# A. STOCK ASSESSMENT FOR BLACK SEA BASS FOR 2016

## TERMS OF REFERENCE

TOR 1. Summarize the conclusions of the February 2016 SSC peer review regarding the potential for spatial partitioning of the black sea bass stock. (The consequences for the stock assessment will be addressed in TOR-6.)

TOR 2. Estimate catch from all sources including landings and discards. Characterize the uncertainty in these sources of data. Evaluate available information on discard mortality and, if appropriate, update mortality rates applied to discard components of the catch. Describe the spatial and temporal distribution of fishing effort.

TOR 3. Present the survey data being used in the assessment (e.g., indices of abundance, recruitment, state surveys, age-length data, etc.). Investigate the utility of fishery dependent indices as a measure of relative abundance. Characterize the uncertainty and any bias in these sources of data.

TOR 4. Consider the consequences of environmental factors on the estimates of abundance or relative indices derived from surveys.

TOR 5. Investigate implications of hermaphroditic life history on stock assessment model. If possible, incorporate parameters to account for hermaphroditism.

TOR 6. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock), using measures that are appropriate to the assessment model, for the time series (integrating results from TORs-1,-4, & -5 as appropriate), and estimate their uncertainty. Include a historical retrospective analysis and past projection performance evaluation to allow a comparison with most recent assessment results.

TOR 7. Estimate biological reference points (BRPs; point estimates or proxies for BMSY, BTHRESHOLD, FMSY, and MSY), including defining BRPs for spatially explicit areas if appropriate, and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the appropriateness of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.

TOR 8. Evaluate overall stock status with respect to a new model or new models that considered spatial units developed for this peer review.

TOR 9. Develop approaches and apply them to conduct stock projections.

a. Provide numerical annual projections (3-5 years) and the statistical distribution (e.g., probability density function) of the OFL (overfishing level) that fully incorporates observation, process and model uncertainty (see Appendix to the SAW TORs). 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, and definition of BRPs for black sea bass).

b. Comment on which projections seem most realistic. Consider major uncertainties in the assessment as well as the 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.

TOR 10. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

**Appendix to the SAW Assessment TORs**: **Clarification of Terms used in the SAW/SARC Terms of Reference**

**Guidance to SAW WG about "Number of Models to include in the Assessment Report":**
In general, for any TOR in which one or more models are explored by the WG, give a detailed presentation of the "best" model, including inputs, outputs, diagnostics of model adequacy, and sensitivity analyses that evaluate robustness of model results to the assumptions. In less detail, describe other models that were evaluated by the WG and explain their strengths, weaknesses and results in relation to the "best" model. If selection of a "best" model is not possible, present alternative models in detail, and summarize the relative utility each model, including a comparison of results. It should be highlighted whether any models represent a minority opinion.

**On "Acceptable Biological Catch" (DOC Nat. Stand. Guidel. Fed. Reg., v. 74, no. 11, 1-16-2009):**

*Acceptable biological catch (ABC)* is a level of a stock or stock complex's annual catch that accounts for the scientific uncertainty in the estimate of Overfishing Limit (OFL) and any other scientific uncertainty…" *(p. 3208) [In other words, OFL ≥ ABC.]*

*ABC for overfished stocks.* For overfished stocks and stock complexes, a rebuilding ABC must be set to reflect the annual catch that is consistent with the schedule of fishing mortality rates in the rebuilding plan. *(p. 3209)*

NMFS expects that in most cases ABC will be reduced from OFL to reduce the probability that overfishing might occur in a year. (p. 3180)

ABC refers to a level of ''catch'' that is ''acceptable'' given the ''biological'' characteristics of the stock or stock complex. As such, Optimal Yield (OY) does not equate with ABC. The specification of OY is required to consider a variety of factors, including social and economic factors, and the protection of marine ecosystems, which are not part of the ABC concept. (p. 3189)

**On “Vulnerability” (DOC Natl. Stand. Guidelines. Fed. Reg., v. 74, no. 11, 1-16-2009):**

“*Vulnerability.* A stock’s vulnerability is a combination of its productivity, which depends upon its life history characteristics, and its susceptibility to the fishery. Productivity refers to the capacity of the stock to produce Maximum Sustainable Yield (MSY) and to recover if the population is depleted, and susceptibility is the potential for the stock to be impacted by the fishery, which includes direct captures, as well as indirect impacts to the fishery (e.g., loss of habitat quality).” (p. 3205)

**Participation among members of a Stock Assessment Working Group:**

Anyone participating in SAW meetings that will be running or presenting results from an assessment model is expected to supply the source code, a compiled executable, an input file with the proposed configuration, and a detailed model description in advance of the model meeting. Source code for NOAA Toolbox programs is available on request. These measures allow transparency and a fair evaluation of differences that emerge between models.

## Executive Summary

**Term of reference 1. Summarize the conclusions of the February 2016 SSC peer review regarding the potential for spatial partitioning of the black sea bass stock. (The consequences for the stock assessment will be addressed in TOR-6.)**

The Black Sea Bass Working Group (WG) presented information to a review panel of the Mid-Atlantic Fishery Management Council Science and Statistical Committee (MAFMC SSC) regarding spatial patterns in the black sea bass northern stock. The WG concluded that recognizing two distinct areas separated by Hudson Canyon would provide the best spatial partitioning for the stock assessment. The WG emphasized that the two areas do not constitute discrete stock areas. The review panel agreed with this spatial boundary as a starting point for evaluation in the assessment.

**Term of reference 2. Estimate catch from all sources including landings and discards. Characterize the uncertainty in these sources of data. Evaluate available information on discard mortality and, if appropriate, update mortality rates applied to discard components of the catch. Describe the spatial and temporal distribution of fishing effort.**

The principal gears used in commercial fishing for black sea bass are fish pots, otter trawls and hand-lines. Commercial landings peaked in 1952 at 9,900 mt then declined substantially during the 1960s until commercial landings during the late 1980s and 1990s averaged 1,300 mt. Commercial fishery quotas were implemented in 1998 but commercial landings remained stable between 1,300 mt and 1,600 mt until 2007. After quota restrictions, commercial landings declined to 523 and 751 mt in 2009 and 2010, respectively. Commercial landings increased to 1,088 mt in 2013 and have since remained above 1,000 mt (1,113 mt in 2015). The recreational rod-and-reel fishery for black sea bass harvests a significant proportion of the total catch. After peaking in 1986, recreational landings averaged 1,700 mt annually until 1997. Recreational fishery harvest limits were implemented in 1998 and recreational landings have since ranged between 500 mt and 2,000 mt. Recreational landings in 2015 were 1,864 mt. Commercial fishery discards, although poorly estimated, appear to be a minor part of the total fishery removals from the stock. Commercial discards were generally less than 200 mt per year, but increased to 416 mt and 335 mt in 2014 and 2015, respectively. Recreational discard losses assuming 15% hook and release mortality are similar, generally less than 500 mt per year. Estimated mortality from recreational discards was 371 mt in 2015. The distributions of the commercial and recreational fisheries were described and maps were produced based on observed trips and vessel trip reports.

**Term of reference 3. Present the survey data being used in the assessment (e.g., indices of abundance, recruitment, state surveys, age-length data, etc.). Investigate the utility of fishery dependent indices as a measure of relative abundance. Characterize the uncertainty and any bias in these sources of data.**

The 2016 assessment model for black sea bass applied spatially explicit age-based statistical catch at age models using catch and age information since 1989. The fishery catch in two areas (north and south of Hudson Canyon) is modeled as two fleets (trawl and non-trawl) with area specific indices of stock abundance from NEFSC winter and spring surveys, the NEAMAP spring survey, recreational catch per angler, as well as state survey indices from VA, MD, DE, NJ in the south and NY, CT, RI and MA in the northern area. Several state survey index series were modeled to standardize factors that influence the indices. The standardized values were used as relative indices of abundance. Indices in the north have increased over the past decade and show a very strong 2011 year class. Indices in the southern area indicated a strong 1999 cohort, however the 2011 cohort is only average in size for the southern area. Recreational catch per angler trip (CPA) was developed using effort targeting a suite of species commonly caught with sea bass and was used as a relative index of abundance.

**Term of reference 4. Consider the consequences of environmental factors on the estimates of abundance or relative indices derived from surveys.**

The significant factors in the state surveys were depth, salinity and temperature. In response to issues raised in previous black sea bass assessments, a study was also conducted to evaluate the influence of winter oceanographic conditions on distribution and survival. The study concluded that warm saline conditions improved juvenile survival and the location of the shelf-slope front dictates the distribution of adults in the winter offshore habitat.

**Term of reference 5. Investigate implications of hermaphroditic life history on stock assessment model. If possible, incorporate parameters to account for hermaphroditism.**
In response to previous research recommendations the implication of black sea bass life history on exploitation, was evaluated in a simulation study. The study concluded that black sea bass in the northern unit stock was more robust to exploitation than typical hermaphroditic species depending on spawning contributions from secondary males. Given these findings and the findings of previously published studies, black sea bass spawning stock biomass (SSB) was defined as male and female mature biomass. Since growth between males and female black sea bass is similar, the WG concluded that use of male and female SSB accounted for the unique life history of black sea bass. Additionally, an operating model conditioned on the available black sea bass data including sex structure and hermaphroditism was used to simulate data for performance testing of alternative estimation models. The pooled-sex modeling approach developed by the WG performed relatively well for determining stock status.

**Term of reference 6. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock), using measures that are appropriate to the assessment model, for the time series (integrating results from TORs 1,4, & 5 as appropriate), and estimate their uncertainty. Include a historical retrospective analysis and past projection performance evaluation to allow a comparison with most recent assessment results.**
Fishing mortality (F) from the combined north and south areas varied between F = 1.34 (1993) and F = 0.24 (2015). The mortality averaged greater than 1.0 prior to implementation of management regulations in 1997. Fishing mortality remained above 0.50 between 1998 and 2008 then declined steadily to 0.24 in 2015 (value not adjusted for retrospective bias). Both the north and south area models had a pattern of retrospective bias. However the direction of patterns was different between areas, with apparently over-estimated fishing mortality (F) in the north and apparently under-estimated F in the south. A combination of retrospective adjusted Fs from each area produced a 2015 F = 0.27. Spawning stock biomass (SSB) increased from about 2,485 mt in 1991 to about 8,500 mt in 2002, then decreased to about 4,072 mt by 2007. With improved recruitment and declining fishing mortality rates, SSB has steadily increased since 2007. Total spawning biomass peaked in 2014 at 17,158 mt then declined in 2015 to 16,552 mt (value not adjusted for retrospective bias) as the 2011 cohort abundance declined. Total biomass

increased from 6,558 mt in 1989 to 16,205 mt in 2002, but decreased to 9,777 mt by 2006. However, beginning in 2007 biomass began increasing, peaking at 27,125 mt in 2014. Total biomass was slightly lower in 2015 at 24,143 mt (retrospective bias adjusted 2015 biomass equaled 32,010 mt) while the SSB retrospective adjusted value equaled 22,176 mt. Recruitment at age 1 averaged 24.318 million fish from 1989 to 2015, with peaks in 1991 (29.149 million, 1990 cohort), 1994 (27.188 million, 1994 cohort), 2000 (37.256 million, 1999 cohort) and most importantly in 2012 (68.932 million) from the 2011 cohort. The distribution of the 2011 cohort was more prevalent in the northern area of the stock. The 2014 cohort in 2015 was estimated as 24.917 million fish with a retrospective adjusted recruitment equal to 18.002 million fish. Model results in both areas show a generally decreasing trend in fishing mortality but different historical trends in recruitment and spawning stock biomass. Recent increased biomass occurred in both areas and relatively high biomass in the last year. Several alternative modeling approaches produced similar results, suggesting that the results are robust to a range of data and model decisions.

**Term of reference 7. Estimate biological reference points (BRPs; point estimates or proxies for BMSY, BTHRESHOLD, FMSY, and MSY), including defining BRPs for spatially explicit areas if appropriate, and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the appropriateness of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.**

The 2008 Northeast Data Poor Stocks Working Group (NEDPSWG) Review Panel (NEFSC 2009a) recommended $F_{40\%}$ be used as a proxy for $F_{MSY}$ and total spawning stock biomass at $F_{40\%}$ ($SSB_{40\%}$) be used as the proxy for the stock biomass target reference point. Considering the weak stock-recruitment relationship in the range of estimated stock sizes and biological reference points for comparable species, F40% was maintained as the proxy for black sea bass MSY related reference points in the 2016 assessment. The average of the two area specific F40% values produced a $F_{MSY}$ proxy of 0.36. Based on a long-term projection at $F_{MSY}$ proxy, the associated $SSB_{MSY}$ proxy equaled 9,667 mt and $B_{MSY}$ proxy equaled 17,256 mt.

**Term of reference 8. Evaluate overall stock status with respect to a new model or new models that considered spatial units developed for this peer review.**

Stock status was evaluated using the combined results of the two area models (2015 retrospective adjusted average fishing mortality F=0.27) compared to the area-averaged $F_{MSY\ proxy}$ (0.36). Results indicate that overfishing is not occurring on the stock. The 2015 combined retrospective adjusted total biomass was (32,010 mt) was much greater than the $B_{MSYproxy}$ (17,256 mt) and biomass threshold of 8,628 mt. In addition, the combined retrospective adjusted SSB of 22,176 mt was well above the $SSB_{MSY}$ proxy of 9,667 mt and SSB proxy threshold of 4,834 mt. Therefore the stock is not considered over-fished.

**Term of reference 9. Develop approaches and apply them to conduct stock projections.**
**a. Provide numerical annual projections (3-5 years) and the statistical distribution (e.g., probability density function) of the OFL (overfishing level) that fully incorporates observation, process and model uncertainty (see Appendix to the SAW TORs). 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, and definition of BRPs for black sea bass).**
**b. Comment on which projections seem most realistic. Consider major uncertainties in the assessment as well as the 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.**

Projections were made for two fishing mortality scenarios. One assumes that fishing mortality from 2017 to 2019 equaled the $F_{MSY}$ proxy, and a second scenario assumes that F equals to the 2015 terminal year status quo value (North $F_{SQ}$=0.14 and South $F_{SQ}$=0.39). Future annual recruitments were drawn from empirical values from 2000 to 2015 and catch in 2016 was assumed equal to the allowable biological catch (3,024 mt). Starting stock size was based on area-specific estimates of 2016 abundance at age with retrospective adjustments and recent selectivity estimates. $F_{MSY}$ projections suggest that spawning biomass would decline to 11,849 mt by 2019 and total biomass would equal 20,788 mt by 2019. Total catch under that scenario would increase to 5,467 mt in 2017 then decline to 3,901 mt by 2019. $F_{SQ}$ projections suggest that combined area spawning biomass would decline to 15,349 mt by 2019 and total biomass would equal 24,704 mt by 2019. Total catch under that scenario would decrease to 3,024 mt in 2017 then decline to 2,764 mt by 2019.

The projections were developed for a single stock using the combined results of the north and south areas. It was clear from the results that the area specific conditions vary and therefore the vulnerability of each area to exploitation at a common F may vary.

**Term of reference 10. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.**

The WG reviewed previous research recommendations and concluded they had been considered and when possible completed. New recommendations for future consideration include:

expand on previous genetic studies with smaller spatial increments in sampling; consider the impact of climate change on black sea bass, particularly in the Gulf of Maine; evaluate population sex change and sex ratio, particularly comparing dynamics among communities;

study black sea bass catchabilty in a variety of survey gear types; investigate and document social and spawning dynamics of black sea bass; increase work to understand habitat use in sea bass and seasonal changes; evaluate use of samples collected by industry study fleets.

## Black Sea Bass Working Group :

The SARC62 Black Sea Bass Working Group conducted two data meetings (June 29-July 2 2015, Warwick RI; June 27-29, 2016, Providence RI), a spatial structure workshop (December 16 2015, Warwick RI), one model meeting (September 6-9 2016, Woods Hole MA), and several video conference calls in the development of this assessment. The formal working group consisted of:

John Maniscalco – New York Dept. of Environmental Conservation - chair

Gary Shepherd – Northeast Fisheries Science Center –assessment lead

Mike Bednarski – Massachusetts Division of Marine Fisheries (currently Virginia Dept. Game and Inland Fisheries)

Jeffrey Brust – New Jersey Department of Environmental Protection

Steve Cadrin – UMass Dartmouth

Steve Doctor – Maryland Dept. of Natural Resources - Fisheries Service

Gavin Fay – UMass Dartmouth

Robert Leaf – University of Southern Mississippi

Chris Legault – Northeast Fisheries Science Center

Jason McNamee – Rhode Island DEM- Division of Fish and Wildlife, Marine Fisheries

Other participants included Kirby Rootes-Murdy (ASMFC), Kiley Dancy (MAFMC), Kiersten Curti (NEFSC), Olaf Jensen (Rutgers Univ.), Joe Myers (ACCSP), Greg Wojcik (CT), Peter Clarke (NJDEP), Tom Wadsworth (NCDMF), Greg DeCelles (UMass Dartmouth), Mark Hoffman (AP), Mark Terceiro (NEFSC), Rich Seagraves (MAFMC), Moira Kelly (GARFO), Rich Wong (DEDFW), Alicia Miller (NEFSC), Marissa McMahan (Northeastern Univ.), Eric Powell (SCEMFIS), Alexei Sharov (MDDNR), Mike Palmer (NEFSC), Paul Nitschke (NEFSC), Chuck Adams (NEFSC), Tim Miller (NEFSC), Jeff Kipp (ASMFC), Jessica Blaylock (NEFSC).

