BLUEFISH BENCHMARK STOCK ASSESSMENT FOR 2015

BLUEFISH WORKING GROUP MEMBERS

Mike Celestino – Working Group Chair – New Jersey DEP Division of Fish and Wildlife
Tony Wood – Lead Analyst – Northeast Fisheries Science Center
Joey Ballenger – South Carolina Department of Natural Resources
Mike Bednarski – Massachusetts Division of Marine Fisheries
Katie Drew – Atlantic States Marine Fisheries Commission
Nicole Lengyel – Rhode Island DEM Division of Fish and Wildlife
José Montañez – Mid-Atlantic Fisheries Management Council
Kirby Rootes-Murdy – Atlantic States Marine Fisheries Commission

Acknowledgments

The Bluefish Working Group gratefully acknowledge the work done by the Bluefish Technical Committee, including Eric Durell (MD DNR), Beth Egbert (NC DMF), Jim Gartland (VIMS), Kurt Gottschall (CT DEP), John Maniscalco (NY DEC), Joseph Munyandero (FL FWC), Kevin Sullivan (NH DFW) and Rich Wong (DE DMF) during the data gathering, preparation, and analysis process, as well as their constructive comments during review of the final document.

In addition, the WG wishes to thank Gary Shepherd, Chris Legault, John Manderson, Jon Hare, Andre Schmidt, Laura Palamara, Josh Kohut, Rich Signell, Chris Bonsek, Sarah Gaichas, Kevin Spanik, Alicia Miller, Tim Miller, Mike Palmer, Mark Terceiro, and Jeff Brust for the analyses and insight they contributed.

B1. Executive Summary

TERM OF REFERENCE #1: Estimate catch from all sources including landings and discards. Evaluate and if necessary update the discard mortality estimate. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data.

Since 1982, fishery removals of bluefish have ranged from 9,617 mt (1999)to 54,091 (1986) mt. Fishery removals over the past five years have ranged from 14,320 mt (2010) to 9,817 mt (2014). Prior to 1981 there are no direct estimates of recreational removals and no attempt was made to hindcast recreational catch pre-1981. Over the assessment time series, recreational harvest has been the dominant source of fishery removals, constituting 37-80% of the total catch. Commercial landings have been a smaller component of fishery removals. Information on commercial discards was limited. There have been few regulatory changes (e.g. seasonal closures, trip limits, etc) that would induce high rates of discards. Based on the uncertainty in the discard estimates and the low level of commercial landings relative to total removals the SAW 60 WG chose not to include commercial discards in the SAW 60 assessment models.

Currently, both the commercial and recreational fisheries are primarily concentrated in the mid-Atlantic region. Historically, the recreational harvest was more broadly distributed between the Mid and South Atlantic.

The SAW 60 Working Group (WG) evaluated standardized catch per unit effort (CPUE) indices from the recreational fishery and considered its utility as an index of abundance. The MRIP index covers the entire range of the Atlantic coast stock of bluefish and includes information on older age classes that are poorly sampled by standard fishery independent surveys, so the SAW 60 WG chose to include it as an index of abundance.

TERM OF REFERENCE #2: Present and evaluate data and trends on life history information including, age, growth, natural mortality, food habits, and maturity.

Bluefish, Pomatomus saltatrix, is a coastal, pelagic species found in temperate and tropical marine waters throughout the world and inhabits both inshore and offshore waters along the east coast of the United States.

Bluefish spawn offshore in the western North Atlantic Ocean, from approximately Massachusetts to Florida. Bluefish are characterized as iteroparous spawners with indeterminate fecundity and spawn continuously during their spring migration. In addition to distinctive spring and summer cohorts, a fall-spawned cohort has been identified, demonstrating the potential of an extended bluefish spawning season.

The working group (WG) expended considerable time and effort tracking down all original sources of age data used at SAW41 as well as new sources of data. The WG recovered NC scale and otolith data from 1983-2000, VA/ODU age data from 1998-2005, and age data from a wide variety of east coast states from 2006 forward. With the expansion of a coast wide biological collection program, bluefish age data have become considerably more robust relative to pre-

SAW41. As in the previous SAW, age data were truncated to a 6+ category to reduce ageing error associated with scale ages.

Bluefish grow nearly one-third of their maximum length in their first year. von Bertalanfy growth curves were fit to data available from 1985-2014. Values for L∞ matched closely with both published estimates (87-128 cm FL) and to the largest individuals in the available catch data. The results from the sex based growth examination confirm the results of previous studies that growth rates do not differ between sexes. Although there was not enough data available from older fish in the south to do a comparison between northern and southern fish, there were data available to compare growth rates between ageing structures. Scale ages typically over-estimate younger ages and underestimate the age of older fish. Changes in the primary age structure for bluefish over the time series makes it difficult to determine if there has been a change in growth rates.

In past stock assessments, a value of 0.20 has been assumed as the instantaneous natural mortality (M) for bluefish over all ages and years. The WG used longevity and life-history based equations to estimate different possible values for age constant and age varying M. Based on the results of all the methods explored to estimate natural mortality for bluefish, the WG reasoned that the assumption of M = 0.2 was justifiable and was maintained for SAW60.

During oceanic larval development, bluefish diets are composed primarily of copepods and fish eggs in the smaller size classes (<30mm) expanding to amphipods, and crab larvae above this size. An onset to piscivory occurs for early juveniles, primarily inhibited by mouth-gape size, in estuarine waters leading to rapid increases in growth rates. Cannibalism has also been documented. Both seasonal and inter-annual differences in diet have been observed and are likely attributed to changes in prey availability, but also due to inter-annual variability in timing of estuarine arrival. The WG also evaluated diet data from three fishery independent surveys and found that overall, the diet of bluefish both in the Chesapeake Bay and the coastal ocean, from Cape Cod to Cape Canaveral, is dominated by fishes, regardless of the index by which the diet is quantified. These findings correspond with those of past studies that have sought to characterize bluefish diet in estuarine and ocean environments.

The WG evaluated maturity at length for all available fish, northern and southern fish, and males and females. The most accurate source of maturity at age for bluefish involved a histological examination of 1,437 female fish. However, because this maturity information did not apply to the entire bluefish stock (females only), the proportion mature at age for all fish was used as the input maturity for the catch-at-age model used in the benchmark assessment.

TERM OF REFERENCE #3: Present the survey data available for use in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, etc.), evaluate the utility of the age-length key for use in stock assessment, and explore standardization of fishery- independent indices. Investigate the utility of recreational LPUE as a measure of relative abundance. Characterize the uncertainty and any bias in these sources of data, including exploring environmentally driven changes in availability and related changes in size structure. Explore the spatial distribution of the stock over time, and whether there are consistent distributional shifts.

States and agencies provided indices from fisheries-dependent and fisheries-independent sources that were assumed to reflect trends in bluefish relative abundance. Bayesian hierarchical modeling was used to combine YOY indices into a single composite index, using the method developed by Conn (2010) that represents the coast wide recruitment dynamics of bluefish. Surveys included in the composite index were from NH Juvenile Finfish Seine Survey, RI Narragansett Bay Juvenile Finfish Beach Seine Survey, NY Western Long Island Seine Survey, NJ Delaware Bay Seine Survey, MD Juvenile Striped Bass Seine Survey, and VIMS Juvenile Striped Bass Seine Survey. In addition, the bluefish working group decided on 8 additional representative indices of bluefish abundance for the SAW60 assessment:

1. *NEFSC Fall inshore strata: 1985-2008 (age-0 – age-6+)*
2. *NEFSC Fall outer inshore strata (FSV Bigelow): 2009-2014 (age-0 – age-6+)*
3. *Marine Recreational Information Program CPUE: 1985-2014 (age-0 – age-6+)*
4. *NEAMAP Fall Inshore trawl survey: 2007-2014 (age-0 – age-6+)*
5. *Connecticut Long Island Sound Trawl Survey: 1985-2014 (age-0 – age-6+)*
6. *Pamlico Sound Independent Gillnet Survey; 2001-2014 (age-0 – 6+)*
7. *New Jersey Ocean Trawl Survey: 1990-2014 (age-0 – age-2)*
8. *SEAMAP Fall Inshore trawl survey: 1989-2014 (age-0)*

The WG thoroughly investigated age length data and evaluated the utility of age length keys for use in this assessment. NC scale and otolith data from early in the time series (1985-2000) required adjustments prior to their eventual use in this assessment. Some additional age data for the middle part of the time series (1997-2005) was available and was incorporated. NC, MA, and NJ resumed or began collecting age data after SAW41, and Addendum to Amendment 1 to the bluefish fishery management plan required additional states to collect age data and this has greatly improved the age length keys for use in this assessment.

Within the NEFSC survey, age 0 and age 1+ bluefish shifted distribution from 1973 through 2014 but not in a systematic direction. Analysis of the centers of biomass (COB) indicated that COB positions were correlated with variations in body size and abundance, but not temperature.

TERM OF REFERENCE #4: Estimate relative fishing mortality, annual fishing mortality, recruitment, total abundance, and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Explore inclusion of multiple fleets in the model. Include both internal and historical retrospective analyses to allow a comparison with previous assessment results and previous projections. Explore alternative modeling approaches if feasible.

The final model configuration included a number of notable changes since the previous peer reviewed model, including the addition of multiple fleets (one commercial, one recreational), updated maturity ogive, model estimated selectivities (two selectivity blocks), addition of new indices, changes to the way indices are fit in the model, and changes to model weighting factors and reduction in model penalties (lambdas and input CVs).

At the SARC review of bluefish the review panel discovered a model misspecification in the selectivity parameters for the MRIP index. A parameter in the function describing the curve for selectivity was fixed when it was intended to have been freely estimated by the model. This was causing patterning in the age composition residuals for this index. The final revised model corrects this misspecification. The values presented in this report reflect the output from the revised model as accepted at the review; for the original model results and diagnostics presented in the draft report, see Appendix B7.

The maximum F at age in 2014 was 0.157 on ages 1 and 2. Average F (age 2) has generally declined since its high in 1987 and in 2014 represents the lowest level in the time series. Recruitment in 2014 was 29.6 million fish, a value that is well above the median for time series. Recruitment has fluctuated over the time series without trend. Total bluefish abundance in 2014 was 82.0 million fish. Abundance was at its highest at the start of the time series at 124.3 million fish. Abundance declined to a low of 53.3 million fish in 1993 then abundance rose steadily through 2006. Abundance declined after 2006 until 2012, and has since risen to levels above the median for the time series. Total biomass in 2014 was 94,328 mt. Total biomass was at its highest at the start of the time series and declined to a low in 1997 and has steadily increased since. SSB in 2014 was estimated at 86,534 mt and trends mimic those of total biomass.

Retrospective patterns suggest that F is underestimated in the model, and that total and spawning stock biomass are overestimated. No clear retrospective pattern appears in model estimates of recruitment.

The working group was able to explore alternate modelling approaches that did not depend on age data (Depletion Corrected Average Catch and Depletion Based Stock Reduction Analysis) both of which suggested that recent harvest of bluefish in the terminal 3 years of the assessment was sustainable.

TERM OF REFERENCE #5. State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, F_{MSY} and MSY) and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.

The current biological reference points for bluefish were determined in SARC 41 and are F_{MSY} (0.19) and B_{MSY} (147,052 mt). The basis for the reference points was the Sissenwine-Shepherd method using the Beverton-Holt stock recruitment parameters and SSB per recruit results generated by the SARC 41 ASAP model results. Overfishing of a stock occurs if F exceeds F_{MSY} and a stock is considered overfished if total biomass is less than half of B_{MSY} ($B_{THRESHOLD}$). The existing definition of overfishing is $F > 0.19$ and $B < 73,526$ mt.

The BTC and the SAW 60 WG concluded that new reference points were required because of the uncertainty present in the stock recruitment relationship estimated by the current model, as the time series of spawning stock biomass and recruitment does not contain any information about recruitment levels at low stock sizes. As a proxy for F_{MSY}, the BTC and the SAW 60 WG *recommend $F_{40\% SPR}$. To calculate the associated proxy for B_{MSY}, the population was projected forward for one hundred years under current conditions with fishing mortality set at the F_{MSY} proxy and recruitment drawn from the observed time series. The resulting equilibrium biomass is the recommended B_{MSY} proxy, with the overfishing threshold set at ½ B_{MSY}.*

The new reference points are $F_{MSY\ proxy}$ = F40% = 0.170 and $B_{threshold}$ = ½ $SSB_{MSY\ proxy}$ = 55,614 mt. The MSY_{proxy} = 13,967 mt.

TERM OF REFERENCE #6: Evaluate stock status with respect to the existing model (from previous peer review accepted assessment) and with respect to a new model developed for this peer review.

When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.

The existing reference points are F_{MSY} = 0.19 and B_{MSY} = 147,052 mt (½ B_{MSY} = 73,526 mt). The 2014 F estimate (0.141) is well below F_{MSY} and the 2014 estimate of B is 92,755 mt, below B_{MSY} but well above ½ B_{MSY}. This indicates that overfishing is not occurring and that the stock is not overfished.

a. **Then use the newly proposed model and evaluate stock status with respect to "new" BRPs and their estimates (from TOR-5).**

The new reference points are F_{MSY} proxy = F40% = 0.170 and SSB_{MSY} proxy = 111,228 mt (½ SSB_{MSY} = 55,614 mt). The 2014 F estimate (0.157) is below $F_{40\%}$ and the 2014 SSB estimate (86,534 mt) is greater than ½ SSB_{MSY}, indicating that overfishing is not occurring and that the stock is not overfished.

Reference Point	**SARC 41**		**Updated**	
	Definition[1]	Value	Definition[1]	Value
$\mathbf{F_{Threshold}}$	F_{MSY}	0.19	$F_{MSY\ proxy} = F_{40\%SPR}$	0.170
$\mathbf{B_{Target}}$	B_{MSY}	147,052 mt	Equilibrium SSB under $F_{40\%SPR}$	111,228 mt
$\mathbf{B_{Threshold}}$	½ B_{MSY}	73,526 mt	½ $SSB_{MSY\ Proxy}$	55,614 mt

[1]: Note that the SARC 41 biomass reference points refer to total biomass, while the updated biomass reference points refer to spawning stock biomass.

TERM OF REFERENCE #7: Develop approaches and apply them to conduct stock projections and to compute the statistical distribution (e.g., probability density function) of the OFL (overfishing level; see Appendix to the SAW TORs).

a. Provide annual projections (3 years). For given catches, each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment).

Short-term projections were conducted using AGEPRO v.4.2.2 (available from the NOAA Fisheries Toolbox, http://nft.nefsc.noaa.gov/AGEPRO.html).

Removals in 2015 were assumed to be equal to the 2015 quota (9,772 mt). For 2016-2018, a constant level of fishing mortality was applied. The population was projected forward under six different F levels (F_{low} = 0.100, F_{2014} = 0.157, $F_{0.1}$ = 0.187, F_{TARGET} = 90% $F_{MSY\ Proxy}$ = 0.153, $F_{MSY\ Proxy}$ = $F_{40\%SPR}$ = 0.170, $F_{35\%SPR}$ = 0.191).

Uncertainty was incorporated into the projections primarily via estimates of recruitment and initial abundance-at-age.

Estimates of recruitment were drawn from the 1985-2014 time-series of observed recruitment from the preferred ASAP model. Initial abundance-at-age estimates were drawn from distributions of terminal abundance-at-age developed from the MCMC runs of the preferred ASAP model. A small amount of uncertainty was incorporated into biological parameters such as weight-at-age, maturity-at-age, and natural mortality; estimates of these parameters were drawn from lognormal distributions with mean values used in the last three years of the assessment and a CV of 0.01.

A sensitivity analysis approach was used to determine the effects of major sources of model uncertainty that could not be encompassed through the MCMC runs of the base model. This included: limiting the empirical recruitment distribution to the CDF of observed recruitment for 2006-2014 (the years of the best available age data), higher M (M=0.26), increased uncertainty in biological parameters (CV of 0.1 instead of 0.01), using the upper and lower 95% confidence intervals for recreational catch, and using the continuity run instead of the new model configuration.

None of the fishing mortality scenarios resulted in total spawning stock biomass going below the biomass threshold (½ $SSB_{MSY\ Proxy}$) in any year of the projection; total spawning stock biomass remained above the SSB threshold with 100% probability in all years.

The overfishing limit (OFL) for 2016 was estimated to be 10,528 mt with a CV of 0.10. A qualitative inflation was applied for known sources of uncertainty that are not adequately captured in the projection process, including retrospective bias and uncertainty in the F_{MSY} proxy estimate, resulting in a recommended CV of 0.15.

a. Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.

The WG considers the base model configuration the most realistic projection scenario. While estimates of recruitment in the most recent 10 years of the time-series (derived in part from the best age information) are likely more reliable than the estimates from the beginning of the time-series, the median recruitment and projection time-series are virtually indistinguishable.

b. Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, and how this could affect the choice of ABC.

Bluefish are a fast-growing, fast-maturing species with a moderately long life span. Although they recruit to the fishery before they are fully mature, larger, older fish are considered unpalatable, reducing demand for those sizes in the commercial market and encouraging the release of those size classes in the recreational fishery. The resulting dome-shaped selectivity of the fleets offers protection to the spawning stock biomass. Although they are a popular gamefish, demand for this species is not extreme and the quota is rarely met or exceeded.

Bluefish are opportunistic predators that do not depend on a single prey species. Their range covers the whole of the Atlantic coast, and their spawning is protracted both temporally and geographically. As a result, they are not as vulnerable as many other species to major non-fishery drivers such as climate change that would result in the loss of critical forage or nursery habitat.

This assessment indicates bluefish are near their target biomass and well above their overfished threshold. Short-term projections indicate no risk of driving the biomass below the overfished threshold while fishing at or near the F_{MSY} proxy. Overall, bluefish have a low degree of vulnerability to becoming overfished, and the ABC can be set on the basis of the F_{MSY} proxy without risk of causing the stock to become overfished.

TERM OF REFERENCE #8: Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in most recent SARC reviewed assessment and review panel reports, as well as MAFMC SSC model recommendations from 2005 and the research recommendations contained in its 23 September 2013 report to the MAFMC. Identify new research recommendations.

The SAW 60 WG reviewed the status of previous research recommendations and proposed new ones to address issues raised during WG meetings. The 2011 bluefish ageing workshop lead directly to the development of Addendum I to the Bluefish FMP (2012), with both items addressing research recommendations from SAW 41. Addendum I has resulted in increased sampling of commercial and recreational biological data (e.g., age, sex, weights) that was utilized by the SAW 60 WG in the assessment. Additionally the SAW 60 WG explored the application of two models designed to provide catch guidance in data poor situations: Depletion Corrected Average Catch Model (DCAC) and Depletion-Based Stock Reduction Analysis.

Lastly, the SAW 60 WG proposed eight new research recommendations to better understanding bluefish dynamics and assessing the population through the current or future models. These included some of the following: developing additional adult bluefish indices of abundance;

investigate species associations with recreational angler trips targeting bluefish; explore age- and time-varying natural mortality from predator-prey relationships; quantify effects of age- and time-varying natural mortality in the assessment model; and continue to evaluate the spatial, temporal, and sector-specific trends in bluefish growth and quantify their effects in the assessment model.

B2. Terms of Reference

1. Estimate catch from all sources including landings and discards. Evaluate and if necessary update the discard mortality estimate. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data.

2. Present and evaluate data and trends on life history information including, age, growth, natural mortality, food habits, and maturity.

3. Present the survey data available for use in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, etc.), evaluate the utility of the age-length key for use in stock assessment, and explore standardization of fishery independent indices. Investigate the utility of recreational LPUE as a measure of relative abundance. Characterize the uncertainty and any bias in these sources of data, including exploring environmentally driven changes in availability and related changes in size structure. Explore the spatial distribution of the stock over time, and whether there are consistent distributional shifts.

4. Estimate relative fishing mortality, annual fishing mortality, recruitment, total abundance, and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Explore inclusion of multiple fleets in the model. Include both internal and historical retrospective analyses to allow a comparison with previous assessment results and previous projections. Explore alternative modeling approaches if feasible.

5. State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates or proxies for BMSY, BTHRESHOLD, FMSY and MSY) and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.

6. Evaluate stock status with respect to the existing model (from previous peer review accepted assessment) and with respect to a new model developed for this peer review.

    a. When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.
    b. Then use the newly proposed model and evaluate stock status with respect to "new" BRPs and their estimates (from TOR-5).

7. Develop approaches and apply them to conduct stock projections and to compute the statistical distribution (e.g., probability density function) of the OFL (overfishing level; see Appendix to the SAW TORs).

a. Provide annual projections (3 years). For given catches, each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment).
b. Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.
c. Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, and how this could affect the choice of ABC.

8. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in most recent SARC reviewed assessment and review panel reports, as well as MAFMC SSC model recommendations from 2005 and the research recommendations contained in its 23 September 2013 report to the MAFMC. Identify new research recommendations.

B3. Introduction

The 60th Stock Assessment Workshop Working Group (SAW 60 WG) prepared the assessment report. The ASMFC Bluefish Technical Committee (TC) and the SAW 60 WG met February 18th - 20th, 2015 in Providence, RI to evaluate data sources in preparation for the SAW 60 WG assessment meeting held April 27-29th, 2015 at the Northeast Fisheries Science Center (NEFSC) in Woods Hole, MA. A complete list of technical committee and working group participants can be found in Appendix B.1 and B.2.

B3.1 Assessment History

Bluefish was assessed through SAW23 (1997) using the CAGEAN model, a catch-at-age model that used commercial and recreational catch tuned by recreational CPUE and survey catch-at-age data. The assessment found that bluefish were at historically low levels of spawning stock biomass and over-exploited. It recommended that fishing mortality should be reduced to halt the decline in SSB.

In 2004, the SAW WG put forward an ASPIC surplus production model at SARC-39. This assessment was not accepted as a basis for fishery management because the recreational CPUE did not correctly handle live-release data, creating a "severe" bias, the NEFSC data used as an index of fishable biomass represent only age-0 and age-1 fish, and the residuals in the commercial catch rate data showed strong autocorrelation, indicating model misspecification

The TC and WG continued work on the assessment, returning in 2005 with an age-structured assessment at SARC 41. The NFT ADAPT version of VPA was used as an initial model. The committee felt that the VPA model produced satisfactory results, but the assumption of no error in the catch-at-age matrix and the ADAPT method of modeling selectivity could produce misleading results. Therefore, a catch-at-age model, ASAP from the NFT models, was used as the primary assessment tool. Many of the results coming out of the ADAPT VPA model were used as input starting value for a statistical catch-at-age model (ASAP). The ASAP model was brought to review and was accepted by 2 out of 3 reviewers. The third reviewer was extremely critical of the way the model had been configured and the way some inputs and assumptions were handled.

The ASAP model from SAW/SARC 41 currently forms the basis of bluefish management advice.

B3.2. Fishery Management History

The Atlantic States Marine Fisheries Commission (ASMFC) and Mid-Atlantic Fishery Management Council (MAFMC) jointly developed the Fishery Management Plan (FMP) for the bluefish fishery and adopted the plan in 1989 (ASMFC 1989, MAFMC 1990). The Secretary of Commerce approved the FMP in March 1990. The FMP defines the management unit as bluefish (*Pomatomus saltatrix*) in U.S. waters of the western Atlantic Ocean.

The ASMFC and MAFMC approved Amendment 1 to the FMP in October 1998 and the National Marine Fisheries Service (NMFS) published the final rule to implement the Amendment 1 measures in July 2000 (MAFMC and ASMFC 1998). Amendment 1 implemented an annual coastwide quota to control bluefish landings. The ASMFC and MAFMC adjust the quota and harvest limit annually using the specification setting process detailed in Amendment 1. The recreational fishery is allocated 83% of the entire quota. Coastwide, the commercial fishery is limited to 17% of the total allowable landings each year. If the commercial quota is less than 10.5 million lbs, the quota can be increased up to 10.5 million lbs if it is anticipated that the recreational fishery will not land their entire allocation for the upcoming year. The coastwide commercial quota is divided into individual state-by-state quotas based on landings from 1981-1989 (Table B3.1). State by state management measures are included in table (Table B3.2)

In 2007, the MAFMC approved Amendment 2 which standardized bycatch reporting methodology (SBRM). The approval of Amendment 2 satisfies the requirement for all federal fisheries management plans that SBRM be included in those plans, as stipulated by the Magnuson-Stevens Act (MAFMC 2007).

In 2011, the MAFMC approved Amendment 3 (effective 1/1/2012) which incorporated the development of annual catch limits (ACLs) and accountability measures (AMs) into the specification process. This specified for Bluefish specifications that ACLs are annually set equal to the acceptable biological catch (ABC) (MAFMC 2011).

In 2012, ASMFC approved Addendum I (ASMFC 2012) that stipulated States that account for more than 5% of total coastwide bluefish harvest (recreational and commercial combined) for the 1998 – 2008 period are required to collect a minimum of 100 bluefish ages (50 from January through June, 50 from July through December). These states are: Massachusetts, Rhode Island, Connecticut, New York, New Jersey, and North Carolina. Virginia was required to continue its sampling regime for bluefish and provide that same minimum 100 samples as the other states.

