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Meta-Analysis of Historical Stock Assessment Uncertainty for U.S. Atlantic HMS Domestic Sharks: An Example Application within a Tiered Acceptable Biological Catch (ABC) Control Rule

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EXECUTIVE SUMMARY

An acceptable biological catch (ABC) control rule is an agreed procedure for setting the ABC for a stock or stock complex as a function of the scientific uncertainty in the estimate of fishery removals at the overfishing limit (OFL) and any other scientific uncertainty. Multiple sources of uncertainty exist within the science and management processes. The method adopted in this example application uses meta-analysis to calculate a minimum estimate of scientific uncertainty within the stock assessment process (σ_{min}) and then uses the σ_{min} value to set the minimum reduction (buffer) from the OFL to obtain an ABC as part of a process of setting annual catch limits (ACLs) and accountability measures (AMs) that prevent overfishing.

An example application of a tiered ABC control rule is provided for U.S. Atlantic domestic shark stocks managed by the National Marine Fisheries Service (NMFS) Atlantic Highly Migratory Species (HMS) Management Division. A minimum estimate of stock assessment scientific uncertainty was obtained from meta-analysis of among assessment variability in historical U.S. Atlantic HMS domestic shark stocks assessed multiple times within the Southeast Data Assessment and Review (SEDAR) process during the last 20 years. The resulting pooled estimate of the among assessment log normal standard error in predicted abundance ($\sigma = 0.4151$) was assumed to represent a minimum estimate of scientific uncertainty, σ_{min}, in the U.S. Atlantic HMS domestic shark stock assessment process. An ABC to OFL ratio (< 1) was calculated from multiples of σ_{min} and the predetermined risk tolerance of ABC exceeding OFL (acceptable probability of overfishing, analogous to P*) within a tiered structure based on stock assessment data availability. The resulting ABC to OFL ratio defined the ABC control rule buffer from the OFL within each tier.

The example Tier 1 ABC obtained here from meta-analysis of historical stock assessment uncertainty was consistent with, but slightly smaller than (more conservative), the sustainable total allowable catch (TAC) level obtained with the status quo projection approach implemented from a recent SEDAR blacktip shark assessment in the U.S. Atlantic region. The Tier 1 ABC obtained from meta-analysis represents a minimum buffer from OFL to ABC calculated from historical stock assessment variability. In contrast, the Tier 1 U.S. Atlantic HMS domestic shark

stock assessment also includes scientific uncertainty estimated within the assessment, for example obtained here from the status quo projection approach based on parameter estimation uncertainty. Because the two methods produced consistent catch specifications for blacktip shark (Atlantic region), we concluded that the ABC determination obtained with the meta-analysis provided a conservative buffer from the OFL consistent with both historical stock assessment uncertainty of the Atlantic HMS domestic shark stock assessment process and the parameter estimation uncertainty within the current assessment, at least for this example application. The lower tier example ABCs obtained here were not validated in comparison with status quo management advice.

This example application of a tiered ABC control rule was developed under contract within the NMFS Southeast Fisheries Science Center (SEFSC) Sustainable Fisheries Division (SFD) and serves as the final report for the contract. However, the methods and results presented here are preliminary and intended only for the purpose of providing a technical description and example application of including historical stock assessment uncertainty within a tiered ABC control rule for U.S. Atlantic HMS domestic sharks. In contrast, Amendment 14 to the Consolidated 2006 Atlantic HMS Fishery Management Plan (FMP), which would revise the framework for establishing annual catch limits (ACLs) and includes an ABC control rule, is currently under development by the NOAA NMFS Atlantic HMS Management Division for U.S. Atlantic HMS domestic shark stocks. Once Amendment 14 is completed, the Atlantic HMS Management Division will conduct a follow on rulemaking where they implement the framework established in Amendment 14 for all Atlantic shark stocks in the management unit. Consequently, any adoption of actual ABCs for U.S. Atlantic HMS domestic shark stocks will be developed separately. The example application described in this report is intended to inform the process for Atlantic HMS Amendment 14 and its follow on rule(s), and is not intended to dictate the results.

Contents

1. INTRODUCTION

The methods and results presented here are preliminary and intended only for the purpose of providing an example application of including historical stock assessment uncertainty within a tiered ABC control rule for U.S. Atlantic HMS domestic sharks. Amendment 14 to the Consolidated 2006 Atlantic Highly Migratory Species (HMS) Fishery Management Plan FMP, which would revise the framework for establishing annual catch limits (ACLs) and includes an acceptable biological catch (ABC) control rule, is currently under development by the NOAA NMFS Atlantic HMS Management Division for U.S. Atlantic HMS domestic shark stocks. The NMFS Atlantic HMS Management Division is also planning an Amendment 14 follow on rule where they will be conducting a rulemaking where they implement the framework in Amendment 14 for all NMFS Atlantic HMS Management Division shark stocks. Consequently, any adoption of actual ABCs for U.S. Atlantic HMS domestic shark stocks will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (MSA 2007)[1] establishes requirements to end and prevent overfishing through the use of Annual Catch Limits (ACLs) and Accountability Measures (AMs; e.g., Methot et al. 2014). The MSA mandates that each federal Fishery Management Plan (FMP) establishes mechanisms for ACLs and AMs for all stocks managed under the FMP. The MSA also specifies additional requirements for the role of scientific advice in this process. Specifically, each regional U.S. Fishery Management Council (FMC) and its Scientific and Statistical Committee (SSC) are responsible for developing and implementing ABC control rules for each stock managed under an FMP.

However, the NOAA NMFS Atlantic HMS Management Division is unique in that it does not operate within a regional FMC, and consequently, does not have an SSC to develop and implement an ABC control rule. In contrast, the Atlantic HMS Management Division operates under a Secretarial FMP. Recent National Standard 1 (NS1) guidelines for the MSA (e.g., U.S. Office of the Federal Register 2009, 2016) indicate that for Secretarial FMPs or amendments,

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[1] E.g., see https://www.fisheries.noaa.gov/resource/document/magnuson-stevens-fishery-conservation-and-management-act (Accessed August 2022).

agency scientists or a peer review process would provide the scientific advice to establish an ABC (also see 50 CFR 600.310 (b)(2)(v)(C)[2]). Consequently, the ABC control rule for Atlantic HMS U.S. domestic shark stocks in the Atlantic Ocean is being developed through the Secretary of Commerce within an amendment process with input from agency scientists within the NOAA NMFS Southeast Fisheries Science Center (SEFSC).

An ABC control rule is an agreed procedure for setting the ABC for a stock or stock complex as a function of the scientific uncertainty in the estimate of fishery removals at the overfishing limit (OFL) and any other scientific uncertainty. Multiple sources of uncertainty exist within the science and management processes. The method adopted in this example application uses meta-analysis to calculate a minimum estimate of scientific uncertainty within the stock assessment process, σ_{min}, and uses multiples of the σ_{min} value to set the minimum reduction (buffer) from the OFL to obtain an ABC as part of a process of setting ACLs that prevent overfishing.

The meta-analytic approach used here to estimate scientific uncertainty is adapted from the Pacific Fishery Management Council (PFMC; Ralston et al. 2011). The PFMC bases scientific uncertainty on empirical estimates of uncertainty in current exploitable biomass (Ralston et al. 2011). An assumption is that a minimum estimate of scientific uncertainty can be approximated by the among assessment variability from two or more historical stock assessments completed for the same stock within the last 20 years (Ralston et al. 2011). The estimate of uncertainty is then applied to reduce the overfishing limit, OFL, to the acceptable biological catch, ABC, as outlined below in Figures 1 – 4.

A minimum estimate of among assessment variability is obtained here from three Atlantic HMS domestic shark stocks assessed multiple times within the last 20 years: the sandbar shark (*Carcharhinus plumbeus;* U.S. Gulf of Mexico and Atlantic regions combined), the blacktip shark (*Carcharhinus limbatus*; U.S. Gulf of Mexico region), and the Atlantic sharpnose shark (*Rhizoprionodon terraenovae;* U.S. Gulf of Mexico and Atlantic regions combined). Scientific uncertainty in stock assessments completed multiple times for these stocks is calculated as the log-normal standard deviation (σ, in total numbers age 1+). A pooled estimate of scientific uncertainty, obtained by combining individual estimates of σ obtained for each stock, is assumed to represent a minimum estimate of scientific uncertainty (σ_{min}, in total

[2] E.g., see https://www.ecfr.gov/current/title-50/chapter-VI/part-600#p-600.310(b)(2)(v)(C) (Accessed August 2022).

numbers age 1+) in the completed stock assessments. Exploitable biomass estimates (for example, used by Ralston et al. 2011) are not available consistently among historical domestic shark stock assessments evaluated in this study. In contrast, total numbers age 1+ are available consistently from the historical assessments. Consequently, total numbers age 1+ are used here as a proxy for exploitable biomass.

In Draft Amendment 14, NOAA Fisheries describes a tiered ABC control rule that considers data availability and stock status (Appendix A). The tier structure in Draft Amendment 14 is adapted in part from ABC control rules proposed by the Caribbean Fishery Management Council (CFMC; Appendix B). In brief, shark stocks that have been assessed domestically and that are healthy (no overfishing/not overfished), experiencing overfishing, or that have an unknown status would be assigned to specific tiers. The ABC for stocks that are overfished, assessed by the science body of the International Commission for the Conservation of Atlantic Tunas (ICCAT), or that are prohibited would be calculated outside the tier structure. Placement of the stock into the tiers would be on a case-by-case basis following review by the NMFS Southeast Fisheries Science Center and the NMFS Atlantic HMS Management Division.

Similarly, for the purposes of this example ABC control rule application, we consider the implications of using σ_{min} as an estimate of scientific uncertainty by assigning Atlantic HMS domestic shark stocks to various tiers. Previously assessed and unassessed Atlantic HMS domestic shark stocks are assigned to one of the following ABC control rule tiers (Appendix C): (Tier 1) Data rich with an accepted assessment available; (Tier 2) Data moderate with an accepted assessment available; (Tier 3) Data limited with an accepted assessment available; and (Tier 4) No accepted assessment available, and, therefore, data quality and data availability have not been fully vetted through an assessment process. However, any adoption of actual ABC tiers for U.S. Atlantic HMS domestic shark stocks will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

In this document, we provide example ABCs for Tiers 1, 2, and 3 calculated using the σ_{min} value obtained from the meta-analytic approach. The Tier 1 example ABC obtained using this approach is compared to the sustainable total allowable catch (TAC) level obtained with a status quo projection approach implemented from a recent Southeast Data Assessment and Review (SEDAR) blacktip shark assessment in the U.S. Atlantic region as described in

Appendix D. Example ABCs obtained here using meta-analysis are provided for illustrative purposes only and should be interpreted as a minimum buffer from OFL to ABC because the σ_{min} value represents a minimum estimate of scientific uncertainty in the stock assessment process obtained between assessments (between assessment uncertainty). In addition, Tier 1 U.S. Atlantic HMS domestic shark stock assessments also include scientific uncertainty estimated within the assessment, for example obtained in Appendix D from the status quo projection approach based on parameter estimation uncertainty (within assessment uncertainty). The two methods are compared in Appendix D to determine if they provide consistent catch specifications for blacktip shark (Atlantic region).

Examples of data-poor Tier 4 OFL and ABC are more difficult to develop and validate. We provide a Tier 4 example of the use of meta-analysis of historical stock assessment uncertainty adapted from both the CFMC ABC control rule (Appendix B) and Ralston et al. (2011). We use the CFMC ABC control rule because it is the most recently available example of an ABC control rule developed within the SEFSC at the time that of this contract work. However, the CFMC ABC control rule assumes that an OFL proxy is not available for Tier 4, and then defines a sustainable yield level (SYL) as the maximum level of landings that can be sustained over the long term, where MSY ≤ SYL, for use when information is not available to determine MSY or corresponding reference points (Appendix B). In addition, the Tier 4 example application developed here is modified from the CFMC ABC control first to use only commercial landings (which are readily available) as an example application and second to incorporate meta-analysis of historical stock assessment uncertainty adapted from Ralston et al. (2011; using multiples of four times the minimum estimate of scientific uncertainty, $4\times\sigma_{min}$), as described below. In contrast, the draft Amendment 14 to the 2006 Consolidated Atlantic HMS Fishery Management Plan differs from our Tier 4 example in at least three main components: First, draft Amendment 14 assumes that an OFL proxy is available for Tier 4 and then defines an OFL proxy within Amendment 14; Second, draft Amendment 14 plans to develop estimates of total removals due to fishing for use in Tier 4, as discussed below; Third, the draft Amendment 14 does not incorporate meta-analysis of historical stock assessment uncertainty for use in Tier 4 (Appendix A). As a result, the Tier 4 SYL and ABC examples developed here are only provided as an example application and are not directly comparable with either the CFMC ABC control rule or the draft Amendment 14 ABC control rule. Any adoption of actual Tier 4 OFL proxy and

ABC methodology for U.S. Atlantic HMS domestic shark stocks will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s). For comparison, the current domestic shark TACs (Appendix E) are provided from NMFS (2021) along with examples of status quo Atlantic HMS domestic shark commercial quota methodology for stocks not on a rebuilding plan (Appendix F) and for stocks on a rebuilding plan (Appendix G).

This document is provided solely for illustrative purposes to provide examples of: (1) approximating scientific uncertainty in OFL for Atlantic HMS domestic shark stocks using measures of variability in historical stock assessments; (2) creating a tier structure and corresponding ABC to OFL ratios for each tier that identify the proportional reduction between OFL and ABC based on the desired level of precaution (probability of overfishing) and the estimated scientific uncertainty; (3) calculating ABC values for representative stocks within each tier based on the ABC to OFL ratio; and (4) comparing the resulting ABC values to currently implemented TACs. Any adoption of an actual tier structure and associated ABCs for U.S. Atlantic HMS domestic shark stocks will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

2. MATERIALS AND METHODS

2.1. Historical U.S. Atlantic HMS Domestic Shark Stock Assessments

This study quantified among-assessment variability for Atlantic HMS domestic shark age-structured stock assessments completed within the Southeast Data Assessment and Review, SEDAR, process. State Space Age Structured Production Model (SSASPM; e.g., NMFS 2012) and Stock Synthesis (Methot and Wetzel 2013) assessments were included in the meta-analysis of assessment variability if there were multiple age-structured stock assessments completed for the same stock within the same management unit (regardless of model structure).

A review of historical assessments indicated that multiple assessments have been completed for the sandbar, blacktip, and Atlantic sharpnose shark stocks assessed within the SEDAR process. Total estimated abundance in numbers age 1+ were obtained here from recently completed assessments for sandbar (three), blacktip (three), and Atlantic sharpnose (two) shark stocks as described below.

Sandbar shark (U.S. Gulf of Mexico and Atlantic regions combined) predicted total population abundance in numbers (*N*, age 1+; Table 1, Figure 5) were obtained from Stock Synthesis base model runs with ending year 2015 (NMFS 2018a) and from SSASPM base runs with ending years 2009 (NMFS 2011) and 2004 (NMFS 2006). Blacktip shark (U.S. Gulf of Mexico region) predicted total population abundance in numbers (*N*, age 1+; Table 2, Figure 6) were obtained from SSASPM base model runs with ending years 2016 (NMFS 2018b, 2018c), 2010 (NMFS 2012), and 2004 (NMFS 2006). Atlantic sharpnose shark (U.S. Gulf of Mexico and Atlantic regions combined) predicted total population abundance in numbers (*N*, age 1+; Table 3, Figure 7) were obtained from SSASPM base model runs with ending years 2011 (NMFS 2013) and 2005 (NMFS 2007).

Blacktip sharks in the U.S. Atlantic region were not included within the calculation of among-assessment variability because the stock was not assessed multiple times. However, blacktip sharks in the U.S. Atlantic region were included in a Tier 1 ABC control rule example described below because the stock was recently assessed stock using Stock Synthesis.

2.2. Scientific Uncertainty in the Stock Assessment Process

Ralston et al. (2011) note that many sources of uncertainty exist within a stock assessment, and that even in data rich scenarios estimates of biomass have been highly variable from a historical perspective. There are many reasons for historical variability in stock size estimates such as 1) model structure, 2) choice of values for prior distributions and key parameters, 3) changes in the available data, modeling platforms, and assessment teams, among others. Consequently, Ralston et al. (2011) asserted that quantifying and accounting for the source of the uncertainty in historical estimates of stock size is the primary factor to consider when establishing a buffer between the OFL and the ABC. This is mainly due to the fact that large fluctuations in the estimates of stock size can have great impacts on the stock status, management decisions, and generally undermine the confidence in the scientific advice (Ralston et al. 2011).

2.3. Variation in Historical Stock Assessments

Ralston et al. (2011) noted that variation in total population size estimates among a set of stock assessments can be quantified in a number of ways, and they evaluated three approaches to calculate variation around a point of central tendency. We evaluated the same three approaches here, except that we used total population abundance (numbers age 1+) obtained from historical assessments for comparison of total population size among historical assessments, whereas Ralston et al. (2011) used total population biomass. Estimation methods, and reporting, for total population biomass were not consistent among historical Atlantic HMS domestic shark stock assessments completed with SSASPM because of data limitations in the estimation of weights from recreational catch in numbers. In contrast, estimation methods, and reporting, were consistent for total population abundance (numbers, age 1+) among historical Atlantic HMS domestic shark stock assessments completed with SSASPM. Total population abundance (numbers, age 1+) was also available for historical Atlantic HMS domestic shark stock assessments completed with Stock Synthesis.

Historical variation approach 1.—All population size estimates for a year were assumed to be equally plausible representations of reality. Population abundance variation between two stock assessments was quantified by forming all possible ratios (R) of estimated population size in common years, and a bias-adjusted estimate of the standard deviation of the natural log of all possible ratios was obtained as a quantitative measure of among-assessment variation. Specifically, if there was an estimate of total population abundance in numbers (N) of age 1+ individuals for year t from assessments i and j, we calculated: $\ln(R_{i|j,t}) = \ln(N_{i,t} / N_{j,t}) = \ln(N_{i,t}) - \ln(N_{j,t})$, i.e., the proportional deviation of assessment i using assessment j as a standard in natural log space. Based on a symmetry argument, we also calculated $\ln(R_{j|i,t})$, because all the ratios were natural log transformed and the distributions were perfectly symmetrical, where $\ln(R_{i|j,t}) = -\ln(R_{j|i,t})$. For each stock under consideration, the standard deviation (σ^*) of the ratios was calculated. This statistic is positively biased, however, because it is based on the ratio of two lognormal random variables $N_{i,t}$ and $N_{j,t}$. Consequently, a bias correction term ($\sqrt{2}$) is provided by Ralston et al. (2011) and also applied here so that the corrected estimator is $\sigma = \sigma^*/\sqrt{2}$.

Historical variation approach 2.—The mean of total population size estimates in a year was considered the best estimate of central tendency. In this approach, variation in total population size was measured as squared deviations from the annual mean population size in natural log space. The mean in the natural log of numbers of age 1+ individuals in year t was calculated as described in equation (1), where $N_{i,t}$ is defined as above and n_t is the number of available assessment time series in year t ($n_t \geq 2$).

$$\overline{\boldsymbol{ln}(\boldsymbol{N_t})} = \frac{\mathbf{1}}{\boldsymbol{n_t}} \sum_{i} \boldsymbol{ln}(\boldsymbol{N_{i,t}}) \tag{1}$$

The standard deviation, σ, was then calculated as in equation (2) below.

$$\sigma = \sqrt{\frac{1}{\sum_t n_t - 1} \sum_t \sum_i \left(\ln(N_{i,t}) - \overline{\ln(N_t)} \right)^2} \tag{2}$$

Ralston et al. (2011) note that variation approach 2 (squared deviations from the mean in log-space; equations 1 and 2 above) had two desirable features. First, deviations were calculated from the best estimate of central tendency. Second, estimated values of σ were unlikely to change markedly with new assessments. Ralston et al. (2011) also note that variation approach 2 was selected by the PFMC SSC as the preferred approach for calculating scientific uncertainty. For these reasons, historical assessment variation approach 2 was also adopted here as the preferred method for calculating historical variation in this example application.

Historical variation approach 3.—Approach 3 was the same as approach 2, except that the most recent stock assessment was considered the best estimate of central tendency. The standard deviation, σ, was calculated as in equation (2), except that the mean of ln(N_t) was replaced by the logarithms of the total numbers age 1+ obtained from the most recent stock assessment, and the most recent assessment was excluded from the summations and the calculation of the n_t. With approach 3, the most current information was assumed to represent the best estimate of the population mean.

As noted in Ralston et al. (2011), if the calculation of variation in historical assessments is updated after new assessments are completed, then the resulting standard deviation estimates obtained from approach 3 may be relatively more unstable over time, compared to those obtained from approach 2.

Coefficient of variation (CV).—For log normally distributed random variables, the coefficient of variation, CV, on the arithmetic scale was obtained from variance on the logarithmic scale (σ^2) using equation (3) below.

$$\boldsymbol{CV = \sqrt{exp(\sigma^2) - 1}} \qquad (3)$$

2.4. Meta-Analytic Calculation of Pooled Historical Stock Assessment Variation

Ralston et al. (2011) proposed pooling individual estimates of variation in historical stock assessments where there is enough data to use one of the methods outlined above in order to develop a meta-analytic estimate of historical variation in the stock assessment process. Two meta-analytic methods of pooling variation in historical assessments were evaluated here following the approaches outlined in Ralston et al. (2011), as described below.

Pooling method 1.—The stratified historical variation in the stock assessment process was calculated as the square root of the average of the stock-specific variances. This method, a stratified approach, gives each assessed stock equal weight and does not overemphasize stocks that have been assessed many times (Ralston et al. 2011) and was chosen as the preferred approach for use with the data set used in this study, as described below.

Pooling method 2.— The pooled historical variation in the stock assessment process was calculated by aggregating all residuals to calculate a pooled standard deviation. This method treats each data point as an independent observation, which gives more weight to stocks that have been assessed many times.

2.5. ABC to OFL Ratio

Mapping reductions from OFL to obtain an ABC.—The pooled uncertainty estimate, σ obtained as described above, is assumed to represent a minimum estimate of scientific uncertainty in the stock assessment process for data rich Tier 1 stocks, and defined here as "sigma min" (σ_{min}). The pooled uncertainty obtained from data rich Atlantic HMS domestic shark age-structured stock assessments completed within the SEDAR process, σ_{min}, is then assumed to represent the minimum amount of historical variation in the stock assessment process for all assessed and unassessed Atlantic HMS domestic shark stock tiers within the ABC control rule.

Examples of mapping reductions from the OFL to obtain an ABC are provided by assuming a probability density function for the OFL with a log normal standard deviation equal to a multiple of σ_{min}. Following Ralston et al. (2011), a lognormal distribution with a mean equal to zero and standard deviation equal to σ_{min} was assumed for the OFL. Half of the probability density was then below a value of 1.00, which represents the median of the OFL distribution (e.g., Figure 3). The probability of overfishing cannot exceed 50% and should be lower. Consequently, a cumulative probability less than 0.50 was calculated that maps onto a multiplier (buffer) interpreted as a reduction from the median of the OFL distribution. The size of the buffer between ABC and OFL depends upon the shape of the assumed distribution in OFL, which in turn is governed by the size of the σ_{min} value.

Following this approach, a species-specific estimate of the OFL from the most recent assessment, preferably in the same units that management decisions are based on, is assumed to represent the median OFL. Scientific uncertainty associated with the OFL is assumed to be lognormally distributed about the median OFL and the shape of the uncertainty distribution is determined by the pooled σ obtained from above, and assumed to represent σ_{min}. The reduction from the OFL to an ABC (e.g., Figure 4) is based on both the resulting shape of the OFL distribution and the predetermined acceptable risk (analogous to a P* probability) that removals equal to the ABC would result in overfishing. Because the same σ_{min} was assumed for all Atlantic HMS domestic shark stocks, the same ABC to OFL ratios were used for all species within each Tier.

We note that this approach differs from a typical P* approach, for example as implemented by the South Atlantic Fishery Management Council (SAFMC), which calculates the P* probability of fishing mortality rate (F) exceeding the fishing mortality rate at OFL (F_{OFL}). In the typical P* approach, for example as implemented by the SAFMC, the F rate is adjusted so that risk of exceeding the F_{OFL} rate is equal to the predetermined P* value < 0.50. For this reason, we note here and below that the P* probability of ABC exceeding OFL implemented in this example application (e.g., Figure 3) is analogous to a predetermined risk policy (P* value < 0.50) of F exceeding F_{OFL}, for example, with a probability of 30% –

50% as proposed within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 (Appendix A).

2.6. Tier 1 OFL and ABC Example

To illustrate how the ABC control rule would be applied in practice, an OFL was obtained from a recent blacktip shark (Atlantic region) stock assessment assumed to be representative of recent U.S. Atlantic HMS domestic shark stocks assessed within the SEDAR process (Appendix D). OFL was assumed to follow a lognormal distribution with σ_{min} obtained from the meta-analysis exercise presented above. The corresponding ABC to OFL ratio was used to reduce OFL to ABC.

Blacktip shark (U.S. Atlantic region).— As noted above, blacktip sharks in the U.S. Atlantic region were not included within the calculation of among-assessment variability because they were not assessed multiple times. However, the recent Atlantic blacktip shark stock assessment is included here as an illustrative example of a Tier 1 ABC control rule implemented in Stock Synthesis.