## INTRODUCTION

*Life History*

Black sea bass (*Centropristis striata*) are distributed from the Gulf of Maine to the Gulf of Mexico, but fish north of Cape Hatteras, NC are considered part of a single unit stock (Figure A1). Over the past decade, the distribution of sea bass has expanded into the Gulf of Maine (Bell et al. 2014) as far as eastern coastal Maine (M. McMahan, Northeastern Univ, pers. comm.). Within the stock area, distribution changes on a seasonal basis and the extent of the seasonal change varies by location. In the northern end of the range (New York to Massachusetts), black sea bass move offshore crossing the continental shelf, then south along the edge of the shelf (Moser and Shepherd 2009). By late winter, northern fish may travel as far south as Virginia, but most return to the northern inshore areas by May. Black sea bass originating inshore along the Mid-Atlantic coast (New Jersey to Maryland) head offshore to the shelf edge during late autumn, travelling in a southeasterly direction. They return inshore in spring to the general area from which they originated. Black sea bass in the southern extent of the stock (Virginia and

North Carolina) move offshore in late autumn/early winter. Given the proximity of the shelf edge, they transit a relatively short distance, due east, to reach over-wintering areas.

Black sea bass are protogynous hermaphrodites and can be categorized as temperate reef fishes (Steimle et al. 1999, Drohan et al. 2007). Transition from female to male generally occurs between the ages of two and five years (Lavenda 1949, Mercer 1978). Based on sex ratio at length from NMFS surveys, males constitute approximately 25% of the population by 15 cm, with increasing proportions of males with size (Figure A2). Following transition from female to male, sea bass can follow one of two behavioral pathways; either becoming a dominant male, characterized by a larger size and a bright blue nuccal hump during spawning season, or subordinate males (secondary males) which have few distinguishing features from females. The initiation of sexual transition appears to be based on visual rather than chemical cues (Dr. David Berlinsky, UNH, Personal communication). In studies of protogyny, among several coral reef fish species, transition of the largest female to male may occur quickly if the dominate male is removed from the reef, however, similar studies have not been published for black sea bass.

Spawning in the Middle Atlantic peaks during spring (May and June) when the fish reside in coastal waters (Drohan et al. 2007). The social structure of the spawning aggregations is poorly known although some observations suggest that large dominant males gather a harem of females and aggressively defend territory during spawning season (Nelson et al. 2003). The bright coloration of males during spawning season suggests that visual cues may be important in structuring of the social hierarchy. Black sea bass populations may also have secondary males present which are capable of spawning but do not present the same morphological features as dominant males (NEFSC 2012). Recent analysis of morphological features in mature female, primary and secondary male black sea bass showed that mature secondary males may be indistinguishable from mature females (Keigwin et al. 2016).

Age estimation for black sea bass has been routinely conducted at the NEFSC and other institutions (e.g. Virginia Institute of Marine Science (VIMS)) using both scales and otoliths. Validation of the ages and comparison between age readers is presented in Appendix A1. The study concluded that age determinations were valid using either structure, but older ages were easier to determine from otoliths. Some discrepancy remains between readers determining age 0 vs age 1 in fall samples. Consequently and for other reasons described below, fall indices were not used in the stock assessment analysis. Any fall catch data age 0 or 1 were based on NEFSC age data.

Black sea bass attain a maximum size around 60 cm and 4 kg. Published growth curves from Lavenda (1949) suggested a maximum age for females of 8 and age 12 for males. However he noted the presence of large males (>45 cm) in deeper water that may have been older. Von Bertalanffy growth curves from NEFSC age and growth data produce estimates of Linf equal to 58.9 cm with K and $t_0$ of 0.22 and 0.207, respectively (Figure A3). Length at 50% maturity for both sexes combined occurs at 21.0 cm (age2), based on NEFSC maturity data from spring and winter surveys since 1984 (Figure A4). Black sea bass reach full maturity by 35 cm (age 5) (Figure A5).

*Habitat*

Black sea bass are commonly associated with live-bottom and reef habitats although use a variety of habitats throughout the year. Habitat use by life stage and season was summarized by Steimle et al. (1999) and provided in Table A1. Fabrizio et al. (2013,2014) examined habitat use and home range with acoustic tags within a defined area of complex habitat. The results showed that black sea bass were relatively mobile, moving among habitats from structure (e.g. rocks, wrecks, reefs) to coarse bottom until leaving the area during the annual migration. A NEFSC outreach project prior to this assessment requested information from stakeholders on habitats where black sea bass were found (Appendix A2). Among the 75 respondents, 50 fishermen (including those using net, hook and line and other gear) noted that black sea bass were common on open bottom (not structured).

Past assessment reviewers expressed concern that indices based on trawl gear used inshore cannot be representative of abundance since such gear cannot tow in structured habitat commonly used by black sea bass. However, the NEFSC spring and winter surveys in offshore strata are conducted in the same area as the commercial winter otter trawl fishery, which is towable bottom. An analysis was done in SARC 53 to examine potential biases in the offshore spring survey indices due to avoidance of structure. The frequency of gear damage during tows was evaluated relative to black sea bass indices to identify tows in structured habitat (Nieland and Shepherd 2011). The analysis concluded that there is no evidence of a bias in black sea bass catches in the offshore strata resulting from structured habitat.

To further address these concerns over the use of inshore trawl surveys to track relative abundance and size/age composition of black sea bass, an in-depth analysis of available data was conducted to compare catch characteristics of black sea bass by different gear types and in different habitats (Appendix A3). Results indicate that both catch rates and size distribution of black sea bass are similar in structured and non-structured habitat. These results are supported by scientific literature, as well as anecdotal information from the NEFSC outreach program, that indicate that black sea bass are not dependent on areas of high relief habitat and commonly occur in areas of open (trawlable) bottom. Additionally, the analysis indicated similarities between the segment of the population sampled by trawl gear and more specialized gear types like fish pots. In fact, trawl gear seemed to sample both small and large fish better than fish pots, again implying that trawl gear is an appropriate sampling gear for black sea bass. Based on the available information and analyzes, it was determined that trawl surveys operating in open bottom areas are sampling the same population of black sea bass as would be found in structured habitat, and as a result, inshore trawl surveys are appropriate for characterizing size structure and relative abundance of black sea bass.

*Food habits*

Black sea bass are visual predators and have a generalized carnivorous diet of predominantly motile, benthic species including amphipods, decapods, and fishes (Sedberry 1988). Items consumed by black sea bass depend on life stage and size. Smaller black sea bass consume mostly small crustaceans; including amphipods, isopods, small crabs and shrimp; but also feed on polychaetes. Larger black sea bass feed more on fish and decapod crustaceans; including rock crabs and juvenile American lobster. Other diet items include molluscs (cephalopods) and ascidians (Steimle et al. 1999).

Stomach content data was collected from fish caught during both the spring and fall NEFSC bottom trawl surveys from 1973-1990. Fish remains found in the stomachs of 802 trawl caught black sea bass included Alepocephalids, Atlantic herring, anchovy, sea horses, northern pipefish, lanternfish, sand lance, short-horned sculpin, cusk eel, scup, windowpane flounder, and rock gunnel. The invertebrate content of black sea bass stomachs was very diverse and included hydrozoans, anthozoans, cerianthids, bryozoans, ctenophores, annelids (including polychaetes), amphipods, isopods, copepods, ostracods, chaetognatha, lancelets, sea spiders, crabs (including cancer, swimming, box, mud, mole, spider, hermit), shrimp, hooded shrimp, krill, mysids, squat lobster, barnacles, molluscs (including bivalves, snails, sea slugs, limpets, pteropods, cephalopods - squid), echinoderms (including brittle star and sea cucumbers) and tunicates (Rountree 1999).

Sampling in the NEFSC Bottom Trawl Survey from 1973-2008 also found black sea bass as prey items in the stomachs of various predators. In order of frequency of occurrence, these included demersal sharks, summer flounder, fourspot flounder, black sea bass, monkfish, spiny dogfish, skate, windowpane, little skate, bluefish, smooth dogfish, red hake, striped bass, silver hake, Atlantic cod and winter skate. Other food web research conducted in Chesapeake Bay found young of the year black sea bass in the stomachs of Age 1 weakfish (Hartman and Brandt 1995).

Sampling of stomach contents from fish caught in the Hudson Raritan Estuary by otter trawl also provides data on black sea bass as both predator and prey. Most of the black sea bass sampled were young of year or juveniles. Prey species were dominated by crustaceans, particularly shrimp, mysids and juvenile rock crab but also included copepods, amphipods, isopods and other juvenile decapods. Several stomachs contained fish species including cunner, goby, menhaden and anchovy. Juvenile black sea bass were found as prey items in the stomachs of summer flounder, striped searobins, northern searobin, clearnose skate, bluefish, and grubby sculpin (Steimle et al. 2000).

The Northeast Area Monitoring and Assessment Program Near Shore Trawl Survey (NEAMAP) samples from Cape Cod, MA south to Cape Hatteras, NC and targets both juvenile and adult fishes. The survey sampled diet composition of 1,245 black sea bass caught by the survey from 2007 through 2013. Gut contents analysis of these black sea bass found 55% crustaceans, 26.7% fishes, 10.8% mollusks, 4.2% miscellaneous, and 2.7% worms by weight. Crustaceans were the largest portion of the diet by weight and rock crabs led the crustaceans in abundance and weight. Bay anchovy was the most frequent of the fishes and the other important food items were squid, mollusks, gastropods, and worms. Sea bass examined were predominately age zero to age four fish.

The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) began in 2002 and uses a large-mesh bottom trawl to sample juvenile-to-adult fishes from the head of Chesapeake Bay at Poole's Island, MD to the mouth of the Bay just outside the Chesapeake Bay Bridge Tunnel. The ChesMMAP survey sampled the diet composition of 233 black sea bass from 2002 to 2013. Black sea bass stomach contents were composed of 70.5% crustaceans, 10.5% fishes, 10.2% miscellaneous, 4.7% worms, and 4.3% molluscs by weight. Crustaceans were dominated by mysids and amphipods. Sea bass examined were predominantly age one and two fish.

The ChesMMAP survey is conducted in the Chesapeake Bay verses the NEAMAP survey which is conducted in near shore waters. Comparison of the two surveys demonstrates the reliance of the smaller fish found in the Chesapeake Bay on mysids, mud crabs, amphipods, and sand shrimp while the larger fish caught in the NEAMAP survey rely more on rock crabs and fishes. Sand shrimp, amphipods, and bay anchovies were popular food items in both surveys.

Stomach contents analyses presented above are all from trawl caught fish but the results agree with those reported by Lindquist et al. (1994) and Steimle and Figley (1996) which collected fish using hook and line, spear and traps from Onslow Bay, NC and the Atlantic Ocean, NJ, respectively.

As part of an NEFSC outreach project of stakeholders as part of the SAW 62 assessment process, fishermen were asked if they had witnessed adult black sea bass preying on young of the year sea bass. They were also asked for their observations regarding predation on adult sea bass. Among 94 respondents only 6 had ever seen evidence of cannibalism. Predation on adults was observed primarily from adult bluefish, striped bass, sharks and dogfish and cormorants.

All of the stomach content analysis done on black sea bass indicates a generalist carnivore that feeds primarily on benthic crustaceans but will opportunistically feed on any prey encountered including small fish. This includes a limited amount of cannibalism. Also common in the datasets noted above is the ontogenetic shift from small crustaceans to larger decapods including juvenile crab and lobster.

*Natural Mortality*

Instantaneous natural mortality (M) has been explored in several previous assessments and a value of 0.4 has been used in most the recent assessment. A maximum age of 12 (oldest age in

NEFSC data) was assumed in re-examining M using available published methods. A constant M was chosen for use in the assessment and the average value among 20 estimates equaled 0.4, with a range from 0.1 to 0.9 (Figure A6, Table A2).

*Fisheries*

In the Northwest Atlantic, black sea bass support commercial and recreational fisheries. In 1939 and 1940, 46-48% of the commercial landings were in New England, primarily in Massachusetts. After 1940, the center of the fishery shifted south to New York, New Jersey and Virginia. Landings peaked in 1952 at 9,883 mt (Figure A7) with the bulk of the commercial landings from otter trawls, then declined steadily to a low point of 566 mt in 1971. Historically, trawl fisheries for sea bass focused on the over-wintering areas near the shelf edge. Inshore pot fisheries, which were primarily off New Jersey, showed a similar downward trend in landings between the peak in 1952 and the late 1960s. The large increase in landings during the 1950's appears to be the result of increased landings from otter trawlers, particularly from New York, New Jersey and Virginia. During the same period, a large increase in fish pot effort, and subsequent landings, occurred in New Jersey. In recent years, fish pots and otter trawls account for the majority of commercial landings with increasing contributions from hand-line fisheries (Figure A8). Inshore commercial fisheries are prosecuted primarily with fish pots (baited and unbaited) and hand-lines. Recreational fisheries, mostly boat based, generally occur during the period that sea bass are inshore. Once fish move offshore in the winter, they are caught in a trawl fishery targeting summer flounder, scup and *Doryteuthis* squid (Shepherd and Terceiro 1994). Hand-line and pot fisheries in the southern areas may still operate during this offshore period. A small sector of the NJ charter fleet targets sea bass offshore during the winter.

*Stock assessment history*

Black sea bass stock assessments have been reviewed in the SARC/SAW process (SAWs 1, 9, 11, 20, 25, 27, 39, 43, Data Poor Workshop and 53) beginning with an index based assessment in 1991 (summary in Table A3). In 1995 a VPA model was approved and the results generally showed fishing mortalities exceeding 1.0 (estimated using an M=0.2). The VPA was reviewed again in 1997 when it was considered indicative of general trends but too uncertain to determine stock status. In 1998, another review was conducted and both VPA and production models were rejected as either too uncertain or inappropriate for use with a hermaphroditic species. A suggestion was made to use an alternative method such as a tag/recapture approach. The NEFSC survey remained the main source of information regarding relative abundance and stock status. A tagging program (Moser and Shepherd 2009) was initiated in 2002 and the first year results were presented for peer review in 2004. The review panel concluded that a simple tag recovery model using the proportion recovered in the first year at large, as well as an analysis of survey indices, produced acceptable results to determine exploitation rate and stock status. The release of tags continued through 2004 and results of tag models as well as survey indices were presented for SARC review in 2006. Their findings were that the tag model did not meet the necessary assumptions and the variability in the survey indices created uncertainty which prevented determination of stock status. The panel did not recommend any alternative reference points, but they recommended continued work on length based analytical models. The black sea bass assessment was reviewed by the Northeast Data-Poor Stocks Working Group (NDPSWG) in December 2008. The review panel considered a statistical catch-at-length model (SCALE) and a variety of natural mortality options. They concluded that the length-based model was suitable for evaluating stock status and recommended a constant natural mortality option of 0.4. Although the stock was considered not overfished or experiencing overfishing, the uncertainty in the results prompted the reviewers to recommend caution in applying the results for management.

A stock assessment using a statistical catch at age model (ASAP, Legault and Restrepo 1998) was most recently reviewed by SAW53 (December 2011) but was not accepted for use in management. The review panel concluded that spatial structure within the stock and the species strong association with complex habitats when inshore compromised the ability of a single age-structured model to adequately capture the dynamics. They also concluded that new data would be required to produce an assessment useful for management.

*Management Overview*

The Atlantic States Marine Fisheries Commission (ASMFC or Commission) and Mid-Atlantic Fishery Management Council (MAFMC or Council) cooperate to develop fishery regulations for black sea bass from Maine through Cape Hatteras, North Carolina (for details see Appendix A4). The Council and Commission work in conjunction with the National Marine Fisheries Service (NMFS), which serves as the federal implementation and enforcement entity. The Fishery

Management Plan (FMP) defines the management unit as black sea bass (*Centropristis striata*) in US waters in the western Atlantic Ocean from Cape Hatteras, North Carolina to the US-Canadian border (MAFMC 1996).