In 2014, the MAFMC approved Amendment 4 which modified recreational accountability measures to accommodate uncertainty in recreational management and catch estimation. NOAA Fisheries disapproved the use of a 3-yr moving average of the lower confidence limit of the recreational catch estimate to determine whether an ACL overage has occurred. By doing so, the status quo (as stipulated in Amendment 3) of a single-year point estimate from MRIP for the Atlantic bluefish fisheries remains as the mechanism to determine whether the recreational fishing ACL was exceeded in a given year (78 FR 76759).

B3.3. Current Assessment Approach

The current assessment model for bluefish has provided management advice since 2005 and was accepted at the Stock Assessment Workshop 41 review (NEFSC 2005). After reviewing several model types including a modified Delury model, a surplus production model, a VPA and catch-at-age models, the bluefish Technical Committee concluded that a statistical-catch-at-age (ASAP) model was the most appropriate for the bluefish assessment.

B3.4 Biology

B3.4.1 Life History

Bluefish, *Pomatomus saltatrix*, is a coastal, pelagic species found in temperate and tropical marine waters throughout the world (Goodbred and Graves 1996; Juanes et al. 1996). Inhabiting both inshore and offshore waters along the east coast of the United States, spawning takes place offshore (Kendall and Walford 1979; Kendall and Naplin 1981) and subsequent to larval development in continental shelf waters, juveniles eventually move to estuarine and nearshore shelf habitats (Marks and Conover 1993; Hare and Cowen 1995; Able and Fahay 1998; Able et al. 2003). Traveling in loose groups of fish aggregated by size, bluefish typically migrate north in the spring/summer and south in the fall/winter (Wilk 1977; Klein-MacPhee 2002). Their range during these periods of migration can extend as far north as Maine and as far south as Florida in the Unites States (Shepherd et al. 2006).

B3.4.2 Growth

Bluefish grow nearly one-third of their maximum length in their first year (Richards 1976, Wilk 1977). Variation in growth rates or sizes-at-age among young bluefish is evident from the appearance of intra-annual cohorts. Lassiter (1962) identified a spring-spawned cohort and a summer-spawned cohort from the bimodal appearance of size at Annulus I for fish aged from North Carolina and found the seasonal cohorts can differ in age by two to three months. Hare and Cowen (1993) however, suggest the bimodal length at age observed in bluefish is not the result of two distinct spawning events but rather a consequence of continuous spawning (March-September) with the summer spawned offspring having a lower probability of recruitment. Previous research suggests different growth rates at age with summer-spawned larvae and juveniles growing faster than spring-spawned larvae and juveniles (McBride and Conover 1991) with size differences at annual age diminishing greatly after three to four years (Lassiter 1962).

B3.4.3 Reproduction

Bluefish spawn offshore in the western North Atlantic Ocean, from approximately Massachusetts to Florida (Norcross et al. 1974; Kendall and Walford 1979; Kendall and Naplin 1981; Collins and Stender 1987). Bluefish are characterized as iteroparous spawners with indeterminate fecundity and spawn continuously during their spring migration (Robillard et al. 2008). In addition to distinctive spring and summer cohorts, Collins and Stender (1987) identified a fall-spawned cohort, demonstrating the potential of an extended bluefish spawning season. Bluefish mature quickly, with approximately half of the population mature at age 1 and close to one hundred percent mature (97%) by age 2.

B3.4.4 Stock Definition

Bluefish in the western North Atlantic are managed as a single stock (NEFSC 1997; Shepherd and Packer 2006). Genetic data support a unit stock hypothesis (Graves et al. 1992; Goodbred and Graves 1996; Davidson 2002). For management purposes, the ASMFC and MAFMC define the management unit as the portion of the stock occurring along the Atlantic Coast from Maine to the east coast of Florida.

B3.4.5 Habitat Description

Adult and juvenile bluefish are found primarily in waters less than 20 meters (m) deep along the Atlantic coast (Shepherd and Packer 2006). Adults use both inshore and offshore areas of the coast and favor warmer water temperatures although they are found in a variety of hydrographic environments (Ross 1991; Shepherd and Packer 2006). Bluefish can tolerate temperatures ranging from 11.8°-30.4°C, however they exhibit stress, such as an increase in swimming speed, at both extremes (Olla and Studholme 1971; Klein-MacPhee 2002). Temperature and photoperiod are the principal factors directing activity, migrations, and distribution of adult bluefish (Olla and Studholme 1971).

B3.5 Description of Fisheries

B3.5.1 Commercial Fishery

Over the last 33 years, commercial landings from the bluefish fishery ranged from a high of 7,162 mt (1983) (15.8 million pounds) to a low of 1,974 mt (2013) (4.4 million pounds). Gill nets are the dominant commercial gear used to target bluefish and account for over 40% of the bluefish commercial landings from 1982 to 2014, with primary use in the Mid-Atlantic and Florida. Other commercial gears including hook & line, pound nets, seines, and trawls, collectively account for approximately 50% of the commercial landings.

B3.5.2 Recreational Fishery

Recreational harvest estimates of bluefish has averaged over 14,000 mt (30.9 million pounds) annually since 1981. There has been an overall decline since 2007 to roughly 5,000-5,400 mt (11-11.9 million pounds) in 2011 and 2012. Harvest estimates for 2014 show a decrease to approximately 4,700 mt (10.4 million pounds). In 2014, recreational anglers along the Atlantic Coast caught 5.8 million bluefish, a 7.4% increase from 2013. The majority of recreational activity occurred from May to October, with the peak activity in July and August.

B4. TERM OF REFERENCE #1: Estimate catch from all sources including landings and discards. Evaluate and if necessary update the discard mortality estimate. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data.

B4.1. Commercial Data

Historical commercial landings (1950 to present) for all species on the Atlantic coast are maintained in the Atlantic Coastal Cooperative Statistics Program (ACCSP) Warehouse. The Data Warehouse is an online database of fisheries dependent data provided by the ACCSP state and federal partners. The Data Warehouse was queried on 11 March 2015 for all commercial bluefish landings (monthly summaries by state, gear and market category) from 1982-2014 for Florida (east coast), Georgia, South Carolina, North Carolina, Virginia, Maryland, Delaware, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine (ACCSP, 2014). Data sources and collection methods are illustrated by state in Figure B4.1, and annual landings summaries were used when trip level data or monthly summaries were not available. The gear categories were decided upon by the working group based on knowledge of the fisheries and reporting tendencies. The specific ACCSP gears included in each category can be found in Table B4.1.

After review of the commercial landings data by ACCSP state partners, differences in the annual landings from 1996-2014 were identified between the Virginia Fishery Mandatory Reporting Program Trip (FSMRPT) historical landings database and the ACCSP data warehouse. Issues such as duplicate state and federal reporting of landings, and failure to sync data across programs when records are updated in local databases, may be responsible for the discordance across the federally reported and state reported commercial bluefish landings, and the Potomac River Fisheries Commission (PRFC) data, between the Virginia historical landings database and the ACCSP data warehouse. The difference in total commercial bluefish landings between the ACCSP data warehouse and Virginia historical landings database was approximately 1.5% from 1982-2014. It was decided that ACCSP would provide two datasets as options to be used in the assessment model for the Virginia commercial landings data for bluefish. Option 1 consists of commercial bluefish landings where each year of data from 1982-2014 was chosen from either the ACCSP data warehouse or the VA historical landings database, depending on which of these two had the greater annual landings total. The data sources for Option 1 can be seen in Table B4.2. Option 2 consists of commercial bluefish landings where the annual federal dealer landings, the annual state dealer landings, and the PRFC data were compared separately for each year from 1982-2014, and the greater selected from either the ACCSP data warehouse or the VA historical landings database. The data sources for Option 2 can be seen in Table B4.3. Both options are intended to err towards the creation of larger datasets in order to avoid underrepresenting the Virginia commercial bluefish landings data in the assessment. At the 27-29 April 2015 Working Group (WG) Modelling Workshop, the WG elected to use Option 1 since model output using the two Options were nearly identical, and Option 1 is less complex and hence less prone to error.

Prior to the SARC 60, the commercial landings data had been provided by the Northeast Fisheries Science Center (NEFSC) Commercial Fisheries Database (CFDBS), and supplemented with state data supplied directly from several local state collection programs. For past bluefish assessment updates, the NEFSC CFDBS was queried for the federal dealer reported landings and length data from Maine to Maryland, and occasionally for Virginia landings data for some years. However, the NEFSC CFDBS does not capture the commercial bluefish landings which are reported by state dealers who do not have federal reporting requirements. Therefore, it was necessary that additional state dealer reported landings and length data would be supplied by the Virginia Marine Resources Commission (VMRC), the North Carolina Department of Marine Fisheries (NCDMF) trip ticket program, and the Florida Fish and Wildlife Conservation Commission (FWC). To improve on the consistency and reproducibility of the data collection for future bluefish assessments, it was decided for SARC 60 that the commercial bluefish landings would be supplied by the ACCSP data warehouse, which maintains fisheries dependent data for all Atlantic coast species across all ACCSP state and federal partners. A comparison of the commercial bluefish landings across the NEFSC CFDBS, the ACCSP data warehouse, and the local state collection programs can be seen in Tables B4.4 and B4.5 for Virginia, North Carolina, and Florida.

Commercial fisheries landings data for states between North Carolina and Maine are collected via the NMFS dealer mandatory reporting system. Beginning in June 2004, an electronic dealer reporting was initiated in the northeast. The states of Florida, Georgia, and South Carolina use a trip ticket system.

B4.1.1 Commercial Landings

Over the last 33 years, commercial landings from the bluefish fishery (Table B4.6) ranged from a high of 7,162 mt (1983) (15.8 million pounds) to a low of 1,974 mt (2013) (4.4 million pounds). During this time landings have been consistently lower than the recreational catch (Figure B4.2). Gill nets are the dominant commercial gear used to target bluefish and account for over 40% of the bluefish commercial landings from 1982 to 2014, with primary use in the Mid-Atlantic and Florida. Other commercial gears including hook & line, pound nets, seines, and trawls, collectively account for approximately 50% of the commercial landings (Table B4.7).

Regional variations in commercial fishing activity are linked to the seasonal migration of bluefish. The majority of commercial fishing activity in the North and Mid-Atlantic occurs from late spring to early fall when bluefish are most abundant in these areas. As water temperatures decrease in late fall and winter, bluefish migrate south. Peak landings in the South Atlantic occur in late fall and winter. The majority of commercial landings over the time series (1950-present) have been taken in the Mid-Atlantic region (New York, New Jersey, and North Carolina), with the exception of Florida which accounted for a larger percent historically (early 1980s) and a diminishing proportion of landings over time (Table B4.6). Since 1982, approximately 64% of the coastwide total landings have been taken in this region.

Commercial landings decreased steadily from 4,819 mt (10.6 million pounds) in 1993 to 3,359 mt (7.4 million pounds) in 2003, and continued to declined less sharply to 1,974 mt (4.4 million pounds) in 2013 (Table B4.6). Commercial landings have been regulated by quota since implementation of Amendment 1 in 2000. Commercial landings for 2014 increased to 2,242 mt (4.94 million pounds).

The top commercial landings ports for bluefish in 2013 are shown in Table B4.8. Ten ports qualified as "top bluefish ports", i.e., those ports where 45.4 mt (100,000 pounds) or more of bluefish were landed. Wanchese, NC was the most important commercial bluefish port with over 272.2 mt (600,000 pounds) landed.

The Northeast Region is divided into 46 statistical areas for Federal fisheries management. According to VTR data, bluefish were commercially harvested in 36 statistical areas in 2013 (Figure B4.3). Six statistical areas, however, collectively accounted for more than 75 % of VTR-reported landings in 2013, with individual areas contributing 6% to 18% of the total. This trend is supported through time by VTR data over the last 20 years (Figure B4.4). These areas also represented 70% of the trips that landed bluefish suggesting that resource availability as expressed by catch per trip is fairly consistent through the range were harvest occurs.

B4.1.2 Revenue

In 2014, commercial vessels landed about 2,242 mt (4.94 million pounds) of bluefish valued at approximately $3.0 million. Average coastwide ex-vessel price of bluefish was $0.61/lb ($1.33/kg) in 2014, a descrease from the previous years (2012 price = $0.65/lb; $1.43/kg; 2013 price =$0.67/lb; $1.48/kg). The relative value of bluefish is very low among commercially landed species, approximately 0.17 % of the total value, respectively of all finfish and shellfish landed along the U.S. Atlantic coast in 2013. A time series of bluefish revenue and price is provided in Figure B4.5.

B4.1.3 Commercial Biological Sampling

Maine to Virginia

Commercial fisheries from Maine to Virginia were sampled as part of the NEFSC data collection program. In addition, the Virginia Marine Resources Commission's (VMRC) Stock Assessment Program (SAP) has collected finfish biological data (length, weight, sex, and age) since 1988. At most sites, bluefish are sampled from 50-pound boxes of landed fish that have been graded, boxed, and iced. At sites associated with pound net or haul seine landings, bluefish are intercepted after they have been graded by market category and weighed. A 50-pound box (or partial box) of graded fish from all available species market categories (i.e. small, medium, large, and unclassified) are chosen for determination of length, weight, and sex information. In most cases, the entire 50-pound box of fish graded by species market category is sampled to account for within-box variation (see Chittenden and Barbieri 1990).

Each fish is measured for size (total length and usually weight). Weight is measured to the nearest 0.1 lbs; total length is measured to the nearest millimeter (mm), accurate to 2.5 mm, using electronic Limnoterra Fish Measuring Boards. Fork length is measured on a subsample basis. All fish, except those with damaged tails, are measured for total length from the tip of the snout to the end of the tail fin.

For ME-VA bluefish, the numbers of fish sampled has ranged from a low in 1995 of 189 fish to a maximum of 10912 fish in 2012 (Table B4.9). Sampling has averaged just over 6000 fish per year since the year 2000. ME-VA length sampling intensity per 100 lbs landed is presented in Tables B4.10-20. Expansion of length data was completed by market category and quarter of the year, with the results merged into half year periods. Market category/quarters with inadequate length samples were filled with length information from adjacent quarters within the same market category. Market category/quarters with landings and no associated lengths were combined with landings information from adjacent quarters.

North Carolina

Commercial bluefish landings are monitored through the North Carolina trip ticket program (1994-present). Under this program, licensed fishermen can only sell commercial catch to licensed North Carolina Division of Marine Fisheries (NCDMF) fish dealers. The dealer is required to complete a trip ticket every time licensed fishermen land fish. Trip tickets capture data on gears used, area fished, species harvested, and total weights of each individual species landed, by market grade. Trip tickets are submitted to NCDMF monthly.

Fishery-dependent sampling of NC commercial fisheries has been ongoing since 1982. Predominant gears sampled include: ocean sink nets, estuarine gill nets, winter trawls, long haul seines/swipe nets, beach haul seines, and pound nets. From the fishery-dependent data, NCDMF derives length and weight estimates by market grade for almost all of the commercial landings except catches by shrimp trawls, pots, long line, gigs, fyke nets, hand harvest, trolling, and rod & reel. Landings from these unsampled or ‘other’ commercial gears combined represent 0.2-1.1% of the 1997-2004 landings. Length frequency distributions from all sampled commercial gear were combined to represent landings by these other gears.

Bluefish length frequency samples, by gear, market category and year were obtained from dealers with a sample representing the landings from an individual trip. Sampling was done by market category as fish were culled at the dealers. Length distributions (and aggregate weights) from sampled trips by gear and market grade were expanded by respective landings, gear, and market grade. Length frequency distributions were combined to represent total landings, market grade, quarter, and year.

The number of bluefish sampled by NCDMF has ranged from a low in 1995 of 1820 fish to a maximum of 11112 fish in 2001 (Table B4.9). Sampling has averaged almost 8000 fish per year since the year 2000. NC length sampling intensity per 100 lbs landed is presented in Tables B4.13-20. Expansion of length data was completed by market category and quarter of the year, with the results merged into half year periods. Market category/quarters with inadequate length samples were filled with length information from adjacent quarters within the same market category. Market category/quarters with landings and no associated lengths were combined with landings information from adjacent quarters. NCDMF has completed aging bluefish otoliths from years 2006 through 2014. There were a total of 792 bluefish otoliths collected in 2014. Each fish was measured for fork and total length, total weight and sex were recorded, as well as sexual maturity and ovary weight for females.

Florida

Biological data collection for the bluefish fishery from Florida to North Carolina is sparse. FWC has collected an average of around 400 lengths per year from 1992 to 2014. However, there is a large range of values depending on year, from a minimum of 25 fish in 2003, to a maximum of 1618 fish in 1992. There is market category or quarter information associated with the FL lengths and lengths are provided by half year. FL length sampling and sampling intensity is presented in Tables B4.13-20. Expansion of FL length data was completed by half year. If half year information for length or landings were inadequate, expansion was carried out at an annual level.

B4.1.4 Commercial Length Frequency Distribution

The length frequency distribution from the commercial fisheries is characterized by a bi-modal distribution for much of the time-series (Figure B4.6). In the most recent years, a skewed distribution is present, lacking the multi-modal distribution seen in previous years; however, in 2014 the bi-modal distribution is present again. This bi-modal pattern has also been observed in recreational landings length frequencies (Figure B4.10A), and to a lesser degree the recreational discard length frequencies (Figure B4.10B). The bi-modal pattern is a result of an apparent low availability to the fisheries of age 3 to age 4 bluefish. Bluefish are known to school by size class and it is likely that unobserved movement dynamics at this age/size range affects availability of the population. It is possible a larger portion of the population at these sizes are staying south or offshore each year. Since the dominant fisheries for bluefish are coastal and north of Cape Hatteras, North Carolina this would account for a reduced available of this size/age class.

B4.1.5 Commercial Discards

Previous TCs and WGs have concluded that commercial discards for the Atlantic coast were minimal. The SAW60 TC and WG agreed, given: the comparatively small amount of discards relative to landings (1.5-10.7% of landings in any given year; Figure B4.2); the total commercial quota has not been landed for any of the years between 2000 and 2014. The bluefish FMP allows states with a surplus quota to transfer a portion or the entire quota to a state that has or will reach its quota; Amendment 1 to the FMP allows quota transfer from the recreational fishery to the commercial fishery; the need for a discard mortality rate where presently none are available; the need for commercial discard length frequency data where presently none are available; and high CVs around the discard estimates. For these reasons the TC and WG agreed that commercial discards are minimal relative to landings and their use would likely introduce more error than they would resolve.

B4.2 Recreational Data (MRFSS/MRIP)

The main source of information on catch, harvest, release numbers, harvest weights, and sizes for bluefish in the recreational fishery come from the National Marine Fisheries Service's Marine Recreational Information Program (MRIP), which was formerly the Marine Recreational Fisheries Statistical Survey (MRFSS). The MRFSS data collection program began in 1979, though estimates of recreationally caught Bluefish are not available until 1981. In 2005, the National Academy of Sciences' Natural Research Council was commissioned to review the MRFSS and provide recommendations for improving recreational fishing estimates. A major finding of the Council was that intercept methods resulted in a non-representative sample of recreational anglers and their catch-per-trip was not accounted for in the estimation methodology, resulting in potentially biased catch estimates and overestimated precision (MRIP website). Interviewers were instructed to maximize the number of intercepts made and site selection was at the interviewer's discretion. Interviewers were more likely to obtain intercepts from high pressure sites and disregard low pressure sites and the catch-per-trip at the low pressure sites was not adequately represented. The Council's review contributed to the implementation of the MRIP and a new estimation methodology. MRIP uses the same basic data as MRFSS but implements a new catch estimate methodology that better matches the sampling design used in the dockside intercept survey. The MRIP methodology is intended to account for the clustered sample design and the non-equal weighting used to select sample sites.

MRFSS/MRIP contain estimates for number of trips anglers are taking, the total amount of fish harvested (numbers or weight), total amount discarded, catch rates, and biological information. The survey is conducted coastwide and usually by state agency employees or contractors. In MRFSS/MRIP, anglers that fish from private boats and from shore are sampled using random dockside intercepts and telephone calls. During a dockside intercept, anglers are interviewed about their trip and the catch is counted, measured, and weighed. Angler access points are randomly selected in proportion to their expected fishing activity. To estimate effort, coastal households are randomly called and anglers are interviewed about the fishing trips taken during the previous 2 months. Similarly, a for-hire telephone survey is used to collect trip information directly from for-hire operators. Angler participation in MRIP surveys is voluntary. For details in addition to the description provided here, visit the NOAA recreational fisheries statistics website (www.st.nmfs.noaa.gov/recreational-fisheries).

Angler Catch Surveys (dockside intercepts) are interviews of anglers intercepted at public fishing access sites (e.g., marinas, piers) that collect information on the catch and fishing trip (see example questionnaire here http://www.st.nmfs.noaa.gov/Assets/recreational/pdf/append_a.pdf). Sampling is stratified by state, mode of fishing, and wave (bimonthly period) and is conducted continuously during the sampled wave. Recreational fishing estimates are provided for four major modes of fishing: private boats (including rentals), shoreline (e.g., pier, jetty, etc.), charter boats, and headboats (party boats). From 1981-1985 all for-hire boats (charter and party boats) were sampled as one category, producing a single mode that was undifferentiated. From 1986-2004 the party/charter mode was continued in the northeast states (Maine to Virginia), while in the southeast states (North Carolina to Florida) charter boats (only; as separate mode) were sampled by MRIP. Party boats are surveyed by the Southeast Head Boast Logbook Program which began in 1986. From 2005-to present the charter and party boats are sampled independently by the for-hire survey and stratified angler intercept survey; as such separate charter and party boat estimates are produced. Each shoreline angler is treated as being on an independent fishing trip whereas boat modes are treated as fishing parties under the assumption that all anglers on a boat are fishing the same. Sampling is conducted in six waves, each wave being two consecutive calendar months starting with wave 1 (January and February) and ending with wave 6 (November and December). Sampling is conducted during all six waves in Florida (except wave 1 in 1981) and during waves 2-6 in Georgia to Maine (with the exception of pilot studies during some years in GA and NC). Prior to 1993 sampling was divided evenly between the two months in a wave. Beginning in 1993, sampling was divided proportional to expected fishing pressure during each month. There are a minimum of 30 intercepts in each stratum for the shore and private boat modes and at least 45 intercepts in each stratum for the party and charter boat modes (to account for clustering effect). Sampling beyond the minimum is allocated

proportional to expected fishing pressure in each stratum based on the previous three year period. The number of Bluefish caught is recorded as harvested fish observed by the interviewer in whole form (type A), fish reported as harvested by the angler but not observed by the interviewer (bait, filleted, discarded dead) (type B1), and fish released alive (type B2).
Estimation of the variances associated with the average catch and weight of catch estimates obtained from the intercept survey is based on the assumptions that the primary sampling unit is a fishing trip by an individual angler and that there is no clustering effect due to the collection of groups of interviews at each visited site. These assumptions have been empirically verified in pilot surveys. Therefore, the variance is estimated using the standard variance equation for a stratified random sample.

The sampling variance of the estimated total catch is calculated in terms of the expected values and sampling variance the average catch and the total number of trips for each stratum. Total catch is not normally distributed and therefore direct examination of the precision of the estimates is difficult. However, simulation experiments indicate that a normal approximation is satisfactory for constructing 95 percent confidence intervals around the estimated total catch.

The proportional standard error (PSE) expresses that standard error as a percentage of the estimate. It provides an alternative measure of precision and is useful in comparing the relative precision of two estimates. A small PSE indicates a more precise estimate than does a large PSE.

Effort data are collected with the Coastal Household Telephone Survey (CHTS). The CHTS is a stratified random digit dialing telephone survey that includes only households in coastal counties (generally counties within 25-50 miles of coastline, depending on state). The CHTS is stratified by county and wave. Sampling is conducted over a two week period at the end of each wave (last week of the wave and first week of the next wave) and is allocated proportional to county population. Information is collected on the number of trips in the previous wave and details about those trips (see example CHTS questionnaire http://www.st.nmfs.noaa.gov/Assets/recreational/pdf/append_a.pdf). Outliers in effort (number of trips during the particular wave) recorded from telephone surveys are reduced to the 95th percentile of the distribution of effort for the last five years for the particular stratum being sampled.

Evaluation of the CHTS indicated that for-hire modes were being underrepresented due to the nature of these fisheries (out of state clients, etc.). Beginning in 2005, angler effort on charter boats and headboats has been sampled through the For-Hire Survey (FHS) and several overlapping sampling programs. The CHTS was replaced by the FHS for charter boats and headboats (the CHTS is still used for private boats and shoreline modes). The FHS is also a random dial telephone survey that uses a vessel directory as a sampling frame. Other overlapping programs include the Vessel Trip Report (VTR) Program for Maine through Virginia (census logbook), the Southeast Headboat Survey (since 1986) for North Carolina though Florida (census logbook), and state census logbook programs in South Carolina, Florida, and Maryland.

MRFSS vs. MRIP Estimates

Estimates of catch using the MRIP methodology are available from 2004 to the present.

However, prior to 2004, only catch estimates using the MRFSS methodology are available, since the site weight information needed to produce the MRIP estimates is not readily available for the older data. For some species, MRIP estimates were consistently higher or lower than MRFSS estimates, usually when catch rates at low pressure sites were significantly different from catch rates at high pressure sites.

