EXCERPTS

# Research Track Assessment

# Bluefish

Bluefish Research Track Working Group

2022

## 2022 BLUEFISH RESEARCH TRACK ASSESSMENT

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### ACKNOWLEDGEMENTS

The Working Group thanks: Sarah Gaichas and her collaborators on development of the forage fish index including Jim Gartland, Brian Smith, Elizabeth Ng, James Thorson. We thank Tim Miller for assistance with WHAM exploration, development, and support. We also thank Joe Myers, ASMFC's Bluefish Technical Committee and Fishery Management Plan Coordinator, Dustin Colson Leaning, for their data collection and analysis support as well as participating in the ASMFC State Data Review Workshop for bluefish. Michele Traver and Alexander Dunn provided helpful administrative support. Matt Seeley participated in the early WG meetings before moving on to the Western Pacific Fishery Management Council. Eric Robillard contributed important information on bluefish ageing and oversaw or conducted the majority of the bluefish ageing for this assessment.

## EXECUTIVE SUMMARY

> *Term of Reference (TOR) #1: Identify relevant ecosystem and climate influences on the stock. Characterize the uncertainty in the relevant sources of data and their link to stock dynamics. Consider findings, as appropriate, in addressing other TORs. Report how the findings were considered under impacted TORs.*

Temperature and photoperiod are the principal factors directing activity, migrations, and distribution of adult bluefish. Based on this mechanistic connection, quantitative indicators of optimal temperature were developed to better understand temperature trends during the bluefish spawning season. Sources of uncertainty are discussed. Analyses suggested that the spawning season may now extend later in the year compared to historical periods, though it is unclear how these changes in potential spawning season may affect bluefish recruitment. On the other hand, the amount of habitat in the optimal temperature range during the peak spawning month of July has not changed over time, indicating stability in spawning conditions and therefore possibly also in recruitment. A Vector Autoregressive Spatiotemporal (VAST) model was developed from the fall NEFSC bottom trawl survey to determine the fall centers of gravity of three bluefish size groups over time; analyses suggested systematic trends in large and medium bluefish, but not small bluefish. Temperature was tested as a covariate in the VAST model, but resulting poor model diagnostics were beyond the scope of the present working group to address.

Using a VAST framework, we also developed a forage fish index to evaluate changes in bluefish prey over time and space that could be used to inform survey and/or fishery availability in the bluefish stock assessment to inform annual deviations in catchability. Small pelagic forage species are difficult to survey directly, so we developed a novel method of assessing small pelagic fish aggregate abundance using predator diet data. The forage fish indices based on fall, spring, and annual datasets all show fluctuations in forage fish biomass, alternating between multiple years or decades with higher and lower levels.

Variability in bluefish life history processes was modeled by splitting life history data by semesters of the year, by decade, by geographic region, and by sex; results and sources of uncertainty are discussed. Natural mortality was updated for this assessment from one based on a "rule of thumb" estimate of 0.2 for all ages to Lorenzen weight-based age-varying estimates. Our findings were considered and/or incorporated into several subsequent TORs, including: spatial domain of the stock (TOR2), estimates of seasonal and regional catch weights (TOR2), development of survey indices of abundance with environmental covariates (TOR3), incorporation of the forage fish index into a companion assessment model (TOR4), updating natural mortality for use in the assessment model (TOR4), and informed several research recommendations (TOR7).

> *Term of Reference #2: Estimate catch from all sources including landings and discards. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data.*

The majority of commercial landings over the time series (1950-present) have been taken in the Mid-Atlantic region (New York, New Jersey, and North Carolina). The majority of recreational activity occurred from May to October, with specific seasonal patterns varying by state.

Recreational offshore (3-miles, or 4.8-km, or more from shore) areas account for only about 7% of total catch.