Commercial and recreational black sea bass fisheries are managed using annual catch limits, commercial quotas, recreational harvest limits, minimum fish sizes, gear regulations, permit requirements, and other provisions as prescribed by the FMP. Based on the allocation percentages in the FMP, 49% of the total allowable landings of black sea bass is allocated to the commercial fishery as a commercial quota and 51% is allocated to the recreational fishery as a recreational harvest limit. These measures are described in more detail in subsequent sections of this document.

The Council and the Commission's Summer Flounder, Scup, and Black Sea Bass Management Board (the Board) developed a cooperative management process for black sea bass including complementary FMPs, regular joint meetings, and joint decision-making on most aspects of management. This cooperative management endeavor was developed because a significant portion of the catch is taken from both state waters (0-3 miles offshore) and federal waters (3-200 miles offshore, also known as the Exclusive Economic Zone or EEZ). Primary responsibility for management in federal waters falls to the Council, while the Commission has primary jurisdiction over the fisheries in state waters. However, many measures, including annual catch limits, are jointly established on a coastwide basis and apply in both federal and state waters.

The Commission operates under the authority of the Atlantic Coastal Fisheries Cooperative Management Act (ACFCMA) of 1993. Commission member states include all Atlantic coast states, and for black sea bass, states that have declared an interest in the fishery include Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Delaware, Maryland, Virginia, and North Carolina. All states that are included in a Commission fishery management plan must implement required conservation provisions of the FMP, or the Secretary of Commerce may impose a moratorium for fishing in the noncompliant state's waters.

The Council operates under the authority of the Magnuson-Stevens Fishery Conservation and Management Act (MSA), passed in 1976 and amended in 1996 and 2007. The MSA extended U.S. jurisdiction to 200 nautical miles and established eight regional fishery management councils with representation from the coastal states and fishery stakeholders. The Mid-Atlantic

Council's representation includes 21 voting members and four non-voting members. Seven of the voting members represent the constituent states' fish and wildlife agencies from the states of New York through North Carolina. Thirteen members are private citizens who are knowledgeable about recreational fishing, commercial fishing, or marine conservation. The four non-voting members represent the Atlantic States Marine Fisheries Commission, the U.S. Fish and Wildlife Service, the U.S. Department of State, and the U.S. Coast Guard.

As mandated under the MSA, the Council's Scientific and Statistical Committee (SSC) gives ongoing scientific advice for annual catch limits and other issues as needed. Other technical issues and analyses are addressed through the joint Summer Flounder, Scup, and Black Sea Bass Monitoring Committee and the Commission's Black Sea Bass Technical Committee. The Monitoring Committee is a joint committee of the Council and the Commission made up of staff representatives of the Mid-Atlantic and South Atlantic Fishery Management Councils, the Atlantic States Marine Fisheries Commission, the Greater Atlantic Regional Office, and the Northeast Fisheries Science Center. The Monitoring and Technical Committees annually review the performance of management measures and recommend any adjustments necessary to account for the current stock status, catch limits, and issues facing the commercial and recreational fisheries.

The Council and Commission each have Summer Flounder, Scup, and Black Sea Bass Advisory Panels, comprised of commercial, recreational, and environmental stakeholders with an interest in these fisheries. The Advisory Panels provide ongoing advice to the Council and Commission regarding on-the-water trends and issues in the fisheries.

In an annual process the Council and Commission review catch and landings limits and a specific set of commercial and recreational measures that can be modified annually. The Council and Board meet jointly each year to consider the annual catch limits for the upcoming fishing year or years, along with the commercial and recreational size limits, seasons, gear requirements, and possession limits. Multi-year specifications may be set for black sea bass for up to three years at a time. The Council and Board consider the recommendations of the SSC, the Monitoring Committee, Advisory Panel members, and public comments before recommending commercial quotas, recreational harvest limits, and other annual management measures for all three species.

More substantial modifications to the FMP or regulations are undertaken through FMP amendments, addenda, and framework actions. FMP "amendments" include major changes to the management regime that require extensive analysis, and are typically developed jointly by both the Council and the Commission. For less complicated actions, the Commission may also make changes through an "addendum" process, while the Council can make minor changes to the FMP through a "framework adjustment" process, both of which typically take less time and resources than an amendment requires.

The Council submits any recommended changes in regulations or FMP elements to the NMFS Greater Atlantic Regional Administrator to consider for implementation. The Regional Administrator reviews the recommendations in this document and may revise them, if necessary, to achieve FMP objectives and to meet statutory requirements. The Commission's actions do not require review by NMFS, and member states are responsible for implementing the Board's decisions.

**TOR 1**. **S**ummarize the conclusions of the February 2016 SSC peer review regarding the potential for spatial partitioning of the black sea bass stock. (The consequences for the stock assessment will be addressed in TOR-6.)

The review panel for the SAW/SARC 53 black sea bass assessment noted "*concerns over the potential for spatial structure and incomplete mixing within the stock area that compromised the ability of the forward projecting catch at age model to index abundance and fishing mortality reliably based on the data available.*" In response to this need to introduce a spatial element into the sea bass assessment, the WG developed a recommendation to partition the stock north of Cape Hatteras, NC into two sub-units divided by the Hudson Canyon for development of the assessment model. The basis for this recommendation was presented to a four member ad-hoc review panel of the Mid-Atlantic Fishery Management Council Science and Statistical Committee (MAFMC SSC) on February 16, 2016. The panel presented its report on March 3, 2016 to the full SSC committee and concluded that the recommended separation was reasonable and appropriate to use as a starting point for developing a black sea bass stock assessment model. The full report to the ad-hoc review panel and their response to the SSC are provided in Appendix A5

The implication of a split area assessment was evaluated using a simulated black sea bass population. Empirical sea bass data was used as the basis to develop a migratory sea bass population within a Stock Synthesis (SS) model framework. The pseudo-datasets were used within an SS model framework to compare results with area partitioning, without area partitioning and with both movement and area partitioning. The details of the simulations are provided in Appendix A6. The conclusion of the simulated assessment was that the two area model was more effective in capturing the dynamics of the overall population than a one-area assessment, and more complex models that account for movement among sub-units did not perform significantly better than the two-area estimation model approach.

**TOR 3.** Present the survey data being used in the assessment (e.g., indices of abundance, recruitment, state surveys, age-length data, etc.). Investigate the utility of commercial or recreational LPUE as a measure of relative abundance. Characterize the uncertainty and any bias in these sources of data.

Survey data considered for the assessment included NMFS winter and spring surveys and state survey data from MA, RI, CT, NY, NJ, DE, MD, VA and NEAMAP (Northeast Area Monitoring and Assessment Program) (Table A4) (see also Maps in Appendix A7 ). A recently published study (see TOR 4) examined the influence of winter oceanographic conditions on black sea bass abundance. The study concluded that overwintering conditions are a critical determinant of juvenile survival and abundance at age 1. Autumn survey indices are generally dominated by age 0 fish but may not be indicative of subsequent cohort strength. Consequently, the WG made a decision to limit survey abundance indices to winter or spring surveys when possible.

*State Surveys*

The Virginia Institute of Marine Science (VIMS) conducts a monthly trawl survey targeting juvenile fish within Virginia tributaries of the Chesapeake Bay and provided a random stratified index of black sea bass abundance (Figure A9). The index is for black sea bass sampled in May, June, and July since 1989 and contains fish that are less than 110, 150, and 175 mm total length, respectively. All are age-1 fish, assuming a Jan 1 birthdate. Thus, the mean number per tow index for 2015 represents the 2014 year class (spawned in 2014). The results shows variable recruitment trends with above average year classes in 1989 (the largest in the time series at 2.36

fish per tow), 2001, 2007 and 2010. The 2010 index (1.11 fish/tow) was above the series average of 0.67 fish/tow. Recruitment since 2013 has been below the series average (0.674 fish per tow) with a 2015 index of 0.290 fish per tow. The VA index was applied to the southern area.

The Maryland Dept. of Natural Resources conducts surveys from April through October in coastal bays using a 16ft trawl. Twenty sites have been sampled monthly since 1989. Black sea bass collected in the survey are all less than 21 cm and age 1 or less. The index (log mean) has shown a downward trend since a 2008 index of (1.42 fish per tow) (Figure A10). The most recent index in 2015 equaled 0.27 fish per tow, below the series average of 0.64 fish per tow. The MD index was applied to the southern area.

The Delaware Division of Fish and Wildlife operates a monthly (April to June) fixed station trawl survey in the Delaware portion of the Delaware Bay using a 16' trawl. The index serves as a spring index of age one abundance for the southern area (Figure A11) with a time series average of 0.26 fish per tow. The peak index occurred in 2001 (2000 cohort) at 1.82 fish per tow. There was evidence of the 2011 cohort in 2012 which had an above average index of 0.565 fish per tow. The 2015 index of 0.22 was below the time series average index.

The New Jersey Department of Environmental Protection conducts a depth and area stratified random trawl survey in state waters during January, April, June, August, and October. Data from June cruises in 1989 to 2016 were used as an index of abundance (Figure A12). The index was developed using a negative binomial GLM. Available covariates included tow depth, bottom temperature (BTmp), bottom salinity (BotS), and bottom DO, but only covariates that explained at least 5% of total deviance were retained. The final model was specified as Catch ~ Year + Depth + BotS. The resulting index was decomposed by annual length frequencies, and indices at age were developed using the southern region ALK. The composite index peaked in 2009 at 13.73 fish per tow. The 2015 total index (4.52 fish/tow) was above the series average (3.29 fish/tow). A 2016 spring index was 1.71 fish per tow, well below the series average. The NJ index was applied to the southern area.

New York Department of Environmental Conservation operates a small mesh trawl survey which targets age 0 and juvenile finfish species in the Peconic Estuary since 1987. Tows are conducted weekly from May through October at 16 randomly chosen stations out of a possible 77. Tows from eastern survey stations that occurred in May, June and July from 1990 to 2015 were used to generate an age 1 spring index. Black sea bass ≤15cm TL in the spring were considered Age 1 (Figure A13). The index was developed using a 0-inflated negative binomial GLM with depth and salinity as significant environmental covariates that explained a combined 7% of total deviance. Bottom temperature was not a useful covariate. While the time series average is 0.11 fish/tow, significant peaks occurred in 2002 (0.34 fish/tow), 2012 (1.11 fish/tow) and 2016 (0.58 fish/tow).

The Connecticut Department of Energy and Environmental Protection Long Island Sound Trawl Survey (LISTS) is conducted from longitude 72° 03' (New London, Connecticut) to longitude 73° 39' (Greenwich, Connecticut). The sampling area includes Connecticut and New York waters from 5 to 46 m in depth and is conducted over mud, sand and transitional (mud/sand) sediment types. Prior to each tow, temperature (°C) and salinity (ppt) are measured at 1 m below the surface and 0.5 m above the bottom using a YSI model 30 S-C-T meter. Water is collected at depth with a five-liter Niskin bottle, and temperature and salinity are measured within the bottle immediately upon retrieval.

Sampling is divided into spring (April-June) and fall (Sept-Oct) periods, with 40 stratified-random sites sampled monthly for a total of 200 sites annually. For this assessment, only the spring leg of the survey was used which is believed to represent age 1 and older black sea bass. The sampling gear employed is a 14 m otter trawl with a 51 mm cod-end. The sampling area is divided into 1.85 x 3.7 km (1 x 2 nautical miles) sites, with each site assigned to one of 12 strata defined by 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). The number of sites sampled in each stratum was determined by dividing the total stratum area by 68 km2 (20 square nautical miles), with a minimum of two sites sampled per stratum. Discrete stratum areas smaller than a sample site are not sampled. The survey's otter trawl is towed from the 15.2 m aluminum R/V John Dempsey for 30 minutes at approximately 3.5 knots, depending on the tide. Black sea bass at each station are counted and total lengths measured to the nearest centimeter.

This survey was not designed to target black sea bass. In order to generate a black sea bass index of abundance, a statistical model-based standardization of the survey data was conducted to account for factors that affect black sea bass catchability. Following the approach described in the ASMFC's standardization guidelines (SEDAR 2015), an index of age 1 and older black sea bass was created using a negative binomial generalized linear model (GLM) with a log link and bootstrapped estimates of uncertainty. Zero inflated negative binomial models were also tested and compared using a Vuong non-nested hypothesis test (Vuong 1996).

A full model that predicted catch as a linear function of year (categorical data), month (categorical data), depth (continuous data), and stratum (categorical data) was compared with nested sub-models using AIC. Temperature and salinity were not able to be used for this analysis because the recording of those covariates began late in the time series. The model that included year and month was selected because it produced the lowest AIC coupled with the lowest variance inflation. The index exhibited a marked increase from low catches early in the time-series with the increase beginning in the early 2000s to present with inter-annual variability. Diagnostics identified slight over-prediction of average annual catch per tow at the end of the time series.

The indices show low abundance until an increasing trend beginning in 2012 (Figure A14). Large age 1 indices occurred in 2002, 2012 and 2014 with the recent cohorts contributing to the sharp increase in abundance. Prior to 2012 the average index was 0.5 fish per tow compared to the 2014 and 2015 indices of 14.3 (CV=0.21) and 14.2 (CV=0.21) fish per tow, respectively.

The Rhode Island Department of Environmental Management research trawl survey is conducted with a ¾ high-rise heavy-duty bottom trawl towed for 20 minutes at 2.5 knots. Sampled areas include Narragansett Bay and Rhode and Block Island Sounds. Data include a mixture of fixed and random sampling stations, depending on the component of the survey being examined (seasonal = random stratified, monthly = fixed station). Data collection has been generally consistent from 1979 to the present, with the exception of tow numbers early in the time series, and a change to the survey doors in 2012. Investigations between survey doors during a calibration experiment indicated that there are not major differences in catchability of black sea bass between the two door designs. Data elements collected include numbers, weights, and lengths caught by species as well as a suite of environmental information including bottom and sea surface water temperature, depth, and sea conditions.

The survey has two seasonal components, a spring (April/May) and a fall (September/October) survey that has been conducted annually since 1979. Sampling is conducted during daylight hours only. For assessment purposes, only the spring survey is used, which involves approximately 42 tows per year. The spring seasonal survey employs a stratified-random sampling design. The sampling area is divided into strata defined by depth. For each seasonal sampling cruise, sites are selected randomly from within each stratum.

All black sea bass collected are weighed (kg) and measured for total length (cm). The number of individuals measured from each tow varies by species, and also depends on the size of the catch and range of lengths. If a species is subsampled, the length frequency of the catch is determined by multiplying the proportion of measured individuals in each centimeter interval by the total number of individuals caught.

In order to generate a black sea bass index of abundance for the stock assessment, statistical, model-based standardization of the survey data was conducted to account for factors that affect black sea bass catchability.  Only ages 1 and above are represented in the spring component of the RI seasonal trawl survey. Following the approach described in the ASMFC's standardization guidelines, an index of age 1 and above black sea bass was created using a negative binomial generalized linear model with a log link and bootstrapped estimates of uncertainty. Proportion of positive tows for black sea bass averaged approximately 11% across the time series, with that average increasing to 19% since 2000.

A full model that predicted catch as a linear function of year (categorical data), bottom temperature (continuous data), month (categorical data), station (categorical data), and depth (continuous data) was compared with nested sub-models using AIC. The model that included year, bottom temperature, and depth was selected because it produced the lowest AIC coupled with the lowest variance inflation. The index exhibited a marked increase from low catches early in the time series with the increase beginning in the mid-1990s to present. There is some degree of small decline at the end of the time series. Diagnostics identified slight under-prediction of average annual catch per tow

The indices have been highly variable over time, although the spring index includes several above-average years since 1999 (Figure A15).  The 2015 overall index (1.025 fish/tow) was well above the series average (0.180 fish/tow, std error = 0.073). The Department also conducts a coastal pond seine survey and although the mean catches per tow are small, it does show an increasing trend, peaking in 2014 at 2.04 fish per tow.

The Massachusetts Division of Marine Fisheries has conducted trawl surveys each spring and fall since 1978. The spring survey occurs in May and the fall survey occurs in September. The survey employs a stratified random design, with stratification based on five bio-geographic regions and six depth zones. The six depth zones include 0-9.1 m, 9.1-18.2 m, 18.2-27.4 m, 27.4-36.6 m, 36.6-54.9 m, and >54.9m. Surveys from 1978-1981 were conducted aboard the F/V Frances Elizabeth. Surveys since 1982 have employed the R/V Gloria Michelle. Trawl design and trawl doors have been consistent for the duration of the survey. The net is a ¾ size North Atlantic type two-seam otter trawl (11.9 m headrope/15.5 m footrope) rigged with an 8.9 cm rubber disc sweep and a 0.6 cm knotless codend liner (1.3 cm stretched mesh). The trawl is spread behind 1.8 m x 1.0 m 147 kg wooden trawl doors, 19 m 1.0 cm chain bottom legs and 18.3 m 1.0 cm wire top legs.