Annual OFLs were calculated using a multiple-year projection approach implemented with the Stock Synthesis model obtained from the base model run of the recently completed SEDAR Atlantic blacktip shark benchmark assessment (U.S. Atlantic region; NMFS 2020; Appendix D). Annual OFL projection methods were adapted from a recently completed SEDAR spiny lobster stock assessment (U.S. Caribbean region; NMFS 2019).

Annual ABCs were obtained here from the projected OFLs using an ABC to OFL ratio assuming σ_{min} equal to 0.415 and an acceptable risk of overfishing, P*, equal to 0.3 (Appendix D). A 30% acceptable probability of overfishing is consistent with recent terms of reference for Atlantic HMS domestic shark projections (e.g., blacktip shark in the U.S. Atlantic region; NMFS 2020): "If stock is neither overfished nor undergoing overfishing, then utilize projections to determine… [t]he *F* needed and corresponding removals associated with a 70% probability of overfishing not occurring (analogous to a P* = 0.3 approach)." A 30% acceptable probability of overfishing is also consistent with previously implemented Atlantic HMS domestic shark rebuilding plans (e.g., sandbar shark in the U.S. Gulf of Mexico and Atlantic regions; NMFS 2018a), which utilized projections to determine the constant catch associated with a 70% probability of rebuilding, analogous to a 30% probability of not rebuilding. Any adoption of an actual risk policy associated with the ABC control rule will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

An example application of a three-year average constant catch Tier 1 ABC is also provided here from annual OFL projections obtained for blacktip sharks (Atlantic region, Appendix D). The example application developed here followed methods used in a recent U.S. Caribbean spiny lobster stock assessment (NMFS 2019). As mentioned above, the CFMC ABC control rule (Appendix B) is a recent example of an ABC control rule approach developed and implemented within the SEFSC. Similarly, the U.S. Caribbean region spiny lobster stock assessment (NMFS 2019) is a recent example of a Stock Synthesis assessment implemented by the SEFSC for use in the CFMC ABC control rule. The projection approach implemented for use in the CFMC ABC control rule is also consistent with recent SEFSC guidance to compute OFL projections annually at the fishing mortality rate that achieves maximum sustainable yield, F_{MSY}, and the projected stock size obtained from the stock assessment model. Consequently, the same approach was implemented here for the blacktip shark example application, as described in Appendix D.

2.7. Tier 2 and Tier 3 OFL and ABC Example

Following Ralston et al. (2011), a minimum estimate of stock assessment uncertainty, σ_{min}, was obtained as described above for Tier 1 stocks. Proxy estimates of uncertainty were obtained for the lower tier stocks based on multiples of 1.5 and 2.0 applied to σ_{min} for Tier 2, and Tier 3 stocks, respectively. Examples of the tradeoffs between buffer size (the ABC to OFL ratio) and the predetermined risk tolerance of ABC exceeding OFL (acceptable probability of overfishing, P*) were obtained for each tier showing the relationship between the decreasing ratio of ABC to OFL results and an increasing buffer from OFL to ABC for decreasing P* values. An arbitrary OFL value (5,000) was chosen for the purposes of this example.

2.8. Tier 4 Commercial Landings and ABC Example

Tier 4 commercial landings.— It was beyond the scope of this study to develop estimates of Tier 4 total removals due to fishing for each unassessed Tier 4 Atlantic HMS domestic shark stock, which will be addressed separately within the framework of the NOAA NMFS Atlantic

HMS Management Division Amendment 14 and its follow on rule(s). Similarly, any adoption of actual Tier 4 OFL proxy landings for U.S. Atlantic HMS domestic shark stocks and the associated methods used to determine the ABC buffers from OFL for Tier 4 will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

Total removals due to fishing (combining landings, dead discards, and post-release mortality) are generally unavailable for Atlantic HMS domestic shark stocks outside of an assessment process. Consequently, for the purposes of this Tier 4 example application, available data from commercial landings (which are readily available) were used as an illustrative example of the Tier 4 ABC control rule buffer method. Commercial landings during the years 2015 to 2019 were obtained from a recent Stock Assessment and Fishery Evaluation (SAFE) report (NMFS 2021). However, it is important to note that the limited data set used in this example does not include the multiple sources of mortality resulting from fishing that are typically included in Atlantic HMS domestic shark stock assessments, as described below, which would be included when implementing Amendment 14 and its follow on rule(s) noted above.

Atlantic HMS domestic shark stock assessments completed within the SEDAR process typically evaluate multiple sources of fishing mortality uncertainty (e.g., NMFS 2020). Sources of commercial fishing mortality uncertainty evaluated within Atlantic HMS domestic shark SEDAR stock assessments typically include, but are not limited to, commercial landings obtained from electronic fish landings reports (eDealer) in weight (e.g., NMFS 2021), estimates of extrapolated commercial live and dead discards obtained from observer programs (generally in numbers), and estimates of commercial live discard post release mortality rates. In addition, the stock assessments typically convert estimates of average weights to numbers and vice versa, and require use of conversion ratios from whole weight to dressed weight (i.e., cleaned headed and gutted normally). The stock assessments often also evaluate the data to produce standardized catch indices. Such indices would not be available for unassessed stocks. Consequently, it is important to understand that depending on the species, there may be significant uncertainty involved in calculating the OFL proxy and total commercial removals for Tier 4 stocks.

Similarly, sources of recreational fishing mortality uncertainty evaluated within Atlantic HMS domestic shark SEDAR stock assessments typically include, but are not limited to, estimates of recreational landings in numbers obtained from multiple creel surveys (e.g., NMFS

2021), estimates of recreational harvest (catch plus dead discards) along with estimates of recreational live discards in numbers obtained from creel surveys (e.g., NMFS 2021), and estimates of recreational live discard post release mortality rates obtained from other studies. Consequently, there may also be significant uncertainty involved in calculating the OFL proxy and total recreational removals for Tier 4 stocks.

For the reasons described above, any Tier 4 OFL proxy developed for Atlantic HMS domestic shark stocks is likely to be more uncertain than Tier 1, 2, and 3 OFLs and, consequently, the Tier 4 OFL proxy will likely require a wider buffer to achieve the same predetermined risk tolerance of ABC exceeding the actual OFL (e.g., an acceptable probability of overfishing, P* = 30%). Using wider buffers for lower tiers, which have more uncertainty in their stock assessment results, is consistent with the concept of achieving risk equivalency within a hierarchical tier structure, i.e., "a common probability of stocks falling below the limit reference point" regardless of their tier (Dichmont et al. 2016).

In contrast, assigning a more conservative predetermined risk tolerance (e.g., acceptable probability of overfishing, P* < 30%) for tiers with more stock assessment uncertainty decreases the probability of stocks falling below the limit reference point (i.e., reducing the risk) when stock assessment data are poorer. For the purposes of the example ABC control rule presented here, risk equivalency was the assumed goal, and a common probability was assigned among tiers (i.e., the acceptable probability of overfishing was fixed for all tiers at P* = 30%).

Tier 4 CFMC SYL.—As noted above, the CFMC ABC control rule assumes that an OFL proxy is not available for Tier 4, and then defines a sustainable yield level, SYL, as the maximum level of landings that can be sustained over the long term, where MSY ≤ SYL, and is intended to be used when information is not available to determine MSY or corresponding reference points (Appendix B). As noted above, available data from commercial landings (which are readily available) were used as an illustrative example of a Tier 4 ABC control rule buffer method for the purposes of this Tier 4 example application. Commercial landings in weight were used to illustrate alternative examples of Tier 4 CFMC SYLs and their associated ABCs, adapted here from the CFMC Tier 4 ABC control rule (Appendix B) and Ralston et al. (2011).

Two methods were used here to obtain a Tier 4 CFMC SYL and its associated ABC. The first method followed the CFMC Tier 4a (Appendix B), except that the CFMC SYL was set equal to a scaler multiplied by the 75th percentile of reference period commercial landings, instead of the 75th percentile of reference period catch. The second method followed the CFMC Tier 4b (Appendix B), except that the CFMC SYL was set equal to a scalar multiplied by the average of the reference period commercial landings, instead of the average of the reference period catch. In contrast, the reference period actual Tier 4 OFL proxy landings for U.S. Atlantic HMS domestic shark stocks would be chosen in consultation with the SEFSC and the Atlantic HMS Management Division on a case by case basis. Here we used the years of commercial landings, 2015 – 2019, available within the most recent SAFE report (NMFS 2021), as described above.

Following the CFMC, the scalar multiple must be ≤ 3 (Tier 4a) or < 2 (Tier 4b), presumably based on some knowledge about the veracity of the catch data, or to account for the assumed effects of past management actions on resulting catches. For the purposes of this example, a scalar = 2 was assumed for both methods implemented here. Under the CFMC ABC control rule (Appendix B), the use of productivity and susceptibility analyses (PSA, also sometimes referred to as Ecological Risk Assessment) to determine stock vulnerability can also inform the species assignments among tiers 4a and 4b, and the resulting scalar multiple. However, the use of productivity and susceptibility analyses was beyond the scope of the current study and was not included in the example application implemented here.

Tier 4 ABC.—Using the example CFMC SYLs obtained as described above, an ABC was obtained from the CFMC SYL by assuming a Tier 4 multiplier equal to $4.0 \times \sigma_{min} = (4 \times 0.4151 = 1.66)$ and assuming a predetermined risk tolerance of ABC exceeding OFL (acceptable probability of overfishing, P*) equal to 30%. The Tier 4 multiplier (4.0) was an arbitrary value obtained from Ralston et al. (2011), and is used here only for the purposes of providing an illustrative example application of one approach to include the results of meta-analysis of historical stock assessment uncertainty within Tier 4. In practice, any adoption of actual methods to determine ABC buffers for Tier 4 will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

2.9. Current TAC and Commercial Quota Methodology

Examples of Atlantic HMS domestic shark TAC and commercial quota methodology for stocks that are both within and not within a rebuilding plan were summarized here for comparison with the example OFLs, SYLs, and ABCs obtained using the methods described above. First, examples of Atlantic HMS domestic shark TAC were obtained by species group from the most recent SAFE report (NMFS 2021; Appendix E). Second, examples of current Atlantic HMS domestic shark commercial quota methodology were obtained from the Atlantic HMS Management Division (Appendices F and G).

2.10. Reproducibility of Calculations

OFL calculations for Stock Synthesis assessment base model runs and SYL calculations from commercial catch were obtained externally to the stock assessment model in MS Excel. Calculations used to obtain σ_{min} and ABCs from OFL and SYL were implemented in R statistical software (R Core Team 2020). The Stock Synthesis base case model runs, MS Excel spreadsheets, and R code used in this study are available from the authors upon request.

3. RESULTS

3.1. Historical Stock Assessment Variation

Calculation of σ from previously assessed U.S. Atlantic HMS domestic shark stocks.— The preferred approach to estimate stock assessment scientific uncertainty, historical-variation approach 2, yielded estimates of σ equal to 0.0824, 0.4509, and 0.5538, for sandbar shark, Gulf of Mexico (GOM) blacktip shark, and Atlantic (ATL) sharpnose shark, respectively (Table 4).

Individual estimates of stock assessment scientific uncertainty, σ, obtained for each stock using each of the approaches described above (equations 1 – 3) are also provided in Table 4. The predicted abundance trajectories for the three stocks (Figures 5 – 7) show that few assessments were available and that the abundance resulting from multiple assessments of the same stock did not always intersect. This in turn created bimodal patterns in the distribution of the log-deviations under historical-variation approach 1 (all ratio combinations) and historical-variation approach 2 (deviations from the mean) (Figures 8 and 9). A skewed pattern in the distribution of the log-deviations was also evident under historical-variation approach 3 (deviations from the most recent assessment) (Figures 8 and 9).

Calculation of pooled σ_{min}.—As noted above, the pooled σ obtained from either of the pooling methods described above was assumed to represent a minimum estimate of scientific uncertainty within the stock assessment process, defined as σ_{min}. Pooling method 1, stratified average of the stock-specific variances, yielded average estimates of σ_{min} equal to 0.5610, 0.4151, and 0.8552, for the three approaches to calculate σ (all ratio combinations, deviations from the mean, and deviations from the most recent assessment; Table 4). In comparison, pooling method 2, aggregating all residuals to calculate a pooled standard deviation, yielded pooled estimates of σ_{min} equal to 0.6916, 0.3955, and 0.7868, for the three approaches to calculate σ (Table 4).

The range and shape of the distribution in the deviations in annual predicted total population abundance in numbers (*N*, age 1+; Figures 8 – 10) were not consistent among stocks, probably as a result of the limited number of assessments completed for each stock (Figures 5 – 7). The limited data availability supports use of a stratified estimate of variation, pooling method 1, which gives equal weight to the sigma estimate obtained from each of the limited number of stocks.

In contrast, aggregating all deviations, pooling method 2, resulted in bimodal patterns in the distribution of the log-deviations under historical-variation approach 1 (all ratio combinations) and historical-variation approach 2 (deviations from the mean), and in a skewed pattern in the distribution of the log-deviations under historical-variation approach 3 (deviations from the most recent assessment) (Figure 11). Pooling method 2, also gives more weight to the stocks with more assessments, although this may not be a concern here because of the limited number of completed assessments in this data set.

Consequently, as noted above, pooling method 1 was chosen here as the preferred approach to obtain an estimate of σ_{min} for these data. For these data, the preferred historical variation calculation (historical-variation approach 2) and the most appropriate method of pooling for this dataset (pooling method 1) resulted in a pooled estimate of scientific uncertainty, σ_{min}, equal to 0.4151 (Table 4).

3.2. Tiered ABC Control Rule Example

Assigning Atlantic HMS domestic shark stocks to tiers.—Although many of the domestic shark species managed by Atlantic HMS Management Division are limited by data availability, management groupings or changes in the assessment methods, the pooled estimate of historical stock assessment variation, assumed to represent a minimum estimate of stock assessment variation for Atlantic HMS domestic shark stocks, σ_{min}, can be utilized to calculate a buffer from the OFL to obtain an ABC within a tiered ABC control rule approach, for example, as described above based on stock status and data availability as implemented by the CFMC[3] (Appendix B). For example, the CFMC classifies stocks into tiers based on data availability, reliability of the time series, and the structure of the stock assessment along with the availability of key derived quantities such as estimates of minimum stock size threshold (MSST), maximum fishing mortality threshold (MFMT), and the probability density function (PDF) of the overfishing limit, OFL. An example assignment of U.S. Atlantic HMS domestic sharks stocks within a four-tier structure based on data availability, along with other management groupings, is provided in Appendix C.

3.3. Tier 1, 2, 3, and 4 ABC to OFL Ratio Examples

Calculating example reductions from OFL to ABC.—The buffer size between OFL and ABC (defined in Ralston et al. 2011, as an ABC to OFL ratio) depends on both σ_{min} and the predetermined risk tolerance of ABC exceeding OFL (acceptable probability of overfishing, analogous to P*). The size of the buffer between ABC and OFL depends upon the shape of the assumed distribution in OFL, which in turn is governed by the size of the σ_{min} value. Examples of ABC to OFL ratios within a tiered ABC control rule are provided in Table 5. For this example, the minimum estimate of stock assessment scientific uncertainty, $\sigma_{min} = 0.4151$ obtained from the meta-analysis results above, was applied for Tier 1 stocks. For the purposes of this illustrative example, multiples of 1.5, 2.0, and 4.0 times σ_{min} were applied for Tier 2, Tier 3, and Tier 4 stocks, respectively. The resulting minimum estimates of stock assessment scientific uncertainty for each tier were $1.5\times\sigma_{min} = 0.62$, $2.0\times\sigma_{min} = 0.83$, and $4\times\sigma_{min} = 1.66$ for Tier 2, Tier 3, and Tier 4 stocks, respectively. The resulting ABC to OFL ratios within each tier are provided for a range of risk tolerance (analogous to a P*) values. Examples of the tradeoffs between the buffer size (OFL to ABC multiplier ratio) and the predetermined risk tolerance of ABC exceeding OFL (acceptable probability of overfishing, analogous to P*) are provided for the example Atlantic HMS domestic shark four-tier structure (Appendix C) with $\sigma_{min} = 0.4151$ (Figure 12).

[3] Caribbean Fishery Management Council Acceptable Biological Catch Control Rule from Action 4, Preferred Alternative 3.

As noted above, the Tier 4 multiplier (4.0) was an arbitrary value obtained from Ralston et al. (2011), and is used here only for the purposes of providing an illustrative example application of the method. In practice, any adoption of actual σ_{min} multipliers for each tier will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

3.4. Tier 1 OFL and ABC Example Implemented in Stock Synthesis

Blacktip shark (U.S. Atlantic region).—Example OFL and ABC for blacktip shark (U.S. Atlantic region) were calculated here with projections implemented in Stock Synthesis based on results obtained from a recent SEDAR blacktip shark stock assessment (U.S. Atlantic region; Appendix D). Projections followed methods analogous to those implemented for the SEDAR blacktip shark base model run, except that the forecast file was modified to project fishery removals at the overfishing limit, OFL, during the years 2019 to 2024. Projected fishery removals at OFL were adjusted for the average commercial landings and average recreational catches plus the recreational post release mortality (PRM) assumed to have occurred during gap years (2019 – 2021) between the terminal year of the assessment (2018) and the first year of management implementation of results from the assessment (2022). ABC was obtained from adjusted OFL assuming an acceptable risk of overfishing, analogous to a P*, equal to 0.3 and a minimum estimate of stock assessment scientific uncertainty, σ_{min}, equal to 0.415. These assumptions resulted in an ABC to OFL ratio (buffer) equal to 0.804 (i.e., 80.4% of OFL[4]), and a corresponding reduction of 19.6% from OFL to ABC (Table 5).

Examples of a three year average constant catch ABC for the years 2022 – 2024 were obtained for blacktip shark (U.S. Atlantic region) in both biomass (mt) and numbers (thousands) using methods analogous to those adopted in a recent SEDAR spiny lobster stock assessment in the U.S. Caribbean region implemented in Stock Synthesis (NMFS 2019), as described above and in Appendix D. An example constant catch ABC in biomass (472.21 mt for blacktip shark (U.S. Atlantic region) was obtained for the years 2022 – 2024, from the three-year average adjusted OFL (587.01, mt) reduced by 19.6% (Table D.5; Figure D.1). An example constant catch ABC in numbers (58.78, thousands) for blacktip shark (U.S. Atlantic region) was obtained

[4] E.g., in MS Excel, 0.804 = LOGNORM.INV(0.3,0,0.415).

for the years 2022 – 2024, from the three-year average OFL (73.07, thousands) reduced by 19.6% (Table D.6; Figure D.2).

The example three year average constant catch ABC obtained in numbers for the years 2022 – 2024 for blacktip shark (U.S. Atlantic region) was compared to the sustainable TAC levels obtained for the same stock from the status quo projection approach implemented for the stock assessment. The commercial constant catch ABC during the years 2022 – 2024 obtained here was consistent with, but about 10% smaller (more conservative) than, the sustainable TAC levels obtained from the status quo projection approach implemented for the stock assessment (Table D.12). Similarly, the recreational constant catch ABC during the years 2022 – 2024 obtained here was consistent with, but about 13% smaller (more conservative) than, the sustainable TAC levels obtained from the status quo projection approach implemented for the stock assessment (Table D.13).

3.5. Tier 1, 2, and 3 Generic OFL and ABC Examples

Calculating generic ABC to OFL ratios for each tier.—The size of the buffer between ABC and OFL depends upon the shape of the assumed distribution in OFL, which in turn is governed by the multiples of the σ_{min} value assigned to each tier. For example, assuming a σ_{min} value equal to 0.451 obtained from this study as described above, the ABC for Tier 1 was obtained for an arbitrary OFL value (5,000) assuming an acceptable risk of overfishing, P*, equal to 0.3 and a minimum estimate of stock assessment scientific uncertainty for Tier 1 of $1.0 \times \sigma_{min} = (1.0 \times 0.415) = 0.415$. These assumptions resulted in a Tier 1 ABC to OFL ratio (buffer) equal to 0.804 (i.e., 80.4 % of OFL), and a corresponding reduction of 19.6% from OFL to ABC (Table 5, Figure 13), as described above. Similarly, ABC for Tier 2 was obtained for the same arbitrary OFL value (5,000) assuming an acceptable risk of overfishing, P*, equal to 0.3 and a minimum estimate of stock assessment scientific uncertainty for Tier 2 of $1.5 \times \sigma_{min} = (1.5 \times 0.415) = 0.623$. These assumptions resulted in an ABC to OFL ratio (buffer) equal to 0.721 (i.e., 72.1% of OFL[5]), and a corresponding reduction of 27.9% from OFL to ABC (Table 5, Figure 13). ABC for Tier 3 was obtained for the same arbitrary OFL value (5,000) assuming an acceptable risk of overfishing, P*, equal to 0.3 and a minimum estimate of stock assessment scientific uncertainty for Tier 3 of $2.0 \times \sigma_{min} = (2.0 \times 0.415) = 0.830$. These assumptions resulted

[5] E.g., in MS Excel, 0.721 = LOGNORM.INV(0.3,0, 0.623).

in an ABC to OFL ratio (buffer) equal to 0.647 (i.e., 64.7% of OFL[6]), and a corresponding reduction of 35.3% from OFL to ABC (Table 5, Figure 13).

Assuming a different σ_{min} value, for example σ_{min} = 0.358 obtained from Ralston et al. (2011), would result in a different ABC to OFL ratio (buffer). Examples of different shapes in the distribution of OFL are provided in Figure 13, which show the relationship between ABC and an arbitrary OFL value (5,000) for σ_{min} values equal to 0.451 obtained from this study (Table 5) and 0.358 obtained from Ralston et al. (2011). The resulting buffers between ABC and OFL within each tier were similar for both σ_{min} values.

3.6. Tier 4 Commercial Landings and ABC Examples

Tier 4 Commercial landings.—As described above, an example catch data set (commercial landings in pounds dressed weight, lb dw, during the years 2015 to 2019) was obtained here from a recent SAFE report (NMFS 2021) and is provided in Table 6 only as an example OFL proxy and defined for the purposes of this example as the sustainable yield level, SYL. However, as described above, the methods and results presented here are preliminary and intended only for the purpose of providing an example Tier 4 application. Any adoption of actual Tier 4 ABCs for U.S. Atlantic HMS domestic shark stocks will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

Tier 4 ABC to SYL ratio examples.—ABC for Tier 4 was obtained from the example SYL assuming an acceptable risk of overfishing, analogous to a P*, equal to 0.3 and a minimum estimate of stock assessment scientific uncertainty for Tier 4 of $4.0 \times \sigma_{min} = (4.0 \times 0.4151) = 1.66$. These assumptions resulted in an ABC to SYL ratio (buffer) equal to 0.419 (i.e., 41.9% of OFL[7]), and a corresponding reduction of 58.1% from OFL to ABC (Tables 5 and 6). The reduction from SYL to ABC under this approach (58.1%) is consistent with the proposed Atlantic HMS ABC control rule (Tier 4 buffer ≤ 90% of OFL proxy, Appendix A) and with the recent CFMC ABC control rule (Tier 4a and Tier 4b buffer ≤ 0.9 × SYL, Appendix B).

Assuming a less conservative predetermined risk tolerance of ABC exceeding OFL (acceptable probability of overfishing, analogous to P*), e.g., ranging from 45% to 35%, would

[6] E.g., in MS Excel, 0.647 = LOGNORM.INV(0.3,0, 0.830).
[7] E.g., in MS Excel, 0.419 = LOGNORM.INV(0.3,0, 1.66).

result in a larger ABC to SYL ratio (0.812 – 0.527; Table 5) interpreted as a smaller buffer between SYL and ABC, where ABC = 0.812 × SYL to ABC = 0.527 × SYL, respectively. Similarly, assuming a more conservative predetermined risk tolerance of ABC exceeding OFL (acceptable probability of overfishing, analogous to P*), e.g., ranging from 25% to 5%, would result in a smaller ABC to SYL ratio (0.326 – 0.065; Table 5) interpreted as a larger buffer between SYL and ABC, where ABC = 0.326 × SYL to ABC = 0.065 × SYL, respectively.

Assuming the least conservative predetermined risk tolerance of ABC exceeding OFL (acceptable probability of overfishing, analogous to P*), i.e., equal to 50%, would result in an ABC to SYL ratio of 1.000 (Table 5) interpreted as no buffer between SYL and ABC, where ABC = 1.000 × SYL. However, as noted above buffers greater than 90% of the OFL proxy, or SYL, for Tier 4 stocks are not consistent with either the proposed Atlantic HMS ABC control rule (Appendix A) or the CFMC ABC control rule (Appendix B).

3.7. Current TAC and Commercial Quota Methodology

TAC (2021).—TAC for Atlantic HMS domestic sharks assessed through the SEDAR process (Appendix E), is currently assumed to be equal to the OFL. Consequently, the TAC for assessed stocks includes discard, recreational, and research catch estimates as well as the commercial quota (NMFS 2021, their p 84)[8]:

> "For sharks assessed through the SEDAR process, NOAA Fisheries establishes an overfishing limit equal to the TAC. Discard, recreational, and research catch estimates are deducted from the TAC and constitute their respective sector ACLs. The remaining TAC is considered the commercial quota or the commercial sector ACL. More details on these calculations and the establishment of TACs and ACLs can be found in amendments to the 2006 Consolidated Atlantic HMS FMP that focus on shark management: Amendment 2 (NOAA Fisheries 2008), Amendment 3 (NOAA Fisheries 2010), Amendment 5a (NOAA Fisheries 2013), Amendment 6 (NOAA Fisheries 2015a), Amendment 9 (NOAA Fisheries 2015b), and Amendment 5b (NOAA Fisheries 2017b)."