Total bluefish removals (total dead catch) have declined since the beginning of the time series. There was a slow increase from 1996 to 2010, but the declining trend has continued to the lowest values in the time-series in recent years. On average, commercial landings account for 14% of the total removals with commercial discards averaging only 0.2%. Dead commercial discards have not contributed to total removals in previous assessments, but since they have been identified as a source of uncertainty, they were included in this assessment. Total removals are dominated by the recreational fishery with recreational landings accounting for 71% of total removals, and recreational dead releases averaging 15% of total removals. The recreational dead release mortality rate was updated for this assessment through reexamination of the methods used in the previous assessment, and an updated literature review; the value changed from 15% to 9.4%. The recreational dead discard component of the catch was calculated using the season/region length frequency distributions developed from all of the recreational biological sampling data for released fish; this is a change from previous assessments to account for regional differences in fish size.

> *Term of Reference #3: Present the survey data used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, application of catchability and calibration studies, etc.) and provide a rationale for which data are used. Describe the spatial and temporal distribution of the data. Characterize the uncertainty in these sources of data.*

The WG participated in an ASMFC Bluefish Technical Committee workshop to review available state datasets. The WG explored standardizing fishery independent indices of abundance using environmental covariates in a GLM framework. However, the standardization process did not notably affect index trends or reduce interannual variability or index coefficients of variation, so the WG did not use the standardized indices in the base run and instead used the stratified arithmetic mean for surveys with a stratified random design and the geometric mean for surveys with a fixed station design. Bayesian hierarchical modeling was used to combine YOY indices into a single composite index, using the method developed by Conn (2010) that represents the coast wide recruitment dynamics of bluefish. Surveys included in the composite index were from NH Juvenile Finfish Seine Survey, RI Narragansett Bay Juvenile Finfish Beach Seine Survey, NY Western Long Island Seine Survey, NJ Delaware River Seine Survey, MD Juvenile Striped Bass Seine Survey, and VIMS Juvenile Striped Bass Seine Survey. In addition, the bluefish working group decided on 8 additional representative indices of bluefish abundance for the assessment:

1. NEFSC Fall inshore strata: 1985-2008 (age-0 – age-6+)
2. NEFSC Fall outer inshore strata (FSV Bigelow): 2009-2021 (age-0 – age-6+)
3. NEAMAP Fall Inshore trawl survey: 2007-2021 (age-0 – age-6+)
4. ChesMMAP trawl survey: 2002-2018 (age-0-3)
5. Pamlico Sound Independent Gillnet Survey; 2001-2021 (age-0 – 6+)
6. Marine Recreational Information Program CPUE: 1985-2021 (age-0 – age-6+)
7. SEAMAP Spring Inshore trawl survey: 1989-2021 (age-1)
8. SEAMAP Fall Inshore trawl survey: 1989-2021 (age-0)

Calculation of the MRIP CPUE was updated for this assessment. Bluefish trips were defined using a guild approach where a trip was considered a bluefish trip if it caught either bluefish or a species that was significantly positively associated with bluefish. This was a change from the previous benchmark assessment where effort was described using "directed trips," which describe trips where bluefish were considered a target species.

Multinomial age length keys were also explored as part of this assessment. Seasonal multinomial age length keys (ALKs) reduced retrospective trends and improved convergence diagnostics in statistical catch at age models relative to alternative ALKs; additionally, the WG did not believe data were sufficient for higher resolution (e.g., regional) ALKs, and so seasonal multinomial ALKs were selected for use in the assessment.

> *Term of Reference #4: Use appropriate assessment approach to estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Compare the time series of these estimates with those from the previously accepted assessment(s). Evaluate a suite of model fit diagnostics (e.g., residual patterns, sensitivity analyses, retrospective patterns), and (a) comment on likely causes of problematic issues, and (b), if possible and appropriate, account for those issues when providing scientific advice and evaluate the consequences of any correction(s) applied.*

The Woods Hole Assessment Model (WHAM), a state-space, age structured stock assessment model, was used as the base model to estimate annual fishing mortality, recruitment, stock biomass, and associated estimates of uncertainty, with data updated through 2021. A suite of model fit diagnostic plots were examined for each model of interest and model fits were examined using conventional residual diagnostics, as well as one-step ahead residual diagnostics. Retrospective patterns in model results were evaluated using Mohn's rho values.