Black sea bass are encountered in both the spring and the fall survey, and are captured in all regions. All sizes of BSB are captured by the survey. Black sea bass are most common in Regions 1-3, which include waters from the Massachusetts-Rhode Island border, the waters of Nantucket and Vineyard Sound, and the eastern shore of Cape Cod.

Only the spring survey was standardized for the assessment. The survey was standardized using negative binomial regression. No offset was included because tow time was standardized throughout the entire time series. Potential predictors included temperature and stratum. Models were evaluated based on AIC. Results indicated that the model with the lowest AIC was one that included an effect of temperature and stratum. Diagnostic criteria, such as qq and residual plots, indicated acceptable model fit.

The MADMF spring index declined during the 1990s, rose briefly in 2000, then again in 2008 (Figure A16). The spring 2012 mean number per tow (3.882 fish/tow and CV=0.309) was the beginning of a period of indices above the series average (1.88 fish/tow). The index spiked in 2014 (10.458 fish/tow with CV=0.29) due to the incoming 2011 year class. The index has remained above average through 2016 (4.301 fish/tow with CV=0.30).

The Northeast Area Monitoring and Assessment Program (NEAMAP) is a stratified random trawl survey conducted in coastal waters between Rhode Island and Virginia. The spring series began in 2008 when the NEFSC dropped sampling of those strata. The overall ln re-transformed mean number per tow increased slowly since 2010 (0.19 fish per tow) to a 2015 mean of 0.30

fish per tow. The spring time series was further divided into two separate north and south series. The south series included strata off the coast of NJ and south, while the north was NY and RI coastal waters. The average catch per tow in the north (1.67 fish per tow with a CV =0.64) (Figure A17) was significantly larger than the south (0.14 fish per tow with CV=0.22) (Figure A18). The northern series increased since 2008, peaking in 2014 at 3.47 fish per tow. The 2015 mean number per tow decreased to 1.93 fish per tow. The southern index had an initial downward trend but has remained generally stable with the 2015 index approximately equal to the time series average. Catches in the southern strata were small and the final assessment model used only the age 1 indices for the southern area.

*NMFS surveys*

The NEFSC winter bottom trawl survey was conducted between Virginia and Georges Bank with stratified random tows from 1992 until 2007. Survey strata used for an index of abundance were offshore strata in areas comparable to the location of the winter trawl fishery. The trawl gear was a flatfish net with a cookie sweep. The overall series peaked in 2003 at 17.70 fish per tow, which followed from the 2002 index of 10.84 fish per tow. In 2007 when the survey was terminated, the survey index equaled 4.36 fish per tow.

For the assessment area models, the survey area was split into north and southern strata groups relative to Hudson Canyon. The northern stratified mean number per tow reached a peak in 2003 of 4.64 fish/tow before declining to average values by 2007 of 1.18 fish per tow (Figures A19). The comparable survey indices for the southern area were considerably larger, peaking at 31.32 fish per tow in 2003 (Figure A20). The index in the final year of the survey was 7.67 fish per tow.

Indices were converted to swept area abundance estimates for use in the assessment model. The area swept per tow between the wings during the winter survey equaled 0.0131 $NM^2$. The winter survey indices were not included in the final northern model.

The NEFSC spring bottom trawl survey has been conducted between Nova Scotia and North Carolina since 1968. The indices (stratified mean number per tow) for black sea bass were developed using offshore strata containing at least one positive tow in the time series. Previous assessments using the NMFS data considered a log transformation of catch per tow to reduce the influence of high catches. The survey is designed to account for variation and the transformation can violate the underlying assumption of the designed survey (T. Miller, NEFSC, pers. comm.), therefore indices were calculated as the arithmetic mean number or mean weight per tow. Sampling was conducted aboard the *FRV Albatross IV* using a Yankee 35 haddock net with a roller sweep. In 2009 the FSV *Henry B. Bigelow* replaced the *FRV Albatross IV* in conducting the survey. The *Bigelow* gear consists of 4-seam, 3 bridle net with a rock-hopper sweep and is towed for 20 minutes rather than 30 minutes with *Albatross*. Although calibration factors for the two vessels are available (calibration factor=3.41), the *Bigelow* time series was considered as a separate index series of black sea bass abundance.

The NEFSC spring mean number per tow in the *Albatross* series followed a pattern of an increasing index during the late 1970s, followed by a decline during the 1980s and 1990s (Figure A21). A second increase in the index occurred beginning in 1998, peaking in 2003 at 9.51 fish per tow, followed by a decline to 0.61 by 2008. The uncalibrated *Bigelow* series began in 2009 with an index of 2.44 fish per tow and peaked in 2013 with 11.42 fish per tow. The 2015 and 2016 indices were 3.12 and 4.97 fish per tow, respectively.

The area split for the NEFSC spring series highlights a general northward spatial distribution shift. The *Albatross* series north of Hudson Canyon peaked in 1986 with 2.30 fish per tow, however the time series average was only 0.21 fish per tow (Figure A22). The numbers per tow increased significantly during the years of the *Bigelow* series, peaking at 11.02 fish per tow in 2014. The 2015 and 2016 indices were 1.88 and 8.20 fish per tow, respectively.

The indices in the southern area reflected the multiple peaks seen in the overall index (Figure A23). The *Albatross* index series peaked in 1977 at 18.25 fish per tow and again in 2003 at 20.60 fish per tow. The *Bigelow* series since 2009 had an index of 22.56 in 2013 but declined to 4.64 and 1.01 fish per tow in 2015 and 2016, respectively.

For the purposes of the area exchange model, the north and south indices were converted to swept area abundance estimates. The area swept per tow between the wings during the spring *Albatross* series equaled 0.0112 $NM^2$ while the *Bigelow* area swept per tow was 0.007 $NM^2$

*Recreational CPUE*

In addition to fishery independent survey indices of abundance, the Working Group also developed a fishery dependent index of abundance from the Marine Recreational Fisheries

Statistics Survey (MRFSS[1]). For this exercise, catch was estimated using the raw (unexpanded) Type 2 and Type 3 MRFSS data files. Estimates of potential effort for a given species can be difficult using the MRFSS data due to the self-reported nature of the data. In an attempt to account for potential effort (rather than just positive trips or self-reported directed trips), effort estimates were based on effort for a species guild. Species to include in a guild were identified using the Jaccard index of similarity (Jaccard 1912). Estimation of the similarity coefficient can be summarized as follows.

1) Determine the number of trips (MRFSS intercepts) that caught the target species
2) Determine which non-target species were caught on trips when the target species was caught.
3) Determine the number of trips (MRFSS intercepts) that caught a given non-target species.
4) Divide the number of trips that caught both the target and non-target species by the number of trips that caught either the target species or the non-target species.

Mathematically, this can be expressed as

$$J = \frac{N_{11}}{N_{10} + N_{01} + N_{11}}$$

where N is the number of trips and the subscripts of 0 and 1 are binary for observation of the target and non-target species. High values of *J* suggest high correlation between the target and non-target species (*e.g.* habitat utilization), so observation of the non-target species implies presence of the target species even if it is not observed.

For the current analysis, species associations were evaluated at the regional level using all years combined. Guilds were composed of the target species and any species with a similarity coefficient greater than 5% ($J \geq 0.05$). Any trip that caught any one of the guild species was considered a potential black sea bass trip. Regional species guilds and time series of effort (# of intercepted trips with guild species) are shown in Tables A5-A6, respectively.

For each potential black sea bass trip identified through the guild analysis, trip level CPUE was estimated as the black sea bass catch divided by the number of anglers contributing to the catch (catch per angler or CPA). Because observed (Type A) and unobserved (Type B1 and B2) catch

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[1] Although the MRFSS was officially replaced by the MRIP in 2012, MRFSS-based raw data files are available through 2015, allowing a continuous time series of MRFSS data for this analysis.

are handled separately by MRFSS and do not necessarily have the same number of anglers associated with the two types of catch on a given trip, it was necessary to develop separate CPA estimates for observed and unobserved fish and sum them (CPA = CPA_A + CPA_B). Admittedly, this is not ideal, but should not have an overall large effect on the results.

Trip specific CPA was then modeled using R software with a delta-lognormal GLM. Full models included covariates of year, area, wave, state, mode, and hours fished. Final models included only covariates that explained at least 5% of total deviance (Table A7).

Effort in the northern region generally increased during the 1980s, rising from less than 1000 intercepted trips in 1981 to over 4000 intercepts by 1990 (Table A6). Effort subsequently leveled off, and varied without trend between 2000 and 4000 intercepts annually for the years 1990 to 2010 before showing a general increase in recent years. CPA in the northern region remained generally stable below 0.25 fish per trip between 1989 and 1998 (Figure A24). Catch rates increased to around 0.5 for a brief period, before dropping back to previous levels in 2004 and 2005. Over the last decade, recreational catch rates of black sea bass in the northern region have shown a dramatic increase, rising from 0.23 fish per trip in 2005 to 1.7 fish per trip in 2015.

From the early 1980s to early 2000s recreational black sea bass effort in the southern region increased more than two-fold, rising from around 3000 intercepted trips per year to a peak of over 9000 intercepts in 2001 (Table A6). Since that time, effort has gradually declined, dropping to approximately 6400 intercepts in 2015. CPA in the southern region follows a similar pattern as the associated effort. Catch rates increased from around 1.0 fish per trip in early to years to over 3.0 fish per trip by the early 2000s (Figure A25). CPA subsequently dropped by approximately 35% by 2004, and has varied without trend around 2.0 fish per trip since that time. Recreational black sea bass CPA in the southern region was estimated at 1.74 fish per trip in 2015.

The overall stock-wide CPA peaked in the late 1990s-early 2000s, which followed the southern CPA pattern (Figure A26). Since 2005 there has been a steady increase in catch rate with a sharp spike in 2012.

**TOR 2.** Estimate catch from all sources including landings and discards. Characterize the uncertainty in these sources of data. Evaluate available information on discard mortality and, if appropriate, update mortality rates applied to discard components of the catch. Describe the spatial and temporal distribution of fishing effort.

*Spatial and Temporal Distribution*

Spatial patterns in the commercial fisheries were examined and distribution maps presented in Appendix A7. The trawl fishery north of Hudson Canyon generally catches black sea bass across the shelf throughout the year. There is a trawl fishery within the New York Bight that targets scup and summer flounder as well as sea bass. As sea bass migrate out to the shelf edge with declining water temperatures, the trawl fleet follows and operates south of Hudson Canyon along the shelf edge. Pot fisheries generally operate further inshore than the trawl fleet as does the hand-line fleet. However, there is a hand-line fishery in the southern end of the stock that operates throughout the winter closer to the shelf edge.

The recreational fishery occurs from late April into October/November while black sea bass are distributed in coastal waters. There are party and charter boats that occasionally target black sea bass in January and February near the Hudson Canyon. The distribution of trips is presented across years due to confidentiality with the limited number of vessels involved. The wave 1 (January- February) fishery has been closed in recent years.

A tagging study in the mid-2000s demonstrated the migratory pathways of black sea bass originating in different areas (Moser and Shepherd 2009). Fish originating north of Hudson Canyon follow the shelf break south and are captured in the winter trawl fishery. Fish originating to the south of Hudson Canyon remain in the south. The pot and hand-line fisheries operate inshore (with the exception of the southern hand-line fishery which operates offshore adjacent to the point of origin). Consequently, mixing among the two defined spatial units is most likely to occur south of Hudson Canyon with fish from both areas present in the southern trawl catch. In order to account for the mixing, the fisheries were divided into trawl and non-trawl components with the winter trawl fishery acting as a proxy for the mixed component of the stock.

*Commercial fishery*

The commercial fishery on the northern black sea bass stock (Maine to Cape Hatteras, NC) is prosecuted primarily with fish pots, otter trawls and hand-lines (Figure A8). Fish pots and hand-lines are generally fished in inshore waters when targeting black sea bass (with the exception of some lobster and sea bass pots in NY). Trawls are generally offshore in the winter months in conjunction with summer flounder and scup fisheries (Shepherd and Terceiro 1994). Fish pots have accounted for 44% of landings since 1989, followed by otter trawls at 41% and hand-lines at 9%. Other gears account for 7%. The majority of the landings occur in January through June, peaking in May.

Trends in landings were relatively stable at around 1,300 mt until 2007 (Table A8, Figures A7, Figure A27). State and Federal management plans were implemented in 1998 which included minimum size restrictions and commercial quotas. In 2008, additional quota regulations were enacted which decreased landings to an average of 739 mt between 2008 and 2012. Since 2013 commercial landings have increased to 1,113 mt in 2015. The commercial sea bass fishery is prosecuted in all states between Massachusetts and North Carolina however Massachusetts, New Jersey, Maryland and Virginia account for over 70% of total commercial landings (Table A8). The majority of landings since 1989 (54.6%) are from areas 611-622 with most trawl landings coming from areas 616 (17%), 622 (26%) and 626 (17%). Total landings by NMFS statistical areas are presented in Table A9. Black sea bass landings have been dominated by medium, large and jumbo sizes since 2000 (Figure A28, Tables A10-A17). Beginning in 2011, large and jumbos have accounted for 60% or greater of the landed fish. In 2015 sea bass from medium, large and jumbos market categories represented 23%, 37% and 29% of overall landings, respectively.

The time series of fishery data in the assessment was limited to 1989 to 2015. The NEFSC fishery observer program began in 1989. Therefore estimates of discards prior to 1989 would have to be determined via ratio estimates to other fisheries. The consensus of the WG was to limit the data series to years with empirical estimates of commercial discards. Commercial data was divided into half year time blocks for gear categories of trawl and non-trawl. The north-south criteria adopted in TOR1 was applied in the expansion of the catch at length and catch-at-age. Spatial coverage of length sampling was insufficient to allow region specific samples to be applied to the landings by market category. The WG concluded that regional variation in landing by market category would adequately capture any size differences between north and south and length distribution within market category was narrow enough to minimize any regional effect.

Average size by market category was also compared across years (Figure A29) and areas (Figure A30) to evaluate the inter-annual stability of size composition within market grades. Length distributions within market categories were relatively stable. Therefore size composition within a market category was applied between adjacent years when needed, i.e. a medium was considered a medium regardless of time or space. In summary, length distributions within market categories (small, medium, large, jumbo and unclassified) by half year period (Jan-Jun, Jul-Dec) were applied to landings by half year, region (north and south), market category and gear category (trawl vs non-trawl) for 1989-2015, using half-year region specific length-weight equations.

Length measurements (cm) of sea bass in the commercial landings are sampled by NMFS in ports from Maine to North Carolina. Samples are collected from boxes of fish available from dealers and sorted by market category. Market categories are extra small, small, medium, large, jumbo and unclassified. Length frequencies by market category and half year were expanded to total catch beginning with 1989. NMFS samples were supplemented with similar information collected by the state of North Carolina between 1989 and 1998. The NC lengths measurements were combined with NMFS data by market category and half year. Landings from the extra small category since 1989 were minimal and the size distributions were comparable to smalls. Therefore extra smalls were combined with smalls. Sample sizes and total number of fish measured from NMFS and NC data are provided in Tables A18. Sampling intensity is expressed as metric tons (mt) of landings per 100 fish measured (Tables A19-A20). Since 1989 the overall commercial sampling has averaged 21 mt per 100 lengths, with the best sampling years between 2008 and 2012 when sampling was on the order of 7 mt per 100 lengths (Figure A31).

Length weight information to convert landed weight to number was available from NMFS spring and autumn survey data since 1992. The equations applied to all length samples by season and region were:

North Spring: 1.0157e-5 * length(cm)^3.0769
North Autumn: 1.2649e-5 * length(cm)^3.0173
South Spring: 1.1448e-5 * length(cm)^3.0435
South Autumn: 1.9053e-5 * length(cm)^2.8937

In the expansion process, missing cells (Figure A32) were replaced with lengths from the same market category and the closest year or years containing measurements. The most frequent substitutions occur in the second half of the year within the unclassified category between 1993 and 2002 (Figure A33). In addition, jumbos in the second half year prior to 2002 were also poorly sampled. However, the lack of samples also reflects limited availability due to minimal landings. Since 2003 the only missing cells were unclassified in the second half of 2010 and 2011, which represented 2% and 3%, respectively, of total annual catch. Cells with substitutions are presented as shaded cells within the sampling intensity table.