[8] References to the quoted amendments can be found in NMFS (2021).

In the 2020 SAFE report (NMFS 2021, their Table 5.2), the TAC equals the sum of all the ACLs. Each ACL (commercial, recreational, and dead discard) for each management group is reported in the table. Unassessed shark stock ACLs are not individually discussed in the SAFE report. However, they would be included in the management groups. Consequently, the TAC obtained from the SAFE report for unassessed stocks is provided by species group (species complex), while the Tier 4 SYLs and ABCs would be obtained by species. As a result, comparisons of TAC obtained from the 2020 SAFE report (NMFS 2021) may not be directly comparable to the Tier 4 SYLs and ABCs obtained here for unassessed stocks.

Commercial quota methodology for stocks not on a rebuilding plan.—The Atlantic smooth dogfish shark commercial quota calculations are provided in Appendix F as an example of the methodology used for Atlantic HMS domestic shark stocks not on a rebuilding plan.

Commercial quota methodology for stocks on a rebuilding plan.—The sandbar shark commercial quota calculations are provided in Appendix G as an example of the methodology used for Atlantic HMS domestic shark stocks on a rebuilding plan.

4. DISCUSSION

The analyses presented here provided example implementations of an ABC control rule for U.S. Atlantic HMS domestic shark stocks within a tiered structure that depended on both stock status and stock assessment data availability for each stock. The buffer size used for the ABC control rule was based on a minimum estimate of scientific uncertainty obtained from meta-analysis of among assessment variability in historical data-rich (Tier 1) Atlantic HMS domestic shark stocks assessed multiple times within the last 20 years, analogously to the Ralston et al. (2011) approach. The resulting pooled estimate of the among assessment lognormal standard error in predicted abundance, $\sigma = 0.4151$, was assumed to represent a minimum estimate of scientific uncertainty in the stock assessment process, σ_{min}, and used to reduce fishery removals from the overfishing limit, OFL, to an ABC within the tiered ABC control rule approach. Examples of Tier 1 ABCs obtained using this approach were slightly smaller (more conservative) relative to the status quo projection approach implemented with Stock Synthesis for the blacktip shark (Atlantic region) example evaluated here (Appendix D).

The Tier 1 ABCs obtained using this meta-analysis approach should be interpreted as a minimum estimate of scientific uncertainty in the stock assessment because the ABC to OFL buffer represented a minimum estimate of stock assessment uncertainty obtained from a limited number of historical assessments. Consequently, the Tier 1 ABCs obtained using this meta-analysis approach should be evaluated within each assessment relative to the status quo stock assessment projection uncertainty on a case by case basis using the Best Scientific Information Available (BSIA) standard, as discussed below.

ABCs for Atlantic HMS U.S. domestic shark stocks are currently established on a case by case basis based on TAC, for example, obtained from a completed stock assessment (e.g. see appendices E, F, and G). Because the Atlantic HMS Management Division does not operate within a regional FMC and does not have an associated SSC, a peer review process is typically used to ensure that fishery conservation and management measures resulting from a completed stock assessment utilize the Best Scientific Information Available, BSIA. National Standard 2 (NS2) of the MSA (U.S. Office of the Federal Register 2013; e.g., see 50 CFR part 600.315[9]) mandates that fishery conservation and management measures shall be based on BSIA. The NS2 guidelines describe what constitutes BSIA. The NOAA Fisheries Stock Assessment Improvement Plan (Lynch et al. 2018) also describes how a well-organized, well-documented, peer-reviewed stock assessment process is critical to improving the BSIA process. For completed Atlantic HMS U.S. domestic shark stock assessments, the BSIA process has typically included a scientific peer review following each completed stock assessment to ensure that assessment results are scientifically sound and that decision makers are provided adequate advice that reflects uncertainties in the data and methods used in the stock assessment. A recently completed regional BSIA framework for Atlantic HMS[10] should increase transparency in how BSIA determinations are made and documented in the context of stock status determinations and catch specifications. Future BSIA processes for Atlantic HMS U.S. domestic shark stocks could also be developed to review the data and methods used to calculate ABC from OFL for each assessed and unassessed stock, for example, in order to evaluate the remaining uncertainties identified below.

[9] E.g., see https://www.ecfr.gov/current/title-50/chapter-VI/part-600#600.315 (Accessed August 2022).
[10] The Final Regional BSIA Framework for Atlantic HMS was released on May 9, 2022. Available: https://www.fisheries.noaa.gov/resource/document/atlantic-highly-migratory-species-best-scientific-information-available-regional?utm_medium=email&utm_source=govdelivery (Accessed August 2022).

In particular, the estimate of minimum scientific uncertainty obtained here, σ_{min}, will vary based on the number of historical assessments available to be included in the analysis. In contrast to the large number of assessments completed multiple times and analyzed by Ralston et al. (2011), there were only a limited number of HMS shark data rich assessments available for this analysis. However, the σ_{min} results obtained from this study were similar to, but slightly larger than those of Ralston et al. (2011). This is to be expected given the relatively data poor nature of the HMS domestic shark stock assessments in relation to the data rich U.S. west coast groundfish assessments analyzed by Ralston et al. (2011).

Ralston et al. (2011) limited the data points under consideration to no more than those that represent the last 20 years to focus attention on variation associated with the estimation of terminal year biomass (current biomass). Here, we followed the same logic and limited the time frame of assessment results included in these analyses to 20 years since the final year of the most recently completed assessment for each stock. Future research could examine the effect of alternative time frames on the σ_{min} results obtained from this study.

Ralston et al. (2011) adopted Pooling Method 2 as the preferred approach for the data in their study. Pooling Method 2 was preferred for the data in that study because of the lack of variation in the sigma values obtained among stocks in their study, possibly as a result of their large sample size of completed assessment. In contrast, Pooling Method 1 was adopted for the data set used in this study as the preferred approach because of heterogeneity in the variation among historical assessments, as discussed above, possibly as a result of the limited number of assessments evaluated in this study. Consequently, the dataset in this study required treating each species as a replicate to obtain a stratified estimate (Pooling Method 1) of scientific uncertainty among stocks.

Age-structured stock assessment models, including Stock Synthesis, account for estimation uncertainty in the distributions of derived parameters included in model output. In principle, derived parameter distributions based on estimation uncertainty can be used to develop ABC recommendations for U.S. domestic shark stocks (Cortés et al. 2015a, their Figure 4). For example, within recent Atlantic HMS U.S. domestic shark stock assessments, the status quo ABC sets a buffer of 30% between the OFL and ABC, i.e. the ABC is the 30th percentile of the projected OFL distribution, which corresponds to a ≥ 70% probability that overfishing will not occur (e.g., Appendices D and F). Within these projection approaches, estimation uncertainty in the distributions of derived parameters was combined with assumptions about future stock recruitment in order to obtain projection uncertainty. Alternate states of nature model runs are also typically evaluated within each completed data-rich Atlantic HMS domestic shark stock assessment to account for additional sources of stock assessment uncertainty (e.g., Appendices D and F).

Consequently, each accepted Tier 1 Atlantic HMS domestic shark stock assessment will in principle have an associated estimate of within assessment scientific uncertainty (σ_a), for example, obtained from parameter and projection uncertainty included in the status quo constant catch projection approach (Appendices D and F) obtained for the base model and for alternate states of nature model runs, as described above. In principle, the larger estimate of scientific uncertainty (largest σ_a obtained from base model and alternate states of nature projections or σ_{min} obtained from meta-analysis of historical stock assessment uncertainty) could then be chosen for implementation within an ABC control rule (e.g. Appendices A and B; where $\sigma \geq \sigma_{min}$). This would ensure use of a precautionary estimate of scientific uncertainty (i.e. the larger sigma value).

In practice, it might also be more practical to compare the ABC obtained from meta-analysis using σ_{min} directly to the sustainable TAC levels obtained from the status quo Atlantic HMS U.S. domestic shark constant catch projection approach from the base model and the alternate states of nature (e.g., Appendices D and F). Such a comparison would also ensure that the ABC determination obtained with the meta-analysis provides a precautionary estimate of scientific uncertainty (and associated buffer from the OFL) consistent with both historical stock assessment uncertainty of the Atlantic HMS domestic shark stock assessment process, σ_{min}, and the within assessment uncertainty obtained from projections for each completed assessment, σ_a .

The ABC to OFL ratio (buffer) implemented here for Tier 1 utilized an acceptable probability of overfishing of 30%. A 30% acceptable probability of overfishing is consistent with recent terms of reference implemented for Atlantic HMS domestic shark projections (e.g., blacktip shark in the U.S. Atlantic region; NMFS 2020), which state that if a stock is neither overfished nor undergoing overfishing, then utilize projections to determine the *F* needed and corresponding removals associated with a 70% probability of overfishing not occurring (analogous to a P* = 0.3 approach). A 30% acceptable probability of overfishing is also consistent with previously implemented Atlantic HMS domestic shark rebuilding plans (e.g., sandbar shark in the U.S. Gulf of Mexico and Atlantic regions; NMFS 2018a), which also utilized projections to determine the constant catch associated with a 70% probability of rebuilding, analogous to a 30% probability of not rebuilding.

Lower tier example ABCs obtained using this approach were more difficult to validate in comparison with status quo management advice and, consequently, should also be interpreted more cautiously. Generic OFLs were used here to provide generic examples of data moderate (Tier 2 and Tier 3) ABCs. In practice, the Tier of a stock assessment would probably need to be evaluated on a case by case basis within an assessment, for example, based on the BSIA standard. The BSIA standard for Atlantic HMS domestic shark stock assessments is generally considered to be acceptance of the assessment results by a scientific peer review process such as implemented within SEDAR, as discussed above.

The choice of a tier specific sigma multiplier governs the amount of uncertainty for data moderate and data poor stocks in lower tiers. Here we used sigma multiples of 1.5 and 2.0, for Tier 2 and 3, respectively. The difference in the resulting Tier 1, Tier 2, and Tier 3 ABCs obtained for a generic example OFL (Figure 13) illustrates that the same OFL will result in different ABCs depending upon the tier of the stock assessment. In particular, the buffer between OFL and ABC increases as the assumed stock assessment uncertainty (specific sigma multiplier increases in lower tiers, even for the same OFL.

An example Tier 4 sigma multiplier was also provided (Table 5 and Figure 12) based on Ralston et al. (2011) who used a value of 4.0 as the multiplier for their data poor tier. In contrast, under the proposed Atlantic HMS ABC control rule, a minimum estimate of scientific uncertainty in the stock assessment process, σ_{min}, is not used to calculate ABC for stocks that do not currently have a formal stock assessment (Tier 4). Instead, Tier 4 ABCs are obtained from reference period catch. Examples of possible Tier 4 stock assignments are provided in Appendix C. Examples of Tier 4 ABC calculations are provided in Table 6. As described in the main text above, an example catch data set (commercial landings in pounds dressed weight, lb dw, during the years 2015 to 2019) is provided here only as an example OFL proxy and defined for the purposes of this example as the sustainable yield level, SYL. However, as described above, the methods and results presented here are preliminary and intended only for the purpose of providing an example Tier 4 application. Any adoption of actual Tier 4 ABCs for U.S. Atlantic

HMS domestic shark stocks will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

Multivariate methods such as productivity and susceptibility analyses (PSA, e.g., Patrick et al. 2009, 2010) could be used to inform the buffer size for Tier 4 stocks (Appendices A and B). In general, the objectives of PSA (Patrick et al. 2010) are threefold: First, provide a uniform framework for evaluating vulnerability of stocks under the MSA NS1 guidelines to identify stocks that should be managed and protected under a fishery management plan; second, group data-poor stocks into relevant management complexes; and third, develop precautionary harvest control rules. PSA (Patrick et al. 2010) was used to determine vulnerability scores as a function of productivity and susceptibility. PSA (Patrick et al. 2010) was also used to develop data quality scores for each productivity and susceptibility category. Overall, the PSA was capable of differentiating the vulnerability of stocks along a gradient of susceptibility and productivity indices, although fixed thresholds separating low-, moderate-, and highly-vulnerable species were not developed.

In practice, an SSC usually determines the acceptable probability of overfishing (analogous to $P^* < 0.5$). However, as mentioned above, the HMS Management Division does not submit management recommendations through an FMC process and therefore does not have an SSC to review management recommendations. Consequently, the actual risk tolerance adopted for the acceptable probability of overfishing will be determined separately for U.S. Atlantic HMS domestic shark stocks within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

In principle, however, PSA methods could also be used to inform the predetermined risk tolerance of ABC exceeding OFL for Tier 1 to Tier 3 stocks. For example, species specific risk tolerances for the acceptable probability of overfishing could be informed by the results of an updated PSA (Patrick et al. 2009, 2010) following methods developed more recently for ecological risk assessment of pelagic elasmobranchs (Cortés et al. 2010, 2015b).

A preliminary review of Patrick et al. (2009, 2010) conducted for this study suggests that the PSA categories, weightings, and scoring criteria adopted in the Patrick et al. (2009, 2010) would need to be adjusted for elasmobranchs (e.g., following methods in Cortés et al. 2010, 2015b) before PSA could be used directly to inform the vulnerability of Atlantic HMS domestic shark stocks. Cortés et al. (2010, 2015b) conducted an ecological risk assessment on eleven species of pelagic elasmobranchs (ten sharks and one ray) to assess their vulnerability to pelagic longline fisheries in the Atlantic Ocean. The ecological risk assessment (Cortés et al. 2010, 2015b) was useful in ranking species based on vulnerability of stocks along a gradient of susceptibility and productivity indices. This ranking can be considered a first step to identify which species are more at risk based on present knowledge of their biology and the effect that fishing fleets operating in the Atlantic Ocean can have on their stocks. However, the studies were not able to assign status to the stocks (e.g., relative to reference points such as overfished or overfishing) because PSAs do not account for the actual level of fishing mortality, F, exerted by each fleet, or the size of the stock relative to unfished equilibrium or MSY (e.g., Cortés et al. 2015a).

In contrast, Sustainability Assessment for Fishing Effects (SAFE; Zhou and Griffiths 2008; Zhou et al. 2011, 2016) has been utilized to identify reference points for elasmobranch species (e.g., Zhou et al. 2019). The SAFE method has also been used within the International Commission for the Conservation of Atlantic Tunas, ICCAT, to compute a sustainable harvest rate expressed as an instantaneous fishing mortality rate, F, and compared to a value of F_{MSY} obtained based on productivity values derived exclusively from life history data (Cortés et al. 2020). Management measures have also previously been adopted by ICCAT based in part on an ecological risk assessment for the effect of pelagic longline fisheries on pelagic sharks (Cortés et al. 2010). In comparison, Cortés et al. (2015a) also note that other analytical methods may be useful for identifying stock vulnerability. For example, elasticity analysis (based on demographic analysis) was the basis for implementing minimum size limits for several shark species in an attempt to protect the vital rate (juvenile survival) that was found to be most important for population growth (Brewster-Geisz and Miller 2000, Cortés et al. 2002).

Our example assignment of stocks within the proposed Atlantic HMS domestic shark ABC control rule excluded some stocks that either may not require an ABC or may require further evaluation before they can be assigned to an ABC control rule tier (Appendix C; Table C.2). Within this example, stocks not assigned to an ABC control rule tier included those which were assigned to one (or more) of the following six groups: (1) overfished, (2) overfishing, (3) approaching an overfished condition, (4) prohibited species, (5) species managed by ICCAT, and (6) ecosystem component species. While these groupings do not match the management groupings currently in Amendment 14 or envisioned in their follow on rule(s), they do offer a level of complexity that could be considered in future modifications to the ABC control rule or could be considered when developing future SEDAR Terms of Reference (TORs). Specifically, Groups 1 – 3 (overfishing, overfished, and approaching an overfished condition) were created to reflect the possible differences in SEDAR TORs that may be necessary to implement Atlantic HMS domestic shark stock assessments under NS1 guidelines. Group 6 (ecosystem component species) considers domestic shark species that may not require conservation and management based on their rare interaction with fisheries, or other considerations. However, an ecosystem species component is not currently included within the Atlantic HMS FMP, although they could be included in the future. The example groupings presented here are preliminary and intended only for the purpose of providing an example. Any adoption of actual U.S. Atlantic HMS domestic shark stock management groups will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

This example implementation of an ABC control rule for U.S. Atlantic HMS domestic shark stocks was adapted from the meta-analysis approach used to develop ABCs for the U.S. west coast (Ralston et al. 2010). However other methods for incorporating assessment model uncertainty are also available (e.g., Privitera-Johnson and Punt 2020a, 2020b). In particular, Privitera-Johnson and Punt (2020b) recommend calculating scientific uncertainty based on historical projected spawning biomass (SSB) and OFLs. In comparison, a projection approach based on within stock assessment estimation uncertainty is currently implemented for data rich Atlantic HMS domestic shark assessments, as described above (e.g., Appendices D and F). The within stock assessment estimation uncertainty has also been implemented in projections analogously to a Kobe II Strategy Matrix for incorporating stock assessment uncertainty within management advice implemented by ICCAT (Courtney et al. 2014; e.g., also see Courtney and Rice 2020 and the references therein). However, a direct comparison of the status quo Atlantic HMS domestic shark projection approach with the historical projection methods recommended by Privitera-Johnson and Punt (2020b) was beyond the scope of this study.

Additional sources of within assessment scientific uncertainty could also be incorporated for data rich Atlantic HMS domestic shark stock assessment. For example, as discussed above, Quinn and Deriso (1999) advocate for the analysis of various states of nature and recommend that assessment scientists "… identify alternative hypotheses about population abundance, productivity, and dynamics." In comparison, models representing alternative states of nature have typically been included within each completed Atlantic HMS domestic shark stock assessment (e.g., NMFS 2020, their Post-Review Workshop Addendum Report summary of High Catch Sensitivity, Low Catch Sensitivity, Low Productivity Sensitivity, and High Productivity Sensitivity model runs and projection results). However, the range of uncertainty obtained from Atlantic HMS domestic shark stock assessment models representing alternative states of nature has not been formally evaluated for use within management advice (e.g., Jardim et al. 2021), and, consequently was not evaluated directly within this study, which focused on a single base model run obtained from each assessment.

Other approaches are also available to quantify uncertainty in fisheries stock assessments, which include varying the software and model framework and evaluating the sensitivity of assessment model outcomes to alternative parameter specifications (Privitera-Johnson and Punt 2020a). Structural uncertainty grids can also be used to simultaneously evaluate the sensitivity of model outcomes to a range of alternative parameter specifications and data inputs including the standardization or estimation methods for catch and CPUE (e.g., Rice 2017).

Methods are also continuing to evolve in response to scientific uncertainty related to the impact of contradictory data included within a stock assessment model (e.g., Quinn and Deriso 1999, Maunder and Piner 2017, Carvalho et al. 2021, Kell et al. 2021). For example, Quinn and Deriso (1999) note that "Although it is straightforward to construct the composite likelihood for different data sets and to look for discrepancies among data sets (through hypothesis testing or analysis of residuals), it is less clear how to deal with uncertainty once it is found… [and]… without prior information on which data sets are accurate and precise, the only solution to the problems induced by contradictory data involve further experimentation, adaptive management, and highlighting the contradiction within a decision-making framework." In particular, Maunder and Piner (2017), Carvalho et al. (2021), and Kell et al. (2021) evaluate methods to identify data conflict within integrated assessment models and propose using diagnostics to assign individual model weights within a risk-based framework such as an ensemble of candidate models. However, attempting to incorporate these additional sources of scientific uncertainty into the ABC control rule was beyond the scope of this example implementation.

5. CONCLUSIONS

The methods and results presented here are preliminary and intended only for the purpose of providing an example application of including historical stock assessment uncertainty within a tiered ABC control rule for U.S. Atlantic HMS domestic sharks. Any adoption of actual ABCs for U.S. Atlantic HMS domestic shark stocks will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

In practice, we recommend comparing Tier 1 ABC obtained under a proposed ABC control rule, for example as obtained here from meta-analysis, to the sustainable TAC levels obtained from the status quo Atlantic HMS U.S. domestic shark constant catch projection approach. As noted above, such a comparison would ensure that the ABC determination obtained with the meta-analysis provides a conservative buffer from the OFL consistent with both historical stock assessment uncertainty of the Atlantic HMS domestic shark stock assessment process and the parameter estimation uncertainty obtained from each completed assessment.

In our example application, we compared the results of an ABC obtained from meta-analysis of historical stock assessment uncertainty, as described in this study, to the status quo sustainable TAC obtained for Atlantic HMS domestic shark stocks currently obtained utilizing a constant catch projection approach (Appendix D). The meta-analysis approach described in this study incorporated a minimum estimate of stock assessment uncertainty obtained from an analysis of historical stock assessment variability from multiple assessments of the same stock (among assessment uncertainty). In contrast, the sustainable TAC levels obtained with the status quo constant catch projection approach included parameter estimation uncertainty from a base model run along with assumptions about future stock recruitment (within assessment uncertainty). Because the two methods produced consistent catch specifications in our example application (Appendix D), we concluded that the ABC determination obtained with the meta-analysis provided a conservative buffer from the OFL for this stock consistent with both historical stock assessment uncertainty of the Atlantic HMS domestic shark stock assessment process and the parameter estimation uncertainty of the most recent assessment for this stock.

We also we recommend additional research to evaluate Tier 1 ABC determination methods relative to additional sources of stock assessment uncertainty including alternative states of nature and structural uncertainty grids. Such an evaluation would ensure that Tier 1 ABCs are robust (i.e., provide consistent and conservative management advice) relative to additional sources of scientific uncertainty obtained from alternative hypotheses about population abundance, productivity, and dynamics (states of nature), as well as to a plausible range of parameter uncertainty evaluated for the base model (structural uncertainty grids).

Additional research may also be needed to determine if Tier 1 ABC determination methods are robust to the number of completed assessments evaluated, the number of years of assessment overlap included in historical assessment analyses, and the definition of stock size used within the analysis of historical stock assessment variability (e.g., Ralston et al. 2011). Similarly, simulation studies may also be useful to determine if the range of historical stock assessment uncertainty obtained from the meta-analysis approach evaluated here is consistent with the range of uncertainty obtained using other approaches such as the calculation of scientific uncertainty based on historical projected spawning biomass, SSB, and OFL (Privitera-Johnson and Punt 2020b).

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TABLE 1. Sandbar shark (U.S. Gulf of Mexico and Atlantic regions combined) predicted total population abundance in numbers (*N*, age 1+, thousands) obtained from Stock Synthesis base runs with ending year 2015 (SEDAR 54; Adapted from base model run time series output corresponding to NMFS 2018a, their Table A7 updated base case model, obtained separately[11]) and from State Space Age Structured Production Model base runs with ending years 2009 (SEDAR 21; Adapted from NMFS 2011 their Table 3.12 base run) and 2004 (SEDAR 11; Adapted from NMFS 2006, their table 4.5 base model).

Years relative to most recent abundance estimate	Year of abundance estimate	SEDAR 54 *N* (age 1+, thousands)	SEDAR 21 *N* (age 1+, thousands)	SEDAR 11 *N* (age 1+, thousands)
20	1996	1,790	2,392	2,027
19	1997	1,735	2,260	1,941
18	1998	1,715	2,154	1,874
17	1999	1,657	2,042	1,793
16	2000	1,570	1,955	1,732
15	2001	1,526	1,895	1,694
14	2002	1,473	1,807	1,618
13	2003	1,432	1,741	1,563
12	2004	1,434	1,689	1,521
11	2005	1,423	1,645	
10	2006	1,485	1,609	
9	2007	1,491	1,565	
8	2008	1,478	1,541	
7	2009	1,467	1,539	
6	2010	1,418		
5	2011	1,402		
4	2012	1,381		
3	2013	1,385		
2	2014	1,391		
1	2015	1,408		

[11] Numbers at age 1+ corresponding to NMFS (2018a, their Table A7) updated base case model were obtained here from Stock Synthesis output (Accessed August 2022).

TABLE 2. Blacktip shark (U.S. Gulf of Mexico region) predicted total population abundance in numbers (*N*, age 1+, thousands) obtained from State Space Age Structured Production Model base runs with ending years 2016 (2018 update to SEDAR 29, NMFS 2018b; Adapted from NMFS 2018c, their p. 35 Table A Panel B1), 2010 (SEDAR 29; Adapted from NMFS 2012, their Table 3.5.16), and 2004 (SEDAR 11; Adapted from NMFS 2006, their Table 5.5).

Years relative to most recent abundance estimate	Year of abundance estimate	2018 update to SEDAR 29 *N* (age 1+, thousands)	SEDAR 29 *N* (age 1+, thousands)	SEDAR 11 *N* (age 1+, thousands)
20	1997	55,300	23,696	21,689
19	1998	56,100	23,678	21,670
18	1999	56,600	23,626	21,636
17	2000	57,100	23,645	21,655
16	2001	57,500	23,611	21,638
15	2002	57,900	23,636	21,653
14	2003	58,200	23,663	21,670
13	2004	58,500	23,659	21,667
12	2005	58,700	23,671	
11	2006	58,900	23,693	
10	2007	59,100	23,701	
9	2008	59,300	23,726	
8	2009	59,600	23,790	
7	2010	59,800	23,844	
6	2011	59,900		
5	2012	60,100		
4	2013	60,200		
3	2014	60,300		
2	2015	60,500		
1	2016	59,700		

TABLE 3. Atlantic sharpnose shark (U.S. Gulf of Mexico and Atlantic regions combined) predicted total population abundance in numbers (*N*, age 1+, thousands) obtained from State Space Age Structured Production Model base runs with ending years 2011 (SEDAR 34; Adapted from NMFS 2013, their Table 3.5.15) and 2005 (SEDAR 13; Adapted from base model run time series output corresponding to NMFS 2007, their Table 5.5, obtained separately[12]).