The final model configuration included a number of notable model and data changes since the previous peer reviewed model, including: a state-space model, updated natural mortality estimate, addition of new indices, including a newly estimated MRIP CPUE index, and addition of several selectivity blocks. Spawning stock biomass from the final base model starts in 1985 high and declines through the late 1990s, remains stable for several years before rising to a localized peak in 2008, declining through 2018, and rising in the years since. This pattern broadly reflects trends from the previously accepted model, albeit with differences in scale. Fishing mortality from the base model starts low in 1985 and rises quickly, then declines and varies without trend over much of the timeseries; fishing mortality reached a high in 2017, and has declined to timeseries lows since. The trend from the previously accepted model is broadly similar, albeit again, with some differences in scale, primarily in estimates of recruitment.

WHAM allows for incorporation of environmental covariates on the catchability of survey indices, and we explored a companion model that leveraged this capability. The companion model that used the forage fish index as a covariate on catchability of the MRIP index showed promise for continued development. The covariate led to an overall decreasing trend in catchability over time.

*Term of Reference #5: Update or redefine status determination criteria (SDC; point estimates or proxies for $B_{MSY}$, $B_{THRESHOLD}$, $F_{MSY}$ and MSY reference points) and provide estimates of those criteria and their uncertainty, along with a description of the sources of uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for reference points. Compare estimates of current stock size and fishing mortality to existing, and any redefined, SDCs.*

Existing status determination criteria from the 2021 management track assessment (data through 2019) were $F_{MSY}$ proxy = $F_{35\%}$ = 0.181 and $SSB_{MSY}$ = 201,729 MT (1/2 $SSB_{MSY}$ = $SSB_{THRESHOLD}$ = 100,865 MT). Updated reference points from the ASAP continuity run are $F_{MSY}$ proxy = $F_{35\%}$ = 0.176 and $SSB_{MSY}$ = 190,771 MT (1/2 $SSB_{MSY}$ = $SSB_{THRESHOLD}$ = 93,386 MT).

Both $F_{35\%}$ and $SSB_{35\%}$ were calculated in WHAM using average recruitment over the time series (1985-2021), and 5-year averages for fishery selectivity, maturity and weights-at-age for SSB per recruit calculations. Reference points from the final model (BF28W_m7) were $F_{MSY}$ proxy = $F_{35\%}$ = 0.248 (95% CI: 0.209 – 0.299) and $SSB_{MSY}$ proxy = $SSB_{35\%}$ = 91,897 MT (95% CI: 66,219–127,534 MT); $SSB_{THRESHOLD}$ =1/2 $SSB_{MSY}$ proxy = 45,949 MT (95% CI: 33,110–66,768 MT). The retrospectively adjusted values of terminal year F and SSB were within the 90% confidence bounds of the unadjusted values, indicating a retrospective adjustment was not necessary to determine stock status. The terminal year SSB was 55,344 MT (95% CI: 35,185 – 87,052 MT) which was above the $SSB_{THRESHOLD}$ and 60% of $SSB_{MSY}$. Full fishing mortality was 0.166 (95% CI: 0.103 – 0.268) in 2021, which was 67% of the $F_{35\%}$ reference point. Stock status determination based on the final model indicates that there is an 87% chance that the bluefish stock is currently not overfished and over-fishing is not occurring.

| Status determination criteria | 2021 Management track assessment | 2022 research track assessment (continuity run) | 2022 research track assessment (WHAM) |
|---|---|---|---|
| **$F_{MSY}$ proxy = $F_{35\%}$** | 0.181 | 0.176 | 0.248 |
| **$SSB_{MSY}$** | 201,729 MT | 190,771 MT | 91,987 MT |
| **½ $SSB_{MSY}$** | 100,865 MT | 93,386 MT | 45,949 MT |

*Term of Reference #6: Define appropriate methods for producing projections; provide justification for assumptions of fishery selectivity, weights at age, maturity, and recruitment; and comment on the reliability of resulting projections considering the effects of uncertainty and sensitivity to projection assumptions.*