The total number of black sea bass landed across both areas combined has declined since 1996 (5.0 million) to a low of 935,000 in 2009 (Figure A34). Total landings since 2010 (1.27 million) have increased steadily to 1.49 million in 2015. Overall mean length in the landings in both areas have increased steadily from around 28 cm in 1989 to 34 cm in 2004 and have remained relatively stable since 2003 around 35 cm (95% CI ±12 cm). The same size trends exist within area, season and gear types (trawl vs non-trawl) (Figures A35-A37). The mean size of landings does not vary much by season, however by gear type there is some area differences with the non-trawl landings smaller in the south.

*Commercial discards*

Estimated discards were calculated from four gear types. Otter trawl and sink gillnet discards were calculated using the Standardized Bycatch Reporting Methodology (SBRM) (Wigley et al 2008). SBRM relies on information collected by NMFS observers on a sub-sample of commercial trips as part of a program begun in 1989. Annual discards per half-year were estimated in each region (north/south) as the ratio of recorded discards for the species in question to recorded kept of all species landed, multiplied by the total reported landings of all species in that time strata. The associated CV for the estimate was also calculated (Table A21). The observed trips for hand-line or fish pot gear was limited, therefore the SBRM approach was not used for discard estimates. Pot and hand-line discards from 1994-2015 were estimated from self-reported vessel trip logs (VTR), adjusted to total landings by gear. VTR logs were not required prior to 1994. For the period 1989-1993, the ratio of the trawl discards to pot discards and hand-line discard per half year from 1994-1996 was multiplied by the associated trawl discard estimates. Management began in 1997 so 1994-1996 was used to avoid regulatory discards influencing the results. Pot and hand-line discards were combined into the non-trawl category. Discards from trawls and sink gillnets were assumed to suffer 100% mortality because of depths fished and length of tow or soak time. Discard mortalities of 15% were applied to pot and hand-line discards. The rationale was that depths fished generally resulted in minimal barotrauma and the volume of fish in a pot catch would result in minimal damage to released fish. Hand-line discard mortality was assumed equivalent to recreational discard mortalities. Discards from sink gillnets was minimal, with an annual average in the time series of less than 0.2 mt. The highest year for discards occurred in 1991 with 1.9 mt, however the CV for the estimate was 0.94.

The largest amount of discard mortality was attributed to the trawl fishery (Table A21). Annual discard losses ranged from 2.0 mt (CV=0.64) in the north during 1991 to 607.2mt (CV=0.62) in the south during 1996. Precision of the trawl discard estimates in the time series varied but CVs averaged 0.53 in the north and 0.42 in the south. Discards in the non-trawl gears was primarily from pots. Discard mortalities from the non-trawl gear averaged 5% of the total discards, however annual proportions ranged from 0.4% to 59.3%. The years with higher proportion of non-trawl discards occur when trawl estimates are low. Total weight of discards in non-trawl gear ranged from 0.7 mt to 23.9 mt (Table A22). In 2015 total trawl discards were 128.9 mt in the north and 186.1 mt in the south. Non-trawl discard losses totaled 17.1 mt in the north and 2.9 mt in the south.

Commercial discard length samples were divided by region (north/south), half year and gear type (trawl/non-trawl) (Table A 22a). Length samples from observed trawl trips prior to 1997 were sporadic, so length samples were pooled (pooled distribution did not include a cluster of fish in 1989 less than 9 cm that were not considered representative) (Table A22b). Length samples from non-trawl gear were limited (although observer data was not used for non-trawl discards estimation, there were limited length samples available). Substitutions for missing lengths were made from other areas, time blocks or gear depending on available alternatives. Most substitutions were made prior to 2000.

Annual commercial discard length distributions show a shift in the size composition over time (Figure A38). Prior to the FMP, discards were composed primarily of sizes below 31 cm. As minimum sizes and quotas went into effect the size distribution increased (likely due to gear changes) and included larger individuals of legal size. The primary reason for discards was quota restrictions or below minimum size (Figure A39).

*Recreational Landings and Discards*

The NMFS Marine Recreational Fishery Statistical Survey (MRFSS) provided catch estimates between North Carolina and Maine beginning in 1981. In 2006 following a review by the National Research Council, the design of the survey was changed and the program became the Marine Recreational Information Program (MRIP) which has continued to evolve. Calibrations have been made to adjust the MRFSS estimates to MRIP estimates from 2004 to present. However, pre-2004 estimate adjustments were left to the discretion of individual analysts. The relationship between the calibrated and uncalibrated black sea bass estimates was linear with a slope of 0.975 ($R^2 = 0.90$) (Figure A40). The WG concluded that re-calibration of the MRFSS estimates was unnecessary.

Estimates were downloaded from the website (http://www.st.nmfs.noaa.gov/recreational-fisheries/data-and-documentation/queries/index.html) for AB1 fish (fish kept or fish filleted, released dead, disposed in some other way) and B2 fish (released alive). Annual estimates are provided for waves (two-month periods) 2 to 6 and by state. Landings and discards were partitioned into half year blocks and regions, with NY north into the northern region and NJ south into the southern region. Wave 1 (Jan/Feb) is not sampled in the Northeast however wave 1 estimates have been produced for North Carolina since 2004. Recreational catch in wave 1 is primarily party and charter vessels which are required to submit VTR logs while fishing in federal waters. The location is designated by NEFSC statistical area, so totals from VTR records were added to the perspective region based on statistical area. North Carolina catch may occur from either stock (partitioned at Cape Hatteras, NC) therefore annual MRFSS catch estimates were split north and south of Hatteras based on intercept sites. MRFSS estimates are provided as number of fish for AB1, B2 and weight (kg) of AB1 catches. Total weight of discards was derived by applying a length-weight equation to the expanded discard length frequencies.

Stock-wide recreational landings averaged 1,438 mt between 1989 and 2003 then declined to an average of 1,138 mt thereafter (Figure A41). Some of the decline could be attributed to changes in the regulations, particularly minimum size and bag limits. Starting around 1995 there has been a steady shift in the distribution of black sea bass recreational landing from predominantly southern states to the states in the northern region (NY and north) (Table A23). The majority of sea bass landings prior to 2007 were taken in the southern region, primarily New Jersey (Figure A42). Since then, the percentage has shifted north such that 86.2 percent of the landings in 2015 were from the northern region. Total landings in weight in 2015 were 1,588 mt in the north and 276 mt in the south, which is the largest disparity in the time series (Table A24).

Length frequencies of the recreational landings were sampled by MRIP personnel during dockside interviews. Lengths were expanded to total landings by region and half year. Average length of fish in the landings has increased over time likely as a function of changing regulations. Mean length (cm) from 1989 to 1997 ranged from 27 to 31 cm. Size increased between 1997 (29 cm) and 2002 (37 cm) then remained stable (Figure A43). Overall mean length of 2015 landings was 38 cm. North and south differences were not apparent until a divergence in 2000 when northern landings were generally larger fish than in the southern region (Figure A44). On average the northern fish were 4 cm larger and the difference was as much as 7 cm in 2014. It should be noted that until 2010 recreational size limits were relatively consistent. After 2010, states from NJ south remained at 12.5” while northern states were required to adopt larger minimum sizes (up to 15”) in an attempt to constrain landings. Although the harvest was not necessarily limited it did produce larger average sizes from New York north.

Regulations of the recreational fishery based on size and bag limits inevitably results in discarding. The survival rate of discarded fish is impacted by multiple factors. Fish captured at depth and brought to the surface undergo pressure changes that can cause barotrauma. In a physoclistous fish like the black sea bass, the most obvious sign of barotrauma is the expanded abdomen and displaced organs by an over-inflated swim bladder. Combinations of angler experience and terminal tackle choice can lead to hook traumas, extended handling and exposure on deck. Conditions at the surface may be significantly warmer or colder than those found at the bottom. Assessments now routinely try to account for discard mortality and there is a growing body of work that addresses it, including several articles that specifically address black sea bass. SAW-43 (NEFSC 2006) assumed a 15% discard mortality rate for black sea bass caught recreationally with a hook and line. Previous assessments (SAW 27) which included recreational discards applied a 25% mortality rate. The assessment cited the Bugley and Shepherd (1991) estimate of 4.7%, generated from black sea bass caught in waters 6-12 meters deep, but noted that fisheries in New Jersey and south accounted for a significant proportion of discards and are often prosecuted in deeper waters. Bugley and Shepherd (1991) noted mildly extended abdomens in some fish but attributed release mortality primarily to anglers with limited experience and the forcible removal of hooks from fish hooked in the esophagus.

The Northeast Data Poor Stocks Working Group (2008) applied a 25% mortality rate to recreational discards but did not offer any justification for the increase from the previous assessment.

SAW-53 (NEFSC 2011) assumed a 15% recreational discard mortality rate, after evaluating the results of black sea bass specific studies (Bugley and Shepherd, 1991 and Rudershausen et al.,2007) and peer reviewed studies for other species. Ruderhausen et al. (2007) found that 3.6 % of 199 black sea bass caught in depths from 19-71 meters (28.5 meter average) were unable to orient themselves and swim down. It was assumed that fish in this release condition would not survive. Black sea bass that were bleeding or non-jaw hooked were also more likely to be unable to swim down, but these findings were not statistically significant, perhaps due to low sample sizes. Gastric distention (barotrauma) was visibly evident in 61% of black sea bass but this condition was not associated with immediate discard mortality (poor release condition). The authors assumed that gastric distension resulted in 100% delayed mortality and estimated that 66% of black sea bass would suffer delayed mortality. Later work by these same authors would test and refute this assumption.

SEDAR 25 (2011) applied a 7% mortality rate to discards from commercial and recreational hook and line black sea bass fisheries whereas prior assessments had used 15%. This decision was based heavily upon work detailed in Rudershausen et al.(2010). Fish were caught in waters from 29-37 meters depth, tagged, release condition noted, and then after 72 hours, recaptured. Recapture rates of fish with visible barotrauma, hook trauma, those unable to swim, and those presumed dead were compared with the recapture rates of fish that were able to swim down without any visible signs of trauma (best release condition). It was assumed that fish in the best release condition survived as well as fish never caught. Six additional fishing trips, independent of tag/recapture trips, were then undertaken and a discard mortality rate for hook and line fisheries was estimated based upon prior return rates and the release condition of fish caught. Discard mortality averaged 4.3% and ranged from 0 to 6.9% over these 6 trips. In addition, Rudershausen et al. explored a number of other questions related to: a)predation on released fish swimming down from surface (not significant), b)non-jaw hook trauma (significantly lower survival rates than fish that were jaw hooked), c) post release floating as a proxy for immediate mortality (an over-estimate), d) tagging acting as inadvertent “venting” (tagging resulted in fewer floaters but did impact survival), e) the trend between discard mortality and depth was positive, but not significant. Over the depths of this study, fish with visible barotrauma that were able to orient and swim down did not have different recapture rates (and estimated survival rates) than fish in the best release condition.

Collins et al. (1999) experimentally tested whether fish able to descend after capture with the assistance of venting had a greater chance of survival. Fish unable to orient and swim down were assumed to not survive and all other fish were held at capture depth in traps. Mortality over 24 hours in the control group (unvented) averaged 13% for black sea bass caught in waters from 20-35 meters deep (n=83). Mortality increased significantly in fish caught between 43-55 meters (39%, n=25). In addition, venting was shown to be an effective way to reduce immediate discard mortality in black sea bass caught across these depths.

Stephen and Harris (2010) collected fishery dependent data on fish release condition during commercial hook and line trips fishing from 20-80 meters depth. They estimated that 66% of released black sea bass (61/92) suffered immediate mortality due to impaired ability to swim down. Their field work occurred at greater depths (majority >40m) than previous studies (e.g. Bugley and Shepherd, 1991; Collins et al., 1999; and Rudershausen et al., 2010) and these depths are likely greater than where the majority of recreational angler activities take place. It is likely that barotraumas are contributing to the greater immediate release mortality, as was also found in Collins et al. (1999). Immediate release mortality in black sea bass did not differ with respect to size.

The data collected and reported on in Rudershausen et al. (2010) was added to, reanalyzed, and later published by Rudershausen et al. (2014), which differs from the 2010 grant report in the addition of a tagging and holding at depth component that acts as a control (no hook, pressure, deck or predation related traumas) to test the assumption that best release condition fish had 100% survival. A total of 5,131 black sea bass were tagged, with an overall tag recapture rate of 23.5%. The model estimated fish in best (surface) release condition to have a survival rate of 87%. Therefore, the fishery related median discard mortality rate (based upon the release condition of fish caught on fishing trips independent of the tag/recapture efforts) over depths from 20-35 meters was estimated to be 19%. The authors noted that in fisheries prosecuted at shallower depths (such as 6-12 meters in Bugley and Shepherd (1991)) the survival rate of surface released fish should be greater.

The five black sea bass specific studies reviewed here include a wide range (5 – 66%) of mortality estimates that could be applied to discards from the recreational hook and line fishery. Important conclusions include: a)visible barotrauma ≠ 100% mortality, b) best release condition ≠ 100% survival, c) non-jaw hook trauma (and angler experience) reduces survival to a greater extent than visible barotrauma, and d) barotrauma related mortality likely increases at depths greater than 40m.

A large proportion of the recreational fishery for black sea bass in the Mid-Atlantic occurs in depths shallower than those covered in many of these studies. Most of the studies, with the exception of Bugley and Shepherd (1991), were conducted in the South Atlantic where productive fishing grounds are generally further offshore and in deeper water. In addition, water temperatures in the South Atlantic are not reflective of most areas fished in the northern (Mid-Atlantic) stock. In the Mid-Atlantic, 75% of the recreational harvest (in pounds) and 82% of its discards (in numbers of fish) over the last 5 years (2011-2015) have been taken from within state waters (inland waters and ≤ 3 miles from the coast).

The hook and line discard mortality rate of 19% estimated by Rudershausen et al. (2014) is well supported by a large sample size, high proportion of recaptures, and an experimental control but the study was conducted in relatively deep water and surface released fish likely exposed to warmer water temperatures. The design of Bugley and Shepherd (1991) also had an experimental control, was conducted in shallower depths in New England, and estimated discard mortality in black sea bass around 5%. The working group concluded that the 15% discard mortality rate used in SAW-43 and SAW-53 is appropriate, slightly decreasing the discard mortality rate estimated in Rudershausen et al. (2014) due to the shallower depths at which most of the Mid-Atlantic recreational black sea bass fishery occurs. A discard mortality rate of 15% is well within the range (2.5 – 20%, avg 11%) of estimates used in recent (2009-2015) assessments for other physoclistous species from the Atlantic and Gulf of Mexico. A review of discard mortality studies related to black sea bass are provided in Table A25.

Overall recreational black sea bass discard losses (B2 *0.15) peaked between 2000 and 2003 with the maximum occurring in 2002 at 771 mt, well above the time series average of 263 mt (Table A24). The 771 mt represented a total number of 1.7 million fish, however the maximum number discarded in the series occurred in 2000 with 1.98 million fish. Discard losses in 2015 were 1.08 million fish equaling 317 mt (Figure A45). Discard trends in the north and south differed over time (Table A24, A26 and Figure A46). Until 2012 the majority of discards occurred in the south but that trend reversed in 2012 (58% north) likely the result of a large incoming year class and diverging minimum sizes and season lengths between areas. The trends continued to diverge through 2015 with 79% of the discards occurring in the northern region. Discard lengths were compiled from several sources. The majority of the recreational fishery occurs from July to October, so the discard data was applied on an annual rather than seasonal basis. The American Littoral Society is a conservation group that promotes fish tagging of recreationally caught fish to follow their movement. Tagged fish are by definition B2s (caught and released alive). The lengths of the fish tagged between 1989 and 2010 were available, but measured in inches which were converted to length in cm. Additional information came from a Volunteer Angler Survey conducted by NJDEP from 2008 to 2015 involving hook and line gear. Released fish below the minimum size were classified as discards. New York DEP provided discard length information collected from party/charter boats between 1995 and 1999 as well as 2011 through 2015. Finally, the MRFSS program began at-sea sampling of party/charter boats in 2004. Mean length of discards follows a comparable pattern as landings with increasing size over time (Figure A47). Prior to 2002 southern releases tended to be larger and increasing in size over time however the trend could be a function of limited length samples. Post 2004 the regional mean lengths were comparable around 25 cm but diverge in 2011 with larger fish discarded in the north. By 2015 mean discard length in the north was 31.7 cm whereas the southern mean was 24.5 cm.

*Total Catch*

The pattern of total catch (commercial landings and discard losses, recreational landings and discard losses) has remained relatively stable with the exception of spikes in the early 2000s and more recently in 2014-2015 (3,631 mt and 3,683 mt, respectively) (Figure A48). The pattern by region is increasing catch in the north while the south remains stable following a decline in the mid-2000s (Figures A49-A50). The commercial catch has been less variable due in part to the quota restrictions monitored in real-time. Mean length in the catch has slowly increased in the north since the mid-1990s while mean length in the south has declined since the early 2000s (Figure A51).