Years relative to most recent abundance estimate	Year of abundance estimate	SEDAR 34 *N* (age 1+, thousands)	SEDAR 13 *N* (age 1+, thousands)
20	1992	24,012	8,322
19	1993	23,686	7,833
18	1994	23,665	7,847
17	1995	23,173	7,941
16	1996	23,093	7,707
15	1997	23,069	7,664
14	1998	22,931	7,716
13	1999	22,448	7,608
12	2000	22,031	7,686
11	2001	21,907	7,566
10	2002	22,114	7,606
9	2003	22,479	7,416
8	2004	22,732	7,502
7	2005	23,294	7,654
6	2006	24,406	
5	2007	25,403	
4	2008	26,325	
3	2009	27,502	
2	2010	28,133	
1	2011	28,864	

12 Pers. Comm. Enric Cortés 4/29/2021.

TABLE 4. Meta-analysis results of scientific uncertainty obtained from previously completed Tier 1 stock assessments for sandbar shark, blacktip shark, and Atlantic sharpnose shark. Estimates of historical stock assessment variation (σ, Panel A) were calculated for each stock as the log-normal standard deviation in predicted total population abundance in numbers using three different approaches, as described in the main text above. Combined estimates of historical stock assessment variation (σ_{min}, Panel B) were obtained using two different pooling methods, as described in the main text above.

A. Individual estimates of historical stock assessment variation.

A.1. Sandbar shark (U.S. Gulf of Mexico and Atlantic regions combined).

Historical variation	Approach 1	Approach 2	Approach 3
σ	0.1066	0.0824	0.1606
CV	11%	8%	16%

A.2. Blacktip shark (U.S. Gulf of Mexico region).

Historical variation	Approach 1	Approach 2	Approach 3
σ	0.5650	0.4509	0.9455
CV	61%	47%	120%

A.3. Atlantic sharpnose shark (U.S. Gulf of Mexico and Atlantic regions combined).

Historical variation	Approach 1	Approach 2	Approach 3
σ	0.7832	0.5538	1.1288
CV	92%	60%	160%

B. Combined estimates of historical stock assessment variation.

B.1. Combined historical stock assessment variation **Method 1***,
(Average of the stock-specific variances).

Average historical variation	Approach 1	**Approach 2***	Approach 3
σ_{min}	0.5610	**0.4151**	0.8552
CV	61%	43.4%	104%
n	3	3	3

B.2. Combined historical stock assessment variation Method 2,
(All residuals were aggregated to calculate a pooled standard deviation).

Pooled historical variation	Approach 1	Approach 2	Approach 3
σ_{min}	0.6916	0.3955	0.7868
CV	78%	41.1%	93%
n	152	101	59

*The preferred historical variation calculation approach (Approach 2) and the preferred method of combining historical stock assessment variation (Method 1) are identified by an asterisk. The resulting preferred combined minimum estimate of historical stock assessment uncertainty obtained from meta-analysis (σ_{min} = 0.4151) is identified in bold text.

TABLE 5. Examples of the tradeoffs between the buffer sizes (ABC/OFL ratios) and the predetermined risk tolerance of ABC exceeding OFL (acceptable probability of overfishing, analogous to P*). Example ABC/OFL ratios were obtained for Tier 1 from meta-analysis of completed assessments for Tier 1 stocks (σ_{min} = 0.4151). Example ABC/OFL ratios were obtained for lower tiers from multiples equal to 1.5, 2.0, and 4.0 times σ_{min} for Tier 2, Tier 3, and Tier 4 stocks, respectively.

	ABC/OFL Ratios			
P*	Tier1 $\sigma_{min} = 0.4151$	Tier 2 ($1.5 \times \sigma_{min}$)	Tier 3 ($2.0 \times \sigma_{min}$)	Tier 4 ($4.0 \times \sigma_{min}$)
0.50	1.000	1.000	1.000	1.000
0.45	0.949	0.925	0.901	0.812
0.40	0.900	0.854	0.810	0.657
0.35	0.852	0.787	0.726	0.527
0.30	**0.804**	**0.721**	**0.647**	**0.419**
0.25	0.756	0.657	0.571	0.326
0.20	0.705	0.592	0.497	0.247
0.15	0.650	0.524	0.423	0.179
0.10	0.587	0.450	0.345	0.119
0.05	0.505	0.359	0.255	0.065

TABLE 6. Examples of commercial landings in pounds dressed weight (lb dw) were obtained for the years 2015 – 2019 from the Atlantic Highly Migratory Species 2020 Stock Assessment and Fishery Evaluation Report (NMFS 2021)[13] for selected Small Coastal Sharks (SCS)[14] and Large Coastal Sharks (LCS)[15] stocks in the Atlantic (ATL), Gulf of Mexico (GOM), and combined (ATL + GOM) management regions. SCS and LSC shark stocks were assigned here to Tier 4 under our example application of a tiered ABC control rule (Appendix C). Example SYLs were calculated here following Appendix B (their Tier 4a) as the 75th quantile of the example landings 2015 – 2019. Example SYLs were also calculated here following Appendix B (their Tier 4b) as the average of the example landings 2015 – 2019. Example ABCs were calculated here for Appendix B (their Tier 4a and Tier 4b) using the ABC to SYL ratio of 0.419 obtained by assuming a P* = 30% as described in Table 5 (i.e., ABC equals 41.9% of the SYL).

Species	2015	2016	2017	2018	2019	75th quantile	SYL_4a	ABC_4a	Avg.	SYL_4b	ABC_4b
SCS-Blacknose[16] (GOM)	2,096	5	-	-	-	5	10	4	351	702	294
SCS-Bonnethead (ATL)	5,885	1,688	6,077	4,240	4,134	5,885	11,770	4,932	4,652	9,304	3,898
SCS-Bonnethead (GOM)	968	9	588	729	-	729	1,458	611	504	1,008	422
LCS-Bull (ATL + GOM)	324,122	186,237	195,100	193,470	100,907	195,100	390,200	163,494	199,156	398,312	166,893
LCS-Lemon (ATL + GOM)	58,471	51,239	37,044	46,503	51,622	51,622	103,244	43,259	49,417	98,834	41,411
LCS-Nurse (ATL + GOM)	62	95	-	-	-	62	124	52	36	72	30
LSC-Spinner (ATL + GOM)	47,298	121,188	109,184	184,596	79,171	121,188	242,376	101,556	110,438	220,876	92,547
LSC-Tiger (ATL + GOM)	54,961	53,430	58,012	48,664	71,971	58,012	116,024	48,614	57,508	115,016	48,192

13 As described in the main text above, an example catch data set (commercial landings in pounds dressed weight, lb dw, during the years 2015 to 2019) is provided here only as an example OFL proxy and defined for the purposes of this example as the sustainable yield level, SYL. However, as described above, the methods and results presented here are preliminary and intended only for the purpose of providing an example Tier 4 application. Any adoption of actual Tier 4 ABCs for U.S. Atlantic HMS domestic shark stocks will be developed separately within the framework of the NOAA NMFS Atlantic HMS Management Division Amendment 14 and its follow on rule(s).

14 Commercial landings (lb dw) of Small Coastal Sharks in U.S. Atlantic and Gulf of Mexico Regions in 2015–2019 (NMFS 2021, their Tables 5.12, and 5.13 obtained from eDealer reports).

15 Commercial landings (lb dw) of Large Coastal Sharks in U.S. Atlantic and Gulf of Mexico Regions in 2015–2019 (NMFS 2021, their Tables 5.9, and 5.10 obtained from eDealer reports).

16 Atlantic blacknose in the U.S. Gulf of Mexico region are prohibited (NMFS 2021,Their Table 5.13). However some limited landings exist.

TABLE 6. Continued.

Species	2015	2016	2017	2018	2019	75th Quantile	SYL_4a	ABC_4a	Avg.	SYL_4b	ABC_4b
Great hammerhead[17] (ATL + GOM)	70,331	50,928	35,782	54,306	59,420	59,420	118,840	49,794	55,031	110,062	46,116
Smooth hammerhead[17] (ATL + GOM)	304	125	1,193	530	661	661	1,322	554	579	1,158	485

[17] Commercial landings (lb dw) of Hammerhead Sharks in U.S. Atlantic and Gulf of Mexico Regions in 2015–2019 (NMFS 2021, their Tables 5.9, and 5.10 obtained from eDealer reports).

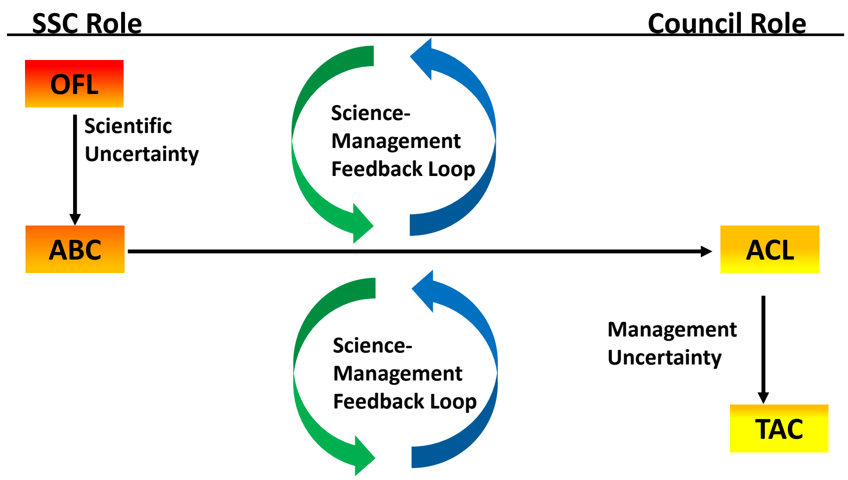


FIGURE 1. Graphical example of reducing the overfishing limit (OFL) to the acceptable biological catch (ABC) within an ABC control rule to account for both scientific uncertainty in the stock assessment and management uncertainty in the implementation (Adapted from Patrick and Cope 2014, their Figure 4; e.g., Methot et al. 2014, their Figure 2). The graphic also identifies the different roles of the Fishery Management Council (Council) and its Scientific and Statistical Committee (SSC) and the anticipated feedback loops between science and management[18]. An annual catch limit (ACL) is a limit on the total annual catch of a stock or stock complex, which cannot exceed the ABC. An annual catch target (ACT; Figure 2), or functional equivalent such as total allowable catch (TAC), can be used to account for management uncertainty in the implementation of the ACL. If an ACT or its functional equivalent is not used, then management uncertainty could be accounted for in the ACL, for example with adaptive management and accountability measures to ensure the ACL does not exceed the ABC.

[18] As noted in the introduction section of the main text above, the Atlantic HMS Management Division does not operate within a regional FMC. In contrast, the Atlantic HMS Management Division operates under a Secretarial FMP. As noted in the main text above, recent National Standard 1 (NS1) guidelines for the MSA (e.g., U.S. Office of the Federal Register 2009, 2016) indicate that for Secretarial FMPs or amendments, agency scientists or a peer review process would provide the scientific advice to establish an ABC (also see 50 CFR 600.310 (b)(2)(v)(C)). Consequently, the ABC control rule for Atlantic HMS U.S. domestic shark stocks in the Atlantic Ocean, along with the anticipated science-management feedback loops, are being developed through the Secretary of Commerce within an amendment process with input from agency scientists within the NOAA NMFS Southeast Fisheries Science Center (SEFSC), as described in the main text above.

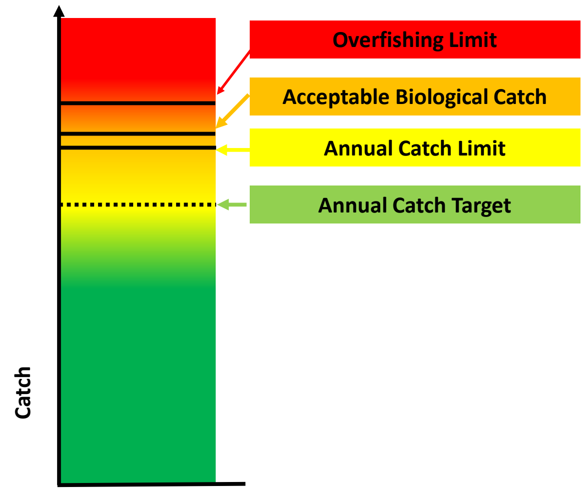


FIGURE 2. Illustration of buffers between an overfishing limit (OFL), the acceptable biological catch (ABC), the annual catch limit (ACL), and the annual catch target (ACT) (Adapted from the U.S. Office of the Federal Register 2009, their Figure 2).

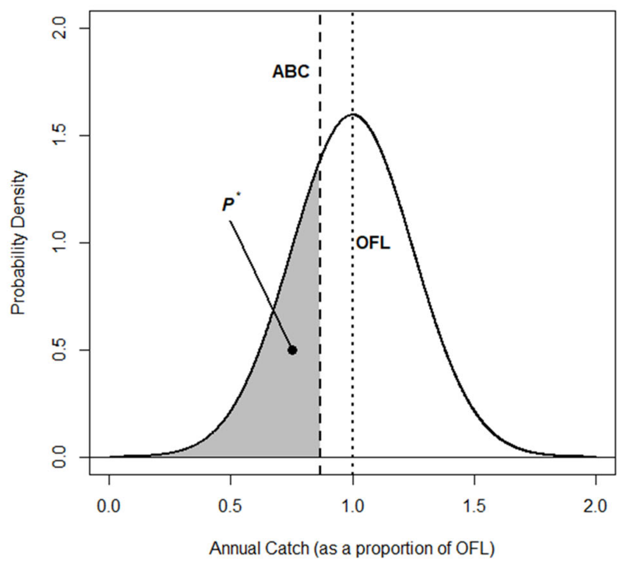


FIGURE 3. Illustration of an approach to establish a buffer between the overfishing limit (OFL) and the acceptable biological catch (ABC) based on scientific uncertainty in the OFL (Adapted from Courtney et al. 2014, their Figure 2). Given a probability density distribution around the OFL, the buffer between the OFL and the ABC is adjusted so that risk of ABC exceeding OFL is equal to the predetermined acceptable probability of overfishing occurring (analogous to a typical P* value < 0.50). In this illustration, the probability of overfishing, P*, is indicated by the shaded area of the distribution.

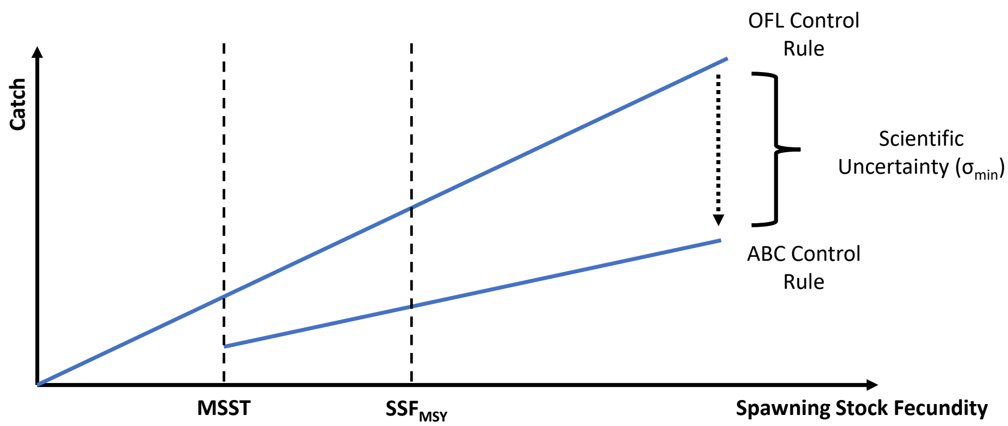
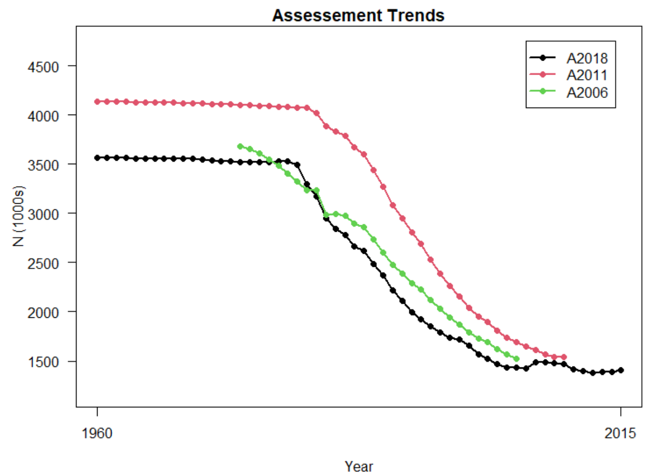


FIGURE 4. Illustration of the reduction from the overfishing limit (OFL) to the acceptable biological catch (ABC) based on scientific uncertainty in the OFL (Adapted from Dichmont et al. 2016, their Figure 1a). For Atlantic HMS domestic shark stocks, given a probability density distribution around the median OFL (Figure 3), the reduction from the OFL to the ABC is a constant proportion of OFL (see the example ABC/OFL ratios resulting from meta-analysis of scientific uncertainty in Atlantic HMS domestic shark stock assessments, $\sigma_{min} = 0.4151$, as described in the main text and summarized in Table 5). For Atlantic HMS domestic shark stocks the constant ABC/OFL ratio could be used to reduce the OFL to the ABC at any spawning stock fecundity (SSF) above the stock's Minimum Stock Size Threshold (MSST)[19].

[19] For Atlantic HMS domestic shark stocks, the spawning stock fecundity (SSF, defined as the sum of numbers at age multiplied by pup production at age) is used to determine the Minimum Stock Size Threshold (MSST; e.g., see Figures D.2 and F.1 below). For the Atlantic HMS Management Division, a domestic shark stock is considered overfished when the current biomass is less than the biomass for the Minimum Stock Size Threshold (MSST; NMFS 2021, their Figure 2.1; e.g., see Methot et al. 2014, their Figure 1). Under draft Amendment 14 to the Consolidated 2006 Atlantic HMS Fishery Management Plan (Appendix A), the ABC for overfished stocks, where required, would be calculated outside of the tiered ABC control rule. For example, the ABC for Atlantic HMS domestic shark stocks below their MSST (overfished stocks) could be based on a rebuilding plan (e.g., see Appendix C, their Group 1, and Appendix G below).



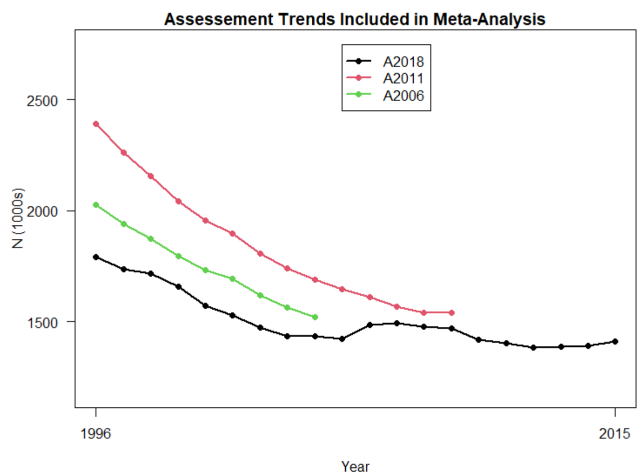
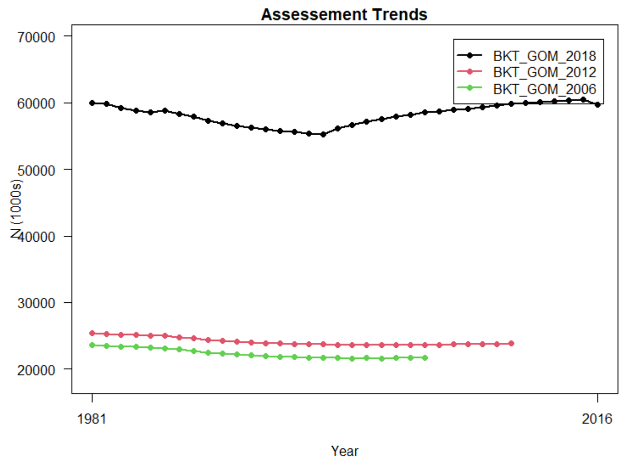


FIGURE 5. Sandbar shark (U.S. Gulf of Mexico and Atlantic regions combined) predicted total population abundance in numbers (*N*, age 1+, thousands) obtained from the Stock Synthesis base run with assessment model ending year 2015 ("A2018"; SEDAR 54 assessment conducted in the year 2018; Adapted from base model run time series output corresponding to NMFS 2018a, their Table A7 updated base case model, obtained separately[20]), from the State Space Age Structured Production Model (SSASPM) base run with assessment model ending year 2009 ("A2011"; SEDAR 21 assessment conducted in the year 2011; Adapted from NMFS 2011, their Table 3.12 base run), and from the SSASPM base run with assessment model ending year 2004 ("A2006"; SEDAR 11 assessment conducted in the year 2006; Adapted from NMFS 2006, their table 4.5 base model). Upper panel includes all annual abundance estimates available, and lower panel includes annual abundance estimates within the most recent 20 years included in meta- analysis (Table 1).

20 Numbers at age 1+ corresponding to NMFS (2018a, their Table A7) updated base case model were obtained here from Stock Synthesis output (Accessed August 2022).



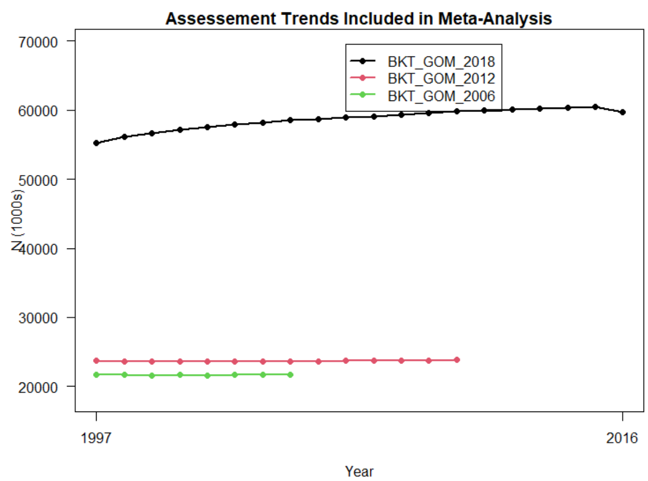


FIGURE 6. Blacktip shark (U.S. Gulf of Mexico region) predicted total population abundance in numbers (*N*, age 1+, thousands) obtained from the State Space Age Structured Production Model (SSASPM) base run with assessment model ending year 2016 ("BKT_GOM_2018"; Update to SEDAR 29 blacktip Gulf of Mexico assessment conducted in the year 2018, NMFS 2018b; Adapted from NMFS 2018c, their p. 35 Table A Panel B1), from the SSASPM base run with assessment model ending year 2010 ("BKT_GOM_2012"; SEDAR 29 blacktip Gulf of Mexico assessment conducted in the year 2012; Adapted from NMFS 2012, their Table 3.5.16), and from the SSASPM base run with assessment model ending year 2004 ("BKT_GOM_2006"; SEDAR 11 blacktip Gulf of Mexico assessment conducted in the year 2006; Adapted from NMFS 2006, their Table 5.5). Upper panel includes all annual abundance estimates available, and lower panel includes annual abundance estimates within the most recent 20 years included in meta-analysis (Table 2).

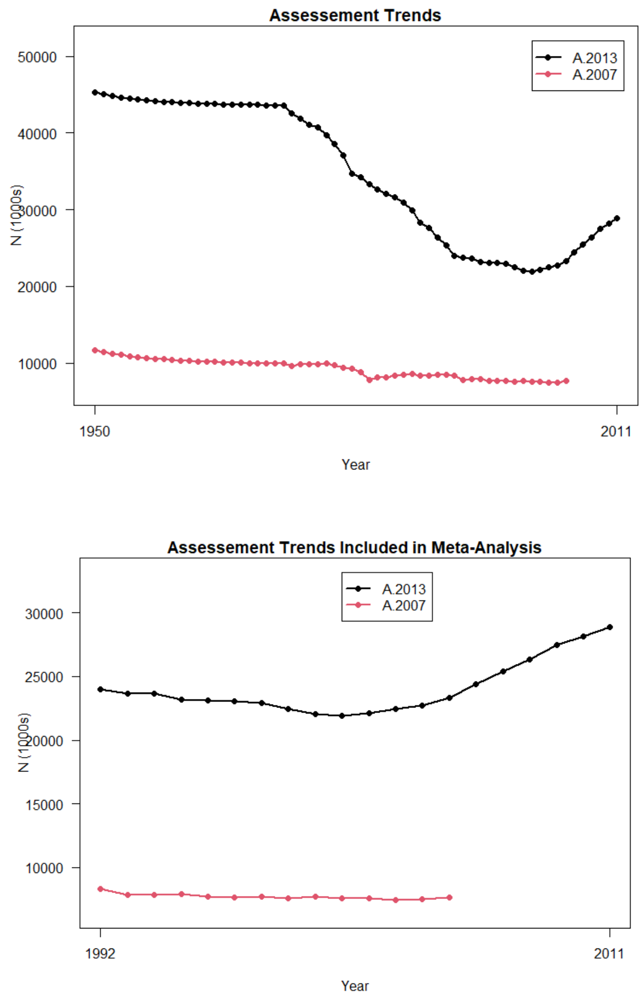


FIGURE 7. Atlantic sharpnose shark (U.S. Gulf of Mexico and Atlantic regions combined) predicted total population abundance in numbers (*N*, age 1+, thousands) obtained from the State Space Age Structured Production Model (SSASPM) base run with assessment model ending year 2011 ("A 2013"; SEDAR 34 assessment conducted in the year 2013; Adapted from NMFS 2013, their Table 3.5.15) and from the SSASPM base run with assessment model ending year 2011 ("A 2007"; SEDAR 13 assessment conducted in the year 2007; Adapted from base model run time series output corresponding to NMFS 2007, their Table 5.5, obtained separately[21]). Upper panel includes all annual abundance estimates available, and lower panel includes annual abundance estimates within the most recent 20 years included in meta-analysis (Table 3).