Short-term projections were conducted in WHAM, and incorporated model uncertainty and auto-regressive processes in recruitment and numbers-at-age. The projections used 5-year averages for natural mortality, maturity, fishery selectivity and weights-at-age. Removals in 2022 were assumed to be equal to the 2022 ABC (11,460 MT), and projections were carried forward for years 2023-2025 with different fishing mortality and harvest assumptions: F = 0, $F_{status\ quo}$ = 0.166, $F_{35\%}$ = 0.248, and that harvest in each year is equal to the acceptable biological catch (ABC) in each year. The probability of SSB in 2025 being above the SSB threshold is > 80% for all scenarios explored. Catch advice will be updated as part of the 2023 Management Track assessment, but catch advice from WHAM under the most likely scenario explored for this research track assessment (MAFMC risk policy assuming CV = 100%) is expected to be stable, but lower, relative to 2022.

*Term of Reference #7: Review, evaluate, and report on the status of research recommendations from the last assessment peer review, including recommendations provided by the prior assessment working group, peer review panel, and SSC. Identify new recommendations for future research, data collection, and assessment methodology. If any ecosystem influences from TOR 1 could not be considered quantitatively under that or other TORs, describe next steps for development, testing, and review of quantitative relationships and how they could best inform assessments. Prioritize research recommendations.*

The SAW 60 WG reviewed the status of previous research recommendations and proposed new ones to address issues raised during WG meetings. Notable accomplishments relative to past research recommendations include: development of an MRIP index using a species-association method to identify bluefish trips, updating the estimate of natural mortality used in the assessment model, evaluating model results that aggregated all model input data at a seasonal and regional level of resolution, multiple fishery independent surveys were combined using VAST as part of this assessment, examination of differences in the calibrated and uncalibrated MRIP estimates of bluefish catch, spatial stratification of recreational release length frequencies when calculating the weight of dead recreational releases, and the migration to the WHAM framework will allow for continued exploration and testing of covariates influencing time-varying catchability and selectivity.

The WG proposed several new research recommendations to better understand bluefish dynamics and assessing the population through the current or future models. These include the following: expand collection of recreational release length frequency data, continue development and refinement of the forage fish / availability index as well as incorporation of this index in to a base model for bluefish management advice, initiate additional fisheries-independent surveys or fishery-dependent sampling programs to provide information on larger, older bluefish, continue coastwide collection of length and age samples from fishery-independent and -dependent sources, refinement and development of indices of abundance, and develop a recreational demand model.

*Term of Reference #8: Develop a backup assessment approach to providing scientific advice to managers if the proposed assessment approach does not pass peer review or the approved approach is rejected in a future management track assessment.*

A backup assessment approach is required to be in place as a hedge against a scenario where the primary catch-at-age model is not suitable for providing management advice. The bluefish Working Group chose the index-based method Ismooth (previously known as PlanBSmooth) as the backup model due to its performance in the analyses performed by the Index Based Model Working Group (NEFSC 2020) and because it has a history of application at the NEFSC as an approach that has been used to develop ABCs (e.g., Georges Bank cod, Gulf of Maine / Northern

Georges Bank and Southern Georges Bank / Mid-Atlantic monkfish). Briefly, this approach applies recent trends in an index or indices to recent dead catch to generate ABC advice.

EXCERPTS

# Research Track Assessment of Northwest Atlantic

# Spiny Dogfish

Spiny Dogfish Research Track Working Group

November 23, 2022

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# EXECUTIVE SUMMARY

A research track assessment for spiny dogfish was planned for peer review in 2022, with several terms of reference (TORs) established to be addressed. This is the Spiny Dogfish Working Group's report to fulfill the TORs.