*Catch at age development*

The primary source of age data for expansion of commercial landings and discards, recreational landings and discards and survey data was the NEFSC spring and autumn bottom trawl surveys since 1989. Commercial age samples were available since 2012 and age data collected in the NEAMAP survey provided the necessary ages for estimation of indices at age. However the available age information was incomplete for all years and in many instances was not available for all length categories. Alternative approaches were evaluated to make best use of the available ages. Sample sizes of ages by year, season, and source from 1989-2015 are given in Table A27. Ages from all years prior to 2015 are based on scales. Ages from 2015 onwards are based on otoliths.

*Age Length Keys*

All age length keys (ALKs) were constructed using multinomial logistic regression (Gerritsen et al. 2006; Stari et al. 2010, Weakfish Stock Assessment Subcommittee 2015) using the *multinom* function in the nnet package for R (Ripley 2016). A set of ALKs was constructed by year for spring (January-June) and fall (July-December) seasons, region (north or south) as well as by gear type (fisheries independent or commercial). Additional ALKs were constructed by year, using additional data from the previous two and subsequent two years, by season, region and gear type. Cumulative ALKs were also made for each season, region and gear type from data pooled among all years. For all ALKs, the plus group was age eight.

Age data from the northern region NEFSC fisheries-independent trawl survey in spring 2015 was insufficient to construct a suitable ALK so the 2015 age data was augmented by including data from the MADMF spring trawl survey and from NYDEC commercial market sampling.

*Catch at Age*

Annual catch at age (CAA) was created from recreational catch, recreational discard, commercial trawl catch, commercial trawl discard, commercial non trawl catch, and commercial non trawl discard catch at length for each region and season combination. Catch at age was calculated in two portions for each season, region and gear type combination. The first portion consisted of selecting all BSB <14 cm TL from the catch data for a specific combination. For the spring season, all BSB <14 cm TL were assumed to be age-1. For the fall season, all BSB <14cm TL were assumed to be age-0. The second portion of the CAA was constructed by selecting all BSB for a given combination ≥14 cm TL. The ALKs were applied to this portion of the catch at length data based on criteria agreed upon by the SASC (see below).

*Criteria for Key Application*

Recreational CAA was created using ALKs constructed from the NEFSC trawl survey. Commercial CAA was created using ALKs constructed from commercial sampling efforts when available, otherwise the survey ALKs were applied. Criteria for key selection were based on sample size (>89) and a maximum age of at least 6. The minimum sample size was based on the median sample size for the fall season, southern region, fisheries independent age data 1984-2015. Median sample size for all other season, region and gear type combinations, with the exception of spring season, northern region, fisheries independent 1984-2015, was greater than 89. In cases where a year, gear, region and season combination ALK met the prescribed criteria, the ALK was applied directly to that catch data. If this criterion was not met, ALKs that included the previous two and subsequent two years of data were applied. If keys were not available that included the previous and subsequent two years, the cumulative key was applied.

Two exploratory exercises were conducted to explore the influence of data pooling and sample size on CAA (Appendix A8). Differences in predicted CAA based on ALKs for individual year vs those pooled among multiple years were examined. This exercise demonstrated that pooling resulted in differences <12% in predicated CAA for a given catch data set. Further, a simulation was done to create a population with a known catch and a known age structure, then ages randomly sampled from the population, ALKs constructed and then CAAs calculated from the random samples. The mean age of the catch for each year in the simulation was compared to the known catch. Using 20 truly randomly sampled ages with 1,000 truly randomly sampled lengths produced a distribution of mean age of the catch that had a median close to the true mean age of the catch for all years and the distributions were relatively small  e.g. they distinguished among years as true mean age of the catch changed. This work demonstrated that the ALKs allowed the calculation of accurate CAAs at sample sizes>20, suggesting that the SASC committee's criteria of 89 was appropriate.

A summary of how the age keys were applied is presented in Table A28. The final product of the length data expansion was a catch at age matrix for 1989 to 2015 for trawl and non-trawl fleets (includes recreational catch) for the north, the south and a combined north/south matrix (Tables

A29-A32). Age 0 fish represented 2% (1989 and 1990) or less and were not included in the assessment model. The overall catch at age profile indicated full recruitment around ages 3 or 4, which constituted 63% of the catch. Black sea bass age 6 and greater represented only 4% of the overall catch in the series. More detail on the age composition of the catch and indices are provided in the assessment model diagnostic plots.

Mean weights at age were determined using the total catch at age and total weight at age by area (Table A33 and A34). Comparison of annual weights at age by area show a difference by area with the southern area consistently smaller at age across all years (Figure A52)

**TOR 4.** Consider the consequences of environmental factors on the estimates of abundance or relative indices derived from surveys.

Miller et al (2015) examined the influence of winter oceanographic conditions on distribution and juvenile survival. Beginning around October, black sea bass along the coast begin to migrate offshore towards the Continental Shelf break. Fish in the northern end of the range move south to the shelf edge then follow the shelf further south depending on conditions. Fish in the Mid-Atlantic move southeast or east to the shelf edge. Age 0 sea bass, which are generally less than 14 cm when they leave coastal regions, tend to be more generally distributed across the shelf, perhaps due to slower swimming speeds. Consequently their survival is related to conditions across the shelf. If warm saline Gulf Stream water moves onto the shelf in winter, survival is high. When cold conditions are the norm, survival decreases. As a result of this variable overwinter survival as a function of oceanographic conditions, indices of young of year sea bass collected in the fall do not reflect subsequent year class strength and were not used as indices of abundance.

State survey indices were evaluated with General Linear models to determine if environmental factors influence the signal from empirical data. Model configurations varied among surveys but depth, bottom salinity and bottom temperature were common factors. New Jersey and New York found depth and salinity were significant, Rhode Island was depth and temperature, Massachusetts was temperature and Connecticut was depth (temperature and salinity not considered due to lack of data). Adjustments to the indices using these covariates altered point estimates but the same overall trends remained.

**TOR 5**. Investigate implications of hermaphroditic life history on stock assessment model. If possible, incorporate parameters to account for hermaphroditism.

Black sea bass, like other hermaphroditic fishes, are challenging to assess (Blaylock and Shepherd 2016) because of the dynamics of length and age-specific sex ratio that vary in space, time, and as a result of differential fishing and mortality. The result is that each sex will have unequal mortality patterns (Blaylock and Shepherd 2016). Standard assessment methods that model the population resilience by understanding patterns of female growth, fecundity, and mortality and temporal changes in female biomass may not be appropriate and unique modeling approaches may be warranted (Blaylock and Shepherd 2016) because the reproductive rates at levels of fishing mortality that would not be problematic for a gonochoristic species may be so for a hermaphroditic one (Alonzo et al. 2008).

Variations in reproductive strategies in fishes are diverse and include the ability to change sex from male to female (protandry) or from female to male (protogyny), simultaneous hermaphroditism and gonochoristic sex determination (McBride et al. 2013). Aside from interest in understanding the ecology and evolutionary dynamics of species, sex change as a response to sex ratio has implications for assessment and management. Black sea bass is a protogynous hermaphrodite and its stock dynamics and life-history characteristics can be impacted by size-selective fishing mortality (Provost and Jensen 2015). Such dynamics are challenging to fishery managers because the effects of size- and age-selective fishing on hermaphroditic stocks is not well understood (Provost 2013) though recent work has shown that skewed sex ratios can make a stock more vulnerable to overexploitation (Brooks et al. 2008, Blaylock and Shepherd 2016).

In a review of such challenges and the implications for management, Provost (2013) and Provost and Jensen (2015) documented the impacts to population dynamics that sex change may have and the variety of strategies that are used to model such alterations in age-specific sex ratio in quantitative stock assessments.

There are two potential primary impacts that fishing mortality has on the dynamics of a hermaphroditic stock. The first is that fishing may cause a greater skew in sex ratios and the second is that size-selective fishing mortality may decrease the size or age at sex change (Provost and Jensen 2015). A suite of behavioral strategies including sex-specific aggression and aggregating mating strategies may reinforce the vulnerability to fishing of one sex at a greater frequency than another and serve to increase stock vulnerability. For protogynous hermaphrodite fishes, sex-specific behavioral responses may serve to change sex ratios. For example, aggressive behavior by male Scamp may have a greater fishing mortality than females because they are more likely to bite hooks (Gilmore and Jones 1992). Another behavioral aspect of size-selective mortality on hermaphroditic fishes is the impact that removing large males from harem groups may have. The interruption of social hierarchies may reduce spawning success. The effects of differential mortality on the stock are not limited to ecological impacts. The removal of males and the resulting increasingly skewed sex ratio may have evolutionary implications as well, resulting in stocks that have fundamentally different population dynamics. Simulation modeling work has indicated that populations that are subject to sex-specific mortality may be at a greater risk of overexploitation (Brooks et al. 2008).

Work to understand, in an assessment context, the impacts of differential sex-, age- and length-specific mortality dynamics (Shepherd and Idoine 1993) has indicated that alterations to the sex ratio should be explicitly included in assessment. Departures from model assumptions from hermaphroditism result in breaking one or more model assumptions in age-structured modeling approaches (Heppell and Heppell 2012). The primary issue is that in sex changing species the catch at age time series and selectivity curve may vary by sex because the fishery differentially targets older males. The implications to management for protogynous species is that fertilization rates may be lowered (sperm limitation) resulting in reduced production which has been explored in simulation (Brooks et al. 2008) and shown to be critical in determination of biological reference points.

A simulation study specific to black sea bass populations (Blaylock and Shepherd 2016) demonstrated the vulnerability to exploitation in this hermaphroditic species. Previous work (SAW 53 WP) has shown that the sex ratio in the northern stock of black sea bass was approximately 30% males at small sizes and 30-40% female at larger sizes. This contrasts with the expectation of a typical hermaphroditic species first maturing as females then a nearly complete transformation to male at older ages. In addition, it was shown (as well as in previous work by Alonzo et al. 2008, Brooks et al.2008) that the presence of mature secondary males (males without bright coloration or nuccal humps, sometimes called sneaker males during spawning) increases the resilience of a population to exploitation. If the large dominant male is removed and smaller mature males are available to spawn, the population is more robust than a population totally dependent on the large males or requiring mature females to change sex to replace the male. The black sea bass simulation study concluded that the northern stock of black sea bass was not a typical protogynous hermaphrodite and was more resilient to exploitation. The resilience is a result of a sex ratio which is not completely male at larger sizes and contributions by the secondary males which in combination bring black sea bass life history more in line with gonochoristic species.

Incorporating parameters into the assessment model to account for hermaphroditism would require empirical data that is not available, particularly the type of males present. A study by Brooks et al. (2008) showed that when adequate information about sex composition is unavailable, it is prudent to characterize spawning stock biomass (SSB) as the combined male and female mature biomass. To that end, this assessment incorporated that definition of SSB for modeling and development of biological reference points.

As part of the simulation work conducted using a Stock Synthesis model (Appendix A9) the implication of hermaphroditism was examined. The operating model used to simulate pseudo-data included sex structure and hermaphroditism, but sex-aggregated models performed well for recovering simulated population parameters. Simulation indicates that model results are largely unaffected by the presence or absence of the hermaphroditism criteria. Growth models between sexes are comparable so once sex change occurs, there is little change in productivity. Additionally, with SSB defined as male and female mature biomass, a change of sex does not remove fish from the SSB calculation. Nevertheless, the spawning success in black sea bass is dependent on a balanced sex ratio ensuring the presence of both sexes during spawning.

**TOR 6**. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock), using measures that are appropriate to the assessment model, for the time series (integrating results from TORs-1,-4, & -5 as appropriate), and estimate their uncertainty. Include a historical retrospective analysis and past projection performance evaluation to allow a comparison with most recent assessment results.

*Model Development*

A statistical catch at age model (ASAP) was developed for the black sea bass assessment reviewed during SAW53. The SARC 53 review panel concluded that the results were not adequate for management purposes. Spatial patterning within the stock was suggested as a reason the model did not perform to their standards. Consequently, there are no historical retrospective or past projections to evaluate, however previous biological reference points are noted under TOR7.

Fishing mortality rates and stock sizes were estimated using the Age Structured Assessment Program (ASAP) statistical catch at age model (Legault and Restrepo 1998) available in the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/). ASAP is an age-structured model that uses forward computations assuming the 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 time. The user can choose to estimate or hold fixed the various parameters and input uncertainty estimates associated with data 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 compositions are generally modeled assuming a multinomial distribution, while most other model components are assumed to have lognormal error including penalties when used. 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-recruitment relationship). For more technical details refer to the ASAP technical manual.

The current assessment developed an ASAP model with several scenarios. The first scenario was modeling the stock under the assumption of a single unit stock, similar to previous approaches (note: this approach served as a bridge to previous assessments). Second, two unique area-specific models were developed for north and south of Hudson Canyon. Finally, a model was developed to account for exchange between the areas within the trawl fleets as well as within the NEFSC offshore surveys. Based on the performance of the two-area approach relative to more complicated models, as evaluated by simulation testing (Appendix A6), parsimony and practical familiarity with ASAP, the WG concluded that the use of the two area models combined for status determination provided the best results for use in management. The WG also determined that the conclusions were robust to the modeling approach. The various approaches are presented in the following text, however the Overall and Area exchange approaches are provided for comparison to the final models, which are the North and South area models.

The catch at age data described in TOR 2 (north trawl and non-trawl; south trawl and non-trawl; overall trawl and non-trawl), total catch weight by fleet and survey indices at age described in TOR 3 were input to the model. Maturity at age, weight at age and natural mortality (0.4) described in the Introduction were input for each area. The single stock model (Overall model) represented the sum of catch at age and catch weight by fleet across area.

Model exploration began with a series of trial runs (Table A35) using only NEFSC surveys to establish baseline settings which produced a model solution. The Overall model began with two selectivity blocks with a change occurring in 1997-1998 when management was introduced. Incrementally the full suite of survey indices at age were added, with adjustments to index CVs to produce root mean square error values approaching 1.0. Initial NEFSC indices were an *Albatross* and *Bigelow* combined series. Input effective sample sizes (ESS) were chosen to conform with estimated values which were based on the approach of McAllister and Ianelli (1997). The model evolved (Table A36) as catch selectivities and index selectivity patterns were explored, beginning with selectivities that were freely estimated. The final model selectivities were fixed as flat topped beyond a chosen age and freely estimated in younger ages. The age of full selection was 4 in indices at age, age 4 in the non-trawl fleet as well as the trawl fleet from 1989 to 1997 then increasing to age 5.

The final Overall model incorporated a split series in the NEFSC spring index resulting in an *Albatross* series (1989-2008) and a *Bigelow* series (2009-2015). Additional indices at age included MADMF, NEAMAP, RI, CT, NEFSC winter, Recreational CPA and NJ. Indices from NY, DE, MD and VIMS were limited to age 1 indices only.

Variation in the catch at age, by fleet, is specified by the coefficient of variation values input for each fleet and year. Commercial trawl catch was given a CV equal to 0.05 since it is based on a census of dealer reports (discards are a function of the same reported landings). However, fleet 2 includes recreational catch which is based on a survey design that has undergone multiple changes. The input CV on fleet 2 was increased with an input value of 0.2 from 1989 to 2008 then a value of 0.15 from 2009 to 2015 to reflect better commercial reporting and improved estimates in the MRIP survey.

Recruitment in black sea bass throughout the stock is regionally influenced and not well determined by traditional stock recruitment models. Consequently, recruitment in ASAP was modeled as deviations from the geometric mean (steepness fixed at 1.0). The model allows deviations to be constrained by applying a penalty on the deviations from the stock-recruitment curve, however this constraint was weak due to an input CV of 1.0.

Development of area specific models followed a similar sequence (Tables A37-A40). Selectivity was freely estimated for catch and indices, then fleets and indices with estimates at bounds were fixed. Additional variance was added to indices to produce model estimates consistent with input values and effective sample sizes were adjusted to reflect model output. The final model for the north was model 26 and for the south model 24.

The split into northern and southern areas was an attempt to address the spatial components of the stock as it was understood that the southern offshore area during winter would likely contain fish originating in the north. In an attempt to address this issue, an area exchange model was developed to permit the exchange of individuals between northern and southern areas. For black sea bass, the intent of this exchange was to account for fish caught in the southern area during the winter/spring offshore trawl fishery and NEFSC bottom trawl surveys that originated in the north. The modeling framework did not explicitly incorporate movement into the dynamics of the stock, but instead moved both fishery dependent and independent catch from the southern to the northern component before running two separate, area-specific ASAP models. The exchange of individuals impacted only total catch and aggregate indices, and did not alter age compositions.