[21] Pers. Comm. Enric Cortés 4/29/2021.

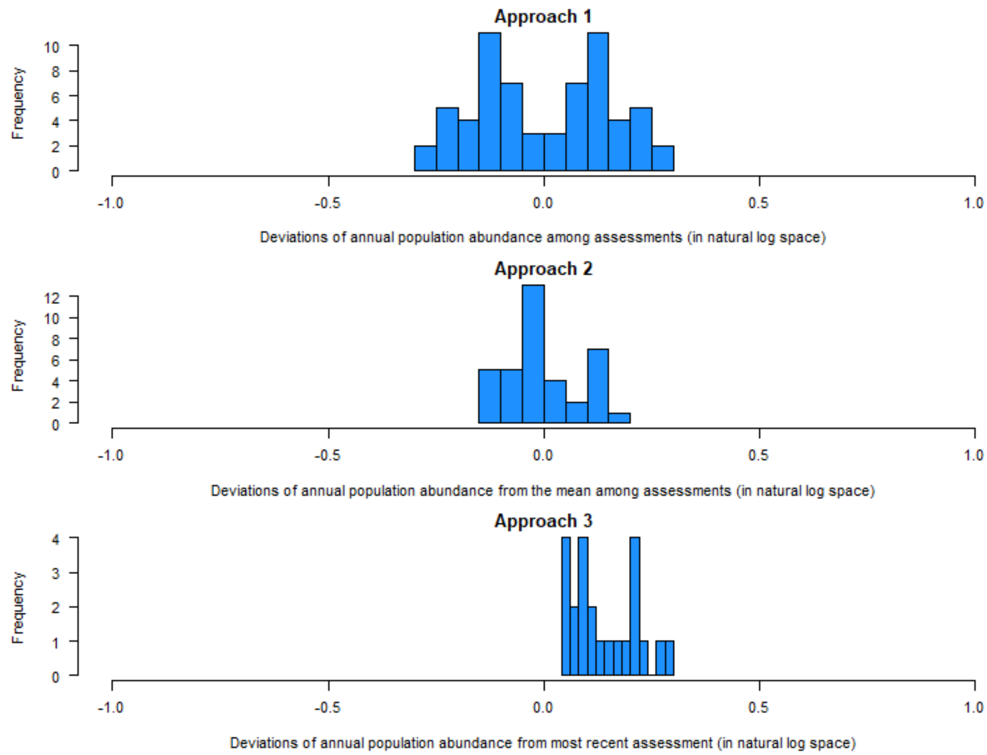


FIGURE 8. Sandbar shark (U.S. Gulf of Mexico and Atlantic regions combined) deviations in annual predicted total population abundance in numbers (N, age 1+) obtained from multiple base runs (Table 1; Figure 5) using three approaches for the calculation of historical assessment variation, as defined in the methods section above.

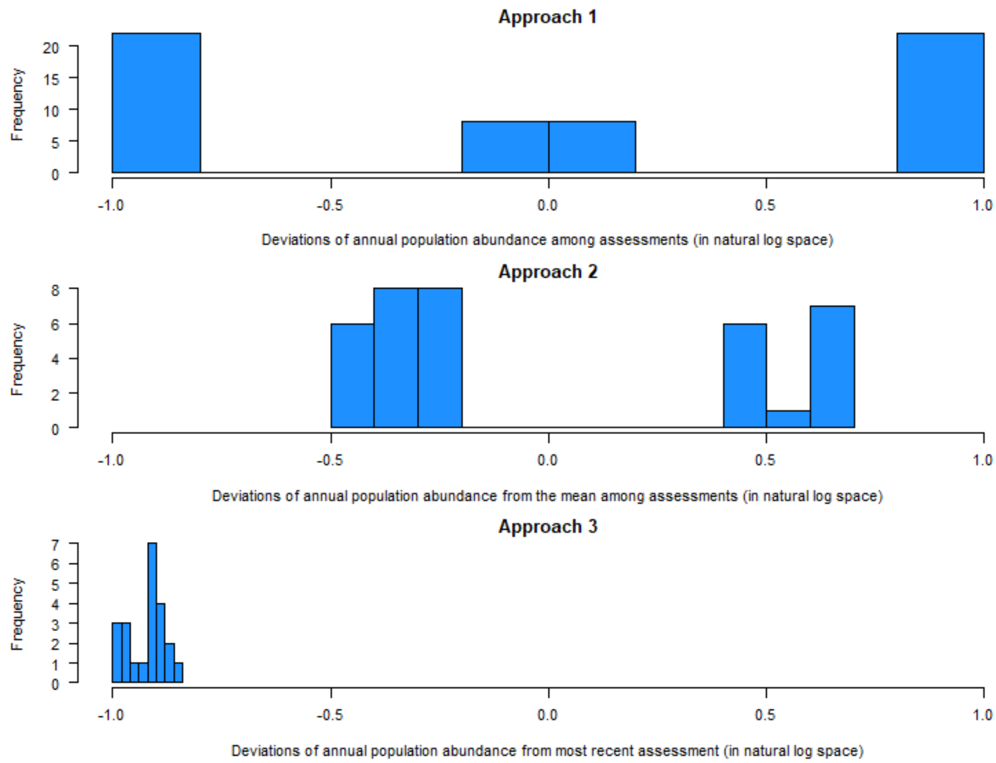


FIGURE 9. Blacktip shark (U.S. Gulf of Mexico region) deviations in annual predicted total population abundance in numbers (*N*, age 1+) obtained from multiple base runs (Table 2; Figure 6) using three approaches for the calculation of historical assessment variation, as defined in the methods section above.

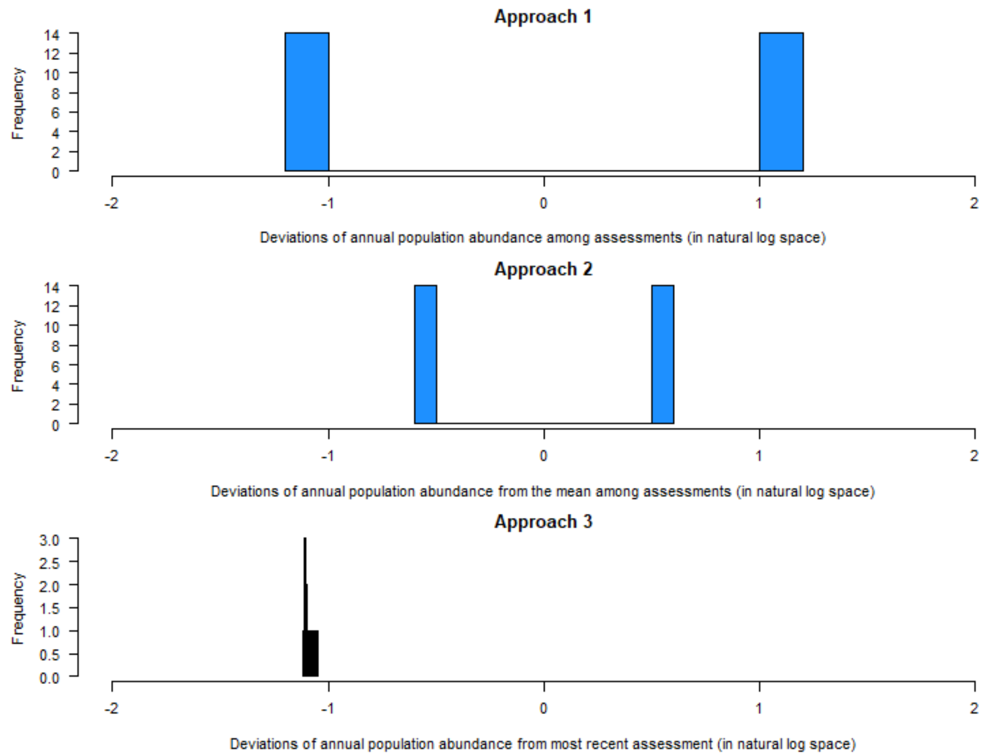


FIGURE 10. Atlantic sharpnose shark (U.S. Gulf of Mexico and Atlantic regions combined) deviations in annual predicted total population abundance in numbers (*N*, age 1+) obtained from multiple base runs (Table 3; Figure 7) using three approaches for the calculation of historical assessment variation, as defined in the methods section above.

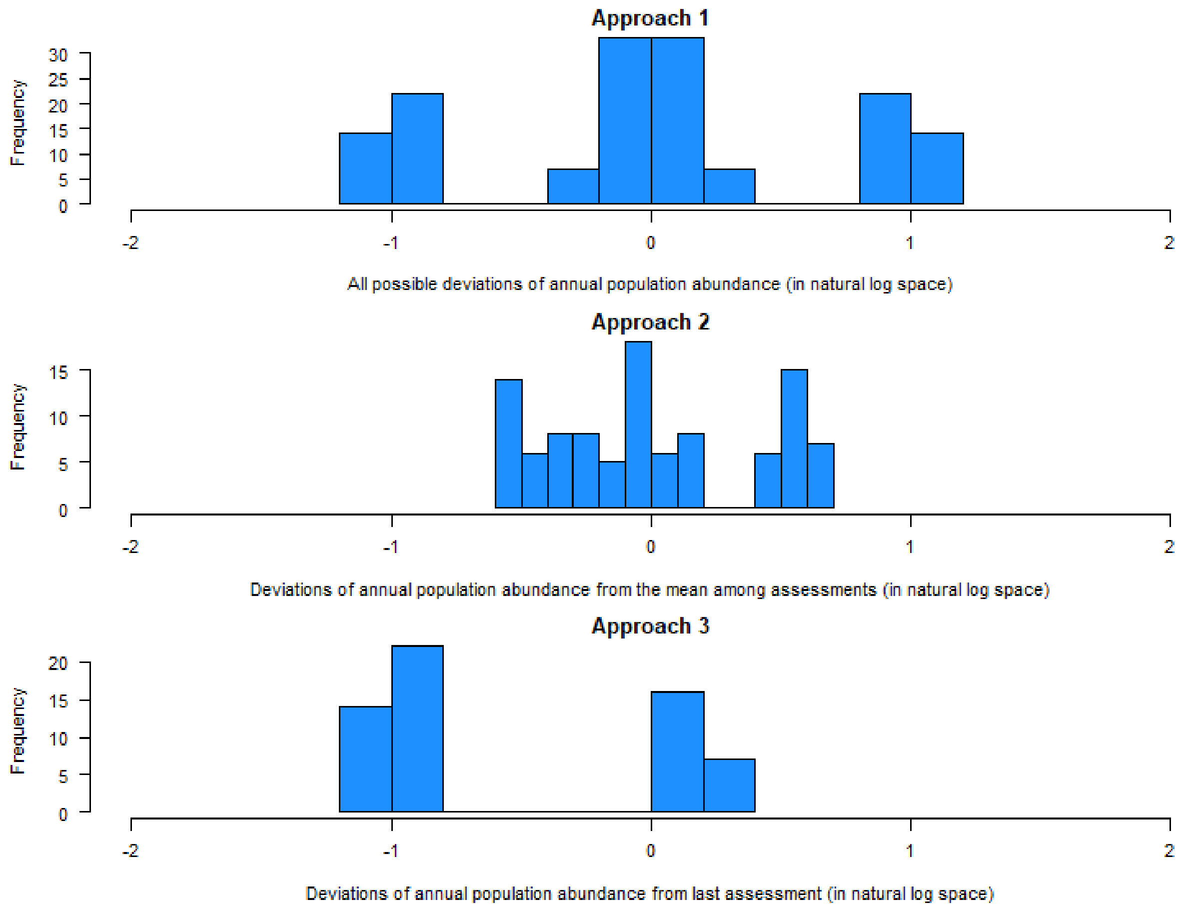


FIGURE 11. Aggregated deviations in annual predicted total population abundance in numbers (*N*, age 1+) obtained from multiple base runs (Figures 8 – 10) using three approaches for the calculation of historical assessment variation, as defined in the methods section above.

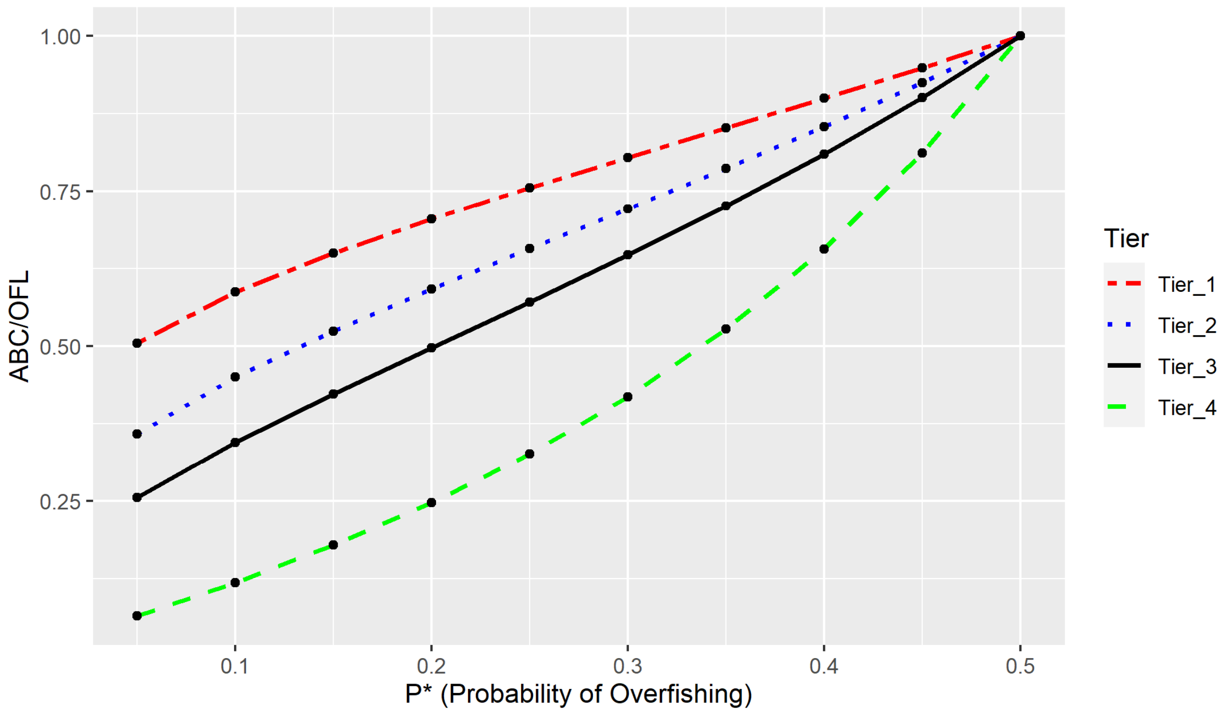


FIGURE 12. Examples of the tradeoffs between the buffer size (ABC/OFL ratio) and the predetermined risk tolerance of ABC exceeding OFL (acceptable probability of overfishing, analogous to a P* < 0.05) for an example Atlantic HMS domestic shark tier structure with σ_{min} = 0.4151 obtained from meta-analysis of completed assessments for Tier 1 stocks (Table 4). Example ABC/OFL ratios were obtained for lower tiers from multiples equal to 1.5, 2.0, and 4.0 times σ_{min} for Tier 2, Tier 3, and Tier 4 stocks, respectively (Table 5).

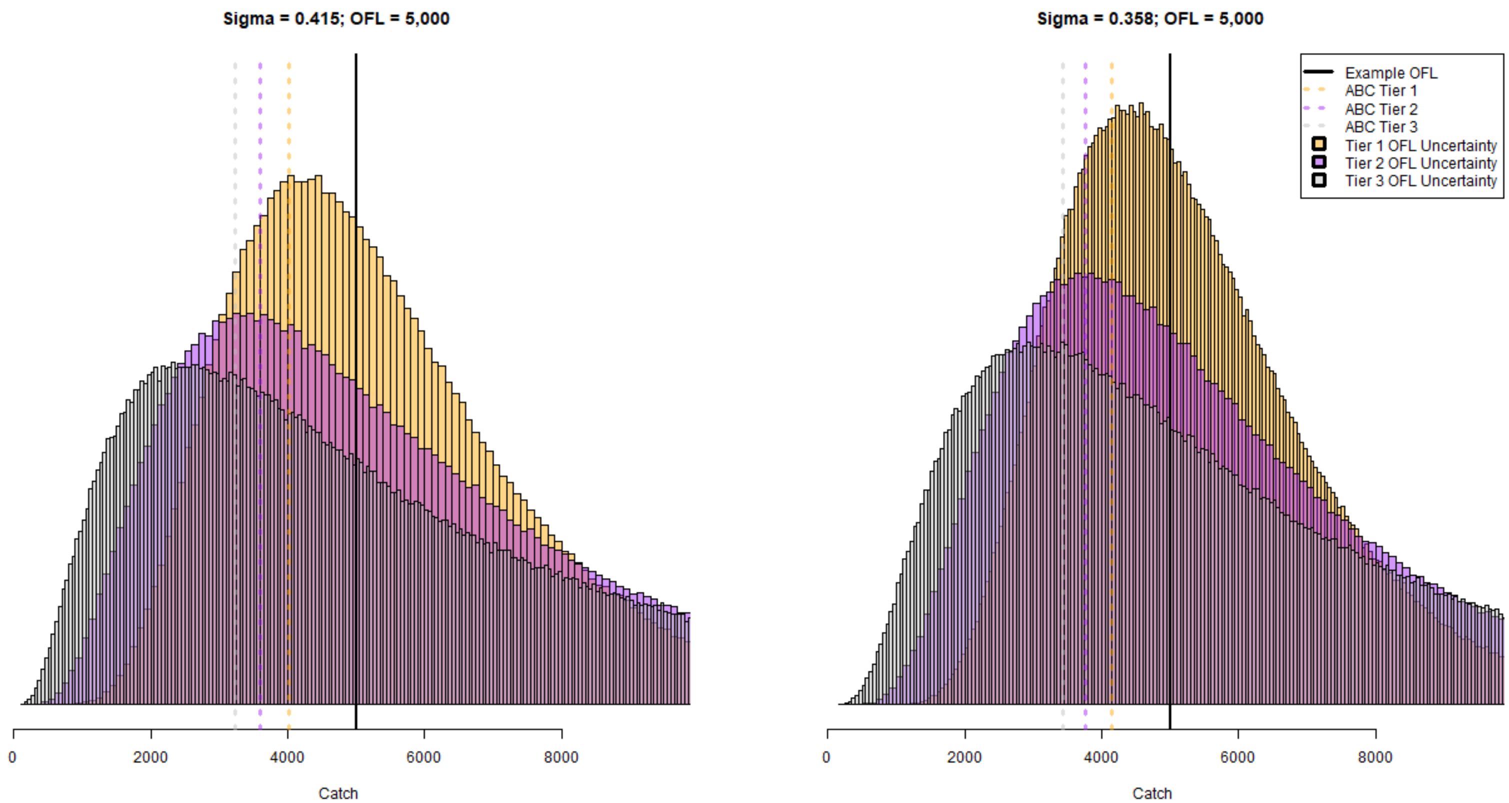


FIGURE 13. Hypothetical examples showing the relationship between the ABC and OFL for two σ_{min} values (0.415 and 0.358) within a tiered ABC control rule established as described in the main text above. Uncertainties within the example calculations are based on the pooled σ_{min} values obtained for Tier 1 stocks, as described in the main text above. Proxy estimates of uncertainty for the lower tier stocks equal to 1.5 and 2.0 times σ_{min} are applied for Tier 2, and Tier 3 stocks, respectively. The ABC was obtained from an arbitrary OFL value (5,000) based on a predetermined risk tolerance of ABC exceeding OFL equal to 30% (acceptable probability of overfishing, analogous to P* = 0.30) for both σ_{min} values in each tier (e.g., Table 5 and Figure 12).

APPENDIX A. Draft Amendment 14 to the 2006 Consolidated Atlantic HMS Fishery Management Plan: ABC Calculations (August 2022)

TABLE A.1. Calculating ABC for shark stocks with a status of healthy, experiencing overfishing, or unknown.

Tier Level	Condition of Use	Method to Determine OFL	Method to Determine ABC
1	Accepted data-rich stage-structured stock assessment approach (e.g., catch-at-age or catch-at-length model with sufficient life history data to fully parameterize the population dynamics) that includes, at a minimum, reliable time series of: (1) catch, (2) size or age composition, and (3) index of abundance. The assessment provides estimates of MSST, MFMT, and OFL or provides proxies for MSST, MFMT, and OFL.	OFL (or the OFL proxy) = catch at MFMT (or the MFMT proxy)[A.1].	ABC = OFL (or the OFL proxy) as reduced (buffered) as needed to account for scientific uncertainty[A.2] and reflecting the acceptable probability of overfishing[A.3].
2	Accepted data-moderate stock assessment approach (e.g., insufficient time series or life history data to fully parameterize catch-at-age or catch-at-length population dynamics) that includes two of the three reliable time series listed in Tier 1. The assessment provides estimates of MSST, MFMT, or OFL, or provides proxies for MSST, MFMT, or OFL.	OFL (or the OFL proxy) = catch at MFMT (or the MFMT proxy)[A.1].	ABC = OFL (or the OFL proxy) as reduced (buffered) as needed to account for scientific uncertainty[A.4] and reflecting the acceptable probability of overfishing[A.3]. The ABC reduction would likely be greater than Tier 1.

TABLE A.1. Continued.

Tier Level	Condition of Use	Method to Determine OFL	Method to Determine ABC
3	Accepted stock assessment available, but the data used are relatively limited and do not meet the standards regarding time series set for Tiers 1 and 2. The assessment provides estimates of MSST, MFMT, or OFL or provides proxies for MSST, MFMT, or OFL.	OFL (or the OFL proxy) = catch at MFMT (or the MFMT proxy)[A.1].	ABC = OFL (or the OFL proxy) as reduced (buffered) as needed to account for scientific uncertainty[A.5] and reflecting the acceptable probability of overfishing[A.3]. The ABC reduction would likely be greater than Tiers 1 and 2.
4	No accepted stock assessment available, and, therefore, data quality and data availability have not been fully vetted through an assessment process.	OFL is unknown. OFL proxy = mean of reference period[A.6] catch multiplied by a scalar ≤ 3, as refined per life history characteristics (e.g., productivity), susceptibility to fishing pressure, or other appropriate considerations (e.g., results of an ecological risk assessment).	ABC ≤ 90% of OFL proxy as determined by scientific uncertainty[A.7].

Note: For shark stocks with other statuses (overfished, assessed or could be assessed by ICCAT, or in the prohibited shark complex), the ABC, where required, would be calculated outside of the tiered ABC control rule.

[A.1] See 50 CFR 600.310 (e)(2)(i)(D) defining OFL as “annual amount of catch that corresponds to the estimate of MFMT applied to a stock or stock complex's abundance and is expressed in terms of numbers or weight of fish[,]” where (MFMT) is maximum fishing mortality threshold.

[A.2] Scientific uncertainty is based on the larger value of either the most recent stock assessment (sigma), for example if available from stock assessment projections, or the pooled meta-analysis estimate from multiple Tier 1 assessments (sigma_min).

[A.3] Acceptable probability of overfishing determined by the HMS risk policy would take into account, but not be limited to, the species life history and ecological function.

[A.4] The ABC reduction could range from the larger value of either sigma, if available, or 1×sigma_min through 2×sigma_min.

[A.5] The ABC reduction could range from the larger value of either sigma, if available, or greater than or equal to 2×sigma_min.

[A.6] Reference period to be determined on a stock or complex basis, based on life history characteristics, susceptibility to fishing pressure, or other appropriate considerations.

[A.7] The reduction from OFL proxy to ABC to take into account scientific uncertainty could include, but is not limited to, deficiencies in catch data, availability of ancillary data, species life history, ecological function, perceived level of depletion, and vulnerability of the stock to fisheries.

APPENDIX B. Example of Caribbean Fishery Management Council (CFMC) ABC Control Rule Tier Structure (August, 2022)

TABLE B.1. Example of CFMC ABC control rule tier structure[22].