However, for bluefish, there was not a consistent trend in the difference between MRFSS and MRIP estimates, and MRFSS estimates were within the 95% confidence intervals calculated from the MRIP PSEs (Figure B4.7). The TC and WG used the method developed by the MRIP calibration working group to calibrate pre-2004 MRFSS estimates. Difference between the two time-series were minimal.

B4.2.1 Recreational Catch and Harvest

Recreational harvest estimates of bluefish has averaged over 14,000 mt (30.9 million pounds) annually since 1981 (Table B4.23). From the early 1980s to the early 1990s, recreational harvest declined by about 70% [avg. 1981-1983 = 40,433 mt (89.1 million pounds); avg. 1991-1993 = 11,713 mt (25.8 million pounds)]. Recreational harvest estimates continued to decline at a somewhat slower rate until reaching their lowest level at 3,310 mt (7.3 million pounds) in 1999, but since have grown to a peak of 10,204 mt (22.5 million pounds) in 2007. There has been an overall decline since 2007 to roughly 5,000-5,400 mt (11-11.9 million pounds) in 2011 and 2012. Though harvest increased to approximately 7,000 mt (15.4 million pounds) in 2013, harvest estimates for 2014 show a decrease to approximately 4,700 mt (10.4 million pounds). In 2014, recreational anglers along the Atlantic Coast caught 5.8 million bluefish, a 7.4% increase from 2013 (Table B4.24). Recreational harvest has generally increased from a low of 3.6 million fish in 1999, the lowest harvest in the time series. Since then, recreational harvest averaged over 6.2 million fish annually. The majority of recreational activity occurred from May to October, with the peak activity in July and August. Most of the recreational activity occurs from July to October, when almost 70% of the bluefish harvest is taken.

Trends in recreational trips associated with targeting or harvesting bluefish from 1991 to 2013 are provided in Table B4.25. The lowest annual estimate of bluefish trips was 1.727 million trips in 1999, but last year (2013) was also very low with 1.733 million trips. The highest annual estimate of bluefish trips in this timeframe was 5.9 million trips in 1991. Relative to total angler effort in 2013, bluefish were the primary target of recreational trips only about 4.7% of the time.

Recreational Catches by Mode

Figure B4.8 reflects MRFSS/MRIP-based estimates of total removals by mode and indicates that the primary catch modes for bluefish are private boats and shore-based fishing. Less than 10 % of the catch came from for-hire boats over the same time period.

Recreational Catches by Area

MRIP classifies catch into three fishing areas: inland, nearshore ocean (< 3 mi), and offshore ocean (> 3 mi). About 54% of the catch of bluefish on a coastwide basis came from inland waters, followed by nearshore ocean (39%) (Figure B4.9). Offshore ocean is only about 7% of the total catch.

B4.2.2 Recreational Releases

MRFSS/MRIP Recreational release estimates have ranged from a low of 3.2 million fish (1985) to a high of 15 million fish (2007) from 1981-2014 (Table B4.26). Recreational release estimates have generally increased in proportion to harvested fish over the time series, increasing from approximately 4% of the total coastwide catch in 1981 to over approximately 60% in 2014. Recreational discards in 2014 were estimated at 2,808.4 mt and after adjusting for a 15% mortality rate the resulting discard loss was 421.4 mt.

B4.2.3 Recreational Discard Mortality

Since the 1997 assessment (23rd SAW), recreational discard mortality has been estimated at 15%. This was based on estimates calculated in a study by Malchoff (1995), and modified by the ASMFC Bluefish Technical Committee. Prior estimates used in 1994 (18th SAW), estimated a hooking mortality rate of 25% and was based on analogy with species such as striped bass (Diodati 1991), black sea bass (Bugley and Shepherd 1991), and Pacific halibut (IPHC 1988). The Technical Committee thoroughly reviewed the bluefish discard mortality literature (working paper B1) for SAW60. Four methods to calculate a point estimate of post release mortality were conducted, resulting in a range of estimates between 14% and 17%. The TC and WG approved a 15% (SD=0.143%) discard mortality estimate for use in SAW60 based on bluefish specific estimates from five known studies using Bartholomew and Bohnsack (2005) meta-analysis methodology. Supporting analysis using 70 studies and 21 different species from Bartholomew and Bohnsack (2005) (16% post release mortality) and an equal weighted estimate from bluefish specific papers (14% post release mortality) assisted the decision by the WG and TC. For more details see working paper B1.

B4.2.4 Recreational Biological Sampling

Recreational landings are sampled for length as part of the MRIP program. The MRIP length samples were used to expand recreational landings per half year. Recreational discards were characterized using lengths from bluefish tagged and released in the American Littoral Society tagging program (by definition B2 catches), as well as information provided by volunteer angler programs in RI, CT, and NJ.

Rhode Island Volunteer Angler Survey

The Rhode Island Department of Environmental Management Division of Fish and Wildlife (RIDFW) implemented a voluntary on-line angler logbook (eLOGBOOK) in 2010. The eLOGBOOK application, housed by the Atlantic Coastal Cooperative Statistics Program (ACCSP), enables recreational fishers to enter complete trip level catch and effort data online. Information collected includes trip date, fishing mode (party, charter, private, shore), area fished, number of fishers, number of lines, gear type, hours fished, species, disposition, length and quantity.

Connecticut Volunteer Angler Survey

The Connecticut DEEP Marine Fisheries Division has conducted a Volunteer Angler Survey (VAS) since 1979. This survey supplements the National Marine Fisheries Service, Marine Recreational Information Program (MRIP) by providing additional length measurement data particularly for fish that are released. The survey's initial objective was to collect marine recreational fishing information concerning finfish species with special emphasis on striped bass. In 1994, the collection of bluefish length measurements was added to the survey to enhance understanding of the bluefish fishery in Connecticut. In 1997, length measurement information for other marine finfish was added to the survey design.

The CT VAS is designed to collect trip and catch information from marine recreational (hook and line) anglers who volunteer to record their fishing activities by logbook. The logbook format consists of recording fishing effort, target species, fishing mode (boat and shore), area fished (subdivisions of Long Island Sound and adjacent waters), catch information concerning finfish kept (harvested) and released, and length measurements of striped bass (since 1979), bluefish (since 1994), and other common species (since 1997). Instructions for volunteers are provided on the inside cover of all postage paid logbooks. Each participating angler is assigned a personal numeric code for confidentiality purposes. After the logbook data are entered into a database, logbooks are returned to each volunteer for their own personal records.

New Jersey Programs

Recreational discard data were available from several New Jersey programs: the New Jersey volunteer angler survey (VAS) is an online, open access survey that began in 2006. The intent of the survey is to complement and supplement the MRIP survey. Two main objectives of the VAS are to allow anglers to submit data to increase buy-in to management measures as well as address sample size concerns of MRIP, and to collect additional length frequency data of discarded fish. The survey was designed based on the MRIP intercept survey, collecting effort, catch, and length information from marine recreational (hook and line) anglers in New Jersey waters. The survey is available online at http://www.njfishandwildlife.com/marinesurvey.htm.

The NJ Tournament and Party/Charter Boat biological sampling program is designed to collect marine recreational (hook and line) fishing information concerning finfish species. Tournament sampling consists of staff collecting biological data (length, weight, age, sex) of finfish kept (harvested) and released during fishing tournaments. In 2014, logbooks were created for tournament anglers who volunteered to record their fishing activities. The logbook format consists of recording fishing location, number of hours fished, fishing mode (surf or boat), number of anglers reporting on log, water temperature, catch information concerning finfish kept and released, and length measurements.

NJ Party/charter boat sampling consists of staff collecting biological data of finfish kept and released during fishing trips aboard party/charter boats. Party/charter boats can submit trip and catch information by logbook when staff are not present. The logbook format consists of recording fishing location, number of hours fished, number of fisherman, water temperature, weather conditions, catch information concerning finfish kept and released, and length measurements.

Length frequencies from the recreational catch and discards show a similar trend to the commercial length frequency. While previous years were characterized by a bimodal distribution, more recent years reveal a skewed distribution, with a main peak around 28 cm and a flat/slightly-decreasing distribution out to 90 cm (Figure B4.10A & B). Total length frequency distribution by season of the recreational landings and discards are presented in Figure B4.11. The average size of the recreationally released bluefish is larger than the average size of retained fish, an uncommon pattern most likely due to bluefish’s unpalatability at larger sizes.

B5. TERM OF REFERENCE #2: Present and evaluate data and trends on life history information including, age, growth, natural mortality, food habits, and maturity.

B5.1 Life History

Bluefish, *Pomatomus saltatrix*, is a coastal, pelagic species found in temperate and tropical marine waters throughout the world (Goodbred and Graves 1996; Juanes et al. 1996). Inhabiting both inshore and offshore waters along the east coast of the United States, spawning takes place offshore (Kendall and Walford 1979; Kendall and Naplin 1981) and subsequent to larval development in continental shelf waters, juveniles eventually move to estuarine and nearshore shelf habitats (Marks and Conover 1993; Hare and Cowen 1995; Able and Fahay 1998; Able et al. 2003). Traveling in loose groups of fish aggregated by size, bluefish typically migrate north in the spring/summer and south in the fall/winter (Wilk 1977; Klein-MacPhee 2002). Their range during these periods of migration can extend as far north as Maine and as far south as Florida in the Unites States (Shepherd et al. 2006).

B5.2 Age Data

The working group (WG) expended considerable time and effort tracking down all original sources of age data used at SAW41, new sources of data, as well as constructing and reconstructing age length keys. The WG recovered NC scale data files from 1983-1996 and NC otolith data from 1996 to 2000 (scale and otolith samples were collected from the same fish in 1996; the WG elected to use 1996 otolith data only). Samples were primarily from commercial gears. Of note, the raw NC ages included many spring age 0 fish, which are uncommon in biological age samples (WP B5; ASMFC 2011). Exploration of spring NC data suggested, contrary to SAW41 (NEFSC 2005) language, that those data do not use a January 1 birthdate, making them incompatible with all other age data1. The WG initially considered using the raw data (with model adjustments), but at the modeling workshop quantitatively re-assigned NC spring scale ages based on the size and age of known samples from across the time series; for otolith ages, only spring age 0 samples (1996-2000) were adjusted to age 1. See WP B6 and TOR 3 for more details.

Additional data from this general time period (1984-19952) that were recovered included CT Long Island Sound Trawl Survey (LISTS) scale ages, NEFSC trawl scale ages, and NMFS commercial port sampling scale ages (Table B5.1, Figure B5.1). For SAW41, these data were used to age fishery independent or commercial landings only. The SAW60 WG reasoned that bringing all of these data into the ALKs was desirable as it lead to more complete ALKs. Given the limited age data from 1982-1984 the WG elected to start the model in 1985.

The WG recovered VA age length keys from 1998-2004 used at SAW 41. In 1997, VMRC established a cooperative fish ageing lab with Old Dominion University's Center for Quantitative Fisheries Ecology (CQFE) laboratory. The CQFE Lab ages fish harvested from Virginia's marine fisheries and provides the data to VMRC for management purposes. Collection of age samples was based on a quota by inch interval. The Virginia time series (1998-2004) contains

---

1 Fall samples would not have suffered from a birthday concern, and so were used at SAW41, and also retained for SAW60 (WP B6).

2 NMFS port samples and NEFSC trawl samples were also available for 1996 but were inadvertently omitted from ALKs.

age information by gear, sex, market category, and location from approximately 2,700 samples, from sectioned otoliths only. The SAW60 WG augmented the VA spring ALKs with NC spring otoliths after adjusting the age 0s to age 1 (WP B6). This augmentation allowed for disaggregation of the previously combined 1998-2001 spring ALK into ALKs for 1998, 1999, and 2000-2001 (Table B5.2). With this exception, age keys from 1997-2004 were reconstructed according to the protocol specified at SAW41 (Table B5.2).

New sources of age data acquired since SAW41 include otolith ages from MA, RI, CT, NY, NJ, ChesMMAP, NC, NEAMAP, and SEAMAP (Figure B5.1). The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) Trawl Survey samples the main stem of the Chesapeake Bay, from Poole's Island, MD to the Virginian Capes at the mouth of the bay since 2002. ChesMMAP conducts 5 cruises annually, during the months of March, May, July, September, and November. This survey is designed to sample the late juvenile and adult stages of the living marine resources in Chesapeake Bay, and as such the timing of sampling is meant to coincide with the seasonal residency of these life stages in the estuary. The NEAMAP and SEAMAP programs are described in TOR 3. With the addition of these new data sources, age keys since 2005 average a minimum of approximately 30 fish per age (Table B5.3, WP B5).

Several studies document the problems with bluefish ageing information, specifically problems with using scales to accurately age bluefish. False annuli, rejuvenated scales, identifying annuli on scales from larger fish, different annuli counts between scales from the same fish, and the timing of the first annulus formation can all cause inaccuracies (Lassiter 1962; Richards 1976; NCDMF 2000; Robillard et al. 2009). The divergence between scale ages and otolith ages occurs beyond age-6 (E. Robillard, CQFE, pers. comm. 2005). Therefore the catch-at-age matrices were truncated to a 6+ category to reduce ageing error associated with scale ages in the 1985-1995 time period.

The SAW-23 review expressed concern that use of a single age key collected in NC may not be representative of the coastal stock (NEFSC 1997). The SAW-41 review expressed concerns that ALKs have been combined across areas and years. Salerno et al. (2001) examined age data collected along the Atlantic coast in the NEFSC autumn trawl survey and compared the scale ages with the North Carolina commercial ages and concluded that the NC ages were representative of Atlantic coast bluefish. Other studies have used age at length information from commercial and recreational fisheries as well as fishery-independent surveys and have shown similar bluefish growth parameter estimates from Maine to North Carolina, providing further evidence that North Carolina age data are representative of the Atlantic Coast (VMRC 1999, 2000, 2001). Regional trends in age data are available in Figure B5.2A-B (and WP B5) and suggest similarities and differences.

The WG explicitly evaluated borrowing age data across years (WP B8), and the results suggested that this should generally be avoided. The SAW-60 WG accounted for historical borrowing and sparse ALKs (1997-2005) through model considerations (see TOR 4).

The SAW-41 review expressed concerns regarding gaps in sampling age 3, 4, and 5-year old fish (Jones 2005). In response to concerns about the adequacy of bluefish biological data, in February 2012 the Bluefish Management Board passed Addendum I to Amendment 1 to the bluefish fishery management plan that required states that accounted for >5% of total coast-wide bluefish harvest to collect a minimum of 100 bluefish ages (50 from January - June; 50 from July - December). A number of states implemented this program prior to 2012, including NC (2006+), MA (2009+), and NJ (2010+); and as noted above, VA has maintained an ageing program in conjunction with ODU since 1997. With the expansion of the biological collection program, bluefish age length keys have become considerably more robust relative to the time series described above (Figure B5.3 and B5.4). Working paper B5 describes the biological collection program in greater detail. See WP B5, B7, and B8 for more information on trends on age data.

B5.3 Growth and Reproduction
Bluefish spawn offshore in the western North Atlantic Ocean, from approximately Massachusetts to Florida (Norcross et al. 1974; Kendall and Walford 1979; Kendall and Naplin 1981; Collins and Stender 1987). Bluefish are characterized as iteroparous spawners with indeterminate fecundity and spawn continuously during their spring migration (Robillard et al. 2008). In addition to distinctive spring and summer cohorts, Collins and Stender (1987) identified a fall-spawned cohort, demonstrating the potential of an extended bluefish spawning season.

Bluefish grow nearly one-third of their maximum length in their first year (Richards 1976, Wilk 1977). Variation in growth rates or sizes-at-age among young bluefish is evident from the appearance of intra-annual cohorts. Lassiter (1962) identified a spring-spawned cohort and a summer-spawned cohort from the bimodal appearance of size at Annulus I for fish aged from North Carolina and found the seasonal cohorts can differ in age by two to three months. Hare and Cowen (1993) however, suggest the bimodal length at age observed in bluefish is not the result of two distinct spawning events but rather a consequence of continuous spawning (March-September) with the summer spawned offspring having a lower probability of recruitment. Previous research suggests different growth rates at age with summer-spawned larvae and juveniles growing faster than spring-spawned larvae and juveniles (McBride and Conover 1991) with size differences at annual age diminishing greatly after three to four years (Lassiter 1962).

To further explore differences in growth, von Bertalanfy growth curves were fit to data available from 1985-2014 (Table B5.4, Figures B5.5 and B5.6). Historically, scale ages have been used to estimate von Bertalanffy growth parameters (Lassiter 1962; Barger 1990; Terceiro and Ross 1993; Salerno et al. 2001) however more recent research validated otolith ages for bluefish and re-examined growth (Robillard et al. 2008). The values for $L\infty$ from all of these studies (87-128 cm FL) match closely to the largest individuals in the available catch data and are similar to the estimates presented here (Table B5.4).

The results from the sex based growth examination confirm the results of previous studies that growth rates do not differ between sexes (Hamer 1959; Salerno et al. 2001, Robillard et al. 2008) (Figure B5.6, Table B5.4). Although there was not enough data available from older fish in the south to do a comparison between northern and southern fish, there were data available to compare growth rates between ageing structures. Scale ages typically over-estimate younger ages and underestimate the age of older fish. The growth curve for scales from this study had more data to fit at older ages, and asymptotes at a much smaller L-infinity value (92.4cm) than the otolith ages (120 cm). The otolith ages seem to provide more realistic VBL growth parameter estimates (Table B5.4). Finally, the differences in growth curves by time block can be explained by the age structures. From 1985-1994 all of the age data is derived from scales, 1995-2004 age data comes from a mixture of scales and otoliths, and 2005-2014 data is otoliths only. Changes in the primary age structure for bluefish over the time series makes it difficult to determine if there has been a change in growth rates.

B5.4 Natural Mortality

In past stock assessments, a value of 0.2 has been assumed as the instantaneous natural mortality (M) for bluefish over all ages and years. To investigate the validity of this estimate, longevity and life-history based equations were used to estimate different possible values for M. Taking the maximum age for bluefish to be 14 years (observed age in the data used in these analyses), the 'Rule of thumb' method (3/tmax) gives a natural mortality estimate of 0.21. Additional longevity based estimates derived from equations in Hoenig (1983) and Hewitt and Hoenig (2005) give values of 0.32 and 0.3, respectively. Estimates based on equations that use growth parameters from Then et al. (2014) and Jensen (1996) give values of 0.20 and 0.195, respectively. The mean value for natural mortality using the estimates from these 5 approaches is 0.245.

Age-specific estimates were calculated based on the work of Lorenzen (1996, 2000) and Gislason et al. (2010). These values ranged from 1.70-0.17 over the age range of 0-14 (Table B5.5). The WG was concerned with the use of age-specific M estimates due to uncertainty in M particularly for younger ages of bluefish (Table B5.5; e.g., range of M for age 0 = 0.54-1.70). Based on the results of all the methods explored to estimate natural mortality for bluefish, the WG reasoned that the assumption of M = 0.2 was justifiable and was maintained for SAW60.

B5.6 Food habits

During oceanic larval development, bluefish diets are composed primarily of copepods and fish eggs in the smaller size classes (<30mm) expanding to amphipods, and crab larvae above this size (Marks and Conover 1993). An onset to piscivory occurs for early juveniles, primarily inhibited by mouth-gape size, in estuarine waters leading to rapid increases in growth rates with maximum rates reaching 2 mm/day (Juanes and Conover 1994). Cannibalism has also been documented, and therefore bluefish predation may influence recruitment of conspecifics (Bell et al. 1999). Increased predation on commercially important invertebrates such as blue crabs (*Callinectes sapidus*) may occur when fish prey are less available (Scharf et al. 2004). Both seasonal and inter-annual differences in diet have been observed and are likely attributed to changes in prey availability, but also due to inter-annual variability in timing of estuarine arrival (Nyman and Conover 1988). To confirm the findings of previous research and further investigate the diet of bluefish, data on diet composition collected from four surveys were evaluated.

Data from the NEFSC bottom trawl survey from the Mid-Atlantic and Southern New England regions was analyzed in 10 year blocks to look at bluefish diet composition. The proportion of empty stomachs ranged from 20-40% and in each ten year period, around 60-70 bluefish prey items were identified. Anchovies were a significant prey of bluefish across all time periods, as were butterfish and squids (Figure B5.7). Other prey have different levels of importance across time, including sandlances, herrings, bluefish, and scup (which has increased in the past two decades). Drums have also recently increased in bluefish diets. Prey composition percent by weight as shown in Figure B5.7 was calculated using the methods of Link and Almeida (2000).

Since 2007, the NEAMAP survey has sampled a total of 4,250 bluefish for diet from the Mid-Atlantic Bight and Southern New England. Of these, 56.0% (2,379 fish) have had prey in their stomach comprising 86 prey items. Percent by weight (%W) of each prey type was calculated following Bogstad et al. (1995) and Buckel et al. (1999). This data showed that fishes comprised greater than 96% of the bluefish diet by weight, with bay anchovy (53.9%), butterfish (7.4%), and striped anchovy (6.2%) accounting for the bulk of the prey consumed. For the invertebrates, the longfin inshore squid was the main identifiable prey type. Percent by number (%N) of each prey type was calculated following the same %W equation by replacing the biomass values with count data. These calculations presented a similar picture of bluefish diet, with fishes contributing 92.6% of the diet and the same three fishes dominating the diets of bluefish. Invertebrates were shown to be slightly more important in the bluefish diet using %N, likely due the large numbers of small-bodied invertebrates (e.g., crab megalope and mysid shrimps) that were encountered on several occasions.

The ChesMMAP survey has collected a total of 443 bluefish stomachs since 2002, and 54.0% of these have had prey items in their stomach. Of these 239 bluefish stomachs, 34 prey types were identified with fishes again dominating the diet of bluefish collected from Chesapeake Bay, as measured using the %W index. Fishes comprised approximately 87.7% of the bluefish diet by weight, with bay anchovy (39.9%), spot (18.8%), and Atlantic menhaden (9.1%) accounting for the bulk of the fishes consumed by bluefish. Silver perch and weakfish each accounted for 2.4% of the diet by weight. Of the invertebrates, the mysid shrimp was the main identifiable prey type. Fishes comprised nearly the same percentage of the bluefish diet when measured by the %N index. Fishes contributed 84.6% of the diet by number, while invertebrates accounted for 13.7%. The remainder was unidentifiable items.

The SEAMAP trawl survey sampling from Cape Hatteras, North Carolina to Cape Canaveral, Florida has collected 644 stomachs from 2011-2013. A total of 49 different types of prey were identified with the diet composition by weight consisting primarily of fishes (93.5%), most significantly anchovies (49.8%), Atlantic bumper (3.2%), and sciaenid fishes (1.2%). Penaeid shrimp, loliginid squids and cubozoan jellyfish contributed in highest proportions among the invertebrates. A similar composition is depicted in the %N calculations (WP B3).

Overall, the diet of bluefish both in the Chesapeake Bay and the coastal ocean, from Cape Cod to Cape Canaveral, is dominated by fishes, regardless of the index by which the diet is quantified. These findings correspond with those of past studies that have sought to characterize bluefish diet in estuarine and ocean environments. For more information see WP B3.

B5.7 Maturity

Bluefish maturity at age and length has been investigated in previous studies (Salerno et al. 2001, Robillard et al. 2008). To confirm these results and further investigate bluefish maturity, maturity at length is presented for all fish, northern and southern fish, and males and females (Figure B5.8 and B5.9).

This study presents maturity at length all fish, northern and southern fish, and males and females (Figure B5.8 and B5.9). The length estimate at 50% maturity for all fish (29.87 cm) was found to be smaller than the mean value of 33.65 cm estimated in Salerno et al. (2001)(Table B5.6). Given the larger sample size (N = 13,722 vs N = 3,334) and broader geographic region of the data presented here, these differences can be expected. Although it appears that southern fish mature at a smaller length than northern fish, this may also be an artifact of sampling (N = 12,909 fish in north, N = 813 fish in south). The length at maturity for males versus females was found to be slightly smaller for males (Table B5.6 A). Similarly, the data also indicate that female fish mature at an older age than male fish (Table B5.6, Figure B5.10). This is consistent with the maturity information from Robillard et al (2008). Finally, comparing maturity at age for otoliths to scales shifts the maturity ogive to slightly younger ages (Figure B5.10).

The most accurate source of maturity at age for bluefish involved a histological examination of 1,437 female fish (Robillard et al. 2008). However, because this maturity information does not apply to the entire bluefish stock, the proportion mature at age for all fish (estimated via logistic regression: A50 = 1.10, A95 = 1.85) was used as the input maturity for the catch-at-age model used in the benchmark assessment (Table B5.7, Figure B5.11). These estimates are nearly identical to the results from Salerno et al. (2001) (Table B5.7).

B5.8 Stock Definition

Bluefish in the western North Atlantic are managed as a single stock (NEFSC 1997; Shepherd and Packer 2006). Genetic data support a unit stock hypothesis (Graves et al. 1992; Goodbred and Graves 1996; Davidson 2002). For management purposes, the ASMFC and MAFMC define the management unit as the portion of the stock occurring along the Atlantic Coast from Maine to the east coast of Florida.

