in the recent ASMFC stock assessment (ASMFC 2012), but there were concerns over the reliability of this model with respect to species productivity issues. The working group noted that the DBSRA model is based on a production model, and catch is the only removal. If there are no other causes of mortality or unreported catch, the model will assume that the stock is unproductive. Furthermore, discussions indicated that even if a growth parameter were estimated from the DBSRA, projecting it forward would not work. Although DBSRA model results in the ASMFC stock assessment show potential long term changes in spawning stock biomass, it was noted that the stock assessment sub-committee and peer review panel did not feel the DBSRA model was ready for management use at this time and further development was warranted. The DBSRA estimated a F_{msy} rate that was extremely low (an annual exploitation rate of less than 10%) and, given the life history of river herring (e.g., short generation time, high fecundity), the stock assessment sub-committee and the peer review panel felt this rate was too low to be realistic and likely reflected model mis-specification. The DBSRA, as it was parameterized for river herring, could not deal with long-term changes in the productivity of the stock (e.g., due to damming and habitat loss) or non-fishery removals (e.g., increased M, passage mortality), both of which are probably important in determining the current status and productivity of the stock. As a result, the parameters estimated from the model (MSY and F_{msy}) were not considered reliable for management use.

Given hyperstability, the use of a fishery-dependent CPUE index for a schooling fish species such as river herring was discussed and determined to be less than ideal. Fishery-dependent CPUE would not be comparing schools of fish, which can be less and more dense. CPUE would not adequately track abundance due to hyperstability because even if there was no change in fishing effort, information on difficulty in locating the school, school density, or how many other schools may have been present is not available.

During the panel presentations, Dr. Nelson presented on a method for looking at environmental covariance and estimating population trends into the future. Discussions indicated that this method may not work adequately across all areas for river herring. The method worked well for the Monument River as an indicator river; however, it was noted that rainfall may not be a driving factor for all rivers. Given that this model requires stock recruitment relationships along with other parameters and variables that have not been determined for some runs; this model is considered to be preliminary and not the best option for use in the river herring ERA.

The Dennis *et al*. diffusion approximation method requires the same time period for all data (i.e., run counts). However, combining two fishery independent surveys spanning different years would not work because independent surveys measure relative abundance in differing units. In addition, the run counts are not absolute numbers for river herring, except where the counting station at a lift or ladder is in close proximity to the mouth of the river.

For alewife rangewide, the MARSS package was the model that presented the best likelihood for use as an ERA. Inputs for use in the MARSS package were discussed as well as different parameters and sensitivities. The MARSS package permits missing data within observational time series, which eliminates the requirement that all input data time series must span the same time frame.

The MARSS model also allows for more than one hidden state, which could represent one stock complex or a series of individual stocks. Discussions indicated that different hidden states could not represent different age classes, as that would arise with multiple observations.

To avoid having to incorporate multiple hidden states into one model, the MARSS or the Dennis *et al*. methods could be used to predict a growth rate for each individual river with sufficient data. This distribution of growth rates could be used to calculate a distribution of the probabilities of extinction. The distribution of growth rates could also be used to calculate an average growth rate, which could then be used to calculate an average probability of extinction

Another option for evaluating extinction risk was the development of an age-structured projection model based on best available estimates (from ASMFC 2012) of age-structure, total mortality (Z), and maturity at age. Recruitment could be projected into the future assuming an average recruitment from YOY indices or using available stock-recruitment relationships from some rivers. Furthermore, mortality can be projected using total mortality (Z) estimates from recent years. If mortality were to increase due to climatic or environmental factors, predation, or some other unforeseen factor, Z could be modified. Assumptions would need to be made about the starting population size for the regional stocks. Projections would be based on the use of a threshold that is a percentage rather than absolute number (e.g., decrease X % from current status), which may reduce sensitivity to assumptions about starting population size.

In order to use environmental variables, several rivers would need to be chosen as representative of the stock. Although the age-structured projection model approach is more realistic with respect to the life history of river herring, the number of assumptions and lack of data for parameterization of the model make this approach untenable at this time.

Preliminary Results with MARSS Package in R

Dr. Curti conducted a preliminary run with the MARSS model using spring and fall trawl survey data. Population growth rate and initial biomass were estimated, and the population was projected forward to estimate the probability of extinction over 100 years. However, the CI's estimated for each parameter were reported as N/A, indicating that there was a mis-specification in the model set-up.

Using the state equation (see Figure 8 on page 15), the coastwide population was assumed to represent one “state.” It was indicated that preliminary runs by Dr. Sweka using the Dennis *et al*. method yielded higher growth rates than the MARSS model, noting that the MARSS is simply assuming a higher variance. Given the preliminary results, the MARSS method appeared to be the most reasonable model for moving forward in attempting an ERA for alewife coastwide.