Tier 1: Data Rich	
Condition for Use	Full stage-structured stock assessment available with reliable time series on (1) catch, (2) stage composition, and (3) index of abundance. The assessment provides estimates of minimum stock size threshold (MSST), maximum fishing mortality threshold (MFMT), and the probability density function (PDF) of the overfishing limit (OFL).
MSY	MSY = long-term yield at F_{MSY} (or, MSY proxy = long-term yield at F_{MSY} proxy); assumes spawner-recruit relationship known.
SDC	MFMT = F_{MSY} or proxy MSST = 0.75 × long-term Spawning Stock Biomass at MFMT (SSB_{MFMT}) OFL = Catch at MFMT
ABC	ABC = OFL as reduced (buffered) by scientific uncertainty [B.1] and reflecting the acceptable probability of overfishing [B.2]. The buffer is applied to the PDF of OFL (σ), where the PDF is determined from the assessment (where $\sigma > \sigma_{min}$) [B.3]. $ABC = d \times OFL$, where $d = \begin{cases} Scalar & \text{if } B \geq B_{MSY} \\ Scalar \times (B - B_{critical}) / (B_{MSY} - B_{critical}) & \text{if } B < B_{MSY} \end{cases}$ Scalar = 1 if acceptable probability of overfishing is specified (< 0.5), < 1 if not specified (= 0.5). $B_{critical}$ is defined as the minimum level of depletion at which fishing would be allowed.
Footnotes	[B.1] Scientific uncertainty would take into account, but not be limited to, the species life history and ecological function. [B.2] Acceptable probability of overfishing determined by Council. [B.3] σ_{min} could be equal to coefficient of variation; σ_{min} is in a log scale.

[22] The example of a CFMC ABC control rule tier structure was adapted here from a proposed action to establish a new comprehensive Fishery Management Plan (FMP) for the Puerto Rico Exclusive Economic Zone (Puerto Rico FMP). For more information see the Comprehensive Fishery Management Plan for the Puerto Rico Exclusive Economic Zone (their Table 2.4.1. Caribbean Fishery Management Council Acceptable Biological Catch Control Rule from Action 4, Preferred Alternative 3). Available: https://www.caribbeanfmc.com/FMP_Island_Based_2019/EA_FMP_Puerto_Rico_Final.pdf (Accessed August 2022).

TABLE B.1. Continued.

Tier 2: Data Moderate	
Condition for Use, MSY, SDC	Data-moderate approaches where two of the three time series (catch, stage composition, and index of abundance) are deemed informative by the assessment process, and the assessment can provide MSST, MFMT, and PDF of OFL.
ABC	Same as Tier 1, but variation of the PDF of OFL (σ) must be greater than $1.5 \times \sigma_{min}$ (in principle there should be more uncertainty with data-moderate approaches than data-rich approaches).
Tier 3: Data Limited: Accepted Assessment Available	
Condition for Use	Relatively data-limited or out-of-date assessments
MSY	MSY proxy = long-term yield at proxy for F_{MSY}
SDC	MFMT = F_{MSY} proxy MSST = $0.75 \times SSB_{MFMT}$ or proxy OFL = Catch at MFMT
ABC	ABC determined from OFL as reduced (buffered) by scientific uncertainty [B.4] and reflecting the acceptable probability of overfishing [B.2] a. Where the buffer is applied to the PDF of OFL when the PDF is determined from the assessment (with $\sigma \geq 2 \times \sigma_{min}$) **OR** b. Where ABC = buffer × OFL, where buffer must be ≤ 0.9
Footnotes	[B.4] Scientific uncertainty would take into account, but not be limited to, the species life history and ecological function, the perceived level of depletion, and vulnerability of the stock to collapse.

TABLE B.1. Continued.

Tier 4: Data Limited: No Accepted Assessment Available	
MSY	MSY proxy = long-term yield at proxy for F_{MSY}.
SDC	MFMT = F_{MSY} proxy MSST = 0.75 × SSB_{MFMT} Sustainable yield level (SYL) [B.5] = a level of landings that can be sustained over the long-term. OFL proxy = SYL
Tier 4a **Conditions for Use**	No accepted [B.6] assessment, but the stock has relatively low vulnerability to fishing pressure. A stock's vulnerability to fishing pressure is a combination of its productivity and its susceptibility to the fishery. Productivity refers to the capacity of the stock to produce MSY and to recover if the population is depleted. Susceptibility is the potential for the stock to be impacted by the fishery. If SSC consensus [B.7] cannot be reached on the use of Tier 4a, Tier 4b should be used.
SYL	SYL = Scalar × ***75th percentile*** of reference period landings, where the reference period of landings is chosen by the Council, as recommended by the SSC in consultation with the SEFSC. Scalar ≤ 3 depending on perceived degree of exploitation, life history and ecological function.
ABC	ABC = buffer × SYL, where buffer must be ≤ 0.9 (e.g., 0.9, 0.8, 0.75, 0.70…) based on the SSC's determination of scientific uncertainty [B.8].
Tier 4b **Conditions for Use**	No accepted [B.6] assessment, but the stock has relatively high vulnerability to fishing pressure (see definition in Tier 4a Condition for Use), or SSC consensus [B.7] cannot be reached on the use of Tier 4a.
SYL	SYL = Scalar × ***mean*** of the reference period landings, where the reference period of landings is chosen by the Council, as recommended by the SSC in consultation with the SEFSC. Scalar < 2 depending on perceived degree of exploitation, life history, and ecological function.
ABC	ABC [B.9] = buffer × SYL, where buffer must be ≤ 0.9 (e.g., 0.9, 0.8, 0.75, 0.70…) based on the SSC's determination of scientific uncertainty[B.8].
Footnotes	[B.5] MSY ≥ SYL[23] [B.6] Accepted means that the assessment was approved by the SSC as being appropriate for management purposes. [B.7] The SSC defines consensus as having 2/3 of the participating members in favor of a Tier 4a assignment, otherwise the assignment would be Tier 4b of the ABC CR. [B.8] Scientific uncertainty would take into account, but not be limited to, deficiencies in landings data, availability of ancillary data, species life history, and ecological function, perceived level of depletion, and vulnerability of the stock to collapse. [B.9] The ABC for a Tier 4b stock should not exceed mean landings during the reference period.

[23] For a more detailed explanation of SYL see Appendix G of the Comprehensive Fishery Management Plan for the Puerto Rico Exclusive Economic Zone. Available: https://www.caribbeanfmc.com/FMP_Island_Based_2019/EA_FMP_Puerto_Rico_Final.pdf (Accessed August 2022), which notes: "… Tier 4 of the ABC CR defines an MSY proxy along with MFMT and MSST, with respect to assumptions about fishing mortality rate and biomass, but these measures cannot be quantified due to data limitations. Reflecting the data-limited nature of stocks assigned to Tier 4, the SSC chose to specify an SYL for these stocks. The SYL represents a level of catch or yield that the Council's SSC has confidence a stock can sustain through time based on historical trends in catch and the SSC's evaluation of the best scientific information available, including life history information and analysis of the susceptibility of the stock to fishing pressure. Thus, the SYL is similar to the MSY, in that both are measures of catch that can be sustainably taken over the long-term…"

APPENDIX C. Example Assignment of U.S. Atlantic HMS Domestic Shark Stocks to ABC Control Rule Tiers and Other Management Groups

C.1. Introduction

As noted in the main text above, this example assignment of U.S. Atlantic HMS domestic shark stocks to ABC control rule tiers and other management groups is preliminary and intended only for the purpose of providing a technical description and example application of including historical stock assessment uncertainty within a tiered ABC control rule for U.S. Atlantic HMS domestic sharks. In contrast, Amendment 14 to the Consolidated 2006 Atlantic HMS Fishery Management Plan (FMP), which would revise the framework for establishing annual catch limits (ACLs) and includes an ABC control rule, is currently under development by the NOAA NMFS Atlantic HMS Management Division for U.S. Atlantic HMS domestic shark stocks. Once Amendment 14 is completed, the Atlantic HMS Management Division will conduct a follow on rulemaking where they implement the framework established in Amendment 14 for all Atlantic shark stocks in the management unit. Consequently, any adoption of actual ABCs for U.S. Atlantic HMS domestic shark stocks will be developed separately. The example application described in this report is intended to inform the process for Atlantic HMS Amendment 14 and its follow on rule(s), and is not intended to dictate the results.

For the purposes of developing this example application, Atlantic HMS domestic shark stocks are assigned to ABC control rule tiers, or other management groups, based on data availability accepted for use within a stock assessment completed through the Southeast Data Assessment and Review (SEDAR) process or an equivalent scientific peer review process, which is assumed to meet the best scientific information available standard (BSIA; U.S. Office of the Federal Register 2013; e.g., Lynch et al. 2018) in place for that assessment. For Atlantic HMS domestic sharks, which do not have an SSC, the BSIA standard for an accepted stock assessment is generally based on an independent scientific peer review, such as the SEDAR process or a publication following scientific peer review. In addition, some previously assessed and unassessed Atlantic HMS stocks are assigned to other management groups that either may not require an ABC, or may require more evaluation before an ABC is calculated, as described below. As noted in the discussion of the main text above, while these example groupings do not match the management groupings currently in Amendment 14, they offer a level of complexity that could be considered in future modifications to the ABC control rule or could be considered when determining the appropriate buffer for calculating the ABC.

C.2. Example ABC Control Rule Tiers

For the purposes of this example, previously assessed and unassessed Atlantic HMS stocks were assigned to one of the following ABC control rule tiers (Table C.1):

Tier 1) Data rich with an accepted assessment available;
Tier 2) Data moderate with an accepted assessment available;
Tier 3) Data limited with an accepted assessment available; and
Tier 4) No accepted assessment available, and, therefore, data quality and data availability have not been fully vetted through an assessment process.

The tier structure was adapted from those proposed by the Atlantic HMS Management Division (Appendix A) and the Caribbean Fishery Management Council (Appendix B). However, it is important to note that evaluating actual data availability for each stock in order to assign each stock to a tier was beyond the scope of this study and would need to be evaluated on a case by case basis.

C.3. Other Management Groups

For the purposes of this example, some previously assessed and unassessed Atlantic HMS stocks were assigned to other management groups, as described below (Table C.2):

Group 1) Overfished;
Group 2) Overfishing;
Group 3) Approaching overfished condition;
Group 4) Prohibited species;
Group 5) Species managed by ICCAT; and
Group 6) Ecosystems species.

Groups 1 – 3 reflect groupings under SEDAR Atlantic HMS domestic shark stock assessment Terms of Reference (TORs) needed to meet NS1 guidelines, which may not be consistent with Amendment 14 management groupings used to determine ABC. Groups 4 and 5 reflect current management groupings within Atlantic HMS. Species assigned here to the Other Management Groups 1 – 5 may be included within the ABC control rule tier after additional evaluation, as described below. In contrast, Group 6 includes domestic shark species within the Atlantic HMS FMP which may not require conservation and management based on their rare interaction with fisheries, or other considerations which may also not be consistent with Amendment 14 management groupings used to determine ABC.

Group 1.— Group 1 includes U.S. Atlantic HMS domestic shark stocks determined to be in an overfished condition following a completed stock assessment. The ABC for overfished stocks and stock complexes could be set based on a rebuilding plan consistent with the NS1 2016 Guidelines for stocks determined to be overfished (U.S. Office of the Federal Register 2016)[24] analogously to the South Atlantic Fisheries Management Council (SAFMC) ABC control rule[25]. For example, the ABC for U.S. Atlantic HMS domestic shark stocks determined to be in an overfished condition could be based upon the rebuilding plan established within the SEDAR stock assessment Terms of Reference (TORs) using projections to determine the "*F* resulting in 50% and 70% probability of rebuilding by Year-rebuild" or the "Fixed level of removals allowing rebuilding of stock with 50% and 70% probability" (e.g., NMFS 2020, their TOR 9 on Assessment Process Report Section III page 5).

Group 2.—Group 2 includes U.S. Atlantic HMS domestic shark stocks determined to be experiencing overfishing following a completed stock assessment. Stocks that are determined to be experiencing overfishing could be subject to an ABC as long as NS1 2016 Guidelines for stocks determined to be in an overfishing condition are also met (U.S. Office of the Federal Register 2016)[26].

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24 E.g., for further information see NS1 2016 Guidelines (U.S. Office of the Federal Register 2016). Available at https://www.federalregister.gov/documents/2016/10/18/2016-24500/magnuson-stevens-act-provisions-national-standard-guidelines (Accessed August 2022): "… *(f) Acceptable biological catch, and annual catch limits (Section 3) Specification of ABC. (ii) 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 (i.e., Frebuild) in the rebuilding plan. …"

25 E.g., for further information see South Atlantic Fishery Management Council, Comprehensive ABC Control Rule Amendment Decision (September 2021 Accessed August 2022). Available at https://safmc.net/documents/2022/08/fc1_a5a_abccramd_dd_sep2022.pdf/: "… Preferred Alternative 2 specifies that ABC for overfished stocks will be determined according to a rebuilding plan with a probability of success (1-P) of at least 50%. …"

26 E.g., for further information see NS1 2016 Guidelines (U.S. Office of the Federal Register 2016). Available as described above: *"(j) Council actions to address overfishing and rebuilding for stocks and stock complexes (2) Timing of actions— (i) If a stock or stock complex is undergoing overfishing*. Upon notification that a stock or stock complex is undergoing overfishing, a Council should immediately begin working with its SSC (or agency scientists or peer review processes in the case of Secretarially-managed fisheries) to ensure that the ABC is set appropriately to end overfishing. …"

Atlantic HMS domestic shark stock status determination criteria have been in place since the 1999 FMP and were incorporated without change in the 2006 Consolidated FMP and are not anticipated to change under Amendment 14. For example, following a completed Tier 1 age-structured U.S. Atlantic HMS domestic shark stock assessment in which a stock has been determined to be undergoing overfishing, an analysis of annual fishing mortality rates (or associated annual catches) could be obtained from the schedule of projected fishing mortality rates that ends overfishing. In practice this could be accomplished using projections (e.g., consistent with F_{reduce}) established within recent SEDAR shark stock assessment TORs (e.g., NMFS 2020, their TOR 9 on Assessment Process Report Section III page 5), which state that if a stock is undergoing overfishing, then utilize projections to determine $F = F_{\mathrm{reduce}}$ (different reductions in F that should end overfishing with a 50% and 70% probability).

In principle, the ABC obtained from meta-analysis, as described in the main text above, should be consistent with annual fishing mortality rates (or associated annual catches) obtained from the schedule of projected fishing mortality rates that ends overfishing. However, such an analysis was not conducted here because it was beyond the scope of the current study. It also was beyond the scope of this study to develop similar analyses for lower tiered stocks determined to be in an overfishing condition.

Group 3.—Group 3 includes U.S. Atlantic HMS domestic shark stocks determined to be approaching an overfished condition following a completed stock assessment. Stocks that are determined to be approaching an overfished condition could be subject to an ABC as long as NS1 2016 Guidelines for stocks determined to be approaching an overfished condition are also met (U.S. Office of the Federal Register 2016)[27]. However, this type of analysis was beyond the scope of the current study[28].

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[27] E.g., for further information see NS1 2016 Guidelines (U.S. Office of the Federal Register 2016). Available as described above: "… (2) *Status determination criteria—(i)* Definitions. (A) *Status determination criteria (SDC)* mean the quantifiable factors, MFMT, OFL, and MSST, or their proxies, that are used to determine if overfishing has occurred, or if the stock or stock complex is overfished…. (G) *Approaching an overfished condition*. A stock or stock complex is approaching an overfished condition when it is projected that there is more than a 50 percent chance that the biomass of the stock or stock complex will decline below the MSST within two years. …"

"… (j) *Council actions to address overfishing and rebuilding for stocks and stock complexes* in the fishery— (1) *Notification*. The Secretary will immediately notify in writing a Regional Fishery Management Council whenever the Secretary determines that: (iii) "A stock or stock complex is approaching an overfished condition; …"

"… (j) *Council actions to address overfishing and rebuilding for stocks and stock complexes* in the fishery— (2) *Timing of actions*— (ii) *If a stock or stock complex is overfished or approaching an overfished condition*. (A) Upon notification that a stock or stock complex is overfished or approaching an overfished condition a Council must prepare and implement an FMP, FMP amendment, or proposed regulations within two years of notification, consistent with the requirements of section 304(e)(3) of the Magnuson-Stevens Act. Council actions should be submitted to NMFS within 15 months of notification to ensure sufficient time for the Secretary to implement the measures, if approved. …"

[28] E.g., for further information see the "approaching overfished" determination methodology based on projections described in Section 3.2.3.5.2 of the Fishery Management Plan for Groundfish of the Gulf of Alaska, November 2020. North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501. Available: https://www.npfmc.org/wp-content/PDFdocuments/fmp/GOA/GOAfmp.pdf (Accessed August 2022).

Group 4.—Group 4 includes prohibited U.S. Atlantic HMS shark species. Stocks in Group 4, would not have a σ_{min} associated with them, but would automatically get assigned an ABC = 0 (i.e. no retention) whether or not they have a completed stock assessment.

Group 5.—Group 5 includes shark species assessed by ICCAT. Stocks assessed by ICCAT were not included within the meta-analysis of scientific uncertainty evaluated for this study. Consequently, stocks in Group 5 do not have a σ_{min} associated with their stock assessment uncertainty. As a result, the evaluation of methods to determine an ABC for this group was beyond the scope of the current study.

Group 6.—Group 6 includes ecosystem component species[29]. This group is a place holder used here only as an example. Ecosystem component species were also not included within the meta-analysis of scientific uncertainty evaluated for this study. Consequently, stocks in Group 6 do not have a σ_{min} associated with their stock assessment uncertainty. Group 6 could include species that rarely interact directly with the fishery. An assumption is that fishing is unlikely to have a direct effect on ecosystem component species population status determination as defined under NS1 guidelines.

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[29] E.g., for further information see NS1 2016 Guidelines (U.S. Office of the Federal Register 2016). Available as described above: "... (c) *Stocks that require conservation and management*. (5) …Councils may choose to identify stocks within their FMPs as ecosystem component (EC) species (see § § 600.305(d)(13) and 600.310(d)(1)) if a Council determines that the stocks do not require conservation and management based on the considerations and factors in paragraph (c)(1) of this section. EC species may be identified at the species or stock level, and may be grouped into complexes. Consistent with National Standard 9, MSA section 303(b)(12), and other applicable MSA sections, management measures can be adopted in order to, for example, collect data on the EC species, minimize bycatch or bycatch mortality of EC species, protect the associated role of EC species in the ecosystem, and/ or to address other ecosystem issues. …"

TABLE C.1. Example assignment of Atlantic HMS domestic shark stocks to ABC control rule tiers.

A. Tier 1: Data rich stocks.

Stocks were assigned to the data rich tier if they had a completed stock assessment accepted as BSIA[30] that included an age-structured stock assessment model that used all three Tier 1 data types: (1) catch; (2) size or age composition along with the associated life history data necessary to parameterize an age-structured stock assessment; and (3) index of abundance.

- Blacktip (ATL)[ρ] (SEDAR 65 accepted as BSIA; Included an age-structured stock assessment model, Stock Synthesis, which used all three Tier 1 data types: catch; size or age composition along with the associated life history data necessary to parameterize an age-structured stock assessment; and an index of abundance)
- Smooth dogfish (ATL)[ρ] (SEDAR 39 accepted as BSIA; Included an age-structured stock assessment model, Stock Synthesis, which used all three Tier 1 data types: catch; size or age composition along with the associated life history data necessary to parameterize an age-structured stock assessment; and an index of abundance)

B. Tier 2: Data moderate stocks.

Stocks were assigned to the data moderate Tier 2 if they had a completed stock assessment accepted as BSIA that included an age-structured or non-age-structured stock assessment model that used two of the three Tier 1 data types described above, or a completed stock assessment accepted as BSIA that included data obtained from other geographic regions.

- Atlantic sharpnose (ATL)[α] (SEDAR 34 accepted as BSIA; Assigned here to data moderate because the stock was split into ATL and GOM regions following the assessment, while most stock assessment model runs were conducted for a single stock in the ATL + GOM regions combined)
- Atlantic sharpnose (GOM)[α] (see note above)
- Blacktip (GOM)[α] (2018 Update Assessment to SEDAR 29 accepted as BSIA; Assigned here to data moderate because available size composition data and associated length at age relationships were used indirectly within the SSASPM assessment model to calculate selectivity external to the model)
- Finetooth (ATL + GOM)[β] (SEDAR 13 accepted as BSIA; Assigned here to data moderate because stock assessment model runs were conducted with production models)
- Smoothhound complex (GOM)[β] (SEDAR 39 accepted as BSIA; Assigned here to data moderate because model runs were conducted with production models)

C. Tier 3: Data limited stocks with an accepted assessment.

There were no stocks assigned to this tier in this example application.

[30] For Atlantic HMS domestic shark stock assessments, the best scientific information available (BSIA) standard for an accepted stock assessment is generally determined by a scientific review process such as a Committee of Independent Experts (CIE) review implemented within the SEDAR process or an independent scientific peer review process such as required for publication within a scientific journal.

TABLE C.1. Continued.

D. Tier 4: Data poor stocks without an accepted assessment.

- Blacknose (GOM) $^{\alpha}$ (stock split into ATL and GOM regions following SEDAR 21; SEDAR 21 GOM assessment not accepted as BSIA)[31]
- Bonnethead (ATL) $^{\alpha}$ (stock split into ATL and GOM regions following SEDAR 34; SEDAR 34 assessment not accepted as BSIA for the separate ATL and GOM regions)
- Bonnethead (GOM) $^{\alpha}$ (see note above)
- Bull (ATL + GOM) $^{\mu}$ (likely to be Tier 2 or 3 when assessed)
- Great hammerhead (ATL + GOM) * (likely to be Tier 2 or 3 when assessed)
- Lemon (ATL + GOM) *** (likely to be Tier 2 or 3 if external assessment is accepted as BSIA)
- Nurse (ATL + GOM) $^{\mu}$ (likely to be Tier 3 when assessed)
- Smooth hammerhead $^{\mu}$ (ATL + GOM) * (likely to be Tier 3 when assessed)
- Carolina hammerhead $^{\mu}$ (ATL + GOM) * (likely to be assessed as part of a species complex with scalloped hammerhead)
- Spinner (ATL + GOM) $^{\mu}$ (likely to be Tier 2 or 3 when assessed)
- Tiger (ATL + GOM) $^{\mu}$ (likely to be Tier 2 or 3 when assessed)

* Currently being assessed.
** Prohibited but assessed.
*** Assessed externally.

$^{\rho}$ Stock Synthesis.
$^{\alpha}$ Age-structured production or catch-free model.
$^{\beta}$ Data moderate assessment method(s).
$^{\delta}$ Data poor assessment method (s).
$^{\omega}$ Overfished.
$^{\mu}$ Unassessed.

[31] NMFS (2021, their Table 5.13) notes that blacknose shark are prohibited in the Gulf of Mexico, however some landings do exist likely due to misidentification problems or lack of awareness of shark fishing regulations.

TABLE C.2. Example assignment of Atlantic HMS shark stocks to management groups that may require further evaluation before they can be assigned to an ABC control rule tier.

A. Groups 1, 2, and 3: Overfished, Overfishing, and Approaching an Overfished Condition, respectively.

- Blacknose (ATL) [α,ω] (SEDAR 21 ATL assessment accepted as BSIA; stock split into ATL and GOM regions following the assessment; likely be Tier 2 if Not Overfished)
- Sandbar (ATL + GOM) [ρ,ω] (SEDAR 54 assessment accepted as BSIA; likely be Tier 1 if Not Overfished)
- Scalloped hammerhead (ATL + GOM) [*, ***, ω] (external assessment accepted as BSIA; likely be Tier 3 if Not Overfished)

B. Group 4: Prohibited Species within the FMP where ABC = 0.

- Atlantic angel
- Basking
- Bigeye sand tiger
- Bigeye sixgill
- Bigeye thresher (ICCAT) [μ] (unlikely to have sufficient data for even a data-limited assessment)
- Bignose
- Caribbean reef
- Caribbean sharpnose
- Dusky shark (ATL + GOM) [α, ω] (likely be Tier 3 if Not Overfished and Prohibited)
- Galapagos
- Longfin mako (ICCAT) [μ] (unlikely to have sufficient data for even a data-limited assessment)
- Narrowtooth
- Night
- Sand tiger
- Sevengill
- Sixgill
- Smalltail[32]
- Whale
- White

C. Group 5: Species managed by ICCAT.

- Blue [ρ] (ICCAT 2015 assessment accepted as BSIA; Not Overfished and Not Overfishing)
- Oceanic whitetip [μ] (likely to be Tier 3 if assessed and if not managed by ICCAT)
- Thresher (common) [μ] (likely to be Tier 3 if assessed and if not managed by ICCAT)
- Porbeagle [δ,ω] (ICCAT 2020 assessment accepted as BSIA; Overfished and Not Overfishing)
- Shortfin mako [ρ, ω] (ICCAT 2020 assessment accepted as BSIA; Overfished and Overfishing)
- Silky [μ] (likely to be Tier 2 if assessed and if not managed by ICCAT)

[32] The smalltail shark is missing from NMFS (2021, their tables 6.27 and 6.28) but is included in other online lists: E.g., see https://media.fisheries.noaa.gov/dam-migration/hms_commercial_compliance_guide_4_8_19.pdf (Accessed August 2022).

TABLE C.2. Continued.

E. Group 6: Ecosystems group, monitor only.

There were no stocks assigned to this tier; This group is provided here only as an example for future consideration.

* Currently being assessed.
** Prohibited but assessed.
*** Assessed externally.

$^{\rho}$ Stock Synthesis.
$^{\alpha}$ Age-structured production or catch-free model.
$^{\beta}$ Data moderate assessment method(s).
$^{\delta}$ Data poor assessment method (s).
$^{\omega}$ Overfished.
$^{\mu}$ Unassessed.