B5.9 Habitat Description

Bluefish eggs have been collected across the continental shelf from southern New England to Cape Hatteras from May through August, and their depth distribution during those months ranged from 30-70 m, with the majority at 30 m (Shepherd and Packer 2006). Larvae occur near the edge of the continental shelf in the south Atlantic Bight, in open oceanic waters in the mid-Atlantic Bight, and over mid-shelf depths farther north (Shepherd and Packer 2006). Spring spawned larvae are subject to advection to northern waters by the Gulf Stream (Shepherd and Packer 2006). Adult and juvenile bluefish are found primarily in waters less than 20 meters (m) deep along the Atlantic coast Shepherd and Packer 2006). Adults use both inshore and offshore areas of the coast and favor warmer water temperatures although they are found in a variety of hydrographic environments (Ross 1991; Shepherd and Packer 2006). Bluefish can tolerate temperatures ranging from 11.8°-30.4°C, however they exhibit stress, such as an increase in swimming speed, at both extremes (Olla and Studholme 1971; Klein-MacPhee 2002). Temperature and photoperiod are the principal factors directing activity, migrations, and distribution of adult bluefish (Olla and Studholme 1971).

B6. TERM OF REFERENCE #3: Present the survey data available for use in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, etc.), evaluate the utility of the age-length key for use in stock assessment, and explore standardization of fishery- independent indices. Investigate the utility of recreational CPUE as a measure of relative abundance. Characterize the uncertainty and any bias in these sources of data, including exploring environmentally driven changes in availability and related changes in size structure. Explore the spatial distribution of the stock over time, and whether there are consistent distributional shifts.

B6.1 Fishery-Independent Surveys

Fishery-independent surveys from Florida to New Hampshire were reviewed for this assessment (Figure B6.1). Survey methods include estuarine and nearshore bottom trawl and beach seine surveys. The surveys caught predominantly age-0 and age-1 bluefish (<30 cm FL). Indices of relative abundance were calculated based on constraints of catch size, time, and location of sampling. Several surveys sample monthly or bi-monthly. The working group evaluated the timing of each survey and chose the period that had the highest availability of bluefish to the survey gear.

B6.1.1. NH Fish and Game Department, Marine Division Juvenile Finfish Seine Survey

The New Hampshire Fish and Game Department's Juvenile Finfish Seine Survey was initiated in 1997 and has sampled continuously since. The Survey is a fixed station survey. Fifteen fixed stations were chosen through sampling several sites within New Hampshire bays and estuaries in the years before 1997 and selected based on habitat type, depth of less than six feet (1.8 m), and with low enough tidal current to allow for the net to be pulled through the site. The stations, four of which are in the Hampton/Seabrook Estuary, three in Little Harbor, three in the Piscataqua River and five in Little Bay/Great Bay (Figure B6.2), are representative of juvenile finfish nursery habitat along New Hampshire's coastal waters. The beach seine used for this survey is a bag seine, 30.5 m long by 1.8 m high, with 6.4 mm mesh.

A single seine haul is performed at each station each month from June through November, resulting in 90 tows per year. Seine hauls are performed between two hours before and two hours after low tide, and always in daylight. Seine hauls are set by boat about 15-25 m from the beach and, ideally, in water depths less than 2 m, in order to prevent the foot rope of the seine from lifting off of the bottom.

All captured finfish are identified to the lowest possible taxon, measured in total length to the nearest millimeter (with a maximum of 25 individual lengths recorded per species per seine haul), and then enumerated. Water surface temperature (°C), salinity (ppt) and substrate type are recorded at each fixed station for each seine haul. Sampling occurs annually from June to November. All fifteen stations within all four areas (Great Bay, Hampton Harbor, Little Harbor, Piscataqua River) are sampled within each month. This sampling design results in a total of 15 seine hauls being collected monthly and 90 seine hauls being collected annually.

The annual geometric mean catch per tow from the New Hampshire Finfish Seine Survey is used as a measure of relative abundance (Table B6.1). In calculating the index, the full dataset between 1997 and 2014 was used and all survey months (June through November) were included. All fish encountered during time series of the survey ranged between 23 mm and 220 mm. A size cutoff of 250 mm is an assumed level at which bluefish would be classified as age 1 based on discussions of the technical committee, and therefore all bluefish used in the analysis are classified as young-of-the-year.

B6.1.2 Northeast Fisheries Science Center (NEFSC) Fall Inshore Trawl Survey

The NEFSC has conducted bottom trawl surveys over a large portion of the Atlantic shelf since 1963 (Avarovitz 1981). Sampling sites are randomly selected from within depth-defined strata; both inshore and offshore strata are sampled. The surveys run in the spring and fall and cover areas from 5 to 200 fathoms (9.1-365.8 m) deep, from Cape Hatteras, North Carolina to Canadian waters. Trawling locations are allocated according to a stratified-random sampling design. The research vessels F/RV Albatross IV and the F/RV Delaware II were used to conduct these surveys from 1963 to 2008. In 2009 the F/RV Albatross IV was decommissioned and the FSV Henry B. Bigelow took over as the permanent NEFSC survey vessel. This vessel change resulted in changes to the trawl gear and survey protocol (Table B6.2, adapted from Brooks et al. 2010 and NEFSC 2012).

Bluefish are predominantly caught in the fall, and in inshore waters. NEFSC fall inshore strata from Cape Hatteras to Cape Cod were used to build two indices for bluefish (Figures B6.3A-B). An F/RV Albatross index based on all inshore strata (1-46) was constructed from 1985 to 2008. F/RV Albatross tows were 30 minutes in duration and utilized a codend mesh liner of 1.27 cm to retain pre-recruits. An additional NEFSC index representing the current survey vessel, the FSV Henry B. Bigelow, was constructed from 2009 to 2014. The Bigelow is only able to sample the outer inshore band of strata and not able to sample as close to shore as previous vessels. FSV Bigelow tows are 20 minutes long and use a larger codend liner at 2.54 cm. Stratified mean numbers of bluefish per tow for both indices with associated CV estimates are presented in Table B6.1.

Mean number per tow at length were aged using age length keys from 1985 to 2014 developed for the assessment (see TOR 2 for details). The majority of bluefish caught in the fall are age-0 or age-1. The Albatross index shows large cohorts early in the time series in 1986, 1989, and to a lesser degree, later in the time series in 1999, 2003, and 2005 (Figure B6.3A). It is difficult to discern trends from the Bigelow index due to the short (6 year) time series. However, the SAW60 WG decided that while the Bigelow time series was short, it was important to separately include this index in the assessment. Previously, Albatross and Bigelow data were used in a combined index, with Bigelow numbers converted to Albatross units using a conversion factor of 1.16 (Miller et al. 2010). Bluefish have not had a benchmark assessment since 2005 and there will likely be an extended period of time before the next benchmark. The separate Bigelow index will continue to add value, without the need to apply conversion factors, as additional years are added.

B6.1.3 RI DEM Narragansett Bay Juvenile Finfish Beach Seine Survey

The Rhode Island Department of Environmental Management Division of Fish and Wildlife

(DEM) Narragansett Bay juvenile finfish survey began in 1988 to monitor the relative abundance and distribution of the juvenile life history stage of commercial and recreationally important species in Narragansett Bay. These are used to evaluate short and long term annual changes in juvenile population dynamics, to provide data for stock assessments, and to develop Fishery Management Plans. Additionally, the fish community data collected by this survey is used to continue to identify, characterize, and map essential juvenile finfish habitat in Narragansett Bay.

The survey encompasses 18 fixed stations throughout Rhode Island's Narragansett Bay (Figure B6.4. The survey began in 1986 with fifteen stations. The data represented begins in 1988 as the period of time when the survey began using consistent methodology with 15 stations, and then station 16 (Dyer Is.) was added in June 1990, station 17 (Warren R.) was added in July of 1993, and station 18 (Wickford) was added in July of 1995.

Finfish are collected using a 61 meter (200') x 3.05 meter (10'), 6.4 mm stretched (¼") mesh beach seine. The seine has a bag at its midpoint and a weighted footrope. The beach seine is set in a semi-circle, away from the shoreline and back again using an outboard powered 23' (7 m) boat. The net is then hauled toward the beach by hand and the bag is emptied into large water-filled totes. Area swept was calculated, to determine the area covered by an average set (5,837 sq ft; 542.3 sq m).

Physical parameters such as weather conditions, water temperature, dissolved oxygen, salinity, are taken at each station. Fish are sorted by species, measured and counted. If over 50 individuals of one species are collected a sub-sample is taken. Fish collected in the sub-sample are measured and counted. The fish are released immediately after measurements are taken. Relative abundances of invertebrates and aquatic vegetation are also noted. Finfish are sampled monthly, from June through October of each year (all months used in index). The index of abundance used a 25 cm YOY cutoff. Index of abundance is provided in Table B6.1.

The Rhode Island index was standardized using the delta lognormal model approach (Lo et al. 1992). Two generalized linear model (GLM) analyses are used to construct a single index. The first GLM procedure of proportion positive trips assumed a binomial error distribution while the procedure for catch rates on successful trips assumed a lognormal error distribution. The five factors included were year, month, station, temperature (°C), and salinity (ppt).The standardization was accomplished using R statistical software package.

B6.1.4 CT DEEP Long Island Sound Trawl Survey

The Connecticut Department of Energy and Environmental Protection's (CTDEEP) Marine Fisheries Division has conducted the Long Island Sound Trawl Survey (LISTS) since 1984. The LISTS provides fishery independent monitoring of important recreational species, as well as annual total counts and biomass for all finfish taken in the Survey. The LISTS employs a stratified-random sampling and is conducted from longitude 72° 03' (New London, Connecticut) to longitude 73° 39' (Greenwich, Connecticut). The sampling area includes Connecticut and New York waters of Long Island Sound and is divided into 1.85 x 3.7 km (1 x 2 nautical miles) sites (Figure B6.5), with each site assigned to one of 12 strata defined by depth interval design using strata based on depth interval (0-9.0 m, 9.1-18.2 m, 18.3-27.3 m or, 27.4+ m) and bottom type (mud, sand, or transitional as defined by Reid et al. 1979. Sampling is divided into spring (April-June) and fall (Sept-Oct) periods, with 40 sites sampled monthly for a total of 200 sites annually. Species are sorted, weighed, and counted and all or a sub-sample of primary species are measured to nearest cm FL. Some species are sorted and subsampled by length group; so that all large individuals are measured and a subsample of small (often young-of-year) specimens is measured. The length frequency of each group is estimated by the proportion of individuals in each centimeter interval of the subsample expanded across the total number of individuals caught in the length group. The estimated length frequencies of each size group are then appended to complete the length frequency for that species (Gottschall & Pacileo, 2013).

Length sampling for bluefish began in 1984. LISTS bluefish length frequency since 1984 includes 167,132 fish. Connecticut initiated a biological sampling program for bluefish in 2012 as part of implementing Addendum I to Amendment I of the bluefish fishery management plan. Since 2012, the majority of the fish collected for this program have come from LISTS. All bluefish samples have been aged by otolith cross section methodologies approved during the May 2011 bluefish ageing workshop.

LISTS generates a spring and fall geometric mean catch per tow, however, few bluefish are taken in the spring. The current bluefish assessment uses LISTS fall index consisting of September and October samples to generate a geometric mean catch/tow (Table B6.1, Figure B6.5). LISTS employs a stratified-random sampling design. The bluefish index used is an age 0 through age 6+ design based index (non-standardized). The average fall geometric mean over the time series is 22.63 fish/tow, with an average of 91.8% positive tows.

B6.1.5 NY DEC Beach Seine Survey (NYSDEC WLIS)

The New York Department of Environmental Conservation's (NYSDEC) Western Long Island Beach Survey started in 1984, has employed a consistent methodology starting in 1987. The survey uses a 200 x 10 ft (61 m x 3 m) beach seine with ¼ inch (6.4 mm) square mesh to sample sites at fixed stations within western Long Island bays: Little Neck and Manhasset Bay on the north shore of Long Island, and Jamaica Bay on the south shore (1984-present). Oyster Bay has been sampled consistently since 2001, and Hempstead Harbor since 2006. Other bays have been sampled on a shorter time frame. Sites are sampled May through October. Pre-2000 sampling was conducted 2 times per month during May and June, once a month July through October. Now, Little Neck Bay, Manhasset Bay, and Jamaica Bay are sampled 2 times per month (bi-weekly) from May through October. Hempstead Harbor and Oyster Bay are sampled 1 time each month. Generally 5-10 seine sites are sampled in each Bay on each sampling trip.

All finfish species caught identified and counted. As many finfish as possible were measured at each station until 2000 when either all, if less than 30, or a subset of 30 individuals were measured for each species. Environmental information (air and water temperature, salinity, dissolved oxygen, tide stage, wind speed and direction, and wave height) has been recorded at each station. Bottom type, vegetation type, and percent cover have been recorded qualitatively since 1988. Young-of-the-year (YOY) vs. older bluefish have always been recorded, with more species being differentiated over time. 99% of bluefish caught by this survey are YOY, as defined by a 30 cm fork length size cutoff.

The index of abundance (Table B6.1, Figure B6.6) was standardized using a negative binomial GLM with bottom water temperature and bottom dissolved oxygen levels as significant covariates and included sampling during the months of June through October. Bay was not a significant factor.

B6.1.6 NJ DFW Ocean Trawl Survey

The New Jersey Division of Fish and Wildlife (NJDFW) Bureau of Marine Fisheries Ocean Trawl Survey is a multispecies trawl survey that started in August 1988 to monitor the abundance and distribution of marine recreational fishes in the state's nearshore coastal waters. The survey samples from the entrance of the New York Harbor south, to the entrance of the Delaware Bay five times per year in January, April, June, August, and October.

There are 15 strata (five strata assigned to three different depth regimes: inshore – 5.5 to 9 m, mid-shore – 9 to 18 m, and offshore – 18 to 28 m). Stations are randomly selected, and station allocation per stratum is proportional to stratum size. Samples are collected with a three-in-one trawl, so named because all the tapers are three to one. The net is a two-seam trawl with forward netting of 12 cm (4.7 inches) stretch mesh and rear netting of 8 cm (3.0 inches) and is lined with a 6.4 mm (0.25 inch) bar mesh liner. The headrope is 25 m (82 feet) long and the footrope is 30.5 m (100 feet) long.

A consistent protocol has been in place with 20 minute tows and 5 annual cruises since 1990. Exploratory analyses indicated the most consistently high catches (and often the plurality of catches) are from the October cruise. Consequently, the index of abundance is from the October cruise from 1990+. Catches are dominated by young of the year fish, but 7% of the catch over the time series consists of age 1+ fish. The index of abundance is a stratified geometric mean catch per tow of ages 0-2 (Table B6.1, Figure B6.7).For standard catches, the total weight of each species is measured (in kilograms) and the fork length of all individuals is measured to the nearest centimeter. For large catches, a subsample is also weighed and measured (nearest cm), and an expansion factor (total weight / subsample weight) is then applied to each frequency of the length-frequency distribution from the subsample. Each of 39 stations are sampling every October.

B6.1.7 NJ DFW Delaware River Seine Survey

Since 1980, the NJDFW Bureau has conducted a striped bass young-of-year (YOY) seine survey in the Delaware River. This survey collects a variety of other species of fish and invertebrates, with moderate numbers of bluefish collected, over 2,900, since its inception.

The Delaware River is divided into three regions based on habitat; region 1 includes brackish, tidal water extending from the springtime saltwater/freshwater interface to the Delaware Memorial Bridge; region 2 includes brackish to tidal fresh water extending from the Delaware memorial Bridge to the Schuylkill River at the Philadelphia Naval Yard; region 3 includes tidal freshwater from Philadelphia to the fall line at Trenton. In the history of the survey no bluefish have been collected in region 3 and so that region was excluded for purposes of a bluefish abundance index. The region 1 shoreline is dominated by saltmarsh vegetation while region 2 is primarily urban with a shoreline heavily developed for commerce and industry.

The sampling scheme has been modified over the years but the core survey area and station locations have remained consistent. In 2002, the second two weeks of June and first two weeks of July were added to the sampling protocol; exploratory analyses indicated that comparatively large numbers of bluefish are collected during that time, and so the index of abundance includes those months (and consequently starts in 2002).

Field sampling employed a bagged, 30.5 m (100-feet) long, by 2 m (6-feet) deep, with a 6 mm (1/4-inch) mesh beach seine. The seine is deployed as follows: one end of the seine is held fixed at the waterline while a vessel backs off the beach in a half-circle or elliptical pattern before returning to the beach with the other end of the seine. The two ends of the seine are drawn together and hauled on shore at which point all fish are identified to species level, quantified and a sub-sample of up to 30 lengths (FL cm) are recorded for each species from each seine haul; the total size range is also recorded. A size cutoff of less than or equal to 25 cm was used to distinguish young of the year bluefish. Basic water quality parameters, including water temperature, salinity and dissolved oxygen, were also recorded at each station. The geometric mean young-of-year index is reported as the number of young-of-year bluefish per seine haul (Table B6.1, Figure B6.8). The full survey takes place between the 2nd week in June and the last week in October, but exploratory analyses indicated a substantive drop in catch after September, and so the bluefish abundance index includes only the 2nd week of June through the end of September. During this timeframe, each of 24 stations are sampled twice per month (every two weeks).

B6.1.8 MD DNR Juvenile Striped Bass Seine Survey

The Maryland Department of Natural Resources' (MD DNR) Juvenile Striped Bass Seine Survey has documented annual year-class success and relative abundance of many fish species in Chesapeake Bay since 1954. Juvenile striped bass indices are developed from sampling at 22 fixed stations located in major spawning areas in Maryland's portion of the Chesapeake Bay. A subset of 13 sample sites was selected for the development of a juvenile bluefish index from 1981 to present. Other sites were excluded on the basis that bluefish were rarely, if ever, captured there. Each site is visited monthly, from July to September, and up to two samples are collected at each visit.

Fixed sample sites are located in three areas of Maryland's Chesapeake Bay: the Choptank and Potomac rivers and the Upper Chesapeake Bay region north of the Chesapeake Bay Bridge. Sites have occasionally been lost due to erosion, bulkheading, or proliferation of submerged grasses. When necessary, replacement sites are located as close as possible to the original site. Effort was slightly variable prior to 1998, with sample sizes ranging from 72 to 80 seine hauls per year. From 1998 to present effort was standardized and sample size has been constant at n=75.Samples are collected with a 30.5 m x 1.24 m bagless beach seine of untreated 6.4 mm bar mesh set by hand. One end of the net is held on shore, while a biologist pulls the other end of the net perpendicular from shore to the 1.2 m depth contour or the net's full extension, whichever comes first. The net is then pulled parallel to shore to sweep the largest area possible and returned to the beach. All fish captured are sorted and counted by species.

A random subsample of up to 30 individuals is measured for species of interest. Select species are separated into age 0 and age 1+ groups. Ages are assigned from length frequencies and verified by direct examination of scales. Additional data collected at each site include: time of first haul, maximum distance from shore, surface water temperature, surface salinity, primary and secondary substrates types, percent submerged aquatic vegetation, dissolved oxygen, pH, and turbidity.

Annual indices of relative abundance were calculated as the non-stratified Geometric Mean catch per haul of YOY bluefish using data from July-September (Table B6.1, Figure B6.9). Age was assigned by length frequency, with 250 mm FL used as a cutoff for age 0 fish. Attempts at index standardization did not improve indices, so the design-based survey index was recommended.

B6.1.9 NEAMAP Mid-Atlantic/Southern New England Nearshore Trawl Survey

The Northeast Area Monitoring and Assessment Program, Mid-Atlantic/Southern New England Nearshore Trawl Survey (hereafter, NEAMAP) has been sampling the coastal ocean from Martha's Vineyard, MA to Cape Hatteras, NC since the fall of 2007 (Figure B6.10). NEAMAP conducts two cruises per year, one in the spring and one in the fall, mirroring the efforts of the Northeast Fisheries Science Center (NEFSC) Bottom Trawl Surveys offshore. Spring cruises begin during the third week in April and conclude around the end of May, while the fall surveys span from the third week in September until the beginning of November. Sampling progresses from south to north in the spring and in the opposite direction in the fall, so as to follow the general migratory pattern of the living marine resources of these regions.

The survey area is stratified by both latitudinal/longitudinal region and depth. Depth strata between Montauk, NY and Cape Hatteras are 6.1m-12.2m and 12.2m-18.3m, while those in Block Island Sound and Rhode Island Sound are 18.3m-27.4m and 27.4m-36.6m. It is worth noting that, between Montauk and Hatteras, the outer boundary of the NEAMAP Survey any the inner boundary of the NEFSC Survey align. Both programs sample in Block Island Sound and Rhode Island Sound.

Sampling sites are selected for each cruise using a stratified random design; site allocation for a given stratum is proportional to the surface area of that stratum. A total of 150 sites are sampled per cruise, except 160 sites were sampled in the spring and fall of 2009 as part of an investigation into the adequacy of the program's stratification approach. A four-seam, three-bridle, 400x12cm bottom trawl is towed for 20 minutes at each sampling site with a target speed-over-ground of 3.0kts. The gear is of the same size as and nearly identical in design to that used by the NEFSC survey, only sweep configuration and trawl door type differ between the two programs. Tow times and tow speeds are consistent between the two programs. The net is outfitted with a 2.54cm knotless nylon liner to retain the early life stages of the various fishes and invertebrates sampled by the trawl. Trawl wingspread, doorspread, headline height, and bottom contact are measured during each tow, and those in which net performance falls outside of defined acceptable ranges are either re-towed or excluded from analyses in an effort to maintain sampling consistency. A number of hydrographic variables (profiles of water temperature, salinity, dissolved oxygen, and photosynthetically active radiation [PAR]), atmospheric data, and station identification information are recorded at each sampling site.

Following each tow, the catch is sorted by species and, if appropriate, by size group within a species. Size groups are not predetermined for each species, but rather are defined relative to the size composition of that species for that tow. As such, size designations and ranges of small, medium, and large for a species may vary somewhat among tows. Such an approach facilitates representative subsampling, and therefore proper catch characterization, for each tow.

A subsample of five bluefish is selected from each size group from each tow for full processing. Specifically, individual fork length (mm), whole and eviscerated weight (kg), sex, and maturity stage are recorded. Stomachs are removed for diet analysis and otoliths are removed for age determination. For specimens not taken for full processing, aggregate weight and individual fork length measurements (mm) are recorded by size group.

While bluefish are sampled during both spring and fall cruises, catches are more sporadic during the spring survey. Specifically, bluefish have been encountered on only 6.5% of tows on average during the spring cruises, with cruise-specific encounter rates ranging from 4.6% to 9.4%. Although a relatively broad size (106 mm FL to 770 mm FL) and age (age-1 to age-9) range of bluefish have been sampled over the course of the NEAMAP spring surveys, individual catches are typically very small, with 97.8% of tows comprised of two or fewer bluefish. In contrast, bluefish have been encountered on 70.5% of fall tows overall, and this rate has ranged from 62.7% to 79.3% among cruises. Spatially, the percentage of tows in which bluefish were collected by survey region has varied between approximately 53.7% and 91.1%. The size and age ranges sampled during fall cruises are similar to those seen on spring surveys (65 mm FL to 785 mm FL; age-0 to age-10, respectively), but the fall cruises typically yield a greater number of bluefish per tow than do the spring surveys. While only 2.2% of spring tows were comprised of greater than two bluefish, 53.8% of fall tows yielded more than 2 specimens, by comparison.

Bluefish abundance indices as measured by the NEAMAP survey included all ages, all strata, but were limited to fall surveys only. Specifically, a geometric mean catch per standard area swept (Table B6.1) was determined for each year (fall only) by:

$$\hat{N} = \exp\left(\sum_{s=1}^{n_s} \hat{A}_s \hat{\bar{N}}_s\right)$$

where n_s is the total number of strata in which the species was captured, $\hat{A}_s$ is an estimate of the proportion of the total survey area in stratum *s*, and $\hat{\bar{N}}_s$ is an estimate of the $\log_e$ transformed mean catch (number or biomass) of the species per standard area swept in stratum *s* during that cruise. The latter term is calculated using:

$$\hat{\bar{N}}_s = \frac{\sum_{t=1}^{n_{t,s}} \log_e\left(\frac{c_{t,s}}{\hat{a}_{t,s}/25000}\right)}{n_{t,s}}$$

where $\hat{a}_{t,s}$ is an estimate of the area swept by the trawl (generated from wing spread and tow track data) during tow *t* in stratum *s*, 25,000m^2 is the approximate area swept on a typical tow (making the quantity [$\hat{a}_{t,s}$ / 25000] approximately 1), $n_{t,s}$ is the number of tows *t* in stratum s that produced the species of interest, and $c_{t,s}$ is the catch of the species from tow *t* in stratum *s*.

B6.1.10 VIMS Juvenile Striped Bass Seine Survey

The Virginia Institute of Marine Science (VIMS) initiated a seine survey in 1967 designed to monitor the abundance of juvenile striped bass in the James, York, and Rappahannock Rivers, as well as in the main tributaries of these systems (Figure B6.11). While primarily designed to collect striped bass in the shore zones, this survey also has consistently sampled bluefish throughout its time series. Specifically, sampling of fixed sites has occurred twice per month during the months of July, August, and September from 1967-1973 and again from 1980 to the present.