Two components impacted the amount of catch exchanged between the areas. The first component was the overall proportion of southern catch that was assumed to originate from the northern area. The second component was related to annual variability in this assumed exchange proportion. The extent of black sea bass seasonal movement is thought to be related to water temperature. Therefore, to account for the impact of temperature on seasonal movement, average bottom temperature from the NEFSC spring bottom trawl survey was used as an annual covariate that modified the assumed exchange proportion. The magnitude of the covariate influence on the exchange proportion was the second component that impacted the amount of catch exchanged. This magnitude was dictated by an assumed range in possible annual fluctuations of the exchange proportion and effectively acted as a covariate scalar. As the range of possible fluctuations in the exchange proportion increased, the more the annual proportions could vary from the assumed average exchange proportion and therefore, the greater the overall impact of the covariate.

For a given average exchange proportion ($\bar{p}$) and range in annual fluctuations ($r$), the annual exchange proportions ($p$) were calculated as:

$$p = lb + \frac{ub - lb}{1 + e^{cov}}$$

where $cov$ represented the covariate as standardized (z-scored) average bottom temperature and $lb$ and $ub$ represented the lower and upper bounds, respectively, of the annual exchange proportion calculated as:

$$lb \text{ or } ub = \bar{p} \pm 0.5r.$$

In warmer years, it is believed that black sea bass do not migrate as far south (Miller et al. 2016); therefore, increased covariate values resulted in decreased annual exchange proportions. These annual exchange proportions were then used to develop adjusted time series of catches for the area-specific models that just represented individuals originating from that specific area.

For a given set of fishery dependent and independent catches, a series of exchange proportions and ranges were evaluated. Exchange proportion and range value combinations were only investigated if all possible annual proportions fell between zero and one. Candidate models based on adjusted time series were evaluated using the resulting combined (unweighted sum) total likelihood values of the area-specific models. The best exchange proportion and range combination was selected as the model set that produced the lowest combined likelihood. The robustness of assessment outputs, including recruitment, fishing mortality and spawning stock biomass, was evaluated across changes in exchange proportion and range values.

The final North and South models were incorporated into the area exchange model. The model was run for exchange rates between 0% (base models) and 50% by 5% increments and with annual ranges from 0 to 50% in 10% increments. The model likelihoods for each area and the sum were evaluated to determine the optimal north-south combination.

*Model Results*

The predicted total index proportions at age in the OVERALL model generally matched the observed values among all the indices. The predicted indices tended to match the trend among all the observed indices but generally were unable to match the large deviations associated with strong cohorts such as the 2011 year class among northern state indices. The root mean square error (RMSE) values ranged from 0.47 for REC CPA to 1.97 for MADMF indices (Figure A53). The model resulted in annual catch estimates that matched fleet 1 (standardized residuals ranged from 0.31 to -0.11) but varied more for fleet 2 (standardized residuals from1.95 to -2.85). Both fleets tended to have positive residuals prior to 2002 and negative after 2002 (Figure A54-A55). Effective sample size for fleet 1 was constant at 60 while fleet 2 equaled 100. Catchability estimates of all the indices were less than 1, however the *Albatross* q was larger than the *Bigelow* q which was opposite of expectations. Detailed diagnostics from the model are presented in Appendix A10.

The model provided total stock number estimates showing a slowly increasing population from a low in 2005 until 2011, at which point the total abundance increased dramatically due to an incoming 2011 cohort (Figure A56). Abundance declined thereafter but remained larger in 2015 than pre-2011 abundance. Average fishing mortality (ages 4-7) was very high in the early 1990s (as high as 1.44) but declined following management implementation in 1997. Estimated F in 2007 was 0.74 but declined steadily to 0.24 by 2011 (Figure A56). The 2015 average fishing mortality was estimated as 0.20.

Spawning stock biomass (male and female combined) steadily increased from1994 to 2002 when it reached 9,796 mt (Figure A56). There was a decline until 2007 (4,081 mt) followed by a steady increase to the 2015 estimate of 19,585 mt. Total biomass and exploitable biomass followed a similar pattern with 2015 total biomass equal to 24,155 mt and exploitable biomass of 23,658 mt (Figure A56). Average recruitment over the time series equaled 25.9 million age 1 fish, with strong cohorts in 1999, 2001 and an exceptional year class in 2011 (Figure A56).

A retrospective analysis of the model, using a 7 year peel, indicated very little impact on the results from additional years in the time series (Figures A57-A62). However, using a 7 year peel resulted in the loss of the Bigelow index and the reduction of the NEAMAP indices to one year. Consequently, the analysis uses a different model once the 7 year peel is completed so the retrospective results should be viewed with caution. The F estimates, with a Mohn's rho equal to -0.11, showed no obvious pattern. Biomass, total stock number and recruitment were similar and had Mohn's rho values ranging from 0.055 (recruitment) to 0.091 (SSB).

A Monte Carlo Markov Chain (MCMC) was implemented using 1000 iterations and a thinning rate of 200. The 2016 recruitment was estimated as the geometric mean recruitment from 2000 to 2015. The 90% confidence interval of the median terminal year Fmult (0.20) ranged from 0.151 to 0.264 (Figure A63-A64). The median 2015 SSB (20,092 mt) was estimated with 90% CI between 16,501 mt to 24,675 mt (Figure A65-A66). The confidence interval for January 1 median biomass in 2015 (24,693 mt) ranged from 20,788 mt to 29,674 mt (Figure A67-A68). The terminal year values of F, SSB and total biomass adjusted for retrospective were all within the 90% CI of the base values.

The NORTH model was developed using trawl and non-trawl catches taken north of Hudson Canyon and indices from the northern strata for NEFSC spring (*Albatross* and *Bigelow* series) and NEAMAP. The NEFSC winter northern index was not included in the final model due to poor diagnostics. Also included were indices from MA, RI, CT, NY and Rec CPA of states NY and north. Model results and diagnostics are provided in Figures A69-A97. The predicted total index proportions at age and the observed values in the model matched reasonably well among indices but annual matches varied among indices. The annual proportions at age from the NEFSC *Albatross* time series fit poorly as did several other indices in the early part of the series. In comparison, indices collected since the mid to late 2000s captured the age composition reasonably well. The predicted indices tended to match the trend among all the observed indices and were generally able to match the strong 2011 year class although not always of the magnitude within an index. The root mean square error (RMSE) values ranged from 0.74 for the Rec CPA to 1.88 for NY age 1 indices. The final model configuration resulted in annual catch estimates that matched fleet 1 (standardized residuals ranged from 0.06 to -0.18) and less so for fleet 2 (standardized residuals from 0.90 to -0.67). Both fleets tended to have positive residuals after 2009 and negative prior to 1997. Effective sample size for fleet 1 was constant at 50 while fleet 2 equaled 100. Catchability estimates of all the indices were less than 1. In addition estimated *Albatross* catchability was two times smaller than the Bigelow catchability which was comparable to the between vessel calibration coefficient (3.4), especially when considering the uncertainty in the q estimates from the model and changes in selectivity. Additional diagnostics from the model are presented in Appendix A11.

The model provided total stock abundance estimates showing a steadily increasing population beginning around 1993 until 2011, at which point the total abundance increased dramatically due to an incoming 2011 cohort (Figure A98). Abundance declined thereafter and 2015 total abundance was equivalent to abundance in 2011. Average fishing mortality (ages 4-7) was very high in the early 1990s (as high as 1.32 in 1992) but steadily declined to 0.17 by 2011 (Figure A98). Estimated fishing mortality since 2012 has remained steady at around 0.23.

Spawning stock biomass (male and female combined) steadily increased from 1994 (259 mt) to 13,119 mt in 2014 (Figure A98). There was slight decline to 11,719 mt in 2015. Total biomass and exploitable biomass followed a similar pattern with a peak total biomass equal in 2014 of 21,376 mt and exploitable biomass of 14,737 mt (Figure A98). Total biomass in 2015 decreased to 17,306 mt while exploitable biomass increased slightly to 15,079 mt. Average recruitment over the time series equaled 8.353 million age 1 fish, with an exceptional year class in 2011 of 49.88 million age 1 fish (Figure A98). Recruitment in 2013 was also above average followed by a low recruitment year in 2014.

A retrospective analysis of the model, using a 7 year peel, indicated a general mis-specification of fishing mortality, abundance and biomass. However, using a 7 year peel resulted in the loss of the Bigelow index and the reduction of the NEAMAP indices to one year. Consequently, the analysis uses a different model once the 7 year peel is completed so the retrospective results should be viewed with caution. The F estimates, with a Mohn's rho equal to 0.703, showed a pattern of over-estimation (Figure A99). Biomass, total stock number and recruitment were under-estimated and had Mohn's rho values ranging from -0.484 (recruitment) to -0.325 (exploitable biomass) (Figures A100-A104). The direction of the rho values are opposite to the pattern typically seen and results in decreased F and increased SSB following retrospective adjustments.

A Monte Carlo Markov Chain (MCMC) was implemented using 1000 iterations and a thinning rate of 200. The 2016 recruitment was estimated as the geometric mean recruitment from 2000 to 2015. The 90% confidence interval of the median terminal year Fmult (0.247) ranged from 0.181 to 0.337 (Figures A105-A106). The median 2015 SSB (11,959 mt) was estimated with 90% CI between 9,606 mt to 15,003 mt (Figures A107-A108). The confidence interval for January 1 median biomass in 2015 (17,656 mt) ranged from 14,569 mt to 21,449 mt (Figures A109-A110).

The terminal year (2015) values of F, SSB and total biomass were adjusted for retrospective patterns. The retro adjusted value of F (0.14), SSB (19,211 mt), total Jan 1 biomass (27,733 mt) fell outside the 90% confidence bounds of the terminal year estimate (Figure A110a)

The final SOUTH model was developed using trawl and non-trawl catches taken south of Hudson Canyon and indices from the NEFSC spring (*Albatross* and *Bigelow* series), NEAMAP (age 1 only because of poor diagnostics in older fish), and NEFSC winter southern strata. Also included were indices from NJ, DE, MD, VIMS and Rec CPA from states NJ and south. The only indices beyond age 1 were from the NEFSC *Albatross* and *Bigelow*, NEFSC winter, NJ and Rec CPA. The remainder provided indices of age 1 abundance. Model results and diagnostics are provided in Figures A111-A138.The predicted total index proportions at age and the observed values matched reasonably well among indices but annual matches varied among indices. The annual proportions at age from the NEFSC *Albatross* time series fit poorly. The predicted indices tended to match the trend among all the observed indices and were generally able to match the strong 1999 and 2001 year classes although not always of the magnitude within an index. The 2011 cohort was apparent as above average in several indices but not of the magnitude seen in the northern model. The root mean square error (RMSE) values ranged from 0.68 for the Rec CPA to 1.45 for NEFSC *Bigelow* indices. The final model configuration resulted in annual catch estimates that matched fleet 1 (standardized residuals ranged from 0.27 (1996) to -0.13) and less so for fleet 2 (standardized residuals from 1.73 to -1.74). Both fleets had positive residuals prior to 2002 and negative from 2003 to 2015. Effective sample size for fleet 1 was constant at 30 while fleet 2 equaled 40. Catchability estimates of all the indices were less than 1. In addition estimated *Albatross* catchability was two times smaller than the *Bigelow* catchability which was comparable to the between vessel calibration coefficient of 3.4, especially when considering the uncertainty in the q estimates from the model and changes in selectivity. Additional diagnostics from the model are presented in Appendix A12.

The model provided total stock number estimates showing a relatively stable population beginning between 1989 and 2002, at which point the total abundance declined reaching a low point in 2006 (Figure A139). Abundance steadily increased thereafter and 2015 total abundance approached the abundance seen in 2002. Average fishing mortality (ages 4-7) was very high in the early 1990s (as high as 1.43 in 1993) but declined to 0.55 by 1999 (Figure A139). Estimated fishing mortality increased again to 0.94 in 2007 but steadily declined to 0.23 by 2015.

Spawning stock biomass (male and female combined) steadily increased from1989 (2,088 mt) to 5,801 mt in 2002 (Figure A139). There was a decline to 1,732 mt by 2007 followed by another steady increase reaching 4,834 mt by 2015. Total biomass and exploitable biomass followed a similar pattern with a peak total biomass in 2002 equal to 9,728 mt and exploitable biomass of 6,718 mt (Figure A139). Total biomass decreased to 3,614 mt in 2007 with an exploitable biomass of 2,171 mt in 2008 but both have since increased to 6,838 mt and 5,168 mt, respectively, in 2015. Average recruitment over the time series equaled 15.92 million age 1 fish, with higher recruitment between 1989 and 2002 (Figure A139). Recruitment in 2015 was above average with 21.57 million age 1 recruits.

A retrospective analysis of the model, using a 7 year peel, indicated a general mis-specification of fishing mortality, abundance and biomass (Figures A140-A145). However, using a 7 year peel resulted in the loss of the *Bigelow* index and the reduction of the NEAMAP indices to one year. Consequently, the analysis uses a different model once the 7 year peel is completed so the retrospective results should be viewed with caution. The F estimates, with a Mohn's rho equal to -0.419, showed a pattern of under-estimation. Biomass, total stock number and recruitment were over-estimated and had Mohn's rho values ranging from 0.550 (exploitable biomass) to 0.873 (recruitment).

A Monte Carlo Markov Chain (MCMC) was implemented using 1000 iterations and a thinning rate of 200. The 2016 recruitment was estimated as the geometric mean recruitment from 2000 to 2015. The 90% confidence interval of the median terminal year Fmult (0.233) ranged from 0.162 to 0.343 (Figures A146-A147). The median 2015 SSB (4,901 mt) was not as well estimated with 90% CI between 3,628 mt to 6,529 mt (Figures A148-A149). The 90% confidence interval for

January 1 median biomass in 2015 (6,920 mt) ranged from 5,432 mt to 8,845 mt (Figures A150-A151).

The terminal year values of F, SSB and total biomass were adjusted for retrospective patterns. The retro adjusted value of F (0.39), SSB (2,966 mt), total Jan 1 biomass (4,276 mt) fell outside the 90% confidence bounds of the terminal year estimate (Figure A110a)

*Area Exchange Model*

A model using 40% exchange in trawl catch and indices with a 10% range in annual exchange proportions produced the lowest value for the combined likelihoods (Table A41). The best model for the southern area occurred with a 50% exchange and 50% range which were at the upper bound for both exchange rate and range. The northern model minimum likelihood occurred by moving 35% of southern catch and indices to the north and no annual fluctuations in this exchange rate (0% range).

Results from the optimal area exchange model showed minimal impact on the final overall estimates but did produce some regional differences (Figures A152). The catch in the north increased substantially in the early part of the time series (1993 total catch increased 127%) but by 2015 the exchange increased the northern total catch by only 3.7%. The effect of the catch increased abundance estimates an average of 22% but only resulted in reducing F by 3%. The average trawl catch reduction in the south of 40% reduced total catch by 9% which resulted in an 8-10% decrease in total abundance, SSB, recruitment and exploitable biomass. Fishing mortality decreased by only 1%. Overall, temporal trends in area-specific assessment outputs were robust to both the selected exchange proportion and range, though they were more robust to changes in the assumed range than the exchange proportion. Additional diagnostic plots are available in Appendices A13-A14.

The area exchange approach had minimal impact on the area-specific retrospective values with the exception of the fishing mortality in the north. The Mohn's rho in the north decreased 25% from 0.70 to 0.53 but adjusted F only decreased from 0.14 to 0.13. Rho only decreased 15% in exploitable biomass, 9% in total stock number and 6% in age one recruitment. Rho values for the south model increased but only by 3% or less.

*Model Comparisons*

Although models were developed for a northern area and a southern area, the final product for determining stock status was a single combined estimate for the unit stock. These combined area results as well as the combined area exchange estimates were compared with results from the single overall model (Table A42). The F values from North and South were averaged to compare to the Overall model results.

In general, the overall model produced larger estimates of abundance and biomass and lower estimates of F than the area-specific models and the combined areas estimates from the exchange model were nearly identical to the overall model (Figure A153). Despite the difference in point estimates among models, the trends were nearly identical. The WG concluded that the area exchange model as configured did not produce any benefits beyond the simple area combined or the overall model. However, it did prove informative as a sensitivity run to evaluate the impact of catch misspecifications to each area and showed that the model was robust to migration effects.