APPENDIX D. OFL and ABC Calculations Obtained with Projections from a Recent SEDAR Blacktip Shark Assessment (U.S. Atlantic Region) Implemented in Stock Synthesis

D.1. Introduction

Ralston et al. (2011) illustrate how an estimate of log-scale standard error can be used to form the basis of an acceptable biological catch, ABC, control rule. The median of a lognormal distribution with a mean equal to zero and a standard error equal to a minimum estimate of stock assessment scientific uncertainty, σ_{min}, is assumed to be indicative of the best risk-neutral point estimate of scientific uncertainty in the overfishing limit, OFL. The value of σ_{min} can be obtained from meta-analysis of historical stock assessment uncertainty, for example as described above in the main text with the resulting σ_{min} equal to 0.415. Selecting a cumulative lognormal probability less than 0.50 provides a buffer from the median OFL, which can then be used to incorporate the acceptable risk of overfishing (analogous to P*) into the ratio of ABC to OFL (ABC/OFL) based on both the historical stock assessment uncertainty in the OFL and the risk of exceeding the OFL.

An example of reducing OFL to ABC is provided here using results obtained from a recent SEDAR blacktip shark stock assessment in the U.S. Atlantic region implemented in Stock Synthesis (NMFS 2020) modified to follow methods adapted from a recent SEDAR spiny lobster stock assessment in the U.S. Caribbean region implemented in Stock Synthesis (NMFS 2019).

D.2. ABC from Meta-analysis using an ABC Control Rule

Projections were obtained as in the SEDAR blacktip shark stock assessment in the U.S. Atlantic region (NMFS 2020), except that the forecast file was modified to project fishery removals at the overfishing limit, OFL, for the years 2019 to 2024, analogous to methods adopted in the recent SEDAR spiny lobster stock assessment in the U.S. Caribbean region (NMFS 2019). OFL projections were implemented in Stock Synthesis at the fishing mortality rate that achieved maximum sustainable yield, F_{MSY}, obtained from the end year (2018) of the base model run (NMFS 2020). Projection selectivity and catchability by gear type were set equal to the values obtained at the end year (2018) of the base model run

(NMFS 2020). Projected recruitment was obtained from the stock recruit relationship implemented within the base model run (NMFS 2020) without uncertainty.

Projections were implemented with average commercial landings and with average recreational catches plus recreational post release mortality, PRM, implemented for the projection gap years (2019 – 2021) between the terminal year of the assessment (2018) and the first year of management implementation of results from the assessment (2022). Average commercial landings by fleet during the years 2014 – 2018 were obtained from commercial landings of blacktip sharks in the U.S. Atlantic region in metric tons whole weight (mt ww; Table D.1). Average recreational catches and PRM during the years 2014 – 2018 were obtained from smoothed recreational catch estimates of blacktip sharks in the U.S. Atlantic region in numbers (thousands; Table D.2). Recreational catch data were smoothed during the assessment as described in NMFS (2020). The OFL during projection years 2022 – 2024 was adjusted (OFL-Catch-Adj-1) for the assumed commercial landings and recreational catches removed from the population during the projection gap years.

ABC.—A minimum estimate of the log-scale standard error in OFL (σ_{min} equal to 0.415) was obtained as described above in the main text. An acceptable risk of overfishing equal to 0.3 was assumed (analogous to P*) , consistent with projections under previous Atlantic HMS domestic shark rebuilding plans (e.g., NMFS 2018a). Projected fishery removals at ABC were obtained from projected OFL adjusted (OFL-Catch-Adj-1) for the average commercial landings and average recreational catches plus recreational post release mortality, PRM, implemented for the projection gap years.

ABC allocation.—Example ABC allocations for blacktip sharks in the U.S. Atlantic were obtained from ABC projections separately for commercial landings in metric tons and recreational catches plus recreational PRM (A + B1 + B2PRM) in numbers (thousands).

D.3. Comparison to TAC Obtained from Status Quo Projections

Status quo projections implemented during the assessment for the base model run (Courtney 2020; NMFS 2020) were compared to the ABC obtained from meta-analysis using an ABC control rule. Status quo projections were conducted for the spawning stock fecundity (SSF, sum of number at age times pup production at age) and the fishing mortality rate, *F*, relative to their values at MSY, with projection uncertainty. Status quo projection results provided examples from 10,000 Monte Carlo projections of a given fixed level of total annual removals due to fishing (thousands of sharks) which resulted in both the $Pr(SSF_t > SSF_{MSY}) \geq$

70% and Pr ($F_t > F_{\mathrm{MSY}}$) ≤ 30% during the years 2019 – 2043. See Courtney (2020) and NMFS (2020) for a detailed description of the status quo projection methodology.

D.4. Resulting ABC Obtained from Meta-analysis using an ABC Control Rule

OFL projections in biomass.—Projected fishery removals in biomass (mt) at the overfishing limit, OFL, for commercial landings, recreational catch, and recreational PRM are provided in Figure D.1 and Table D.3. As described above, OFL was obtained from Stock Synthesis projections implemented at F_{MSY} based on the underlying population dynamics assumed during the projection period. As described above, projected OFL in biomass (*B*, mt) was adjusted for commercial landings in biomass (*B*, mt) and recreational catch plus recreational PRM in numbers (*N*, thousands) input in Stock Synthesis projections during the gap years 2019 – 2021 (OFL-Catch-Adj-1; Figure D.1 and Table D.3). The resulting projected fishery removals at OFL in biomass (*B*, mt) obtained from Stock Synthesis projections during the years 2022 – 2028 include both the assumed removals during the gap years 2019 – 2021, and the OFL adjusted for the assumed removals during the gap years (Table D.3).

OFL projections in numbers.—Projected fishery removals in numbers (*N*, thousands) at the overfishing limit, OFL, for commercial landings, recreational catch, and recreational PRM are provided in Figure D.2 and Table D.4. As described above for OFL projections in biomass, OFL in numbers was also obtained from Stock Synthesis projections implemented at F_{MSY}. Projected OFL in numbers (*N*, thousands) was then adjusted as described above. The resulting projected fishery removals at OFL in numbers (*N*, thousands) obtained from Stock Synthesis projections during the years 2022 – 2028 include both the assumed removals during the gap years 2019 – 2021, and the OFL adjusted for the assumed removals during the gap years (Table D.4).

ABC to OFL ratio obtained from meta-analysis.—Selecting a 30% cumulative lognormal probability provides a buffer from the median OFL at the 30% acceptable risk of overfishing (analogous to P* equal to 0.3). Given a minimum estimate of scientific uncertainty in OFL (e.g., σ_{min} equal to 0.415, obtained as described in the results of the main text above), the 30% cumulative lognormal probability density is found at values ≤ 0.804. Consequently, the value of the ABC to OFL ratio is 0.804 (i.e., ABC = 80.4% of the OFL), which is defined as the buffer from the OFL to the ABC (Tables D.5 and D.6) and results in a 19.6% reduction from OFL to ABC.

ABC projections in biomass obtained from meta-analysis.—Projected fishery removals in biomass (mt) at the acceptable biological catch, ABC, are provided in Figure D.1 and Table D.5. OFL was adjusted for actual commercial landings and recreational catch plus recreational PRM during the years 2019 – 2021 (Table D.3**;** OFL-Catch-Adj-1), as described above. ABC was obtained from adjusted OFL using the ABC to OFL ratio of 0.804 (i.e., ABC = 80.4% of the OFL), as described above.

An example of a three year average constant catch (CC) ABC in biomass (mt) is also provided in Figure D.1 and Table D.5, following methods adapted from those in a recent SEDAR spiny lobster stock assessment completed within the U.S. Caribbean region (NMFS 2019). The three-year average adjusted OFL was obtained for the years 2022 – 2024. A three year average CC ABC of 472.21 (mt) was obtained from adjusted OFL using the ABC to OFL ratio of 0.804.

ABC projections in numbers obtained from meta-analysis.—Projected fishery removals in numbers (thousands) at the acceptable biological catch, ABC, are provided in Figure D.2 and Table D.6. OFL was adjusted for actual commercial landings and recreational catch plus recreational PRM during the years 2019 – 2021 (Table D.4**;** OFL-Catch-Adj-1), as described above. ABC was obtained from adjusted OFL using the ABC to OFL ratio of 0.804, as described above.

An example of a three year average constant catch, CC, ABC in numbers (thousands is also provided in Figure D.2 and Table D.6, following methods described above. The three-year average adjusted OFL was obtained for the years 2022 – 2024. A three year average CC ABC of 58.78 (thousands) was obtained from adjusted OFL using the ABC to OFL ratio of 0.804.

Constant catch ABC allocation in biomass obtained from meta-analysis.—An example of a three year average constant catch, CC, ABC allocation in biomass is provided in Table D.7 for three fleets of commercial gear types: F1 (Com-LL Kept), F2 (Com-GN Kept), and F3 (Com-Other Kept), as defined in the Atlantic blacktip shark base model run (NMFS 2020). The three year average CC ABC (472.21 mt; Table D.5) was allocated to commercial gear types in proportion to the average commercial landings in biomass by gear type during projection years 2019 – 2021 (Table D.7). This resulted in a three year average CC ABC allocation of 103.83, 30.04, and 2.02 mt to gear types F1, F2, and F3, respectively.

Commercial landings of blacktip sharks in the U.S. Atlantic in biomass (mt) whole weight (ww) were converted to lb ww, and then to dressed weight (dw) using the same conversion ratio (ww = 1.39 dw) as defined in the Atlantic blacktip shark base model run

(NMFS 2020) to transform reported landings from dw to ww. This resulted in a three year average CC ABC allocation of 164,682, 47,649, and 3.206 lb dw to gear types F1, F2, and F3, respectively (Table D.7).

Constant catch ABC allocation in numbers obtained from meta-analysis.—An example of a three year average constant catch, CC, ABC allocation in numbers is provided in Table D.8 for one recreational fleet: F4 (Recreational Catch and Post Release Mortality), as defined in the Atlantic blacktip shark base model run (NMFS 2020). The three year average CC ABC (58.78, thousands; Table D.6) was allocated to the recreational fleet in proportion to the average recreational catch plus post release mortality in numbers during projection years 2019 – 2021 (91.71%; Table D.8). This resulted in a three year average CC ABC allocation of 53,906 Atlantic blacktip sharks to the recreational fleet (Table D.8).

D.5. Comparison of ABC Obtained from Meta-analysis to TAC Obtained from Status Quo Projections

With the present allocation of effort among fishing sectors obtained from the base model run for the assessment (NMFS 2020), the status quo projection results obtained from the stock assessment indicated that the stock appeared to be capable of sustainably supporting total annual removals due to fishing (i.e., with both the Pr($SSF_t > SSF_{MSY}$) ≥ 70% and Pr($F_t > F_{MSY}$) ≤ 30% during the years 2019 – 2043) of 1.08×(average removals during the years 2014 – 2018) (Tables D.9 – D.11; Figures D.3 and D.4).

Sustainable commercial TAC levels identified with status quo projections.—Status quo projections implemented during the assessment for the base model run (Courtney 2020) indicated that a commercial TAC of 115.0, 33.3, and 2.2 mt allocated to gear types F1 (Com-LL Kept), F2 (Com-GN Kept), and F3 (Com-Other Kept), respectively, would be sustainable (Table D.11). In comparison, ABC obtained from meta-analysis using an ABC control rule for the base model run indicated that commercial CC ABCs of 103.83, 30.04, and 2.02 mt allocated to gear types F1, F2, and F3, respectively, would be sustainable (Table D.7). Consequently, commercial CC ABCs obtained from meta-analysis using an ABC control rule were consistent, but about 10% smaller (more conservative), when compared to the sustainable TAC levels obtained from the status quo projection approach implemented for the stock assessment (Table D.12; Courtney 2020; NMFS 2020).

Sustainable recreational TAC levels identified with status quo projections.—Status quo projections implemented during the assessment for the base model run (Courtney 2020) indicated that a recreational TAC of 62.416 (thousands) allocated to gear type F4

(Recreational Catch and Post Release Mortality) would be sustainable (Table D.11). In comparison, ABC obtained from meta-analysis using an ABC control rule for the base model run indicated that a recreational CC ABC of 53.906 (thousands) allocated to gear type F4 would be sustainable (Table D.8). Consequently, the recreational CC ABC obtained from meta-analysis using an ABC control rule was consistent, but about 13% smaller (more conservative), when compared to the sustainable TAC levels obtained from the status quo projection approach implemented for the stock assessment (Table D.13; Courtney 2020; NMFS 2020).

D.6. Discussion

Commercial discards were not included in the Atlantic blacktip shark base model run (NMFS 2020) because of uncertainty in bycatch estimation. Consequently, commercial discards were not included here. Commercial discards were included within Atlantic blacktip shark sensitivity analyses model runs (NMFS 2020). Consequently, this additional uncertainty would need to be accounted for separately within the assessment when determining OFL and ABC with an ABC control rule.

Commercial landings of blacktip sharks in the U.S. Atlantic region were obtained in weight (mt; thousands kg whole weight) based on a conversion ratio for dressed weight (dw) to whole weight (ww) of ww = 1.39 × dw. However, uncertainty in the dw to ww conversion was not accounted for within the Atlantic blacktip shark base model run (NMFS 2020). Similarly, uncertainty in the estimates of post release mortality obtained by gear type were also not accounted for within the Atlantic blacktip shark base model run (NMFS 2020). Consequently, uncertainty in conversion ratios and post release mortality were also not included when determining OFL and ABC with an ABC control rule. Uncertainty in conversion ratios and post release mortality were addressed within the original assessment by evaluating stock status under alternate states of nature model runs (NMFS 2020). Consequently, the additional uncertainty evaluated with alternate states of nature model runs in the original assessment (NMFS 2020) would also need to be accounted for on a case by case basis within an assessment when determining OFL and ABC with an ABC control rule.

TABLE D.1. Annual commercial landings of blacktip sharks in the U.S. Atlantic in metric tons whole weight (mt ww; NMFS 2020, their Table 2.2; Adapted from Courtney 2020, his Table 1).

Year	F1 Bottom longlines (mt ww)	F2 Gillnets (mt ww)	F3 Other gears (mt ww)
2014	130.126	41.000	6.678
2015	121.858	22.712	0.333
2016	110.737	44.723	1.202
2017	110.825	26.754	1.105
2018	58.961	18.886	1.047
Average (2014 – 2018)	106.501	30.815	2.073

TABLE D.2. Annual smoothed recreational catch estimates (thousands, reported as a 3-year moving average) of blacktip sharks in the Atlantic (2014 – 2018; NMFS 2020, their Table 2.3). Type A is the number of sharks killed or kept seen by the interviewer, type B1 is the number of sharks killed or kept reported to the interviewer by the angler, and type B2PRM is the number of sharks released alive reported by the fisher multiplied by a post-release mortality rate of 18.5%. Total Mortality is A + B1 + B2PRM (Adapted from Courtney 2020, his Table 2).

	F4 Recreational catch and post release mortality (thousands)		
Year	A + B1	B2PRM	Total mortality
2014	3.437	81.810	85.247
2015	4.701	68.243	72.944
2016	4.451	51.887	56.338
2017	2.849	34.367	37.216
2018	2.849	34.367	37.216
Average (2014 – 2018)			57.792

TABLE D.3. Projected fishery removals in biomass (*B*, mt) at the overfishing limit, OFL, for commercial landings, recreational catch, and recreational PRM. OFL was obtained from Stock Synthesis projections at F_{MSY} based on the underlying population dynamics assumed during the projection period (Panel A). Projected OFL (mt) was adjusted for commercial landings in biomass (*B*, mt) and recreational catch plus recreational PRM in numbers (*N*, thousands) input in Stock Synthesis projections during the years 2019 – 2021 (Tables D.1 and D.2; OFL-Catch-Adj-1). The resulting projected fishery removals at OFL in biomass (*B*, mt) obtained from Stock Synthesis projections during the years 2022 – 2024 include both the assumed removals during the gap years 2019 – 2021, and the OFL adjusted for the assumed removals during the gap years.

A. Stock Synthesis projected biomass.

Year	OFL (*B*, mt)	Projected fishery removals at adjusted OFL OFL-Catch-Adj-1 (*B*, mt)	Actual removals (2019 – 2021) and adjusted OFL (2022 – 2028) (*B*, mt)
2019	604.2584	604.2584	483.784
2020	594.8668	599.1242	485.819
2021	585.6744	592.7787	483.452
2022	581.9342	591.2452	591.245
2023	579.3714	586.9559	586.955
2024	576.1161	582.8436	582.843
2025	572.6191	579.0955	579.095
2026	569.665	576.0281	576.028
2027	567.3245	573.5737	573.574
2028	565.2007	571.3218	571.322

B. Color code definitions.

Blue	Blue: Actual fishery removals in biomass (mt) obtained from Stock Synthesis (forecast_report.ss loop 3) based on the commercial landings (mt) and recreational catch plus PRM (thousands) input in Stock Synthesis projections during the years 2019, 2020, and 2021 (forecast.ss).
Yellow	Yellow: Projected fishery removals in biomass (mt) for commercial landings, recreational catch, and recreational PRM obtained from Stock Synthesis projections (forecast_report.ss loop 1) at FMSY based on the underlying population dynamics assumed during the projection period.
Orange	Orange: Projected fishery removals at OFL in biomass (mt) adjusted for input commercial landings (mt) and input recreational catch plus PRM (thousands) during the years 2019, 2020, and 2021 obtained from Stock Synthesis projections (forecast_report.ss loop 1) [Provided as OFLCatch (2019 – 2028) in the report.ss management quantities section along with the standard error of the estimates obtained from the Hessian].
Green	Green: Projected fishery removals in biomass (mt) at OFL adjusted for the input removals during the years 2022 – 2028 (orange) [Provided as ForeCatch (2019 – 2028) in the report.ss management quantities section along with the standard error of the estimates obtained from the Hessian].

TABLE D.4. Projected fishery removals in numbers (*N*, thousands) at the overfishing limit, OFL, for commercial landings, recreational catch, and recreational PRM. OFL was obtained from Stock Synthesis projections at F_{MSY} based on the underlying population dynamics assumed during the projection period. Projected OFL (thousands) was adjusted for commercial landings in biomass (*B*, mt) and recreational catch plus recreational PRM in numbers (*N*, thousands) input in Stock Synthesis projections during the years 2019 – 2021 (Tables D.1 and D.2; OFL-Catch-Adj-1). The resulting projected fishery removals at OFL in numbers (*N*, thousands) obtained from Stock Synthesis projections during the years 2022 – 2024 include both the assumed removals during the gap years 2019 – 2021, and the OFL adjusted for the assumed removals during the gap years.

A. Stock Synthesis projected numbers.

Year	OFL (*N*, thousands)	Projected fishery removals at adjusted OFL (*N*, thousands)	Actual removals (2019 – 2021) and adjusted OFL (2022 – 2028) (*N*, thousands)
2019	74.21	74.21	63.02
2020	72.77	73.32	63.01
2021	72.31	73.15	63.02
2022	72.45	73.47	73.47
2023	72.40	73.09	73.09
2024	72.09	72.65	72.65
2025	71.77	72.30	72.30
2026	71.55	72.09	72.09
2027	71.37	71.94	71.94
2028	71.18	71.77	71.77

B. Color code definitions.

Blue	Blue: Actual fishery removals in numbers (thousands) obtained from Stock Synthesis (forecast_report.ss loop 3) based on the commercial landings (mt) and recreational catch plus PRM (thousands) input in Stock Synthesis projections during the years 2019, 2020, and 2021 (forecast.ss).
Yellow	Yellow: Projected fishery removals in numbers (thousands) for commercial landings, recreational catch, and recreational PRM obtained from Stock Synthesis projections (forecast_report.ss loop 1) at FMSY based on the underlying population dynamics assumed during the projection period.
Orange	Orange: Projected fishery removals at OFL in numbers (thousands) adjusted for input commercial landings (mt) and input recreational catch plus PRM (thousands) during the years 2019, 2020, and 2021 obtained from Stock Synthesis projections (forecast_report.ss loop 1) [Provided as OFLCatch (2019 – 2028) in the report.ss management quantities section along with the standard error of the estimates obtained from the Hessian].
Green	Green: Projected fishery removals in numbers (thousands) at OFL adjusted for the input removals during the years 2022 – 2028 (orange) [Provided as ForeCatch (2019 – 2028) in the report.ss management quantities section along with the standard error of the estimates obtained from the Hessian].

TABLE D.5. Projected fishery removals in biomass (mt) at the acceptable biological catch (ABC) for commercial landings, recreational catch, and recreational post-release mortality (PRM). Projected OFL (mt) was adjusted for commercial landings (mt) and recreational catch plus recreational PRM (thousands) input in Stock Synthesis projections during the years 2019 – 2021 (Table D.3; OFL-Catch-Adj-1). A ratio was obtained for the reduction from OFL to ABC (ABC/OFL = 0.804) from the acceptable risk of overfishing (P* = 0.3; σ_{min} = 0.415). The three-year average adjusted OFL was obtained for the years 2022 – 2024. Annual ABCs and a three year constant catch (CC) ABC were obtained for the years 2022 – 2024 from the adjusted OFL and the ABC/OFL ratio.

A. ABC to OFL ratio parameters and values.

Parameter	Value
P*	0.3
σ_{min}	0.415
Risk tolerance and σ	(P* = 0.3, σ_{min} = 0.415)
Resulting ABC/OFL	0.804[33]

B. Three year annual adjusted OFL and ABC in biomass.

	Projected fishery removals at adjusted OFL	Projected fishery removals at ABC	
Year	OFL-Catch-Adj-1 *B*, mt	ABC/OFL ratio	ABC *B*, mt
2022	591.25	0.804	475.61
2023	586.96	0.804	472.16
2024	582.84	0.804	468.85

C. Three year average adjusted annual OFL and constant catch CC) ABC in biomass.

Year	Annual OFL-Catch-Adj-1 *B*, mt	ABC/OFL ratio	Annual CC ABC *B*, mt
(2022 – 2024)	587.01	0.804	472.21

[33] E.g., in MS Excel, 0.804 = LOGNORM.INV(0.3,0,0.415).

TABLE D.6. Projected fishery removals in numbers (thousands) at the acceptable biological catch (ABC) for commercial landings, recreational catch, and recreational post-release mortality (PRM). Projected OFL (thousands) was adjusted for commercial landings (mt) and recreational catch plus recreational PRM (thousands) input in Stock Synthesis projections during the years 2019 – 2021 (Table D.3; OFL-Catch-Adj-1). A ratio was obtained for the reduction from OFL to ABC (ABC/OFL = 0.804) from the acceptable risk of overfishing (P* = 0.3; σ_{min} = 0.415). The three-year average adjusted OFL was obtained for the years 2022 – 2024. Annual ABCs and a three year constant catch (CC) ABC were obtained for the years 2022 – 2024 from the adjusted OFL and the ABC/OFL ratio.

A. ABC to OFL ratio parameters and values.

Parameter	Value
P*	0.3
σ_{min}	0.415
Risk tolerance and σ	(P* = 0.3, σ_{min} = 0.415)
Resulting ABC/OFL	0.804[34]

B. Three year annual adjusted OFL and ABC in numbers.

	Projected fishery removals at adjusted OFL	Projected fishery removals at ABC	
	OFL-Catch-Adj-1	ABC/OFL	ABC
Year	*N*, thousands	ratio	*N*, thousands
2022	73.47	0.804	59.10
2023	73.09	0.804	58.79
2024	72.65	0.804	58.44

C. Three year average adjusted annual OFL and constant catch CC) ABC in numbers.

Year	Annual OFL-Catch-Adj-1 *N*, thousands	ABC/OFL ratio	Annual CC ABC *N*, thousands
(2022-2024)	73.07	0.804	58.78

[34] E.g., in MS Excel, 0.804 = LOGNORM.INV(0.3,0,0.415).

Table D.7. Example of a three year average constant catch (CC) ABC allocation in biomass to three fleets of commercial gear types: F1 (Com-LL Kept), F2 (Com-GN Kept), and F3 (Com-Other Kept) as defined in the Atlantic blacktip shark base model run (NMFS 2020). The three year average CC ABC (472.21 mt; Table D.5) was allocated to commercial gear types in proportion to the average commercial landings in biomass by gear type (21.99%, 6.36%, and 0.43%, respectively) during projection years 2019 – 2021. Commercial landings of blacktip sharks in the U.S. Atlantic in biomass (mt) whole weight (ww) were converted to lb ww, and then to dressed weight (dw) using the same conversion ratio (ww = 1.39 dw) originally used in the base model run to transform reported landings from dw to ww for use in the assessment. This resulted in a three year average CC allocation of 164,682, 47,649, and 3.206 lb dw to gear types F1, F2, and F3, respectively.

Year	F1	F2	F3	F4	Total
2019	106.50	30.82	2.07	344.40	483.78
2020	106.50	30.82	2.07	346.43	485.82
2021	106.50	30.82	2.07	344.06	483.45
Average values	106.50	30.82	2.07	344.96	484.35
Average % of total	**21.99%**	**6.36%**	**0.43%**	71.22%	**100%**
Allocation based on average % of total					
Annual CC ABC total (3 yr Avg ABC; mt)					**472.21**
Annual CC ABC allocation (3 yr Avg ABC; mt)	**103.83**	**30.04**	**2.02**	336.32	**472.21**
Annual CC ABC allocation (3 yr Avg ABC; lb)	**228,909**	**66,232**	**4,456**	741,448	**1,041,045**
Annual CC ABC allocation (3 yr Avg ABC; lb dw)	**164,682**	**47,649**	**3,206**	533,416	**748,953**

TABLE D.8. Example of a three year average constant catch (CC) ABC allocation in numbers to one recreational fleet: F4 (Recreational Catch and Post Release Mortality) as defined in the Atlantic blacktip shark base model run (NMFS 2020). The three year average CC ABC in numbers (58.78, thousands; Table D.6) was allocated to the recreational fleet in proportion to the average recreational catch plus post release mortality in numbers during projection years 2019 – 2021 (91.71%). This resulted in a three year average CC ABC allocation of 53,906 Atlantic blacktip sharks to gear type F4 (Recreational Catch and Post Release Mortality).