At each site, a 30.5m long by 1.2m deep bagless seine (0.64cm bar mesh) is deployed perpendicular to the shore and then swept back to the land, resulting in the sampling of a quarter-circle quadrant. Two tows are made at each "index" sampling site, while a single sweep is made at auxiliary locations. The two index tows are separated by a minimum of a half hour. Length measurements (mm, fork length) are recorded for up to 25 bluefish per tow. If greater than 25 specimens are collected, the remainder are counted.

In developing an index of abundance (Table B6.1) for young-of-the-year (YOY) bluefish from this survey, areas in which this species have never been encountered (i.e., freshwater reaches of tributaries) were removed from the dataset. All months were included, and bluefish less than 260 mm FL were considered YOY. Overall, since 1981, bluefish have been encountered on 5.5% of the seine tows. This encounter rate varied between 0% and 17.5% across years, and 4.7% and

6.5% among the bi-monthly sampling rounds. Catches ranged from 0 to 19 bluefish. The YOY index of abundance was calculated as geometric mean catch-per-tow and, while variable throughout the time series, seem to show relatively few instances of large recruitment after 1997.

B6.1.11 NC Pamlico Sound Independent Gill Net Survey

The North Carolina Division of Marine Fisheries (DMF) Pamlico Sound Independent Gill Net Survey was initiated on March 1, 2001 and field sampling began in May 2001. The primary objective of the project is to provide independent relative abundance indices for key estuarine species in Pamlico Sound and adjacent rivers.

A stratified random sampling design is used, based on area and water depth. The SAS procedure PLAN was used to randomly select sampling grids within each area (SAS Institute 1985). Sampling gear consists of an array of nets consisting of 30-yard (27.4 m) segments of 3, 3½, 4, 4½, 5, 5½, 6, and 6½ inch (7.6, 8.9, 10.2, 11.4, 14.0, 15.2, 16.5 cm) stretched mesh webbing [240 yards (219.5 m) of gill net per sample]. Gear was typically deployed within an hour of sunset and fished the following morning to keep all soak times at a standard 12 hours.

For every random grid selected, both a deep (1.8 m contour) and shallow array of nets are set. Some deep grids outside the 1.8 m contour were dropped in 2005 due sea turtle interactions and low catch rates of target species. The PSIGNS study is divided into two regions that includes eastern Pamlico Sound and western Pamlico Sound.

Floating gill nets are used to sample shallow strata while sink nets are fished in deep strata. Catches from an array of gill nets comprised a single sample and two samples (one shall, one deep), totaling 480 yards (438.9 m) of gill nets fished, are completed in each field trip.

Sampling initially occurred during all 12 months of the year. This was changed in 2002 and sampling no longer occurs between December 15 - February 14 due to extremely low catches and unsafe working conditions (limited daylight hours and cold temperatures) for the technicians.

Each area within a region is sampled twice monthly during most of the year. This sampling design results in a total of approximately 32 gill net samples (16 deep and 16 shallow samples) being collected per month in each the PSIGNS areas. Beginning in 2011, Area 1 of Region 1 is not sampled during the months of June through August. This reduction in sampling results in loss of 12 samples per year.

Catch rates of bluefish are calculated annually and expressed as an overall CPUE along with corresponding length class distributions. The overall CPUE provides a relative index of abundance showing availability of each species to the study, while the length distribution and age CPUE estimates show the size structure of each species for a given year. The overall CPUE was defined as the number of a species of fish captured per sample and was further expressed as the number of a species of fish at length per sample, with a sample being one array of nets fished for 12 hours. Due to disproportionate sizes of each stratum and region, the final CPUE estimate was weighted. The total area of each region by stratum was quantified using the one-minute by one-minute grid system and then used to weight the observed catches for calculating the abundance indices. Based on these modifications, uniform weighting factors by region and strata were applied to all years and were as follows:

Eastern Pamlico 1: Shallow water - 134.5 square nautical miles (461.9 square km)
Eastern Pamlico1: Deep water - 70.5 square nautical miles (242.1 square km)
Western Pamlico 2: Shallow water - 82.5 square nautical miles (283.3 square km)
Western Pamlico 2: Deep water - 54.5 square nautical miles (187.2 square km)

The CPUE for each age is calculated as an arithmetic mean weighted by strata (Table B6.1, Figure B6.12). The length frequency was determined for both seasons (spring, February – June, and fall July – December), and all four strata. The seasonal Catch-at-age (CAA) was estimated for both seasons using the seasonal length frequencies with seasonal age-length-keys (ALKs). The annual CAA was calculated by number of fish at each age for spring and fall. The annual CAA, in each stratum was multiplied by the stratum weight, and added across stratum to produce the weighted estimate for each age. The weighted estimate for each age is then divided by the total number of samples summed across all strata, producing a weighted annual CPUE for each age. All ages and sizes available were used to calculate the CPUE.

B6.1.12 SEAMAP

The Southeast Area Monitoring and Assessment Program (SEAMAP) fishery-independent trawl survey has sampled the coastal zone of the South Atlantic Bight between Cape Hatteras, North Carolina and Cape Canaveral, Florida since 1989. Its primary intent is to sample the coastal zone of the South Atlantic Bight (SAB) between Cape Hatteras, NC, to Cape Canaveral, FL.

A stratified random sampling design is used, based on area and water depth. For this design, coastal waters of the SAB are divided into 24 coastal latitudinal strata bounded inshore and offshore by the 4 m and 10 m depth contours, respectively. During each sampling season, a random subset of stations within each strata are selected for sampling using paired 75-ft (22.9 m) mongoose-type Falcon trawl nets towed for 20 minutes at 4.6 km/hr (2.5 knots).

Since the inception of the program the SEAMAP-SA Coastal Trawl Survey has used the R/V Lady Lisa to conduct annual surveys of finfish and invertebrate species. During each season, at each randomly selected station the SEAMAP-SA Coastal Trawl Survey deploys paired 75-ft (22.9 m) mongoose-type Falcon trawl nets to conduct bottom trawl surveys. At each randomly selected station, a bottom trawl is conducted by deploying the paired nets for 20 minutes at a constant speed of 4.6 km/hr (2.5 knots). Data elements include numbers caught by species, individual fork lengths (FL; nearest cm), and a suite of environmental information including bottom and sea surface water temperature, depth, and salinity.

The survey is conducted seasonally, with a spring (mid-April to mid-May), summer (mid-July to mid-August), and fall (late-September to mid-November) cruise annually. During each cruise, 52-112 stations between North Carolina and Florida (Figure B6.13) are selected for sampling via optimal allocation among strata for a total of approximately 158-336 stations sampled annually. The proportion of positive tows for age-0 Bluefish averaged approximately 27% across the time series for the fall survey. Index values are provided in Table B6.1.

B6.2 General Survey Results
Correlations among survey indices at age are shown in Figure B6.15. Of 131 comparisons (pairwise n > 0), 89 were positive and 40 were negative. Positive correlations outnumbered negative correlations for all ages except age 0.

Biases

All surveys were designed to sample either species in addition to bluefish or species other than bluefish. However, the BCT set a minimum for % positive tows and minimum for consecutive years of sampling (to eliminate intermittent sampling), consistent with other species (e.g., black sea bass, Atlantic menhaden, tautog), to help ensure surveys were representative of bluefish abundance. In several instance indices were standardized (e.g., RI and SEAMAP), but biases could result if important factors that affect standardization were not included. In most cases, the standardized index and the design-based index resulted in nearly identical trends.

B6.3 Composite YOY Index
States from New Hampshire to Virginia conduct seine surveys for juvenile finfish that capture YOY bluefish (Figure B6.14). These surveys are noisy and cover small geographical areas, compared to the range of bluefish. Bayesian hierarchical modeling was used to combine these indices into a single composite index, using the method developed by Conn (2010), that represents the coast wide recruitment dynamics of bluefish. Surveys included in the composite index were from NH Juvenile Finfish Seine Survey, RI Narragansett Bay Juvenile Finfish Beach Seine Survey, NY Western Long Island Seine Survey, NJ Delaware Bay Seine Survey, MD Juvenile Striped Bass Seine Survey, and VIMS Juvenile Striped Bass Seine Survey (Figure B6.16).

Conn's (2010) method assumes that all indices are tracking the abundance of recruits, but are also influenced by sampling error and process error (e.g., sampling different components of the coastwide recruit population).

$$\log(U_t) = Normal(\log(\mu_t) + \log(q_{it}), (\sigma_{it}^p)^2 + (\sigma_{it}^p)^2)$$

A Bayesian analysis was performed to estimate the true trend in relative abundance of recruits as well as the process error and catchability associated with each survey. The input parameters and priors were chosen to be the same as Conn (2010) and the Atlantic Menhaden assessment (SEDAR 2015) used.

A Normal(log(100), 1) distribution was chosen for $\nu_t = \log(\mu_t)$ The mean of this distribution, log(100), was chosen so that the mean of the relative abundance time series would be approximately 100. This number is arbitrary, since we are interested in the trends in relative abundance, not the actual number.

For catchability, which is assumed constant and estimated in log-space, χ_i was set as χ_i = Normal(log(0.01), 0.5), which gives reasonable support to plausible parameter values.

Finally, for process error, Gelman (2006) suggests that a Uniform(0,m) distribution may outperform other choices when there is a small number of group effects. We specified a Uniform(0, 5) prior distribution for σ^p, which gives equal weight to all plausible precision values.

The observed CVs from the surveys was used as the input sampling error. Zero observations were treated as missing data.

All posterior simulation was performed using the software package WinBUGS (Lunn et al. 2000), with the package R2WinBUGS (Sturtz et al. 2005) used to pass data sets between WinBUGS and the R programming environment (R Development Core Team 2007). Standard Bayesian diagnostics were used to assess convergence and stability of results.

The final composite index (Table B6.3) tracked several consistently strong recruitment events that were registered by multiple surveys, and smoothed out the noise somewhat in years with weaker signals (Figure B6.16).

B6.4 MRIP CPUE

The MRIP intercept data was queried to develop a set of directed bluefish trips, defined as any trip that caught bluefish (regardless of disposition) or where the angler reported targeting bluefish. This resulted in a total of 208,947 trips with the complete suite of explanatory variables, of which 46.2% were positive bluefish trips (Figure B6.17 and B6.18).

Factors considered for standardization included:

- Year
- Wave
- Mode (Shore, For Hire, Private/Rental Boat)
- Area Fished (Inshore, Offshore)
- State (Maine – Florida)
- Avidity (number of days that the angler reported fishing in the past year)

An interaction term between State and Wave was also considered, but the model did not converge with that included. The log of effort (number of contributing anglers) was treated as an offset in the models. GLMs using a Poisson distribution and a negative binomial distribution were explored, as well as a zero-inflated model.

Initial model comparisons suggest a negative binomial distribution is more appropriate than a Poisson distribution. (Dispersion = 1.62 with the negative binomial distribution vs. 9.76 with the Poisson distribution; likelihood ratio test of overdispersion of count data was significant at $p < 0.0001$). The zero-inflated model did not converge. The negative binomial was chosen as the final standardization approach, although there is still some overdispersion in the data (Figure B6.19).

All factors were significant for the negative binomial model. However, Area Fished reduced the deviance by less than 5% (Table B6.4) and was dropped from the model. This also resulted in a lower AIC value compared to the full model. The final GLM-standardized estimates of catch-per-unit-effort from the MRIP survey are provided in Table B6.5.

The MRIP CPUE shows a decline in catch per trip during the 1980s and mid-1990s, before rebounding in the late 1990s to fairly stable levels since 2000 (Figure B6.20).

B6.5 Spatial distribution of stock over time

For SAW60 Manderson et al. (2015; WP B4) investigated bluefish distributions and the degree to which spatial distribution shifts were statistically related to changes in ocean temperature, abundance and body size. Manderson et al. (2015) also described the development and evaluation of time varying estimates of the proportion of thermal habitat suitability for bluefish sampled on the NEAMAP & NEFSC bottom trawl surveys that could be used to account for effects of ocean temperature on the availability of the population to surveys in the stock assessment. The details are available in WP B4.

Within the NEFSC survey, age 0 (≤ 28 cm) and age 1+ bluefish (> 28 cm) shifted distribution from 1973 through 2014 but not in a systematic direction. Analysis of the centers of biomass (COB) indicated that COB positions were correlated with variations in body size and abundance, but not temperature. A parametric thermal niche model for bluefish using data from the NEFSC and NEAMAP bottom trawl surveys from 2008-2014 was used to evaluate with data collected by NEFSC before 2008 and 6 inshore surveys performed on along the US east coast at locations ranging from Jacksonville, Florida to Massachusetts. The model estimated that ~44% of thermal habitat suitability available from Cape Hatteras to Nova Scotia was sampled by the NEFSC inshore and "offshore" inshore strata to be used in the 2015 assessment. In the NEAMAP survey ~20% of available thermal habitat suitability on the northeast US shelf was sampled. Yearly estimates of the proportion of thermal habitat suitability surveyed did not exhibit consistent trends (Figure B6.21).

B6.6 Age-length data and utility of age data for stock assessment

As noted elsewhere in this document (TOR 2), the WG expended considerable effort investigating age length data and evaluating the utility of age length keys for use in this assessment. The WG could not recover any age data from 1982 (the first year in the SAW41 model) and determined that age data were too sparse from 1983 and 1984 to be considered reliable. Consequently, the WG elected to start the model in 1985.

NC scale and otolith data from early in the time series (1985-2000) required adjustments prior to their eventual use in this assessment. The SAW41 assessment document suggested that the raw spring NC data used a January 1 birthday and that other sources of spring data were incompatible with the NC data, but the WG determined that the reverse situation existed. The WG graphically demonstrated that a birthday problem existed with the spring early NC scale and otolith data (Figure B6.22, Figure B6.23), subsequently demonstrated that a birthday problem did not exist in other sources of spring data, and ultimately used all sources of age data with a January 1 birthday to inform a reclassification of spring NC age data (see WP B6 for more details).

In response to concerns expressed at SAW41 about sharing data across time, the WG conducted an analysis (WP B8) and quantitatively determined that in general sharing age data across time should be avoided. This put the WG in the position to have to either reclassify spring NC age data on an annual basis where sample sizes were small, not use spring NC age data (which would have truncate the time series considerably), or pool spring January 1 birthday data to inform reclassifying spring NC data. The WG felt comfortable that the adjustment algorithm3 provided reliable results (Figure B6.24) and was a superior outcome to the alternatives of further truncating the times series (especially in light of available data from 1997-2005) or using the raw data. It is important to note that all fall data used a January 1 birthday and therefore required no adjustments.

Age data from 1997-2004 garnered a lot of attention from reviewers at SAW41 (Jones 2005). An additional source of age data from this time period was evaluated by the SAW60 WG and used for the present assessment. As noted above, NC otolith data from 1996-2000 was considered incompatible with existing data for SAW41; but the SAW60 WG determined that with the exception of spring age 0 fish (Figure B6.23), which were changed to age 1 based on biological considerations, those data could be used for this assessment. This addition allowed for some disaggregation of multi-year spring keys (Table B5.2), however, since no additional sources of fall data were available for the same years, the SAW60 WG was not in a superior position with respect to the age data for this general time period. In terms of utility for stock assessment, the WG elected to set effective sample sizes to a low value for this time period (1997-20044) in acknowledgement of the data uncertainty. See TOR4 for more details.

The situation for age data in the years following SAW41 is very good. Beginning in 2006 NC resumed a bluefish biological collection program. Substantial numbers of bluefish otoliths have been collected as part of this program (Table B6.6). In an effort to further improve coast wide age length keys, MA initiated its own biological collection program in 2009, and NJ followed in 2010. In 2012, Addendum to Amendment 1 to the bluefish fishery management plan required additional states (those that accounted for >5% of total coast-wide bluefish harvest) to collect a minimum of 100 bluefish ages (50 from January - June; 50 from July - December), further improving the quality of age length keys. These additions to the coast wide biological collection program have greatly improved the age length keys for use in this assessment (Figure B5.3 and B5.4 and WP B5).

---

3 Briefly, based on biological considerations, all NC spring age 0 fish were changed to age 1. For all other ages, save 6+ which would not require any adjustments, from all data (by age) known to have a January 1 birthday, use the mean + $t_{0.05(2)}$ * SD (~ 2 * SD) of age i fish as the criterion to determine whether NC spring fish become age i+1. That is, for example, if the length of an age 1 NC fish was > the mean + $t_{0.05(2)}$ * SD of all other data sources of age 1 spring fish, the NC fish age would change to 2.
4 The WG also used a low ESS for 1995, which had a very sparse spring ALK (Table B5.3).

B7. TERM OF REFERENCE #4: Estimate relative fishing mortality, annual fishing mortality, recruitment, total abundance, and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Explore inclusion of multiple fleets in the model. Include both internal and historical retrospective analyses to allow a comparison with previous assessment results and previous projections. Explore alternative modeling approaches if feasible.

B7.1 Bluefish SAW 60 Assessment model

B7.1.1 History of the current (SAW41) bluefish assessment model

The current assessment model for bluefish has provided management advice since 2005 and was accepted at the Stock Assessment Workshop 41 review (NEFSC 2005). After reviewing several model types including a modified Delury model, a surplus production model, a VPA and catch-at-age models, the bluefish Technical Committee concluded that age-based models such as a VPA or catch-at-age were the most appropriate for the bluefish assessment. The bluefish data were truncated to an age-6+ category to reduce the influence of ageing error. In addition, the catch-at-age distribution in past assessments was bimodal, which was reduced with inclusion of more ages into a plus group.

The NFT ADAPT version of VPA was used as an initial model with a catch-at-age matrix from 1982 to 2004 through age-6+. The SAW-17 review of a bluefish assessment suggested that values of M should range from 0.2-0.25 instead of M=0.35 (NEFSC 1994a). Since the oldest aged bluefish is 14, an M of 0.2 was appropriate, using M=3/oldest age. The initial input PR was bimodal with a maximum value at age-1 of 1.0 and age-5 value of 0.74. The F ratio was set at 1.4 to create a higher F in the age-6+ group, forcing the model towards a bimodal F pattern. Full F was calculated as an average of F from age-2 to age-4.

Maturity at age was held constant over time as 0 at age-0, 0.25 at age-1, 0.75 at age-2 and 1.0 thereafter. Following initial runs including all available indices, the tuning indices were truncated based on proportional variance contributions to the overall model variance. The final tuning indices were limited to those with adults present:

1. NEFSC inshore (age-0 – age-6+)
2. CT trawl indices (age-0 – age-6+)
3. NJ trawl indices (age-0 – age-2)
4. DE adult trawl indices (age-0 – age-2)
5. Recreational CPUE (age-0 – age-6+)
6. SEAMAP series to include an age-0 recruitment series from the South Atlantic Bight.

Tuning was made to mid-year population size.

The Technical Committee concluded that although the VPA produced satisfactory results, the assumption of no error in the catch-at-age matrix and the way ADAPT handles selectivity may produce misleading results. Therefore, a catch-at-age model, ASAP from the NFT models, was chosen as the primary assessment tool. The ability of the ASAP model to allow error in the catch-at-age as well as the assumption of separability into year and age components makes it better suited to handle the selectivity patterns and catch data from the bluefish fishery.

The input values from ADAPT were used as initial values for the ASAP model. ASAP allows selectivity and catchability patterns to vary over time. The model was structured to allow greater deviations from the indices than from the catch-at-age data. A selectivity pattern was fitted to the data and held constant for the periods 1982-1990, 1991-1998 and 1999-2004. Recruitment was allowed to deviate from the fitted model after the 4th year. Full details of the SAW41 model characteristics and settings are provided in the 'SAW60 Model Building' section under 'Update the current model.'

The Bluefish Technical Committee concluded that the results of the ASAP model were the best representation of the Atlantic coast bluefish population. There was some tradeoff in the goodness of fit between the catch-at-age and survey indices in the model, but the overall model results were considered acceptable. The results also corresponded well to ADAPT model results. Although the agreement between models did not validate either model, it indicates that there was some signal in the data that could produce consistent output in two models with different assumptions. The model results lead to the conclusion that the Atlantic stock of bluefish was not experiencing overfishing nor was it overfished.

B7.2 SAW60 Model Building Introduction

The SAW60 model building procedure for bluefish was accomplished over multiple steps. The first step was to carry out a continuity run, which updated the current assessment model with data through 2014. A base model was then constructed by adding new data (CAA, WAA, and maturity) and indices to the continuity run, keeping the same model settings and weights. A model bridge was then built from the base model to a final model by changing model settings, weights, and data. In total, about 75 models were explored during this bridge building procedure. The model steps with the most important changes that provide a linear path from the base model to the final model are presented below. Table B7.1 provides a brief model description and a summary of the important parameters at each step.

The SAW60 working group maintained ASAP as the model for assessing bluefish. ASAP is an age-structured model that uses forward computations assuming separability of fishing mortality into year and age components to estimate population sizes given observed catches, catch-at-age, and indices of abundance. The separability assumption is partially relaxed by allowing for fleet-specific computations and by allowing the selectivity-at-age to change in blocks of years. Weights (Lambda and input CVs) are input for different components of the objective function which allows for configurations ranging from relatively simple age-structured production models to fully parameterized statistical catch-at-age models. The objective function is the sum of the negative log-likelihood of the fit to various model components. Catch-at-age and survey age composition are modeled assuming a multinomial distribution, while most other model components are assumed to have lognormal error. Specifically, lognormal error is assumed for: total catch in weight by fleet, survey indices, stock recruit relationship, and annual deviations in fishing mortality. Recruitment deviations are also assumed to follow a lognormal distribution, with annual deviations estimated as a bounded vector to force them to sum to zero (this centers the predictions on the expected stock recruit relationship). For more technical details, the reader is referred to the technical manual (Supporting documentation: ASAP manual, Legault 2012).

B7.3 Building a model bridge from the current model to the final model

B7.3.1 Update the current model through 2014: Model B001: Continuity Run

The current model for bluefish is heavily weighted towards the catch. Recreational landings, recreational discards, and commercial landings are input into the model as a single fleet. The input CV around catch is set at 0.01 and the effective sample size is constant at a value of 30. The model weighting parameter (lambda) for the catch is set at twice the value of the indices. Selectivities are fixed for both catch and the indices and multiple penalties constrain different estimates included in the objective function. These include penalties on recruitment deviations, FMult in the first year, index catchabilities, and numbers in the first year. A stock recruitment relationship is not fit in the model and steepness is fixed at a value of 1. The weighting factors and penalties in the continuity run result in a very constrained model.

Model B001, the continuity run, is the first model explored in the model building process for SAW 60. The continuity run was carried out as update of the SAW41 final model. Total catch, catch-at-age, weight-at-age, and indices-at-age were updated for 2014. The fishery was modeled as a single fleet with selectivity fixed as a bimodal pattern with full recruitment at age 1 (selectivity values = 0.338, 1.0, 0.942, 0.476, 0.343, 0.694, and 0.914, for ages 0-6+, respectively). In addition, 6 indices of abundance were updated for 2014:

1. NEFSC inshore (age-0 – age-6+)
2. CT trawl indices (age-0 – age-6+)
3. NJ trawl indices (age-0 – age-2)
4. DE adult trawl indices (age-0 – age-2)
5. Recreational CPUE (age-0 – age-6+)
6. SEAMAP series to include an age-0 recruitment series from the South Atlantic Bight.

Indices were input at age with full selectivity (1.0) fixed on the input age. Natural mortality was kept constant at 0.2 for all ages and all years. Maturity was fixed across years at a value of 0 for Age 0, 0.25 for Age 1, 0.75 for Age 2, and full maturity at Age 3+. Complete model specifications and weightings for model B001 are presented in Table B7.2.

The component contribution of the objective function for model B001 show how the model is weighted very heavily towards the single catch fleet (Figure B7.1). Estimates from the model show a decrease in total abundance since 2006, declining from 83.6 million to 57.7 million fish (Figure B7.2). Following a peak in recruitment in 2006 of 30.8 million fish, recruitment has remained below the time series average of 20.5 million, and stays below average in 2014 at an estimate of 14.7 million fish (Figure B7.3). Total biomass in 2014 (Jan 1) equaled 92,755 mt, a slight decrease from the 2013 estimate of 107,443. Corresponding spawning stock biomass (SSB) in 2014 was 84,800 mt, a slight decrease from the 2013 estimate of 98,070 mt (Figure B7.4).

The 2014 F_{MULT} value equals 0.141. Fishing mortality steadily declined from 0.35 in 1987 to 0.12 in 2012 and has increased over the past two years (Figure B7.5).