*Terms of Reference (TOR) 1:* "*Identify relevant ecosystem and climate influences on the stock. Characterize the uncertainty in the relevant sources of data and their link to stock dynamics. Consider findings, as appropriate, in addressing other TORs. Report how the findings were considered under impacted TORs.*"

Ecosystem and climate influences on the Northwest Atlantic spiny dogfish stock (simply "spiny dogfish" hereafter) were assessed by the Working Group in the context of their distribution and life history processes. The literature on spiny dogfish distribution was reviewed to provide context on its historical range, migration patterns, and perceived stock structure. Spatial distribution of the species was described specifically for within the Northeast U.S. Continental Shelf, and the geographic, climate, and environmental variables that have been known to influence spiny dogfish. To assess how climate has influenced the stock's abundance and distribution, a Vector Autoregressive Spatiotemporal (VAST) model was developed from the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey to calculate the center of gravity and effective area occupied for male and female dogfish. Largely, these metrics suggested that the annual distribution of dogfish has not changed significantly over time. Temperature and depth were explored as covariates in the VAST model, as they were the most common variables associated with spiny dogfish abundance and distribution from the literature. Results indicated that depth was the only significant factor in predicting occurrence and abundance.

The Working Group also discussed the environment and potential effects on life history characteristics: recruitment, growth, maturity, and diet. The Working Group explored the correlation between environmental conditions (e.g., spring bottom temperature, the North Atlantic Oscillation) on recruitment and recruits per spawner indices from the NEFSC spring bottom trawl survey, with little correspondence. Temperature was also evaluated in the context of a stock-recruit relationship, which indicated no statistical improvement over a non-environmentally explicit relationship. While environmental and climate influences on growth may be occurring, the lack of time series growth information prevented the Working Group from conducting related formal analyses. Updated maturity time-series data indicated a decline in maturity over time, but several causes are possible, including either harvest or environmental forcings. As such, better understanding the drivers in the declining maturity over time is considered a research recommendation.

*TOR 2: Estimate catch from all sources including landings and discards. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data.*

Commercial and recreational landings and discards are estimated over time, with methods for deriving them presented. Commercial landings increased rapidly from the late 1960s to 1974, with substantial spiny dogfish harvest by foreign trawling fleets beginning in 1966. After 1978, landings by foreign fleets were curtailed, and landings by U.S. and Canadian vessels increased. The U.S. commercial fishery intensified in 1990, and landings were reduced in the 2000s due to restrictions imposed by federal and interstate fisheries management plans. When the stock was declared rebuilt in 2009, the allowed biological catch, trip limits and landings increased. Otter trawl and gill nets have been the primary U.S. commercial gears used to harvest spiny dogfish. Estimation of discards was uncertain prior to establishment of the at-sea observer program in 1989, which informed the starting year of the assessment model. There is some uncertainty in landings and discards for each fleet's size and sex composition information based on the available data and thus associated assumptions made to produce catch information for the assessment model. Catch per unit effort indices were developed for the U.S. commercial otter trawl fleet to assess prospective correspondence to fisheries independent surveys.

*TOR 3: Present the survey data used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, application of catchability and calibration studies, etc.) and provide a rationale for which data are used. Describe the spatial and temporal distribution of the data. Characterize the uncertainty in these sources of data.*

The Working Group evaluated several fisheries-independent surveys within the stock boundaries to inform modeling efforts of TOR 4: NEFSC Bottom Trawl Surveys, NEFSC

Bottom Long Line Survey, Northeast Area Monitoring and Assessment Program (NEAMAP) Inshore Trawl Survey, Massachusetts Division of Marine Fisheries (MADMF) Bottom Trawl Survey, Atlantic States Marine Fisheries Commission (ASMFC) Shrimp Survey, Rhode Island Coastal Trawl Surveys, the Maine-New Hampshire (ME-NH) Inshore Groundfish Trawl Survey, and Canadian Bottom Trawl Surveys. Where available, indices were evaluated for both male and female spiny dogfish by season. Concerns as to whether surveys that only sampled a portion of the stock unit adequately track temporal population changes led the Working Group to only use the NEFSC spring bottom trawl survey for modeling purposes. Of the available data, this survey best samples the entirety of the stock. Fall indices are not optimal for assessing annual changes because substantial portions of the stock are outside the survey domain during that season.