There existed a trade-off between the use of the overall model and the combined area-specific models. The area-specific models resulted in retrospective patterns which were in opposite directions. However because of the reduced areas in each, the local indices of abundance were more informative (i.e. fit better) than in the overall model. In the overall model the residuals in the catch and indices were greater, however the retrospective patterns of each area essentially cancelled each other resulting in low rho values. The WG concluded that the combined area specific models provided the most information for management purposes. There were clearly local variations in recruitment strength of the 2011 cohort which was most apparent in the area models. Fortunately the overall, combined area and area exchange models all produced similar results.

*Sensitivity analysis*

A sensitivity analysis was conducted to evaluate the influence of individual indices on the model results for each area. The models were run with each index removed from the model (only one index missing per run). The results show that the model was robust and not dependent on any single index. Model results with any particular index dropped remained within the 90% confidence interval of the base model. Results are presented in Figures A154-A163.

The models were profiled over a range of possible values of natural mortality. Each model was run using a new M value ranging from 0.01 to 1.0. The analysis was conducted on the two area models, the areas combined and the overall model and calculated the difference between each model negative log-likelihood and the model with the minimum negative log-likelihood (Figure A164). In the southern model, the minimum negative log-likelihood occurred for M at 0.8 whereas the northern model minimum occurred at 0.15. The combination of the north and south produced a minimum at an M=0.4 while the overall model minimum was at M=0.55.

An additional sensitivity test was made to examine the implications of the higher CV values used for the non-trawl catches. The CVs in the base model were 0.2 from 1989-2008 and 0.15 in 2009-2015). These values were varied from (0.05, 0.025) to (0.35, 0.3). The results (Figure A165) suggest that the North models F and SSB were robust to the range of values explored. The South model was impacted in the early 2000s when the SSB was highest, but remained robust to the range of CV over the past decade.

In addition to developing a model using the ASAP approach, the fishery and survey data was also explored using the Stock Synthesis framework (Methot and Wetzel, 2013). The model (Appendix A9) incorporated tagging data from a project in 2003-2005 (Moser and Shepherd, 2009) and modeled the population seasonally by length and sex, accounting for hermphroditism. Although the model was not fully vetted by the BSB WG, and therefore not presented as a working model, the results were similar to ASAP. The exploratory model suggested that the stock has increased in the last decade in both areas from strong recruitment and that fishing mortality decreased to relatively low values in the last decade. Sensitivity analyses indicate that these results are robust to alternative model configurations.

**TOR 7**. Estimate biological reference points (BRPs; point estimates or proxies for BMSY, BTHRESHOLD, FMSY, and MSY), including defining BRPs for spatially explicit areas if appropriate, and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the appropriateness of existing BRPs and the “new” (i.e., updated, redefined, or alternative) BRPs.

Black sea bass north of Cape Hatteras, NC have been managed as a single stock since the inception of the management plan in 1997. Although the evidence presented for TOR 1 suggests regional differences within the stock, there is no evidence that more than one stock exists north of Cape Hatteras. Although the preferred model approach of the WG has been the two area model with no exchange, development of reference points and subsequent evaluation of stock status was made on the unit stock (Cape Hatteras to the Gulf of Maine).
The WG examined the two-area models for a relationship between SSB and subsequent recruitment and concluded there was no evidence of any stock/recruitment relationship in the range of estimated stock size in the assessment time series (Appendices A11 & A12). Consequently there was no direct calculation of MSY and associated F or biomass. Instead, an average value of F40% between the two areas was chosen as a proxy for $F_{MSY}$. In similar situations, and for species with similar life histories, the South Atlantic snapper-grouper fishery management plan uses $F_{30\%}$ or $F_{40\%}$ as $F_{MSY}$ proxies when $F_{MSY}$ cannot be directly estimated. Thorson et al. (2012) suggest that $F_{35\%}$ is an appropriate proxy for $F_{MSY}$ based on a meta-analysis of stock-recruitment information from Perciformes. Zhou et al. (2012) suggested that $F_{MSY}$ is approximately 0.922xM for Perciformes, which would correspond to $F_{MSY}$~0.37 for the assumed M=0.4. The estimate of F40% in the north equaled 0.355 and was 0.365 in the south. An average of 0.36 was adopted as the proxy $F_{MSY}$.

An approach was adopted for developing biomass reference points using empirical recruitment in a long term projection. Inputs for projections included averages from 2013 to 2015 total (Jan 1) and SSB weights at age, selectivity at age weighted by contributing catch, and natural mortality =0.4. Recruitment was chosen from a random draw for the combined area recruits between 2000 and 2015. The WG felt that recruitment over this time period was more reflective of current population dynamics. Catch input for 2016 was the Allowable Biological Catch (ABC) established by the MAFMC for 2016. Distributions of abundance at age from each model MCMC run were combined for a single stock projection. A 100 year projection with 1000 bootstrap iterations was run and the average of the final 20 years calculated as the biological reference points ($SSB_{MSY}$ proxy, $B_{MSY}$ proxy and MSYproxy) associated with the $F_{MSY}$ proxy. In previous assessments using a length based model (SCALE (Northeast Data Poor Stocks Working Group 2009)) $B_{MSY}$ proxy was chosen as a biomass reference point. Traditionally spawning stock biomass is preferred because of the potential relationship with subsequent recruitment, however hermaphroditism presents unique challenges in defining female SSB due to sex changes. Analyses by Brooks et al. (2009) showed that SSB defined by both sexes provided a reasonable alternative. Consequently combined male and female SSB is recommended for use as a biomass reference point for black sea bass although both SSB and total biomass estimates are provided. The final estimate of $SSB_{MSY}$ proxy equaled 9,667 mt with $\pm$ 2 SD of 4,149 mt, $B_{MSY}$ proxy of 17,256 mt with $\pm$ 2 SD of 7,453 mt, and an MSYproxy estimate of 3,097 mt with $\pm$2 SD of 1,299 mt (Table A43). The previous basis for determining if a stock is overfished is ½ of $B_{MSY\ proxy}$ which in this stock equals 8,628 mt ($\pm$ 2 SD of 3,722 mt). An alternative approach for biomass reference point estimation using the single overall model produced results similar to the combined area model, although generally higher. Those estimates are $SSB_{MSY}$ proxy = 10,296 mt, $B_{MSY}$ proxy = 18,379 mt, and MSY = 3,298 mt.

Biological reference point estimates from the 2008 assessment black sea bass assessments were an $F_{MSY}$ proxy = 0.42, $SSB_{MSY}$ proxy of 12,537 mt and an MSY of 3,903 mt and the 2012 assessment (which was not accepted in SAW53) produced reference points of an $F_{MSY}$ proxy = 0.32, $SSB_{MSY}$ proxy of 8,128 mt and an MSY of 3,197 mt.

**TOR 8**. Evaluate overall stock status with respect to a new model or new models that considered spatial units developed for this peer review.

Retrospectively adjusted values of SSB and F from the ASAP model are being used for stock status determination. The stock of black sea bass north of Cape Hatteras, NC is not overfished, nor is it experiencing over fishing (Figures A169-A170). The retrospective adjusted estimates of F, SSB and B from each area were combined for comparison to biological reference points. The retro-adjusted 2015 biomass (32,010 mt) is currently 86% above $B_{MSY}$ proxy and retro-adjusted 2015 SSB (22,176 mt) is 129% above the $SSB_{MSY}$ proxy (9,667 mt). Retro-adjusted fishing mortality in 2015 ($F_{MULT} = F_{Ages\ 4\text{-}7} = 0.27$) is 25% below the $F_{MSY}$ proxy = 0.36.

The 2015 stock biomass prior to adjustment (24,143 mt) is 40% above $B_{MSY}$ proxy (17,256 mt) and 2015 SSB (16,552 mt) is 71% over $SSB_{MSY}$ proxy (9,667 mt). Fishing mortality in 2015 before adjusting for the retrospective bias ($F_{MULT}$= 0.24) is 35% below $F_{MSY}$ proxy = 0.36.

It should be noted that the area specific conditions are different. Relative to F40% (0.355 in the north, 0.365 in the south), the retro adjusted F in the north (0.14) is well below the threshold whereas retro adjusted F in the south (0.39) is slightly above (although well within the 80% CI of 0.30 to 0.52). Biomass reference points were not independently estimated for each area.

**<u>TOR 9</u>**. Develop approaches and apply them to conduct stock projections.

a. Provide numerical annual projections (3-5 years) and the statistical distribution (e.g., probability density function) of the OFL (overfishing level) that fully incorporates observation, process and model uncertainty (see Appendix to the SAW TORs). 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, and definition of BRPs for black sea bass).

b. Comment on which projections seem most realistic. Consider major uncertainties in the assessment as well as the 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.

Catch projections are presented for the unit stock, however they represent the sum of each area specific projection. Projections for the north and south area were made for years 2017 through 2020 under the assumption of either $F_{MSY\ proxy}$ or status quo F. Since 2016 catch estimates were not available, 2016 catch was interpreted as the ABC (3,024 mt) split into area based on the 3 year average ratio of catch by area. The 2013 to 2015 average catch ratio was 71% in the north and 29% in the south, therefore 2016 catch in the north was 2,150 mt and the south as 874 mt. Additional runs were included which allowed a 10% and a 20% overage in the north 2016 catch since recent years have exceeded the ABC. The 2013-2015 average weights at age, selectivity (fleets combined, weighted by catch at age), and empirical recruitment from 2000 to 2015 were input to the stochastic projection software AGEPRO. A distribution of starting numbers at ages 2 to 8+ were produced by the MCMC run of each final model. Projections were also made in each area using rho adjusted estimates. The results of each area were summed for the final catch projections. The final products were projections for area combined, area combined rho adjusted and a comparison to projections using the overall model under $F_{MSY}$ and F status quo ($F_{SQ}$).

Results <u>without</u> rho adjustments from the area combined model under $F_{MSY\ proxy}$ (0.36) shows a substantial increase in total catch beginning in 2017 at 4,446 mt (± 2 SD  1,687 mt) (Table A44, Figure A171). However as the 2011 cohort abundance declines, catch declines such that 2018 projected catch would drop to 3,822 mt (± 2 SD 1,299 mt) and 3,493 mt (± 2 SD 1,481 mt) in 2019. Total biomass would also decline beginning in 2016 (23,374 mt ± 2 SD 7,351 mt) and declining to 18,764 mt (± 2 SD 8,977 mt) by 2019 which is above $B_{MSY\ proxy}$ (17,256 mt, Table A44, Figure A172). Spawning biomass follows a similar trajectory, declining from 15,055 mt (± 2 SD 5,621 mt) in 2016 to 10,782 mt (± 2 SD 5,083 mt) by 2019 (Table A44, Figure A173).

Results <u>without</u> rho adjustments from the area combined model under $F_{SQ}$ (0.24) shows a substantial increase in total catch beginning in 2017 at 3,127 mt (± 2 SD 1,189 mt) (Table A45, Figure A174). However as the 2011 cohort abundance declines, catch declines such that 2018 projected catch would drop to 2,904 mt (± 2 SD 996 mt) and 2,809 mt (± 2 SD 1,147 mt) in 2019. Total biomass would also decline beginning in 2016 (23,374 mt ± 2 SD 7,351 mt) and declining to 20,848 mt (± 2 SD 9,423 mt) by 2019 which is above $B_{MSY\ proxy}$ (17,256 mt, Table A45, Figure A175). Spawning biomass follows a similar trajectory, declining from 15,055 mt (± 2 SD 5,168 mt) in 2016 to 12,805 mt (± 2 SD 5,663 mt) by 2019 (Table A45, Figure A176).

Results <u>with</u> the rho adjustments from the area combined model under $F_{MSY\ proxy}$ (0.36) have the same trend with higher abundance (Table A43). A substantial increase in total catch would occur beginning in 2017 at 5,467 mt (± 2 SD 1,984 mt) (Table A46, Figure A171). However as the 2011 cohort abundance declines, catch declines such that 2018 projected catch would drop to 4,494 mt (± 2 SD 1,457 mt) and 3,901 MT (± 2 SD 1,502 mt) in 2019. Total biomass would decrease from 29,350 mt (± 2 SD 9,028 mt) in 2016 to 20,788 mt (± 2 SD 9,063 mt) by 2019 which is above $B_{MSY\ proxy}$ (Table A46, Figure A172). Spawning biomass follows a similar trajectory, declining from 18,670 mt (± 2 SD 6,721 mt) in 2016 to 11,849 mt (± 2 SD 5,143 mt) by 2019 (Table A46, Figure A173).

Results <u>with</u> the rho adjustments from the area combined model under $F_{SQ}$ (0.27) have the same trend with higher abundance (Table A47). A decrease in total catch would occur beginning in 2017 at 3,006 mt (± 2 SD 1,126 mt) (Table A47, Figure A174). Catch continues to decline through 2018 as projected catch would drop to 2,859 mt (± 2 SD 953 mt) and 2,764 mt (± 2 SD 986 mt) in 2019. Total biomass would decrease from 29,246 mt (± 2 SD 8,993 mt) in 2016 to 24,704 mt (± 2 SD 9,839 mt) by 2019 which is above $B_{MSY\ proxy}$ (Table A47, Figure A175). Spawning biomass follows a similar trajectory, declining from 18,587 mt (± 2 SD 6,690 mt) in 2016 to 15,349 mt (± 2 SD 6,099 mt) by 2019 (Table A47, Figure A176).

The Overall model, with no rho adjustments, was similar to the area combined estimates with the rho adjustment. Projected catch in 2017 at $F_{MSY}$ would be 6,615 mt compared to the rho adjusted combined area model with 5,467 mt (Figure A171). SSB in 2017 in the overall model equaled 19,125 mt compared to the rho adjusted combined estimate of 15,918 mt (Figure A172).

Given the convergence of estimates from the overall model and the rho adjusted area combined model, the rho adjusted values appear to provide reasonable projection estimates. The projections assume the 2016 ABC was not exceeded. If the 2016 ABC was exceeded by 20%, the projected rho-adjusted 2017 catch at $F_{SQ}$ would only decrease 2% to 2,993 mt. The projections also assume the selectivity estimated for 2013-2015 would apply to the future catches. Due to overages in 2015, states from NJ north adjusted regulations to reduce harvest in 2016, which may have influenced selectivity to some degree.

The assessment model and consequently the projections do not explicitly account for hermaphroditism in sea bass beyond using male and female SSB. However, hermaphroditism is unlikely to have a large impact on the assessment results but should be considered in developing management options. Finally, there is evidence in 2016 survey indices that in some areas the 2015 cohort is above average. This incoming year class would not have much influence on projections until 2018, at which time it will be included in the assessment estimates.

**TOR 10.** Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

Research recommendations from SAW 53:

**1.** *The panel recommends multiple age-structured models be evaluated for use in a future model. Specifically, we recommend:*

*a. A simple model such as a separable model with smoothing on F among years.*
Not attempted for this assessment, however evaluation of catch curves is a routine diagnostic.

b. *A more complex, spatially structured model with 6 month time step within independent stock areas in spring and mixing in winter with natal homing, if data area adequate to support such a model.*

Completed in the form of the area exchange model and explored within the SS3 model.

c. *Consideration should be given to including tag return data in an age-structured (and possibly spatially-structured) assessment model.*

Tag results were considered in developing the area exchange bounds but not explicitly within the model. Explored within the SS3 model.

2. *The Panel recommends evaluation of a species specific survey, such as a pot survey to provide increased information on abundances and biological characteristics.*

Previously existed but was terminated by the MAFMC following a review of the program design.

3. *Continue and expand the tagging program to provide:*
    a. *increased age information.*
    b. *increased resolution on mixing rates among putative populations.*

No additional designed tagging projects were conducted.

4. *Continue and expand genetic studies to evaluate the potential of population structure north of Cape Hatteras.*

Some genetic work being evaluated for the Gulf of Maine by Marissa McMahon, Northeastern University.

5. *Continued research on rate, timing and occurrence of sex-change in this species. Recent research findings discussed at the SARC lead to the hypothesis that protogyny is not obligate in this species – some individuals may never have been female before maturing as a male.*

Some further work conducted by NEFSC as well as Rutgers University.

6. *The validity of the age data used in the assessment requires further evaluation, in particular the reliability of scale-based ageing needs to be determined. A scale- otolith intercalibration exercise might be of utility.*

Working paper included which explores this issue.

SAW 62 Black Sea Bass Working Group research recommendations:

1. Expand on previous genetic studies with smaller spatial increments in sampling.
2. Consider the impact of climate change on black sea bass, particularly in the Gulf of Maine.
3. Evaluate population sex change and sex ratio, particularly comparing dynamics among communities.
4. Study black sea bass catchabilty in a variety of survey gear types.
5. Investigate and document social and spawning dynamics of black sea bass.
6. Increased work to understand habitat use in sea bass and seasonal changes.
7. Evaluate use of samples collected by industry study fleets.

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