Retrospective bias for the continuity run was examined for F, SSB, and recruitment (Figure B7.6). The analysis shows consistent but minor bias in the estimates of F and SSB, with Mohn's rho values of -0.09 and 0.10, respectively. A more prominent retrospective bias is present in the recruitment estimates going back to the early 2000's (Figure B7.6). This bias has been increasing in recent years, and has flipped from a positive bias early on to negative bias more recently (Mohn's rho avlue = -0.19). The variation in the final continuity model estimates for F and SSB was determined using a Monte Carlo Markov Chain with 1000 iterations and a thinning factor of 100. The MCMC distribution for SSB ranged from 74,656 to 98,154 mt, with an 80% CI between 79,384 mt and 89,590 mt. (Figure B7.7). The MCMC results of variation around F ranged from 0.12 to 0.161, with the 80% CI between 0.132 and 0.150 (Figure B7.8).

Model B002: Cropping the continuity run to start in 1985

The working group re-built catch-at-age and weight-at-age information back to 1985 using all available age data and length samples. The working group was unable to find original age length keys and was unable to find raw age data from 1982-1984. Instead of using the current CAA and WAA information from those years (carried over from SAW41) the working group made the decision to start the new model in 1985. Model run B002 examines the effects of cropping off data from 1982-1984 on the continuity run. The main effect of starting the model in 1985 was to shift recruitment and total stock numbers upwards. F, SSB, and TSB increased minimally while TSN (000s) increased from 57,671 to 70,867, and recruitment (000s) increased from 14,696 to 21,528 (Table B7.1).

B7.3.2 Moving from the continuity run to a final model

Model B004: Base Model

The base model run uses continuity model specifications with newly calculated CAA, WAA, and total landings data from 1985-2014, and new survey indices of abundance. The new indices of abundance are input at age to maintain consistency with the continuity run. The bluefish working group decided on 9 representative indices of bluefish abundance for the SAW60 assessment:

1. NEFSC Fall inner inshore strata: 1985-2008 (age-0 – age-6+)
2. NEFSC Fall outer inshore strata: 1985-2014 (age-0 – age-6+)
3. Marine Recreational Information Program CPUE: 1985-2014 (age-0 – age-6+)
4. NEAMAP Fall Inshore trawl survey: 2007-2014 (age-0 – age-6+)
5. Connecticut Long Island Sound Trawl Survey: 1985-2014 (age-0 – age-6+)
6. Pamlico Sound Independent Gillnet Survey; 2001-2014 (age-0 – 6+)
7. New Jersey Ocean Trawl Survey: 1990-2014 (age-0 – age-2)
8. SEAMAP Fall Inshore trawl survey: 1989-2014 (age-0)

9. Composite YOY seine survey: 1985-2014 (age-0)

In past stock assessments, the instantaneous natural mortality (M) for bluefish has been assumed constant over all ages and years at a value of 0.2. This study used longevity and life-history based equations to estimate different possible values for M. Taking the maximum age for bluefish to be 14 years (observed age in the data used in these analyses), the 'Rule of thumb' method (3/tmax) give a natural mortality estimate of 0.21. Additional longevity based estimates from equations in Hoenig (1983) and Hewitt and Hoenig (2005) give values of 0.32 and 0.3, respectively. Estimates based on equations that use growth parameters from Then et al. (2014) and Jensen (1996) give values of 0.20 and 0.195, respectively. The mean value for natural mortality using the estimates from these 5 approaches is 0.245. Age-specific estimates were calculated using based on the work of Lorenzen (1996, 2000) and Gislason et al. (2010). These values ranged from 1.70-0.17 over the age range of 0-14 (Table B5.5). Based on the results of all the methods explored to estimate natural mortality for bluefish, the assumption of M = 0.2 is reasonable and is maintained for the benchmark assessment.

The results from the base model are very similar to the continuity run (B001), and differ in total number and recruitment estimates when compared to model B002. Using the newly calculated data and new indices in model B004 resulted in almost no change in the 2014 F between model B002 (F = 0.145) and model B004 (F = 0.146). However, estimates of F from model B004 were consistently higher from 2002 to 2013 (Figure B7.9). Total stock numbers (000s) decreased from 70,867 to 57,534, and recruitment estimates (000s) decreased from 21,528 to 15,731. These changes are driven by lower estimates of Age 0 through Age 2 numbers from the new data (Table B7.1 and Figure B7.10).

Model B006: Change indices from at-age to estimate age composition

The preferred approach for including survey indices of abundance in ASAP has shifted from at-age input to a catch-at-age matrix input. In this model run, the new input survey indices are shifted from at-age to a catch-at-age matrix, and are modeled with multinomial error to estimate proportions at age. The total numerical index for each survey is modeled with lognormal error to estimate overall population trend. Young of the year indices (SEAMAP and the composite YOY index) are still input at-age.

Estimating age composition for each of the survey indices in model B006 resulted in a noticeable increase in all 2014 model estimates except for F. The objective function increased considerably and while a direct comparison cannot be made to the objective function from model B004, the increased contribution of the index fit and index age composition is important to note. This model, while still heavily weighted towards the catch is now being driven more by the indices (Figure B7.11). The estimate of F decreased to 0.119, and estimates for total stock numbers, spawning stock biomass, total stock biomass, and recruitment all increased considerably. The scale of total biomass and spawning stock biomass was shifted downwards at the beginning of the time series resulting in flatter trends from 1985-2014 (Table B7.1, Figure B7.12). Figure B7.13 shows the estimates for index selectivity from model B006.

Model B007: From single catch fleet to two fleets: Commercial and Recreational

The fishery for bluefish is predominantly a recreational fishery (80+%) and the recreational data on landings, lengths, and discards are collected very when compared to the commercial fishery data. There is enough information for both fisheries to build separate catch-at-age, weight-at-age and total landings time series. Model B007 separates the single fleet fishery into a commercial and recreational fleet. Incorporating multiple fleets addresses a specific portion in term of reference 4 which tasks the working group to “Explore inclusion of multiple fleets in the model.” In addition, it is more appropriate method for modeling the bluefish stock because of the differences between the fisheries.

Separating the fleet data into two fisheries scaled up the entire time-series of fishing mortality estimates and decreased estimates of total stock numbers and biomass (Table B7.1, Figure B7.14). The recruitment time-series from model B007 is similar to model B006 but seems to be smoothed at the end of the time series (Figure B7.15).

Model B008: Update maturity information

Maturity-at-age was updated from a preliminary analysis of data presented in the section and working paper for TOR2. Estimates of maturity-at-age for bluefish have persisted from the 2005 ADAPT VPA model (modeling work prior to the final SAW41 ASAP model) where values were (arbitrarily?) chosen to be: 0, 0.25, 0.75, and 1.00 for ages 0 to 3+, respectively. For this model run a maturity ogive was fit using logistic regression to a preliminary bluefish age/maturity dataset and the estimates of: 0, 0.41, 0.86, and 1.00 for ages 0 to 3+, respectively, were used. It should be noted that further along in the model building process final estimates for the maturity ogive were used (model B023). At this step, the new maturity information was not that different from the maturity-at-age previously used, and only resulted in a slight increase in spawning stock biomass (Table B7.1, Figure B7.14).

Model B011: Change from fixed fleet selectivities to estimated

Prior to model B011, fleet selectivity has been fixed assuming a bi-model selectivity at-age carried over from SAW41. The bi-modal selectivity pattern for the bluefish fishery has been present since the beginning of the assessment time-series. This pattern has been observed in both commercial and recreational length frequencies and as a result in the CAA matrix input to the model. There is a dynamic of the bluefish population that occurs at age 3 – age 4 that is unobserved and likely affects availability of the population at these ages. Bluefish carry out sized based migrations so a larger portion of the population at these ages may be staying south or offshore each year. Since the main fisheries for bluefish are coastal and operate north of Cape Hatteras, North Carolina this would result in reduced available of this size/age class.

Model B011 estimates fleet selectivites and assumes starting values equal to the previously fixed values. Full selectivity is fixed at age 1 in both the commercial and recreational fleet. Estimated selectivities for both fleets maintain a bi-modal pattern, with the recreational fleet having higher selectivity at all ages (Figure B7.16). Estimates of F slightly increased in model B011 to a value of 0.145. Total stock numbers, recruitment, and biomass estimates increased at a larger scale as a result of estimating fleet selectivities (Table B7.1).

Model B020: Estimate 2 selectivity blocks per fleet

A number of model iterations were conducted that investigated different selectivity blocks for each fleet between model B011 and B020. The working group decided to continue the model building process with two selectivity blocks per fleet: 1985-2005, 2006-2014. These blocks were chosen based on data quality assumptions associated with age data early on in the time series (scale age data) versus later in the time series (otolith age data). The working group put a great deal of effort into uncovering, addressing and resolving these issues. A full write up on the age data can be found in TOR 2 and 3 sections of this document.

Changing the model to include two estimated selectivity blocks per fleet resulted in significant shifts in all estimates (Table B7.1). Selectivity in block 1 for both fleets was estimated assuming bi-modal selectivity-at-age with full selectivity fixed at age-1. Selectivity in block 2 for both fleets was estimated assuming a bi-modal selectivity-at-age with full selectivity at age-2. The shift to full selectivity at age-2 was made after multiple iterations and fitting both at-age selectivity and assuming a double logistic fit. Commercial and recreational fleet selectivity in time block 2 are dome shaped with a single mode, unlike the bi-modal selectivities estimated in the early time block (Figure B7.17). The domed selectivity at older ages in block two is resulting in the large increase in biomass estimates from Model B011 to B020 (Figure B7.18).

Model B020A: ESS = 0 in middle time-block (1997-2005)

The age keys used from 1997-2005 have the least amount of year specific information. As described in TOR 2 and 3 of this document many of the seasonal keys borrow across years during this time period. Previous reviews (SAW41) highlighted the negatives of this approach and the how it is likely inappropriate to borrow across years or seasons to fill in the sparse age keys. A number of analyses were carried out and confirm that borrowing across years is not valid for bluefish (WP B8). Unfortunately, the keys are too sparse during this time period and borrowing is unavoidable. To mitigate the effects of borrowed keys model B020A sets the effective sample size for these years equal to 0, and does not fit to the age composition. This has a minimal effect on the model estimates when compared to model B020A (Table B7.1 and Figure B7.18).

Model B021: Change weighting factor input style. Set Lambdas = 0 or 1.

Model B021 was an important step in the model building process. Up until this point, model weighting factors (lambdas) were consistent with the inputs used in the continuity run (Table B7.1). The method of weighting used in the continuity run is not the preferred method, and in some cases was emphasizing portions of the objective function more than expected. The preferred method is to use the lambda values as a switch to turn on or off portions of the objective function (0 = off, 1 = 0). When these weighting factors are switched on, the input value and input CV act as a prior during the minimization of the associated portion of the objective function. In the continuity run, and all models in the bridge up to this point, many of the lambda values were > 1 and acting as both a switch, and a weight. This resulted in very constrictive priors around the associated portions of the objective function.

The switch in weighting style for this model gave equal weight to the two catch fleets, and the 9 survey indices. This equal weighting is reflected in the likelihood contribution for each of the components in the objective function (Figure B7.19). Estimates of F did not significantly change from Model B020A, however the entire scale of total population numbers and biomass time-series decreased dramatically. Surprisingly, recruitment estimates remained almost identical to model B020A (Table B7.1).

Model B021A: Turn likelihood constants off in the objective function

Recently, an issue with constants in likelihood function of ASAP has been uncovered. The specific issue has to do with a constant that depends on recruitment parameters. The lognormal distribution with notation specified for application to recruitment deviations is:

$$\frac{1}{R_{y,v}\sqrt{2\pi}\sigma} e^{-\frac{(\ln(R_{y,v})-\ln(R_{y,e}))^2}{2\sigma^2}}$$

where $R_{y,v}$ is the recruitment value estimated in year y, σ is the user supplied standard deviation of the recruitment deviations, and $R_{y,e}$ is the recruitment expected from the underlying stock-recruit curve. The negative log likelihood, $-\ln(L)$, which is what is used in the objective function for most applications, equals:

$$-\ln(L) = n_{rec}\frac{ln(2\pi)}{2} + \sum ln(R_{y,v}) + n_{rec}ln(\sigma) + \frac{1}{2}\sum\frac{(\ln(R_{y,v}) - \ln(R_{y,e}))^2}{\sigma^2}$$

where n_{rec} is the number of recruitment deviations. The first three terms on the right hand side of the equation are often referred to as constants (assuming σ is not an estimated parameter) that do not affect model estimation and so are often dropped from the likelihood. However, in this case, the term $\sum \ln(R_{y,v})$ is not a constant and depends on model parameters. Consequently, ignoring this term as a constant is technically incorrect, while retaining the term may have unintended consequences for model fit. Preliminary work demonstrates that including this term can, in some cases, lead to underestimates of recruitment because the objective function can be reduced by lowering the estimated recruitment values.

Model B021A turns off the likelihood constants in the objective function, the current preferred method for dealing with the above issues. All estimates from the model increased when these likelihood constants were turned off (Table B7.1). The recruitment estimates are no longer being lowered by the specific likelihood constant which is likely resulting in the increased estimates.

Model B022: No penalty on numbers in the first year deviations

Model B022 removes one of the two remaining penalties on numbers in the first year deviations. Lambda for these values was switched on in all previous model runs and the input CV was set at 0.9. This penalty served to scale the initial population biomass by assuming a prior distribution around the numbers in the first year. We do not have any prior information relating to initial stock numbers so it is preferable to allow the model complete flexibility around these estimates. Turning off this penalty reduced the estimates of F from model B021A, and caused numbers and biomass estimates to scale up again (Table B7.1 and Figure B7.20).

Model B023: Finalized maturity-at-age data

Maturity-at-age was updated from a final analysis of data presented in TOR 2 and WP B2. In previous models, the estimates of maturity-at-age were from an analysis of a preliminary bluefish age/maturity dataset: 0, 0.41, 0.86, and 1.00 for ages 0 to 3+, respectively, were used. After compiling a final dataset of all available bluefish maturity-at-age information a logistic regression was refit to estimate a maturity ogive. The final values used in model B023 were: 0, 0.40, 0.97, and 1.00 for ages 0 to 3+, respectively. Spawning stock biomass estimates were the only minor change resulting from this new maturity ogive (Table B7.1).

Model B 024: Increase the CV around recruitment deviations from 0.5 to 1.0

Model B024 increased the CV around the recruitment deviations from 0.5 to 1.0 to give the model more flexibility around these estimates. This causes very little change in estimates from the previous model (Table B7.1). It should be noted that sensitivity runs were carried out in an attempt to remove this penalty completely; however, the resulting models had issues with convergence and scale.

Model B025 and Model B027: Change some selectivities

Model B025 and B027 shifted selectivities on time block 2 of the fleets from selectivity-at-age to double logistic, and from double logistic to selectivity-at-age for the NEFSC survey indices. These changes were to better match the selectivity patterns coming out of the previous models. Making these changes resulted in very little differences in model estimates from previous model runs (Table B7.1).

Figure B7.21 shows the differences in model estimates from model B022 and B027 to gauge the impacts of the various minor changes between these model steps. The total effect was to minimally decrease the main estimates coming out the model.

Model B028: Revert back to 1 selectivity block per fleet

During the model meeting for the SAW60 bluefish assessment the working group discovered an issue with the early spring scale age data coming from North Carolina. The working group was always aware of a disparity between the scale age data in the early time series (1985-1996) and the otolith age data later (2006-2014). The reason for the disparity was pinpointed to spring North Carolina ages and the likelihood that some of these ages represent a biological birth date as opposed to assuming a Jan 1 birth date (the accepted ageing protocol practice for bluefish). A very detailed description of the analyses and the correction the working group made to these scale ages can be found in the TOR3 age section of this document and WP B6.

Model B028 was run in anticipation of including corrected data in the model. The working group's initial justification for splitting the fleets into selectivity blocks was the disparity in age data between time blocks. Having corrected these data, there was no longer justification to split the fleet selectivities into two blocks. It should be noted there have been no specific fishery changes or management changes for bluefish over the time series that would result in a fishery selectivity change.

Fleet selectivity was estimated at-age for both fleets assuming starting values equal to the fixed selectivity values from SAW41. Shifting back to one selectivity block per fleet had a small effect on the model estimates and shifted the scale of all estimates down (Table B7.1).

Model B029: Change the NEFSC surveys to split off the Bigelow survey

For model runs previous to this model, the NEFSC fall survey has been split into inner inshore strata and outer inshore strata. The inner inshore strata time-series was sampled by F/V Albatross IV from 1985-2008. The sampling of these strata has been taken over by the NEAMAP survey, which is included as an index of abundance from 2007-2014. The outer inshore strata were sampled by F/V Albatross IV from 1985-2008, and from the NEFSC new research vessel the R/V Bigelow from 2009-2014. The Bigelow is not able to sample the shallower inner inshore band which the NEAMAP survey now samples. For the outer inshore survey, a conversion factor has always been applied to Bigelow units to correct them to Albatross equivalents. The value used in past update assessments was 1.16 and comes from an extensive calibration study between the vessels (Miller et al. 2010).

At the model meeting for SAW60, the working group decided to shift the NEFSC indices and move forward with the Bigelow split off a separate time series. It has been a decade since the last benchmark assessment for bluefish and it is likely there will be an extended period before the next benchmark. While the Bigelow time series is currently only 6 years, the value of this time series to the model, without having to use a conversion factor, will increase over the next few years.

In model run B029, an NEFSC inshore survey using all inshore strata (all Albatross data) and a Bigelow survey representing the outer inshore band of strata were used as indices of abundance. Splitting off the Bigelow time-series and changing the input indices for the NEFSC fall survey had very minor impacts on the model estimates. The estimates of fishing mortality, total stock numbers, recruitment and biomass all decreased very slightly from the previous model run (Table B7.1).

Model B030: Switch MRIP selectivity to match fleet 2

Model B030 is a result of questions raised at the bluefish SAW60 model meeting. Previous to Model B030, the MRIP index assumed different starting values for selectivity than the recreational fleet. The question was raised as to why the two selectivities did not match even though the time series of landings and the CPUE index are derived from the same data. This fact is not entirely true, and the working group has addressed that in a later model run (B042).

The comparison to the selectivity of fleet 2 was not the only issue discovered with the input selectivity for the MRIP Index. The previous selectivity was not fixed at any age and the model was free to estimate all parameters. Previous model runs should have had a fully selected age for this index and without it the biomass estimates from these models were biased low. The MRIP index is the most important index in the bluefish assessment as it drives age composition estimates for the older ages. Most of the other surveys do not catch many older fish.

Model B030 changes the starting values for the MRIP index selectivity to match the starting values for the selectivity of fleet 2. Fish are fully selected at age one and the input matches the previously described bi-modal pattern. Figure B7.22 presents the model B029 selectivity estimates for the MRIP index, as well as model B030 selectivity estimates for both the MRIP index and Fleet 2. The MRIP index has higher selectivity at older ages than Fleet 2. See the write up for B042 for an explanation of why the selectivities are different, and why at-age selectivity for MRIP is probably not appropriate.

Switching the input selectivity patterns for the MRIP index significantly increased biomass estimates. As mentioned previously, MRIP is the most important index in the model, especially for tracking older ages. The doming of the selectivity estimates at older ages seemed to create a lot of cryptic biomass in model run B030. Estimates of fishing mortality declined slightly from previous models and estimates of total stock numbers, and recruitment increased (Table B7.1 and Figure B7.23).

Model B033: Early NC scale ages corrected and data were re-calculated

Model B033 has the same model specifications as Model B030 except revised data are used. In this model issues with NC scale age data from 1985 to 1996 have been corrected (see TOR 2 and 3 of this document and WP B6 for a detailed explanation). The implemented correction decided up on by the working group bumped groups of scales up 1 age. This had a predictable outcome of decreasing F, and increasing the estimates of numbers and biomass when compared to model B030 (Table B7.1, Figure B7.23).

Model B035: Switch PSIGN selectivity from double logistic to at-age

This model made minor change to the PSIGN selectivity which was being estimated as a double logistic selectivity curve. The selectivity for this index was switched to at-age and the resulting changes to the model estimates were minor increases in stock numbers and biomass (Table B7.1).

This model was final model formulation coming out of the SAW60 model meeting. Plans were to make minor changes to input CVs, and effective sample size changes to finalize the model. The working group was concerned about the inflated biomass estimates and the problem of cryptic biomass. However, no cause or resolution was determined prior to the end of the meeting. Part of the finalization of the model involved running a retrospective analysis. The results indicated somewhat severe retrospective bias in all of the estimates (Figure B7.24). In order to determine the cause of the retrospective patterns, retrospective analyses were carried out in a stepwise manner, for each previous model in the model building process. It was determined that the dome in MRIP selectivity was causing the retrospective patterns as well as the cryptic biomass.

Model B042: Change MRIP selectivity to single logistic and increase fleet 2 input CV

In model B042, a flat-top, single logistic curve was input for the MRIP selectivity. This fixed both the retrospective patterns seen in model B033 and removed the cryptic biomass being estimated by the model.

Re-visiting an earlier question: Why is the selectivity of the MRIP index different from Fleet 2 (the recreational catch) if they are developed from the same data? For the recreational catch the working group assumed a 15% mortality rate for the recreational discards. However, to calculate the MRIP index at-age, all of discard data were used. This is important because there is a very noticeable difference in the size distributions of landed fish versus discarded fish. Bluefish are a unique recreational species in that the size distribution of the discards is much larger than the landed fish (Figure B4.11). This can be attributed to the fact that bluefish are a very oily fish, more so at larger sizes, and for many people large bluefish are unpalatable. This leads to a domed selectivity for the recreational catch because most of the larger sized fish are released. However, it is safe to assume these ages are fully selected by the discards and should be fully selected for the MRIP index since 100% of the discards are used to calculate the age proportions. The working group used this reasoning to justify shifting the selectivity for MRIP from a selectivity-at-age to a flat-top, single logistic curve, that fully selects the older ages.

The estimates from model B042 are have shifted drastically from prior model runs. Fishing mortality increased, and total stock numbers, recruitment, and biomass estimates have decreased. As mentioned previously, the new selectivity estimates for MRIP eliminated the cryptic biomass being estimated by earlier models and greatly reduced the retrospective bias in the estimates. Total biomass and spawning stock biomass estimates from model B042 were around 50% of the estimates from the previous model (Table B7.1 and Figure B7.25).

Model B043: adjustments to input CVs and effective sample sizes

One of the final changes in the model building process was iterative adjustments to the input CV of each index to account for additional process error. The model was re-run and adjustments were made for each index until the root mean square error of the index was close to a value of 1.0. In addition to fine tuning the input CVs of the surveys, a low effective sample size was assigned to the middle period time block 1997-2005. The working group decided while the age information in this time block was poor (because of pooled age keys and borrowing across years) a small effective sample size should be input to generate some information about age composition in these years.

Model B043 had similar estimates to model B042 with slightly greater fishing mortality, total stock number, and recruitment estimates, and slightly decreased estimates of biomass (Table

B7.1).

Please note, this model was the final SAW60 WG model that was taken to the SARC60 review. For full diagnostics and results from this model please see appendix B7.

B7.3.3 A Final Model

Model B044 (BFINAL): Final model after SARC60 review

Model B044 is the new final bluefish model resulting from the SARC60 benchmark review. At the review, the review panel discovered a model misspecification in the selectivity parameters for the MRIP index. A parameter in the function describing the curve for selectivity was fixed when it was intended to have been freely estimated by the model. This was causing patterning in the age composition residuals for this index. The final revised model corrects this misspecification. The values presented in this report reflect the output from the revised model as accepted at the review.

Final model data summary: Catch proportions for the recreational fleet ranged from 66% to 84% of the total catch (Figure B7.26). Catch-at-age for both fleets is predominantly age 0 to age 3, with the recreational fleet catching more age 0, and both fleets catching lesser numbers at older ages (Figures B7.27 and B7.28). Overall survey index trends are generally flat, with noticeable peaks for some of the indices early in the time series, and around 2005 (Figure B7.29). Input age composition for the indices are presented in Figures B7.30 through B7.35. Final model inputs for weight-at-age of the fleets, natural mortality, and maturity-at-age are presented in Figures B7.36 through B7.41.

The main contributions to the objective function were from the likelihood components of the index and catch age compositions (Figure B7.42). Compared to the previous assessment model from SAW41, which was heavily weighted towards the single catch fleet, model BFINAL gives equal weight to all components.

B7.4 Final Model Diagnostics

BFINAL model diagnostic plots for the fit to the two catch fleets are presented in Figures B7.44 through B7.51. Diagnostic plots for the 9 survey indices are presented in Figures B7.52 through B7.81. For reference when viewing some of the plots:

Fleet 1 = Commercial
Fleet 2 = Recreational
Index 1 = NEFSC Inshore trawl
Index 2 = NEFSC Bigelow trawl
Index 3 = MRIP recreational CPUE
Index 4 = NEAMAP trawl
Index 5 = SEAMAP Age 0
Index 6 = PSIGN gillnet

Index 7 = CT LISTS trawl
Index 8 = NJ Ocean trawl
Index 9 = Composite YOY seine

The final model estimated higher fishing mortality and lower abundance and biomass than model B043 (Table B7.1). Selectivity at-age estimates for the two catch fleets were both domed, with a bi-modal pattern still evident in the commercial fleet (Figures B7.82 and B7.83). Fishing mortality for the recreational fleet has always been higher than the commercial fleet, in some year two to three times as much. Fishing mortality estimates in 2014 for the commercial and recreational fleets were 0.049 and 0.108, respectively (Figure B7.84). Final model estimates for the index selectivities show a rapid decrease in selectivity after age 0. A few of the indices have higher selectivity towards larger/older fish, the most important being MRIP and PSIGNS, and to a lesser extent the Bigelow survey (Figure B7.85). Observed and predicted catch-at-age for the two fleets and nine indices are presented in Figures B7.86 through B7.103. Estimates of age composition at older ages are poorly predicted for some of the components.