VAST models were developed to integrate multiple surveys' information and produce a single index and associated length composition for each sex in a given season. VAST models for this exercise included the NEFSC Bottom Trawl Survey, NEAMAP Inshore Trawl Survey, MADMF Bottom Trawl Survey, and ME-NH Inshore Groundfish Trawl Survey. A comparison of NEFSC spring bottom trawl relative abundances indices and the VAST model spring indices indicated similar patterns over time. Abundance indices produced by VAST were developed for spiny dogfish by season and sex for use in the assessment model as a sensitivity run. However, VAST model fitting proved challenging for the length composition data and the Working Group was unable to get a converged model at the resolution of the length bins used by the assessment model. Model sensitivity analyses included testing the NEFSC fall bottom trawl survey indices, NEFSC spring and fall bottom long line survey indices, as well as the VAST spring index with interpolated length compositions.

*TOR 4: Use appropriate assessment approach to estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Compare the time series of these estimates with those from the previously accepted assessment(s). Evaluate a suite of model fit diagnostics (e.g., residual patterns, sensitivity analyses, retrospective patterns), and (a) comment on likely causes of problematic issues, and (b), if possible and appropriate, account for those issues when providing scientific advice and evaluate the consequences of any correction(s) applied.*

Stock Synthesis 3 (SS3) was chosen as the primary assessment tool, due to its ability to model sexes separately, and to accommodate length-based approaches. The SS3 base case model ran from 1989-2019 because the sea sampling data used to estimate discards was not available prior to 1989. Input data to the model included the NEFSC spring trawl survey, landings, discards, and length compositions for all of these data sources. Growth was modeled as von Bertalanffy, using the parameters estimated by Nammack et al. (1985), except that $L_\infty$ for 2012-2019 was estimated within the model; the estimated female $L_\infty$ for that period (89.24 cm) is considerably smaller than that used for 1989-2011 (100.50 cm). Natural mortality was taken to decline with age (Lorenzen 1996), and was assumed to average 0.102 over the 50 year potential lifespan of Atlantic spiny dogfish. The survival spawner-recruitment relationship was used, which was specifically designed for low fecundity species such as spiny dogfish (Taylor et al. 2013). Alternative stock-recruit models (Beverton-Holt and Ricker) were tested in SS3, but output from these runs appeared to be much less credible than that from the survival spawner-recruitment relationship.

The base case SS3 run showed declines in spawning output from 1989 to 1997; these quantities increased until 2012, then declined again. The estimated base case spawning output trends reasonably matched survey trends during 2000-2019 and exhibited almost no retrospective pattern (Mohn's $\rho = 0.06$). However, the base case estimated smaller declines in spawning output during 1989-1997 than those observed in the NEFSC spring trawl survey. Estimated female fishing mortality (numbers based, age 12+) peaked in 1992 at about 0.17, declined to less than 0.025 between 2002-2010, and averaged about 0.033 during the most recent period (2014-19).

The SS3 base case run was compared to the output from the Stochastic Estimator, the model used in previous spiny dogfish assessments. The Stochastic Estimator is based on swept area calculations under the assumption that the survey trawl efficiency is one, and uses bootstrapping to quantify the uncertainties. The SS3 model generally estimated somewhat higher biomass and spawning output and lower fishing mortality than the Stochastic Estimator because it estimated a slightly lower survey efficiency ($q = 0.83$). The Stochastic Estimator estimated much higher $F$ and a larger decline in female biomass and spawning output in the early portion of the time series.