Model Inputs and Assumptions

The working group discussed all the available data and determined that moving forward with the MARSS model, inputs for both species coastwide would include the following: 1) the spring and fall NMFS trawl surveys incorporating offshore strata only (1963 to present); 2) the spring and fall NMFS trawl surveys incorporating both offshore and inshore strata (1975 to present); 3) the spring, fall and winter NMFS trawl surveys (1975 to present); 4) the spring, fall, winter and shrimp trawl surveys; 5) the spring, fall, winter and shrimp trawl surveys plus the DFO trawl surveys data including the DFO summer RV series from the Scotian Shelf/Bay of Fundy (1970 to 2011) and the DFO Georges Bank survey series from Georges Bank and the Northeast Peak to the Great South Channel (1987 to 2012); and 6) surveys that sample all age classes including ME/NH inshore trawl surveys (spring 2001, fall 2000), NJ ocean trawl survey (1989 annual average), NEAMAP (fall 2007), and RI combined coastal trawl survey (1979 annual average).

Four different model runs will be conducted with the MARSS package in R. Two separate model runs (one for indices incorporating only offshore strata, and a second for indices incorporating both inshore and offshore strata) will be conducted where the first model year is the first year of the earliest survey included in the model, while noting missing observations in the two time series respectively. One model run will begin in 1998 based on the rationale that this time series includes 3-4 generations of river herring. Additionally, one run will be conducted where the first model year is the first year where data are available for all incorporated surveys, keeping in mind generation time limitations.

The frequency distribution of the estimated growth rates will be plotted as well as the distribution of the probabilities of extinction at specific points in time, given a particular extinction threshold. If time permits, a truncated time series will be created using varying time series lengths, and the distribution of probabilities of a particular percentage decline will be plotted for each window to portray how the probabilities could vary with varying time series lengths. If the MARSS model cannot be successfully implemented, the Dennis *et al*. method will be implemented for each survey and/or river-specific run count separately.

Inputs for the MARSS model for the stock complexes were also discussed for both species. For all run counts and YOY surveys, a 4-year running sum will be used because these types of abundance indices only count a segment of the total population. For the CAN alewife, data inputs will include the DFO trawl survey data including the DFO summer RV series from the Scotian Shelf/Bay of Fundy (1970 to 2011) and the DFO Georges Bank survey series from Georges Bank and the Northeast Peak to the Great South Channel (1987 to 2012), as well as the N output from an SCAA model if applicable. NNE alewife inputs will include run counts from the Androscoggin (1983-2010), Damariscotta, Union, Cochecho, Exeter, Lamprey and St. Croix Rivers. In addition NNE alewife data will include the ME alosine YOY seine survey. SNE alewife inputs will include run counts from the Monument, Mattapoissett, Nemasket, Gilbert-Stuart, and Nonquit Rivers. In addition, SNE alewife will include the GSO trawl survey, as well as the Narragansett Bay/Salt Pond survey and the YOY survey if these latter two datasets can be split by species. Inputs for SNE alewife will also include run counts from the Thames River/Greenville Dam, CT, the spring LIS survey (initiated in 1984), as well as YOY surveys from NY. Data inputs for MAB alewife will include YOY surveys from NJ, MD, D.C., and VA, the DE Bay juvenile trawl survey, the DE Bay adult trawl survey, the VIMS trawl survey, and potentially ChesFIMS. If possible, the cluster analysis for the YOY surveys for the MAB alewife will be used to inform the covariance structure. The CAR alewife inputs will include the Albemarle Sound YOY seine survey (1972), the NC assessment, and the independent gillnet survey (1990).

Inputs for blueback herring for each of the five genetically unique stock complexes will also employ a 4-year running sum for all run counts and YOY surveys. CAN blueback herring inputs will include the DFO trawl survey data including the DFO summer RV series from the Scotian Shelf/Bay of Fundy (1970 to 2011) and the DFO Georges Bank survey series from Georges Bank and the Northeast Peak to the Great South Channel (1987 to 2012). For the NNE blueback herring inputs, run counts from the Oyster and Taylor Rivers will be used, as well as the ME alosine YOY seine survey. SNE blueback herring data will include run counts from the Monument River as well as the Narragansett Bay/Salt Pond seine survey, the YOY survey and the GSO trawl survey. The YOY seine survey and Albemarle Sound survey as well as YOY surveys from NY, NJ, MD, D.C., and VA will also be included for LIS/MAB blueback herring. In addition, LIS/MAB blueback herring data will include the Holyoke Dam fish lift counts, spring LIS survey (initiated in 1984), the DE Bay juvenile and adult trawl surveys, the VIMS trawl survey (averaged over all strata), potentially ChesFIMS, the independent gillnet survey, and predicted abundance from the Chowan River. Data inputs for the SAT blueback herring will include minimum biomass estimates and commercial CPUE for the Santee-Cooper River.

Conclusions

NMFS will continue with the ERA modeling as described above. Results from this modeling effort, information from the working group discussions that are included in this report, as well as the supporting materials, including peer review of this report, will be considered by NMFS in determining the appropriate models to use in the river herring ERA. The results from these modeling efforts will be considered and included in a listing determination for alewife and blueback herring.

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