B7.5 Final Model Results

Average F for from 1985 to 2014 from the final model was 0.284 and average SSB was 79,449 mt (Table B7.4). Spawning stock biomass dipped from a high of 154,633 mt in 1985 to a low of 52,775 mt in 1997 and has steadily increased to a value of 86,534 mt in 2014 (Table B7.4, Figure B7.104). The majority of the spawning stock biomass (50-60%) is in the age 6+ group for the entire time-series (Figure B7.105). Estimates of F have remained below average since 1997 and the 2014 estimate of 0.157 is well below the time series average (Table B7.4, Figure B7.104). There has been a steady decline in fishing mortality since 2007.

Estimates from model BFINAL showed a decrease in total abundance since 2006, declining from 91.5 million to 65.2 million fish in 2012 (Table B7.5, Figure B7.106). Total abundance increased in 2013, and 2014, to 72.1 and 82.0 million, respectively. Age 0 and age 1 fish collectively average around 50% of abundance for the time-series. Below average (24.0 million) recruitment began in 2008 with an estimate of 23.1 million fish (Table B7.4, Figure B7.107). Low recruitment persisted through 2012 to the lowest estimate of the time-series at 16.7 million. Recruitment for 2013 and 2014 have increased above the average to 25.1 and 29.6 million fish, respectively. Throughout the time series the plus group contains the majority of the biomass (Table B7.6). Biomass estimates for 6-plus bluefish have remained above the time series average of 41,600 mt since 2010. Total mean biomass in 2014 equaled 94,328 mt, a slight decrease from the 2013 estimate of 96,922 mt (Table B7.6, Figure B7.108).

Retrospective bias for the final model was examined for F, spawning stock biomass, recruitment, total biomass, exploitable biomass, total abundance, and abundance-at-ages 1 through 6. The analysis shows small bias in the estimates of F (Mohn's rho = -0.12), SSB (Mohn's rho = 0.19), and recruitment (Mohn's rho = 0.05) (Figure B7. 109). Similarly, there is little retrospective bias in estimates of total biomass (Mohn's rho = 0.18), exploitable biomass (Mohn's rho = 0.10) and total abundance (Mohn's rho = 0.06) (Figure B7.110). There does appear to be minor retrospective bias in some of the estimates of abundance-at-age, particularly numbers at age 5 (Mohn's rho = 0.19) and numbers at age 6 (Mohn's rho = 0.23) (Figures B7.111 and B7.112).

The variation in the final model results for F and SSB was determined using a Monte Carlo Markov chain with 1000 iterations and a thinning factor of 1000 (1,000,000 iterations). Trace plots for both SSB and F show little to no patterning (Figures B7.113 and B7.114).There is no significant autocorrelation in the F chain (Figure B7.115). Autocorrelation plots show minor autocorrelation in the SSB (both 1985 and 2014) chain at a lag of 1, with no autocorrelation at a lag greater than 2 (Figure B7.116). The MCMC results of SSB for 2014 ranged from 50,804 mt to 112,588 mt, with a median estimate of 76,062 mt, and 80% confidence interval ranging from 65,078 mt to 86,752 mt. The 2014 SSB point estimate from the final model (86,534 mt) is greater than the median estimate from the MCMC distribution (Figure B7.117 and B7.118). Variation around F ranged from 0.110 to 0.282, with the 80% CI between 0.139 and 0.202. The point estimate from the final model (0.157) is less than the median estimate (0.166) from the MCMC distribution (Figure B7.119 and B7.120).

B7.6 Final model sensitivity runs

A number of sensitivity runs were carried out by changing data inputs to the final model.

Changes to the recreational data

The first group of sensitivities explored different changes made to the estimation of various components of the recreational catch. A total of 5 sensitivity runs were conducted for the recreational data: 1. Assume recreational landings (AB1) lengths apply to the recreational discards (B2), 2. Assume recreational catch at the upper 95% CI of estimates, 3. Assume recreational catch at the lower 95% CI of the estimates, 4. Use MRFSS numbers prior to 2004 (no conversion to MRIP equivalents), and 5. Assume 17% recreational discard mortality instead of 15%. Comparisons between final model and sensitivity run estimates of F, total stock numbers, recruitment, and SSB are presented in Figures B7.121 through B7.125.

Changes to data structure and inputs

Additional final model sensitivity runs were conducted that changed other components of the input data: 1, A regional sensitivity run was explored that used northern and southern regional age-length keys to age the fleets and surveys from 2006 to 2014, 2. Length-weight coefficients were varied over time by three time blocks, 1985-1994, 1995-2004, 2005-2014, 3. Virginia landings date were calculated using a different methodology (VA set 2). Comparisons between final model and sensitivity run estimates of F, total stock numbers, recruitment, and SSB for these sensitivity runs are presented in Figures B7.126 through B7.128.

Sensitivity runs were also carried out the final model assuming different input values for natural mortality. A profile of the objective function was calculated over a range of natural mortality estimates, and the objective function was minimized at a value of 0.263 (Table B7.7 and Figures B7.129 and B7.130). Age-based inputs for natural mortality were also explored (Table 1.50 and Figure B7.131). The estimates assuming age-based M derived from equations in Gislason et al. 2010 resulted in unrealistic model estimates (Table B7.8).

Changes to the survey indices

Sensitivity of the final model to individual survey indices was also tested by removing each index and re-running the model (Table B7.9). The model is fairly insensitive to the removal of all the indices except for the MRIP recreational CPUE index, which is driving the model along with the two catch fleets. The reason this index is so important is because it provides most of the information for model estimates at older ages. Removing the MRIP index and re-running the final model results in a significant decrease in fishing mortality estimates and an increase in abundance and biomass estimates (Table B7.9 and Figure B7.132). An additional model run using just the two catch fleets and the single MRIP index was also conducted. Without the other indices the model loses some information to inform estimates of younger ages and recruitment is scaled up. However, the overall trend and scale of biomass and fishing mortality estimates are not that different from the final model (Figure B7.132).

Investigating habitat suitability indices

Habitat suitability information was also investigated for the NEFSC surveys as well as the NEAMAP survey. Annual estimates of habitat suitability were input as a covariate on availability in the ASAP model (catchability = availability*efficiency, where efficiency was assumed = 1). The use of the habitat suitability indices did not improve the fit of the model to the respective indices. This is not surprising, since the annual estimates of available thermal habitat sampled by the NEFSC and NEAMAP surveys did not show significant trends which would cause a bias in trends of relative abundance (Figure B6.21). In addition, these indices used a hindcasted estimate of sea bottom temperature to derive estimates of bluefish habitat suitability. The ocean model used to hindcast these temperatures was not available for 2013 and 2014 and as a result no index of habitat suitability was available for these years (See WP B4 for full details). The working group decided to go forward without incorporating habitat suitability in the model. There was concern because recent information was not available, as well concern for the ocean model that was used to develop the indices. A habitat suitability index developed from an ocean model using real-time or forecasted sea-surface temperature would be more appropriate for bluefish. This is included as a research recommendation and could be developed for future bluefish assessments.

B7.7 Historical retrospective analysis

Historical retrospective comparisons between the final model and both the continuity run, and the SAW41 assessment show fairly consistent results among estimates (Figure B7.133). Over time, annual updates of the SAW41 model shifted model estimates of total stock numbers, recruitment and fishing mortality. The shift can be observed in comparisons of the continuity run and the SAW41 model. The SAW60 final model for bluefish brings these estimated time-series back in line with the SAW41 model estimates.

B7.8 Alternative Model Runs

B7.8.1 Depletion Corrected Average Catch Model

As an alternative to the base model run using the statistical catch-at-age (SCAA) framework detailed above, we estimated sustainable yield using MacCall's (2009) Depletion-Corrected Average Catch (DCAC). The sum of landings from 1985-2014 is approximately 550,000 mt with an annual average of 18,325 mt (Table B7.10). DCAC requires an estimate of fractional depletion ("delta," which is the change in relative biomass, in units of unfished relative biomass). Our delta estimate is based on preliminary model runs and results of the last update (47.1%; http://www.asmfc.org/uploads/file/552ea3fe2014BluefishStockAssessmentUpdate.pdf) that suggested approximately a 50% depletion in spawning stock biomass over the catch period. Our point estimate for natural mortality (M) was based on the work of Then et al. (2015) and their Pauly$_{nls\text{-}T}$ estimator ($M = 4.118k^{0.73}L_{\infty}^{-0.33}$; $k = 0.311$ and $L_{\infty} = 815.3$ from Robillard et al. 2009). This is very similar to the M estimate assumed in ASAP SCAA base model. Other DCAC parameters were set to be consistent with MacCall (2009) and Dick and MacCall (2011) (Table B7.10; Figure B7.134). DCAC was implemented with software available from the NMFS toolbox (DCAC V2.1.1; http://nft.nefsc.noaa.gov/DCAC.html). The median of the DCAC distribution was 13,479 mt (Figure B7.135). The average harvest of bluefish throughout the region during the period 2012-2014 was 10,618 mt, with no year exceeding 11,254 mt. This suggests that recent annual harvests were at sustainable levels.

We performed a number of DCAC sensitivity analyses to look at the impact assumed model parameters had on sustainable yield estimates (Table B7.11). All possible combinations of input parameters were investigated, resulting in a total of 192 individual model runs (including the base run presented above). Results of all runs suggested that recent average harvest of bluefish in the terminal 3 years of the assessment (10,618 mt) were sustainable as median sustainable yield levels from all DCAC runs exceeded this value (Figure B7.136).

B7.7.2 Depletion Based Stock Reduction Analysis (DBSRA)

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.

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

We can select reasonable values to describe the productivity of the population, 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 (1) sustain those catches without being driven to extinction and (2) end up at some known fraction of *K* at the end of the time series?

Similar to DCAC, input parameters (Table B7.12, Figure B7.137) are drawn from distributions based on expert opinion about bluefish and meta-analysis of similar stocks. Uncertainty about these parameters is incorporated into the final estimates of *K* and the management parameters of interest (MSY, OFL). DBSRA requires as complete a time-series of catch as possible, so harvest from 1950-2014 was used. Estimates of commercial landings were available from 1950 onwards through ACCSP. Recreational harvest estimates are available from MRFSS/MRIP from 1982 onwards. To hindcast recreational landings, the average ratio of recreational to commercial harvest from 1982-2014 was used to scale the commercial landings up from 1950-1982. Dick and MacCall (2011) assume that catch is known without error, which is not the case with a recreationally important species like bluefish. 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. Natural mortality was assumed to be 0.2, consistent with the ASAP model runs. The ratio of F_{MSY} to M and B_{MSY} to K followed distributions recommended by MacCall (2009), as was done with the DCAC runs. The ratio of B_{2014} to K was based on the estimates of B_{2014} to B_{MSY} from the most recent update of the ASAP model where a stock-recruitment model was used to estimate MSY-based reference points.

DBSRA estimated a median MSY for bluefish of 19,954 mt, with an OFL for 2015 of 20,0245 mt (Table B7.13, Figure B7.138). This method cannot be used to assess stock status (i.e., overfished or experiencing overfishing), because status relative to K is one of the inputs to the model. However, the management parameters (MSY, OFL) derived from this model are robust to assumptions about stock status. Results of all runs suggested that recent average harvest of bluefish in the terminal 3 years of the assessment (10,618 mt) were sustainable, as they are below the estimated MSY from the DBSRA.

B7.7.3 Model Comparisons

The data poor models corroborate the scale of the ASAP model and agree with the determination that harvest in recent years has been sustainable.

All three models produced roughly similar estimates of sustainable harvest for bluefish, and indicate that recent harvest has been below the maximum sustainable yield. DBSRA estimated the highest MSY, but encompasses the estimates of the other two models in the 5th and 95th percentiles of the estimate.

B8. TERM OF REFERENCE #5: State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, F_{MSY}, and MSY) and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.

The current biological reference points for bluefish were determined in SARC 41 and are F_{MSY} (0.19) and B_{MSY} (147,052 mt). The basis for the reference points was the Sissenwine-Shepherd method using the Beverton-Holt stock recruitment parameters and SSB per recruit results generated by the SARC 41 ASAP model results. B_{MSY} was calculated using mean weights at age and is therefore comparable to mean biomass in year *t*. Overfishing of a stock occurs if F exceeds F_{MSY} and a stock is considered overfished if total biomass is less than half of B_{MSY} ($B_{THRESHOLD}$). The existing definition of overfishing is F > 0.19 and B < 73,526 mt.

The TC and WG concluded that new reference points were required because of the uncertainty present in the stock recruitment relationship estimated by the current model. The time series of spawning stock biomass and recruitment does not contain any data about recruitment levels at low stock sizes (Figure B8.1), and the BTC and the SAW 60 WG did not believe the fitted parameters adequately described the stock-recruitment relationship for bluefish.

Because MSY based reference points require a stock recruitment relationship, MSY proxies are required. As a proxy for F_{MSY}, the BTC and the SAW 60 WG recommend $F_{40\%\ SPR}$. The input maturity and composite selectivity curves are shown in Figure B8.2. The resulting YPR and SPR curves are shown in Figure B8.3.

To calculate the associated target and threshold for biomass, the population was projected forward for one hundred years under current conditions with fishing mortality set at the F_{MSY} proxy and recruitment drawn from the observed time series. The WG originally proposed that the biomass threshold be based on total biomass, to be consistent with the previous assessment and current management, but the SARC panel determined that spawning stock biomass was a more appropriate reference point. The resulting equilibrium spawning stock biomass is the recommended SSB_{MSY} proxy, with the overfishing threshold set at ½ SSB_{MSY}. Similarly, the equilibrium landings under projected under F_{MSY} proxy = $F_{40\%SPR}$ were set as the MSY proxy.

The revised reference points are F_{MSY} proxy = F40% = 0.170 and B_{MSY} proxy = 111,228 mt (½ SSB_{MSY} = 55,614 mt). The MSY proxy is 13,967 mt.

The usage of these proxies has been accepted in many other assessments and is considered adequate in cases where a stock recruitment relationship is not estimable. Recent SAW assessments where MSY proxies have been used include the Gulf of Maine haddock (2014), summer flounder (2013), and white hake (2013).

SPR-based reference points are not sensitive to uncertainty in the stock-recruitment relationship, but do not link future recruitment to spawning stock biomass. The projection approach used to establish the B_{MSY} proxy incorporates the observed variability in recruitment, but assumes that recruitment is independent of SSB. This assumption is not unreasonable over the observed high levels of bluefish abundance, and maintaining the stock close to the proposed target should minimize the risk of this assumption.

B9. TERM OF REFERENCE #6: Evaluate stock status with respect to the existing model (from previous peer review accepted assessment) and with respect to a new model developed for this peer review.

B9.1 Stock status from the continuity run

a. **When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.**

The existing reference points are F_{MSY} = 0.19 and B_{MSY} = 147,052 mt (½ B_{MSY} = 73,526 mt). The 2014 F estimate (0.141) is well below F_{MSY} and the 2014 estimate of B is 92,755 mt, below B_{MSY} but well above ½ B_{MSY}. This indicates that overfishing is not occurring and that the stock is not overfished (Figure B9.1).

B9.2 Stock status for the current assessment

b. **Then use the newly proposed model and evaluate stock status with respect to "new" BRPs and their estimates (from TOR-5).**

The new reference points are F_{MSY} proxy = F40% = 0.170 and SSB_{MSY} proxy = 111,228 mt (½ SSB_{MSY} = 55,614 mt). The 2014 F estimate (0.157) is below $F_{40\%}$ and the 2014 SSB estimate (86,534 mt) is greater than ½ SSB_{MSY}, indicating that overfishing is not occurring and that the stock is not overfished (Figure B9.2 and B9.3).

Reference Point	**SARC 41**		**Updated**	
	Definition[1]	Value	Definition[1]	Value
$\mathbf{F_{Threshold}}$	F_{MSY}	0.19	$F_{MSY\ proxy} = F_{40\%SPR}$	0.170
$\mathbf{B_{Target}}$	B_{MSY}	147,052 mt	Equilibrium SSB under $F_{40\%SPR}$	111,228 mt
$\mathbf{B_{Threshold}}$	½ B_{MSY}	73,526 mt	½ $SSB_{MSY\ Proxy}$	55,614 mt

[1]: Note that the SARC 41 biomass reference points refer to total biomass, while the updated biomass reference points refer to spawning stock biomass.

B10. TERM OF REFERENCE #7: Develop approaches and apply them to conduct stock projections and to compute the statistical distribution (e.g., probability density function) of the OFL (overfishing level; see Appendix to the SAW TORs).

B10.1 Provide annual projections (3 years). **For given catches, each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment)**

Short-term projections were conducted using AGEPRO v.4.2.2 (available from the NOAA Fisheries Toolbox, http://nft.nefsc.noaa.gov/AGEPRO.html).

Removals in 2015 were assumed to be equal to the 2015 quota (9,722 mt). For 2016-2018, a constant level of fishing mortality was applied. The population was projected forward under five different F levels:

- F_{low} = 0.100
- $F_{status\ quo}$ = 0.136
- $F_{0.1}$ = 0.203
- F_{TARGET} = 90%$F_{MSY\ Proxy}$ = 0.163
- $F_{MSY\ Proxy}$ = $F_{40\%SPR}$ = 0.181

Uncertainty was incorporated into the projections primarily via estimates of recruitment and initial abundance-at-age.

Estimates of recruitment were drawn from the 1985-2014 time-series of observed recruitment from the preferred ASAP model. Initial abundance-at-age estimates were drawn from distributions of terminal abundance-at-age developed from the MCMC runs of the preferred ASAP model. A small amount of uncertainty was incorporated into biological parameters such as weight-at-age, maturity-at-age, and natural mortality; estimates of these parameters were drawn from lognormal distributions with mean values used in the terminal year of the assessment and a CV of 0.01.

The projections were conducted with a single fleet. Selectivity was calculated by summing the commercial and recreational F-at-age for each age from the preferred ASAP model over the last three years of the model and dividing by the maximum F-at-age to develop a composite selectivity curve. A CV of 0.01 was also applied to the selectivity-at-age estimates.

The model exhibited a minor retrospective pattern. Estimates of retrospective bias-adjusted SSB and F were within the credible intervals from the MCMC runs of the accepted model estimates Figure B10.1), so a retrospective adjustment was not deemed necessary.

None of the fishing mortality scenarios resulted in total biomass going below the biomass threshold (½ $SSB_{MSY\ Proxy}$) in any year of the projection; spawning stock biomass remained above the biomass threshold with 100% probability in all years (Table B10.1, Figure B10.2).

The overfishing limit (OFL) for 2016 was estimated to be 10,528 mt (23.2 million lbs) with a CV of 0.10 (Table B10.1, Figure B10.3). A qualitative inflation was applied for known sources of uncertainty that are not adequately captured in the projection process, including retrospective bias and uncertainty in the F_{MSY} proxy estimate, resulting in a recommended CV of 0.15.

A sensitivity analysis approach was used to determine the effects of major sources of model uncertainty that could not be encompassed through the MCMC runs of the base model. This included:

- Limiting the empirical recruitment distribution to the CDF of observed recruitment for 2006-2014 (the years of the best available age data)
- Higher M (M=0.26)
- Increased uncertainty in selectivity-at-age, weight-at-age, and maturity-at-age (CV of 0.1 instead of 0.01)

Please note: these sensitivity runs were carried out with the results of Model B043, not the revised BFINAL model.

Using the more limited recruitment time series did not significantly change the estimates of landings or biomass from the projections (Table B10.2, Figure B10.4). This is not surprising, since the median recruitment of the 2005-2014 period (26.4 million fish) is not significantly different from the median recruitment of the entire time series (24.5 million fish). Higher M values resulted in higher estimates of landings and biomass, but did not change the probability of going below the biomass threshold (0% in all years). Increasing the CV on the biological parameters did not significantly change the median of the distributions for biomass or landings in each year, but did increase the confidence intervals. The probability of being above the biomass threshold remained 100%.

B10.2 Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.

The WG considers the base model configuration the most realistic projection scenario. While estimates of recruitment in the most recent 10 years of the time-series (derived in part from the best age information) are likely more reliable than the estimates from the beginning of the time-series, the median recruitment and projection time-series are virtually indistinguishable.

B10.3 Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, and how this could affect the choice of ABC.

Bluefish are a fast-growing, fast-maturing species with a moderately long life span. Although they recruit to the fishery before they are fully mature, larger, older fish are considered unpalatable, reducing demand for those sizes in the commercial market and encouraging the release of those size classes in the recreational fishery. The resulting dome-shaped selectivity of the fleets offers protection to the spawning stock biomass. Although they are a popular gamefish, demand for this species is not extreme and the quota is rarely met or exceeded.

Bluefish are opportunistic predators that do not depend on a single prey species. Their range covers the whole of the Atlantic coast, and their spawning is protracted both temporally and geographically. As a result, they are not as vulnerable as many other species to major non-fishery drivers such as climate change that would result in the loss of critical forage or nursery habitat.

This assessment indicates bluefish are near their target biomass and well above their overfished threshold. Short-term projections indicate no risk of driving the biomass below the overfished threshold while fishing at or near the FMSY proxy. Overall, bluefish have a low degree of vulnerability to becoming overfished, and the ABC can be set on the basis of the FMSY proxy without risk of causing the stock to become overfished.

B11. TERM OF REFERENCE #8: Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in most recent SARC reviewed assessment and review panel reports, as well as MAFMC SSC model recommendations from 2005 and the research recommendations contained in its 23 September 2013 report to the MAFMC. Identify new research recommendations.

B11.1 Progress Made in Addressing Previous Research Recommendations.

Commercial Data

- Increase sampling of size and age composition by gear type and statistical area
- Target landings for biological data collection and increase intensity of sampling for biological data.

Addendum I to the Bluefish FMP has resulted in additional commercial biological data (e.g., age, sex, weights) being available (e.g., from NC and NY). Prior to Addendum I, the NC biological collection program targeted commercial landings for biological data (e.g., 2006-2011, age, sex, weight).

Recreational Data

- Increase sampling of size and age composition by gear type and statistical area
- Target landings for biological data collection and increase intensity of sampling for biological data

Addendum I to the Bluefish FMP has resulted in additional recreational biological data (e.g., age, sex, weights) being available from all participating states; in addition, volunteer recreational angler surveys from several states (CT, RI, and NJ) are now providing recreational discard data for use in the bluefish stock assessment.

Ageing Data

- Complete a scale-otolith comparison study

Both independent research and an inter-agency bluefish ageing workshop confirmed that the use of sectioned otoliths is the preferred method by which to age this species (Robillard et al. 2009; ASMFC 2011). Further, each agency follows the standard otolith processing, reading, and age-assignment protocols developed by ODU. Some variations do exist with respect to processing, but these are relatively minor (e.g., baking before or after sectioning, mounting sections using various adhesives, etc.) and allowable as determined by the 2011 Bluefish Ageing Workshop. In response, all organizations that currently are involved with efforts to age bluefish for the purposes of informing the stock assessment for this species do so using sectioned otoliths and the 2011 protocol. The WG determined at the model meeting (WP B6) that historic age scale ages (excluding NC spring scales) were comparable to otolith ages and hence historic scale age data were retained for model runs.

- Conduct study or workshop to address discrepancies between estimated bluefish age from scales and otoliths and the chronological age. Examine issues of inter- and intra-reader variation in interpretation of ages

It was unclear to the WG exactly what this research recommendation was suggesting (especially in light of the previous research recommendation). To the extent that this research recommendation is related to a non-January 1 birthday for early NC spring age data, at the model meeting the WG made adjustments to the NC spring scale and otolith data (WP B6); those corrected spring ages were incorporated into the final assessment.

For the second part of the research recommendation, an ageing workshop was held in 2011 to produce guidelines for future aging work on bluefish. Intra-agency measures of ageing precision are available for nearly all of the organizations currently collecting age data (WP B5). The few organizations that were unable to provide estimates of precision due to staffing limitations (i.e., no second reader), will likely will be able to do so in the future as ageing programs develop further and assuming additional resources become available. Based on inter-agency measures and the 2011 Workshop, the WG felt comfortable using the expanded sources of age data.

- Examine the feasibility of each state collecting samples of hard parts for ageing, with one or two laboratories interpreting the annuli for consistency

The 2011 workshop resulted in Addendum I to the bluefish fishery management plan, which required all states that capture a substantial portion of bluefish landings to collect and age a minimum of 100 bluefish samples per year. Inter-agency comparability of age data is currently maintained through the adherence to standardized processing and ageing protocols for bluefish, while the digital reference collection developed by the states and maintained by the ASMFC also promotes this consistency by serving as a training tool and reference collection. Formal ageing exchanges meant to quantify inter-agency precision and bias have yet to occur for bluefish. It should be noted, however, that recent exchanges for other species, including black sea bass and summer flounder have shown that standard exchange practices are effort-intensive and often suffer from serious design flaws (ASMFC 2013). The latter issue results in measures of inter-agency precision and bias from the exchange that are not representative of the quality of age data provided by the participating organizations to the assessment process, and are therefore wholly uninformative. Further, discussions regarding the consolidation of all processing and ageing of bluefish under a single agency have determined that the current multi-agency approach is the superior design (WP B5). Gains in consistency that are realized using a single set of processors/readers are offset by increases in bias that arise due to lack of localized knowledge regarding life history and growth.