*TOR 5: Update or redefine status determination criteria (SDC; point estimates or proxies for BMSY, BTHRESHOLD, FMSY and MSY reference points) and provide estimates of those criteria and their uncertainty, along with a description of the sources of uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for reference points. Compare estimates of current stock size and fishing mortality to existing, and any redefined, SDCs.*

Per recruit calculations indicate that both yield-per-recruit (YPR) and pups-per-recruit (PPR) calculations are highly sensitive to growth assumptions. Maximum YPR occurred around $F = 0.15$, but using the estimates of $L_\infty$ from the most recent period (89.24 cm for females), fishing above $F = 0.03$ produced less than two pups per recruit, and thus was unsustainable. The Working Group evaluated three SS3 estimated spawners-per-recruit (SPR) reference points: SPR50%, SPR60% and SPR70%. The fishing mortality associated with SPR50% (0.037) would produce less than two PPR. Furthermore, mean fishing mortality was below this value during 2013-2019, but nonetheless, female biomass and spawning output substantially declined during this period. By contrast, these quantities increased when fishing mortality was below $F = 0.025$, the fishing mortality associated with SPR60%, and decreased when F > 0.025 during the most recent period. For these reasons, the Working Group recommended adopting the SPR60% reference points: a spawning output target of 370.8 million pups and $F = 0.025$. This spawning output target corresponds to a considerably higher spawning biomass than previous reference points ($SSB_{MAX}$ = 159,288 or 189,553 mt). However, reestimation of the previous reference points using updated data and parameters produced estimates similar to SPR60% ($SSB_{MAX}$ = 445,349 mt and $F = 0.03$, McManus et al. 2022).

*TOR 6: Define appropriate methods for producing projections; provide justification for assumptions of fishery selectivity, weights at age, maturity, and recruitment; and comment on the reliability of resulting projections considering the effects of uncertainty and sensitivity to projection assumptions.*

The Working Group used the projection tool internal to SS3 for this assessment. The continuity of both the assessment model and projections being conducted with the same software allowed for effective and efficient application of the projection tool. Short-term projections were conducted (2020-2022) under four different fishing mortality rates: one under zero harvest and at $F = 0.017$, 0.025, and 0.037, corresponding to the SPR reference points SPR70%, SPR60%, and SPR50% respectively. Projections indicated a decline in spawning output from 2019 to 2020, and then increases in spawning output under all four alternatives, likely due to maturation of many females in the large 2009-2012 year classes.

*TOR 7: "Review, evaluate, and report on the status of research recommendations from the last assessment peer review, including recommendations provided by the prior assessment working group, peer review panel, and SSC. Identify new recommendations for future research, data collection, and assessment methodology. If any ecosystem influences from TOR 2 could not be considered quantitatively under that or other TORs, describe next steps for development, testing, and review of quantitative relationships and how they could best inform assessments. Prioritize research recommendations."*

The Working Group reviewed the research recommendations presented in the last benchmark stock assessment for spiny dogfish (43rd SAW Stock Assessment Report, NEFSC 2006), and those most recent from the Mid-Atlantic Fisheries Management Council and its Scientific and Statistical Committee. Individual responses were provided to each recommendation on how the work conducted during this assessment addressed them. New research recommendations were also put forth by the Working Group; the highest priority recommendation is in regard for consistent ageing analyses. Movement from data-limited approaches to more sophisticated models often depends on available age or growth information. Aging programs should be established to allow for the continuous inclusion of such data and better inform growth in the assessment model, which can have significant impacts on model performance. Age samples should be collected across the spectrum of significant variables: by sex, across the size spectrum, by season, and over various areas of the stock bounds.

*TOR 8: Develop a backup assessment approach to providing scientific advice to managers if the proposed assessment approach does not pass peer review or the approved approach is rejected in a future management track assessment. A backup assessment approach is required to be in place as a hedge against a scenario where the primary catch-at-age model is not suitable for providing management advice.*

The Working Group evaluated several backup approaches, including the Stochastic Estimator, Depletion-Based Stock Reduction Analysis, Depletion-Corrected Average Catch, and the index-based method Ismooth. Each method uses various data streams (e.g., fisheries-independent indices, landings or catch information, life history parameters) to provide inferences on population size and/or stock status. Of the methods reviewed, the Working Group recommended the Stochastic Estimator be used as the backup approach to providing scientific advice to managers if the preferred SS3 assessment model approach does not pass peer review or if SS3 is rejected in a future management track assessment.