Fishery-Independent Data

- Continue research on species interactions and predator-prey relationships

No progress made on this item beyond development of working paper summarizing diet information (WP B3) for bluefish derived from NEFSC, NEAMAP, ChesMMAP, and SEAMAP which addressed portions of TOR #2.

- Examine alternative weighting schemes for the available fishery-independent surveys (area, inverse variance, N, etc.)

The Conn (2010) hierarchical approach which implicitly weights surveys by uncertainty was applied to combine multiple noisy state YOY indices that were criticized during the previous review as being unrepresentative of coastwide recruitment due to their individual limited spatial and temporal extent. The WG did not have time to explore model runs using weighting schemes alternative to this.

Finally, the WG adjusted fishery independent survey input CVs in the assessment model to get the RMSEs near 1, and ESS for fishery independent surveys to reflect confidence in age data over different time periods.

- Investigate the feasibility of alternative survey methods that target bluefish across all age classes to create a more representative fishery-independent index of abundance

No specific progress made on this item regarding survey gear types. However, the TC included additional fishery independent surveys (e.g., PSIGNS) that do target a wider age range (0-6+) in the current assessment.

- Initiate sampling of offshore populations in winter months

No progress made on this recommendation.

- Conduct research on influences on recruitment including pathways of larval bluefish

Research has been conducted on recruitment dynamics of bluefish (e.g., multiple cohorts; see paragraph below) however, time constraints prevented the WG from incorporating cohort-specific indices in the model.

Recent research has focused on the factors that influence bluefish survival from the young-of-year stage to age-1. Taylor et al. (2006) concluded that young of year bluefish almost exclusively utilize habitats on the inner continental shelf. Scharf et al. (2006) quantified the inter cohort dynamics of young of year bluefish. Taylor and Able (2006) provide additional information on cohort hatch date and differences in growth between spring and summer cohorts. Morely et al. (2007) explored how energy storage influenced juvenile young of year survival. Taylor et al. (2007) provide further information on fine scale habitat selection of young of year bluefish. Wuenschel et al. (2012) synthesized coastwide data to develop a conceptual model of the processes underlying bluefish recruitment. Morely et al. (2013) documented size selective overwinter mortality of young of year bluefish.

- Initiate coastal surf zone seine study to provide more complete indices of juvenile abundance

Research suggests that the coastal surf zone is important habitat (Able et al. 2013). No progress made on this item.

Models, Inputs, and Outputs

- Explore a tag based assessment and associated costs compared to age based assessments

No progress made on this recommendation. The WG determined that this item is no longer relevant given the potential costs and limited benefits.

- Determine if a tag based assessment could supplement or replace other assessment techniques

No progress made on this recommendation. The WG determined that this item is no longer relevant given the potential costs and limited benefits.

- Continue to examine alternative models including a forward projection catch-at-age model

The intent of this item was not entirely clear to the WG since the previous assessment model was a forward projecting catch at age model. This notwithstanding, the SAW 60 WG explored the application of two models designed to provide catch guidance in data poor situations: Depletion Corrected Average Catch Model (DCAC) and Depletion-Based Stock Reduction Analysis. (See Section B7.3 and Appendices for more details.) Both methods suggest that recent annual harvests were at sustainable levels.

B11.2 New Research Recommendations

High Priority

- Determine whether NC scale data from 1985-1995 are available for age determination; if available, re-age based on protocols outlined in ASMFC (2011); if re-aging results in changes to age assignments, quantify the effects of scale data on the assessment
    - Would allow for validation of the adjustments to the early NC spring age data made by WG at model meeting (WP B6)
- Develop additional adult bluefish indices of abundance (e.g., broad spatial scale longline survey or gillnet survey)
    - Given the limited information on older (e.g., age 2+) bluefish collected by existing fishery independent surveys this item addresses the need to adequately characterize dynamics of older fish that are currently not well sampled by fishery independent trawl surveys.
- Expand age structure of SEAMAP index

- Given patterns of bluefish migration and recruitment (Shepherd et al. 2006, Wuenschel et al. 2012), it is important to monitor bluefish abundance in SAB; currently, the SEAMAP index used in the assessment indexes age 0 abundance only, but recent age data from SEAMAP suggests collection of age 1 and 2 fish that would help inform the SAB age structure

Moderate priority

- Investigate species associations with recreational angler trips targeting bluefish (on a regional and seasonal basis) to potentially modify the MRIP index used in the assessment model
  - Given the importance of the MRIP index in the assessment model, this addresses a need to accurately estimate effort for of the MRIP index (reduce risk of hyperstability)
- Explore age- and time-varying natural mortality from, for example, predator prey relationships; quantify effects of age- and time-varying natural mortality in the assessment model
  - This addresses the issue of predation on bluefish by, for example, coastal sharks and/or limited prey resources (top down effects, bottom up effects, and/or environmental effects)
- Continue to evaluate the spatial, temporal, and sector-specific trends in bluefish growth and quantify their effects in the assessment model
  - Addresses appropriateness of WG pooling age data spatially (and temporally) for potential changes regarding the efficiency of the biological collection program
- Continue to examine alternative models that take advantage of length-based assessment frameworks. Evaluate the source of bimodal length frequency in the catch (e.g., migration, differential growth rates);
  - This item would address a source of uncertainty in the assessment with age data from different hard parts & provide means to examine the appearance of bimodal length frequency in the catch data
- Modify thermal niche model to incorporate water temperature data more appropriate for bluefish in a timelier manner [e.g., sea surface temperature data & temperature data that cover the full range of bluefish habitat (SAB and estuaries)].

- This addresses the current limitations of the habitat suitability model for bluefish (limited to hindcast bottom temps, in the MAB).

B12. Literature Cited

Able KW, Fahay MP. 1998. The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight. Rutgers University Press. New Brunswick, NJ.

Able KW, Rowe P, Burlas M, Byrne D. 2003. Use of ocean and estuarine habitats by young of the year bluefish (*Pomatomus saltatrix*) in the New York Bight. Fishery Bulletin 101:201-214.

Able KW, Wuenschel MJ, Grothues TM, Vasslides JM, Rowe PM. 2013. Do surf zones in New Jersey provide “nursery” habitat for southern fishes? Environmental Biology of Fishes 96:661-675.

Atlantic States Marine Fisheries Commission (ASMFC).1989. Fishery Management Plan for Bluefish. 81 pp. + append.

Atlantic States Marine Fisheries Commission (ASMFC). 2011. Proceedings of the Atlantic States Marine Fisheries Commission Bluefish Ageing Workshop. ASMFC, Alexandria, VA. 26p.

Atlantic States Marine Fisheries Commission (ASMFC). 2012. Addendum I: Biological Monitoring Program. Arlington, VA. 3 pp.

Atlantic States Marine Fisheries Commission (ASMFC). 2013. Proceedings of the 2013 Black Sea Bass Ageing Workshop. ASMFC, Alexandria, VA. 18p.

Austin HM, Scoles D, Abell AJ. 1999. Morphometric separation of annual cohorts within Mid-Atlantic bluefish, *Pomatomus saltatrix*, using discriminant function analysis. Fishery Bulletin 97:411-420.

Barger LE. 1990. Age and growth of bluefish *Pomatomus saltatrix* from the northern Gulf of Mexico and U.S. South Atlantic coast. Fishery Bulletin 88:805-809.

Bartholomew A, and Bohnsack JA. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Reviews in Fish Biology and Fisheries 15:129-154.

Beaumariage DS. 1969. Returns from the 1965 Schlitz tagging program including a cumulative analysis of previous results. Florida Dept. of Natural Resources, Marine Research Lab Technical Series No. 59:1-38.

Bednarski MS. 2015. Application of multiple logistic regression for detecting differences in proportion in age at length for bluefish, *Pomatomus saltatrix.* SAW/SARC Working Paper B8.

Bell GW, Buckel, JA, Stoner AW. 1999. Effects of alternative prey on cannibalism in age-1 bluefish. Journal of Fish Biology, 55: 990-1000.

Bogstad B, Pennington M, Volstad JH. 1995. Cost-efficient survey designs for estimating food consumption by fish. Fisheries Research. 23(1-2): 37-46.

Brooks EN, Miller TJ, Legault CM, O'Brien L, Clark KJ, Gavaris S, and Eeckhaute LV. 2010. Determining Length-Based Calibration Factor s for Cod, Haddock and Yellowtail Flounder. Transboundary Resource Assessment Committee Reference Document 2010/08:26.

Buckel JA, Fogarty MJ, Conover DO. 1999b. Foraging habits of bluefish, *Pomatomus saltatrix*, on the U.S. east coast continental shelf. Fishery Bulletin, 97: 758-775.

Bugley K, Shepherd GR. 1991. Effect of catch-and-release angling on the survival of black sea bass. North American Journal of Fisheries. Management, 11:468-471

Chiarella LA, Conover DO. 1990. Spawning season and first year growth of adult bluefish from the New York Bight. Transactions of the American Fisheries Society 119:455-462.

Chittenden ME Jr., Barbieri LR, Jones CM, Bobko SJ. 1990. Initial information on the Atlantic croaker, annual report on the development of age determination methods, life history – population dynamics information and evaluation of growth overfishing potential for important recreational fishes. April. Submitted to the Virginia Marine Resources Commission. 88 p.

Collins MR, Stender BW. 1987. Larval king mackerel (*Scomberomorus cavalla*), Spanish mackerel (*S. maculatus*), and bluefish (*Pomatomus saltatrix*) off the southeast coast of the United States, 1973-1980. Bulletin of Marine Science 41:822-834.

Conn PB. 2010. Hierarchical analysis of multiple noisy abundance indices. Canadian Journal of Fisheries and Aquatic Sciences 67:108-120.

Davidson, WR. 2002. Population structure of western Atlantic bluefish (*Pomatomus saltatrix*). Master’s Thesis. Thesis. University of Delaware., Wilmington, DE.

Dick EJ, MacCall AD. 2010. Estimates of sustainable yield for 50 data-poor stocks in the Pacific coast groundfish fishery management plan. NOAA Technical Memorandum NMFS-SWFSC-460. 201 pp.

Dick EJ, MacCall AD. 2011. Depletion-Based Stock Reduction Analysis: A catch-based method for determining sustainable yields for data poor fish stocks. Fisheries Research 110:331-341.

Diodati, PJ, Hoopes TB. 1991. Fisheries Monitoring Report for the Massachusetts 1990 Striped Bass Fisheries prepared for the ASMFC Striped Bass Technical Committee. Massachusetts Division of Marine Fisheries. 1-26.

Fabrizio MC, Scharf FS, Shepherd GR, Rosendale JE. 2008. Factors affecting catch-and-release mortality of bluefish. North Am. J. of Fisheries Management 28:533-546.

Fahay MP, Berrien PL, Johnson DL, Morse WW. 1999. Essential Fish Habitat Source Document: Bluefish, *Pomatomus saltatrix*, Life History and Habitat Characteristics. NOAA Technical Memorandum, NMFS-NE-144:78.

Gelman A. 2006. Prior distributions for variance parameters in hierarchical models (comment on article by Browne and Draper). Bayesian Anal. 3: 515–534.

Gislason H, Daan N, Rice JC, Pope JG.2010. Size, growth, temperature and the natural mortality of fish. Fish and Fisheries 2: 149-158.

Goodbred CO, Graves JE. 1996. Genetic relationships among geographically isolated populations of bluefish (*Pomatomus saltatrix*). Marine and Freshwater Research 47:347-355.

Gottschall K, Pacileo D. 2013. Marine Finfish Survey, Job 2. In: A Study of Marine Recreational Fisheries in Connecticut. Annual Progress Report, CT DEP/Marine Fisheries Division, Old Lyme, CT. 148 pp.

Graves JE, McDowell JR, Beardsley AM, Scoles DR. 1992. Stock structure of the bluefish *Pomatomus saltatrix* along the Mid-Atlantic coast. Fishery Bulletin 90:703-710.

Hamer PE. 1959. Age and growth studies of the bluefish (*Pomatomus saltatrix* Linnaeus) of the New York Bight. Master’s Thesis. Rutgers University, New Brunswick, NJ.

Hare JA, Cowen RK. 1993. Ecological and Evolutionary Implications of the Larval Transport and Reproductive Strategy of Bluefish *Pomatomus saltatrix*. Marine Ecology Progress Series 98:1-16.

Hare JA, Cowen RK. 1995. Effect of age, growth rate, and ontogeny on the otolith size -- fish size relationship in bluefish *Pomatomus saltatrix*, and the implications for back-calculation of size in fish early life history stages. Canadian Journal of Fisheries and Aquatic Science 52:1909-1922.

Hewitt DA, Hoenig JM. 2005. Comparison of two methods for estimating natural mortality based on longevity. Fish. Bull. 103:433-437.

Hoenig JM. 1983. Empirical use of longevity data to estimate mortality-rates. Fishery Bulletin 81(4): 898-903.

Jensen AL. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Canadian Journal of Fisheries and Aquatic Sciences, 53: 820–822.

Jones CM. 2005. 41st Northeast Regional Stock Assessment Workshop (SAW-41) Stock Assessment Review Committee (SARC) Meeting – Chair's Report prepared for University of Miami's Council for Independent Experts, Independent System for Peer Review. Northeast Fisheries Science Center, National Marine Fisheries Center, Woods Hole, MA June 6-9, 2005. 29 pp.

Juanes F, Conover DO. 1994. Rapid Growth, High Feeding Rates, and Early Piscivory in Young-of-the-Year Bluefish (*Pomatomus saltatrix*). Canadian Journal of Fisheries and Aquatic Sciences, 51: 1752-1761.

Juanes, F, Hare JA, Miskiewicz AG. 1996. Comparing early life history strategies of *Pomatomus saltatrix*: a global approach. Marine and Freshwater Research 47:365-379.

Kendall AWJ, Walford LA. 1979. Sources and distribution of bluefish, *Pomatomus saltatrix*, larvae and juveniles off the east coast of the United States. Fishery Bulletin 77:213-227.

Kendall AWJ, Naplin NA.1981. Diel-depth distribution of summer ichthyoplankton in the Middle Atlantic Bight. Fishery Bulletin 79:705-726.

Klein-MacPhee G. 2002. Bluefish: family Pomatomidae. In Bigelow and Schroeder's fishes of the Gulf of Maine (B. B. Collette, and G. Klein-MacPhee, eds.), p. 400−406. Smithsonian Institution Press, Washington, D.C.

Lassiter RR. 1962. Life history aspects of the bluefish, *Pomatomus saltatrix*, larvae and juveniles off the east coast of the United States. Fishery Bulletin 77: 213-227.

Link JS, Almeida FP. 2000. An Overview and History of the Food Web Dynamics Program of the Northeast Fisheries Science Center, Woods Hole, Massachusetts. US Dep Commer, NOAA Tech Memo NMFS NE 159; 60 p. Available at http://www.nefsc.noaa.gov/publications/tm/tm159/

Lo NC, Jacobson LD, Squire JL. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Canadian Journal of Fisheries and Aquatic Sciences. 49: 2515-2526.

Lorenzen K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. J Fish Biol. 49:627-647.

Lorenzen K. 2000. Allometry of natural mortality as a basis for assessing optimal release size in fish-stocking programmes. Can J Fish Aquat Sci. 57:2374-2381.

Lund WA, Maltezos GC. 1970. Movements and migrations of the bluefish, *Pomatomus saltatrix*, tagged in waters of New York and Southern New England. Transactions of the American Fisheries Society 99:719-725.

Lunn, DJ, Thomas A, Best N, Spiegelhalter D. 2000. Win-BUGS — a Bayesian modelling framework: concepts, structure, and extensibility. Stat. Comput. 10(4): 325–337.

MacCall AD. 2009. Depletion-corrected average catch: a simple formula for estimating sustainable yields in data-poor situations. ICES Journal of Marine Science 66:2267-2271.

Malchoff MH. 1995. Effects of catch and release angling on important northeast marine fishes: mortality factors and applications to recreational fisheries. Final Project Report. New York Sea Grant Extension Program, Cornell Cooperative Extension, Riverhead, New York. P. 1-20.

Marks RE, Conover DO. 1993. Ontogenetic shift in the diet of young-of-the-year bluefish *Pomatomus saltatrix* during the oceanic phase of the early life history. Fishery Bulletin 91:97-106.

McBride RS, Conover DO. 1991. Recruitment of young-of-the-year bluefish *Pomatomus saltatrix* to the New York Bight: variation in abundance and growth of spring- and summer-spawned cohorts. Marine Ecology Progress Series 78:205-216.

Mid-Atlantic Fishery Management Council. 1990. Fishery management plan for the bluefish fishery. Dover, DE. 81 p. + append.

Mid-Atlantic Fishery Management Council and Atlantic States Marine Fisheries Commission. 1998. Amendment 1 to the Bluefish Fishery Management Plan. Dover, DE.341 pp. + append.

Mid-Atlantic Fishery Management Council and Atlantic States Marine Fisheries Commission. 2007. Amendment 2 to the Bluefish Fishery Management Plan (Northeast Region Standardized Bycatch Reporting Methodology). Dover, DE. 289 pp. + append.

Mid-Atlantic Fishery Management Council. 2011. Amendment 3 to the Bluefish Fishery Management Plan (Omnibus ACL/AM Amendment). Dover, DE. 552 pp. + append.

Mid-Atlantic Fishery Management Council. 2013. Amendment 4 to the Bluefish Fishery Management Plan (Omnibus Recreational AM Amendment). Dover, DE. 116 pp.

Miller TJ, Das C, Politis PJ, Miller AS, Lucey SM, Legault CM, Brown RW, Rago PJ. 2010. Estimation of Albatross IV to Henry B. Bigelow calibration factors. NEFSC Ref. Doc. CRD 10-05.

Morley JW, Buckel JA, Lankford TE, Jr. 2007. Winter energy storage dynamics and cohort structure of young-of-the-year bluefish *Pomatomus saltatrix* off North Carolina. Marine Ecol. Progr. Ser., 334: 273–286.

Morley JW, Buckel JA, Lankford TE, Jr. 2013. Relative contribution of spring- and summer-spawned bluefish cohorts to the adult population: effects of size-selective winter mortality, overwinter growth, and sampling bias. Can. J. Fish. Aquat. Sci. 70: 233–244.

Norcross JJ, Richardson SL, Massmann WH, Joseph EB. 1974. Development of young bluefish (*Pomatomus saltatrix*) and distribution of eggs and young in Virginian coastal waters. Transactions of the American Fisheries Society 103:477-497.

North Carolina Department of Marine Fisheries (NCDMF). 2000. Comparison of age assignment and reader agreement for bluefish (*Pomatomus saltatrix*) based on scales, whole otoliths, and sectioned otoliths. NC Dept. of Environment and Natural Resources, Division of Marine Fisheries Annual Progress Report 1999.

Northeast Fisheries Science Center. 1997. Report of the 23rd Northeast Regional Stock Assessment Workshop (23rd SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. NEFSC Reference Document 97-05.

Northeast Fisheries Science Center. 2005. Report of the 41st Northeast Regional Stock Assessment Workshop (41st SAW): 41st SAW Assessment Report NEFSC CRD 05-14. September, 2005. 237 pp. 97-05.

Nyman RR, Conover DO. 1988. The relation between spawning season and the recruitment of young-of-the-year bluefish to New York. Fishery Bulletin, 86: 237-250.

Olla BL, Studholme AL. 1971. The effect of temperature on the activity of bluefish, *Pomatomus saltatrix* L. Biological Bulletin 141: 337-349.

Richards SW. 1976. Age, growth, and food of bluefish (*Pomatomus saltatrix*) from East-Central Long Island Sound from July through November 1975. Transactions of the American Fisheries Society 105:523-525.

Robillard E, Reiss CS, Jones CM. 2008. Reproductive biology of bluefish (*Pomatomus saltatrix*) along the East Coast of the United States. Fisheries Research 90 (2008): 198-208.

Robillard E, Reiss CS, Jones CM. 2009. Age-validation and growth of bluefish (*Pomatomus saltatrix*) along the East Coast of the United States. Fisheries Research 95 (2009): 65-75.

Ross MR. 1991. Recreational Fisheries of Coastal New England. University of Massachusetts Press, Amherst, MA.

Salerno DJ, Burnett J, Ibara RM. 2001. Age, growth, maturity, and spatial distribution of bluefish, *Pomatomus saltatrix*, off the northeast coast of the United States, 1985 – 96. Journal of Northwest Atlantic Fishery Science 29:31-39.

Scharf FS, Manderson JP, Fabrizio MC, Pessutti JP, Rosendale JE, Chant RJ, Bejda AJ. 2004. Seasonal and Interannual Patterns of Distribution and Diet of Bluefish within a Middle Atlantic Bight Estuary in Relation to Abiotic and Biotic Factors. Estuaries, 27(3): 428-436.

Scharf FS, Buckel JA, Rose KA, Juanes F, Cowan JHJ. 2006. Effects of variable prey and cohort dynamics on growth of young of- the-year estuarine bluefish: Evidence for interactions between spring- and summer-spawned cohorts. Trans. Amer. Fish. Soc., 135: 1266–1289.

SEDAR. 2015. SEDAR 40 – Atlantic Menhaden Stock Assessment Report. SEDAR, North Charleston SC. 643 pp. available online at: http://www.sefsc.noaa.gov/sedar/Sedar_Workshops.jsp?WorkshopNum=40

Sipe AM, Chittenden ME Jr. 2002. A comparison of calcified structures for ageing bluefish in the Chesapeake Bay region. Transactions of the American Fisheries Society 131:783-790.

Shepherd GR, Moser J, Deuel D, Carlson P. 2006. The migration patterns of bluefish (*Pomatomus saltatrix*) along the Atlantic coast determined from tag recoveries. Fish. Bull. 104:559-570.

Shepherd GR, Packer DB. 2006. Essential Fish Habitat Source Document: Bluefish, *Pomatomus saltatrix*, Life History and Habitat Characteristics 2nd edition. NOAA Technical Memorandum, NMFS-NE-198:100.

Sturtz S, Ligges U, Gelman A. 2005. R2WinBUGS: a package for running WinBUGS from R. J. Stat. Softw. 12: 1–16.

Taylor DL, Able KW. 2006. Cohort dynamics of summer-spawned bluefish as determined by length-frequency and otolith microstructure analysis. Trans. Amer. Fish. Soc., 135: 955–969.

Taylor DL, Rowe PM, Able KW. 2006. Habitat use of the inner continental shelf off southern New Jersey by summer spawned bluefish (*Pomatomus saltatrix*). Fish. Bull., 104: 593–604

Terceiro M, Ross JL. 1993. A comparison of alternative methods for the estimation of age from length data for Atlantic coast bluefish. Fishery Bulletin 91:534-549.

Then AY, Hoenig JM, Hall NG, Hewitt DA. 2014. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES J Mar Sci.doi:10.1093/icesjm/fsu136.

Recruitment patterns and habitat use of young-of-the-year bluefish along the United States east coast: insights from coordinated coastwide sampling. Reviews in Fisheries Science 20(2):80-102.

VMRC. 1999. VMRC final report on finfish ageing, 1999. Chapter 4 – Bluefish. http://www.odu.edu/sci/cqfe/age&growth/PDF%20&%20Sound%20Files/bluefish_1999.pdf

VMRC. 2000. VMRC final report on finfish ageing, 2000. Chapter 4 – Bluefish. http://www.odu.edu/sci/cqfe/age&growth/PDF%20&%20Sound%20Files/bluefish_2000.pdf

VMRC. 2001. Age validation and age-specific fecundity of bluefish (Pomatomus saltatrix) in the Mid-Atlantic and South Atlantic Bights. Annual progress report to the Bluefish-Striped Bass dynamics research program. http://www.odu.edu/sci/cqfe/age&growth/PDF%20&%20Sound%20Files/Annual%20Progress%20Report%20to%20the%20Bluefish%202001.pdf

Walters CJ, Martell SJ, Korman J. 2006. A stochastic approach to stock reduction analysis. Canadian Journal of Fisheries and Aquatic Sciences 63(1): 212-223.

Wilk SJ. 1977. Biological and fisheries data on bluefish, *Pomatomus saltatrix* (Linnaeus). NOAA, NMFS, NEFC, Sandy Hook Lab. Technical Series Report. No. 11.

Wuenschel MJ, Able KW, Buckel JA, Morley JW, Lankford T, Branson AC, Conover DO, Drisco D, Jordaan A, Dunton K, Secor DE, Woodland RJ, Juanes F, Stormer D. 2012. . Recruitment patterns and habitat use of young-of-the-year bluefish along the United States east coast: insights from coordinated coastwide sampling. Reviews in Fisheries Science 20(2):80-102.