Year	F1	F2	F3	F4	Total
2019	3.499	1.660	0.068	57.792	63.019
2020	3.484	1.667	0.068	57.792	63.010
2021	3.488	1.676	0.068	57.792	63.024
Average values	3.490	1.668	0.068	57.792	63.018
Average % of total	5.54%	3%	0.11%	**91.71%**	**100%**
Allocation based on average % of total					
Annual CC ABC total (3 yr Avg ABC; thousands)					**58.78**
Annual CC ABC allocation (3 yr Avg ABC; thousands)	3.255	1.555	0.063	**53.906**	**58.780**
Annual CC ABC allocation (3 yr Avg ABC; numbers)	3,255	1,555	63	**53,906**	**58,780**

Table D.9. Risk matrix of cumulative normal projection probabilities for $SSF_y/SSF_{MSY} > 1$ in the SEDAR 65 base model configuration at alternative fixed levels of total annual removals due to fishing (TAC; 0-200% of average annual removals from 2014 – 2018 in increments of 10%). The $Pr(SSF_y > SSF_{MSY})$ is color coded to represent $Pr \geq 0.70$ (green), $0.50 \leq Pr < 0.70$ (yellow), and $Pr < 0.50$ (red) (Adapted from Courtney 2020, his Table 3).

TAC (0-200%)	2019	2020	2021	2022	2023	2025	2030	2035	2040	2043
0	77	80	83	83	83	85	92	98	100	100
10%	77	80	83	83	83	84	91	97	99	100
20%	77	80	83	83	83	84	90	96	99	100
30%	77	80	83	83	83	84	89	95	98	99
40%	77	80	83	83	83	83	88	93	97	98
50%	77	80	83	83	83	83	87	91	95	96
60%	77	80	83	83	83	82	86	89	92	94
70%	77	80	83	83	82	82	84	87	89	90
80%	77	80	83	83	82	82	83	84	85	86
90%	77	80	83	83	82	81	81	81	81	81
100%	77	80	83	83	82	81	80	77	76	75
110%	77	80	83	83	82	81	78	74	71	69
120%	77	80	83	83	82	80	76	70	65	62
130%	77	80	83	83	82	80	75	66	60	56
140%	77	80	83	83	82	79	73	63	54	50
150%	77	80	83	83	82	79	71	59	49	44
160%	77	80	83	83	81	79	69	55	44	39
170%	77	80	83	83	81	78	67	51	39	34
180%[1]										
190%	77	80	83	83	81	77	63	44	31	26
200%	77	80	83	83	81	77	61	41	27	22

[1]Model run crashed.

Table D.10. Risk matrix of cumulative normal projection probabilities for $F_y/F_{MSY} < 1$ in the SEDAR 65 base model configuration at alternative fixed levels of total annual removals due to fishing (TAC; 0-200% of average annual removals from 2014 – 2018 in increments of 10%). The $Pr(F_y < F_{MSY})$ is color coded to represent Pr ≥ 0.70 (green), 0.50 ≤ Pr < 0.70 (yellow), and Pr < 0.50 (red) (Adapted from Courtney 2020, his Table 5).

TAC (0-200%)	2019	2020	2021	2022	2023	2025	2030	2035	2040	2043
0	71	70	70	100	100	100	100	100	100	100
10%	71	70	70	100	100	100	100	100	100	100
20%	71	70	70	100	100	100	100	100	100	100
30%	71	70	70	100	100	100	100	100	100	100
40%	71	70	70	100	100	100	100	100	100	100
50%	71	70	70	100	100	100	100	100	100	100
60%	71	70	70	100	100	100	100	100	100	100
70%	71	70	70	97	98	98	99	99	99	99
80%	71	70	70	91	91	92	93	94	94	95
90%	71	70	70	81	81	81	82	82	82	82
100%	71	70	70	70	70	69	69	68	67	66
110%	71	70	70	59	58	57	56	54	52	51
120%	71	70	70	49	48	47	45	43	41	40
130%	71	70	70	41	40	38	36	35	33	32
140%	71	70	70	34	33	32	30	29	28	27
150%	71	70	70	28	28	27	25	24	24	24
160%	71	70	70	24	23	22	22	21	22	22
170%	71	70	70	21	20	19	19	19	20	22
180%[1]										
190%	71	70	70	15	15	15	15	17	20	22
200%	71	70	70	14	13	13	14	16	20	24

[1]Model run crashed.

Table D.11. Commercial and recreational TAC allocation obtained from projections (Adapted from Courtney 2020, his Table 4). Linear interpolation of the cumulative normal probability of $SSF_y > SSF_{MSY}$ in 2043 (Figures D.3 and D.4) indicates that a TAC = 1.08 × Average removals (2014 – 2018) achieves a 70% asymptotic normal probability of $SSF_y/SSF_{MSY} > 1$ in 2043 (Panel A). The resulting projected commercial TAC (mt ww) = 1.08 × (average annual commercial landings 2014 – 2018) is provided in Panel B. The resulting projected recreational TAC (thousands) = 1.08 × (average annual smoothed recreational catch 2014 – 2018) is provided in Panel C.

A. Interpolated TAC 1.08×Average removals (2014 – 2018; Figures D.3 and D.4).

Projection scenario	Model configuration	Example of fixed removals
Base	Atlantic blacktip base model run (NMFS 2020)	108% of average removals (2014 – 2018)

B. 108% of average commercial landings (2014 – 2018; Table D.1).

Commercial TAC obtained from projections	F1 Bottom longlines (mt ww)	F2 Gillnets (mt ww)	F3 Other gears (mt ww)
Average removals (2014 – 2018)	106.501	30.815	2.073
1.08×Average	115.0	33.3	2.2

C. 108% of average recreational catch (2014 – 2018; Table D.2).

	F4 Recreational catch (thousands		
Recreational TAC obtained from projections	A + B1	B2PRM	Total
Average removals (2014 – 2018)	3.6574	54.1348	57.7922
1.08×Average			62.416

Table D.12. Commercial CC ABC in biomass by gear type obtained from meta-analysis during the years 2019 – 2021 (Panel A; Table D.7). Commercial TAC in biomass by gear type obtained from projections during the years 2019 – 2043 (Panel B; Table D.11). Difference between commercial CC ABC obtained from meta-analysis and commercial TAC obtained from projections (Panel C).

A. Commercial CC ABC by gear type obtained from meta-analysis during the years 2019 – 2021 (Table D.7).

	F1 Bottom longlines (mt ww)	F2 Gillnets (mt ww)	F3 Other gears (mt ww)
Commercial CC ABC (Meta-analysis)	103.83	30.04	2.02

B. Commercial TAC by gear type obtained from projections during the years 2019 – 2043 (Table D.11).

	F1 Bottom longlines (mt ww)	F2 Gillnets (mt ww)	F3 Other gears (mt ww)
Commercial TAC (Projections)	115.0	33.3	2.2

C. Difference between commercial CC ABC by gear type obtained from meta-analysis (Panel A) and commercial TAC by gear type obtained from projections (Panel B).

	F1 Bottom longlines (mt ww)	F2 Gillnets (mt ww)	F3 Other gears (mt ww)
Difference	-11.17	-3.26	-0.18
% Difference	-9.7%	-9.8%	-8.2%

Table D.13. Recreational CC ABC in numbers obtained from meta-analysis during the years 2019 – 2021 (Panel A; Table D.8). Recreational TAC in numbers obtained from projections during the years 2019 – 2043 (Panel B; Table D.11). Difference between recreational CC ABC obtained from meta-analysis and recreational TAC obtained from projections (Panel C).

A. Recreational CC ABC obtained from meta-analysis during the years 2019 – 2021 (Table D.8).

	F4 Recreational catch and post release mortality (thousands)
Recreational CC ABC (Meta-analysis)	53.906

B. Recreational TAC obtained from projections during the years 2019 – 2043 (Table D.11).

	F4 Recreational catch and post release mortality (thousands)
Commercial TAC (Projections)	62.416

C. Difference between recreational CC ABC obtained from meta-analysis (Panel A) and recreational TAC obtained from projections (Panel B).

	F4 Recreational catch and post release mortality (thousands)
Difference	-8.51
% Difference	-13.6%

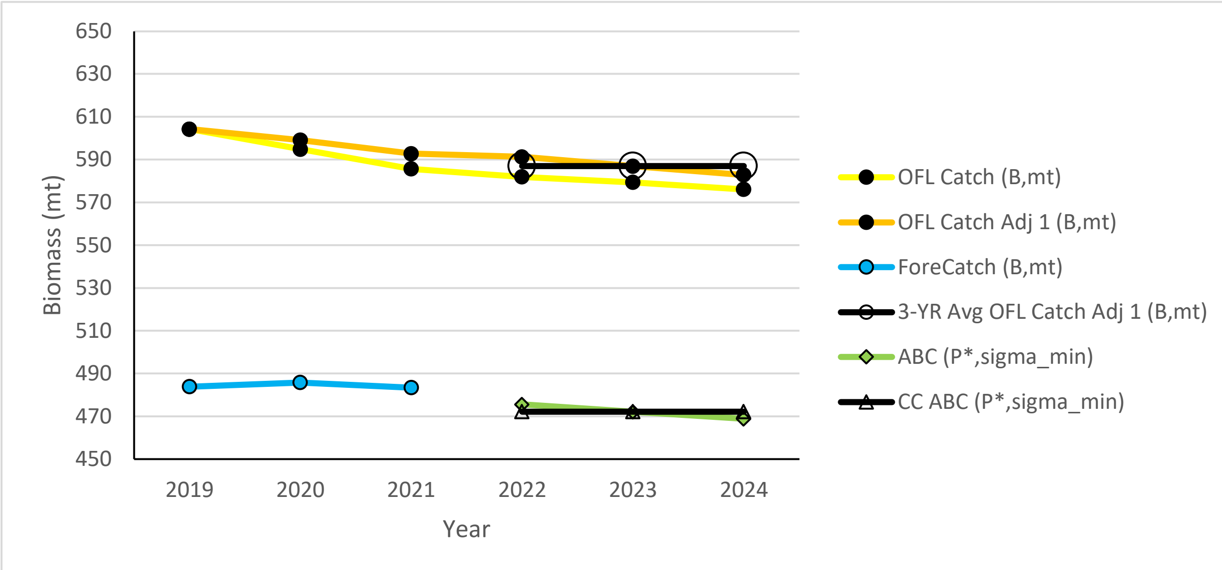

FIGURE D.1. Examples of the acceptable biological catch (ABC) in commercial landings and recreational catch plus recreational PRM in biomass of 475.61, 472.16, and 468.85 mt for the years 2022, 2023, and 2024, respectively (light green line and diamond marker) were obtained from the overfishing limit (OFL-Catch-Adj-1; 2022, 2023, and 2024; orange line with solid circle marker) after adjusting the OFL for estimated removals (2019, 2020, and 2021; blue line with blue circle marker). Example of a constant catch (CC) ABC of 472.21 mt (black line with open triangle marker) was obtained from the three-year average of the overfishing limit (Avg-OFL-Catch-Adj-1; 2022, 2023, and 2024; black line with open black circle marker).

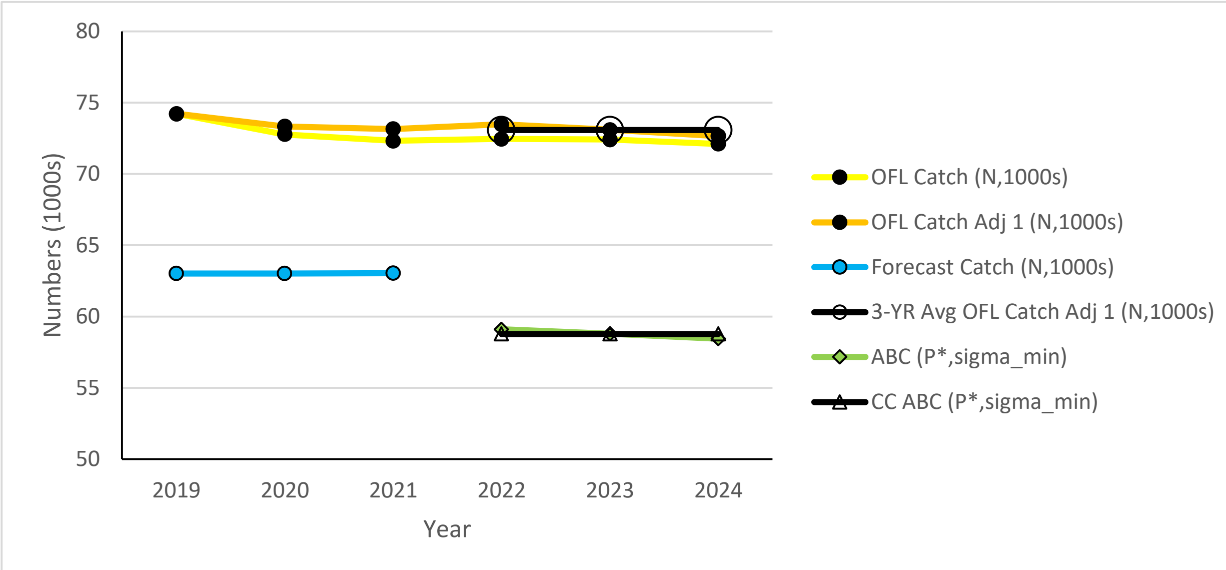

FIGURE D.2. Examples of the acceptable biological catch (ABC) in commercial landings and recreational catch plus recreational PRM in numbers of 73.47, 73.09, and 72.65 (thousands) for the years 2022, 2023, and 2024, respectively (light green line and diamond marker) were obtained from the overfishing limit (OFL-Catch-Adj-1; 2022, 2023, and 2024; orange line with solid circle marker) after adjusting the OFL for estimated removals (2019, 2020, and 2021; blue line with blue circle marker). Example of a constant catch (CC) ABC of 58.78 (thousands; black line with open triangle marker) was obtained from the three-year average of the overfishing limit (Avg-OFL-Catch-Adj-1; 2022, 2023, and 2024; black line with open black circle marker).

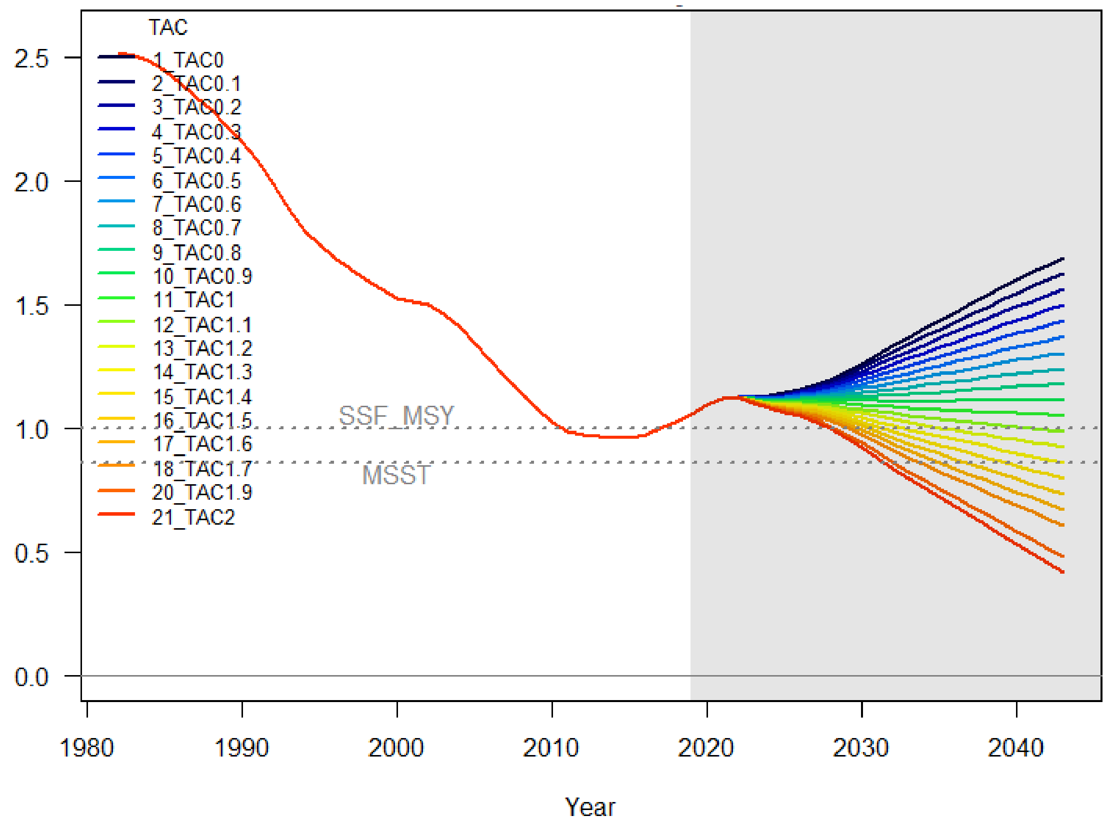

FIGURE D.3. Projection results (shaded area) for the SEDAR 65 base model configuration at alternative fixed levels of total annual removals due to fishing (TAC; 0-200% of the average annual removals from 2014 – 2018 in increments of 10%). Projection results are provided for the ratio of spawning stock fecundity in projection year *y* relative to spawning stock fecundity at equilibrium maximum sustainable yield (SSF_y/SSF_{MSY}; y-axis). Lines represent the 70% projection probabilities (30% of the cumulative normal distribution) obtained with MLE at each TAC. The minimum stock size threshold (MSST) is $\left(1-\bar{M}_a\right)\times SSF_{MSY}$ (Adapted from Courtney 2020).

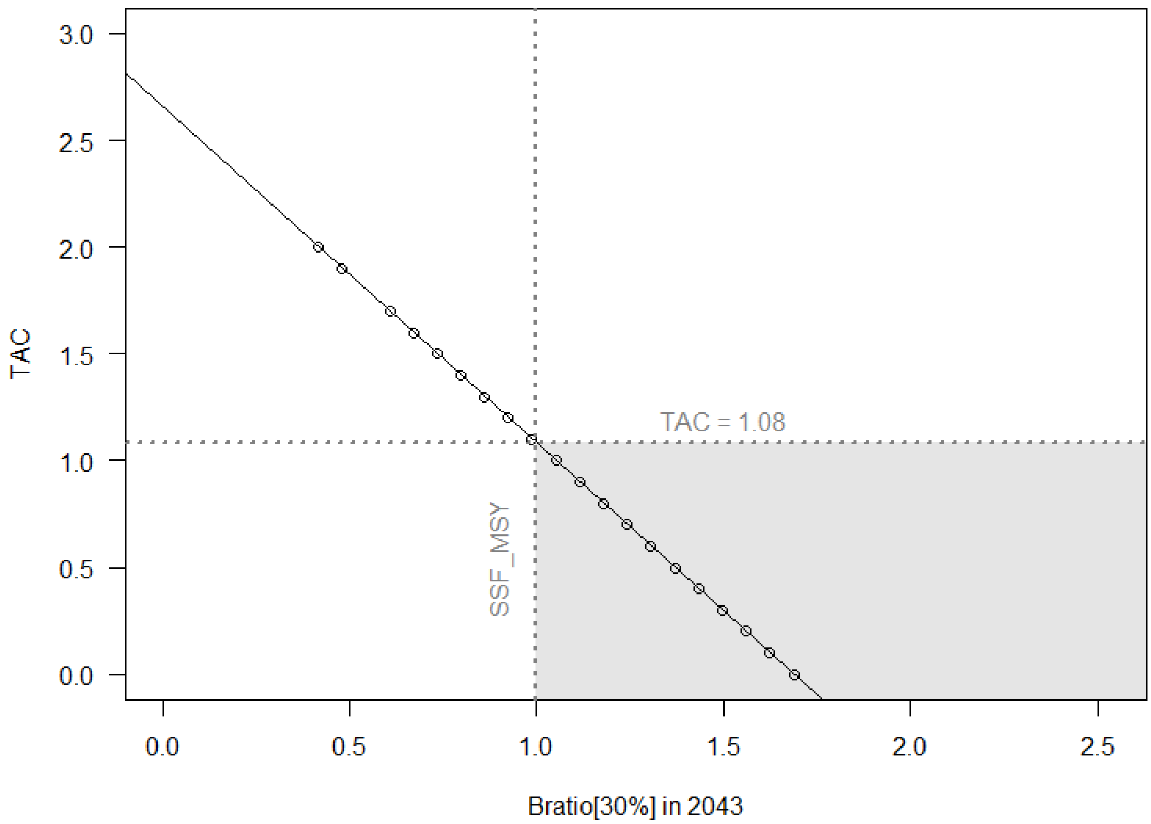

FIGURE D.4. Linear interpolation of TAC at 70% cumulative normal probability for $SSF_y/SSF_{MSY} > 1$ in 2043 (Bratio[30%] in 2043) indicates that a 70% asymptotic normal probability of $SSF_y/SS_{FMSY} > 1$ in 2043 is achieved at TAC = 1.08×Average removals (2014 – 2018) (Adapted from Courtney 2020).

APPENDIX E. Status Quo TACs for Atlantic HMS Domestic Sharks

E.1. Examples of Current Total Allowable Catch (TAC)

TAC (2021).—Status quo Total Allowable Catch, TAC, was obtained by stock group from the 2020 Stock Assessment and Fishery Evaluation report (SAFE; NMFS 2021). A table of the current TAC is shown below in Table E.1. The table also identifies amendments to the 2006 Consolidated Atlantic HMS FMP that focus on shark management. References to the quoted amendments can be found in NMFS (2021). In addition, NMFS (2021) notes[35]:

> "…NOAA Fisheries establishes TACs and ACLs for shark species consistent with Section 303(a)(15) of the Magnuson-Stevens Act. These TACs and ACLs are generated from information provided through stock assessments. For sharks assessed through the SEDAR process, NOAA Fisheries establishes an overfishing limit equal to the TAC. Discard, recreational, and research catch estimates are deducted from the TAC and constitute their respective sector ACLs. The remaining TAC is considered the commercial quota or the commercial sector ACL. More details on these calculations and the establishment of TACs and ACLs can be found in amendments to the 2006 Consolidated Atlantic HMS FMP that focus on shark management: Amendment 2 (NOAA Fisheries 2008), Amendment 3 (NOAA Fisheries 2010), Amendment 5a (NOAA Fisheries 2013), Amendment 6 (NOAA Fisheries 2015a), Amendment 9 (NOAA Fisheries 2015b), and Amendment 5b (NOAA Fisheries 2017b). NOAA Fisheries released Draft Amendment 14 to the 2006 Consolidated Atlantic HMS FMP on September 24, 2020, and accepted comments through December 31, 2020 (85 FR 60132). Draft Amendment 14 was undertaken to consider revising the mechanism or "framework" used in establishing quotas and related management measures for Atlantic shark fisheries. The current framework was established in Amendment 3 to the 2006 Consolidated Atlantic HMS FMP. The revised framework would modify the procedures followed in establishing the ABC and ACLs for Atlantic sharks and the process used to

[35] References to the quoted amendments can be found in NMFS (2021).

account for carryover or under harvests of quotas. It would also allow the option to phase-in ABC catch control rules and to adopt multi-year overfishing status determination criteria in some circumstances. Amendment 14 would not make changes to the current quotas or other management measures."

TABLE E.1. Total allowable catches (TAC) by shark management group, as of 2016, provided by Atlantic HMS Management Division. Citations refer to the 1999 Atlantic HMS shark fisheries management plan (FMP), and its associated amendments (A1 – A9)[36].

Fishery	Unit	Citation	TAC (mt dw, or number)
Exempted Fishing Permits	Metric Tons Dressed Weight	1999 FMP	41.0
Large Coastal Sharks All)	Metric Tons Dressed Weight	A2, App C	1182.2
Aggregated LCS	Metric Tons Dressed Weight	A2,A5a,A6	669.0
Aggregated LCS-Atlantic	Metric Tons Dressed Weight	A5a,A6	346.2
Aggregated LCS-GOM	Metric Tons Dressed Weight	A5a,A6	322.8
Aggregated LCS-GOM-East	Metric Tons Dressed Weight	A6	175.2
Aggregated LCS-GOM-West	Metric Tons Dressed Weight	A6	147.6
LCS Shark Research Fishery	Metric Tons Dressed Weight	A2 App C	50.0
Hammerhead Complex	Metric Tons Dressed Weight	A5a,A6	79.6
Hammerhead Atlantic	Metric Tons Dressed Weight	A5a,A6	41.2
Hammerhead GOM	Metric Tons Dressed Weight	A5a,A6	38.4
Hammerhead GOM-East	Metric Tons Dressed Weight	A6	20.4
Hammerhead GOM-West	Metric Tons Dressed Weight	A6	18.1
Blacktip Shark GOM	Metric Tons Dressed Weight	A5a,A6	413.4
Blacktip GOM-East	Metric Tons Dressed Weight	A5a,A6	40.5
Blacktip GOM-West	Metric Tons Dressed Weight	A5a,A6	372.9
Sandbar Shark	Metric Tons Dressed Weight	A2 App. A	158.3
Blacknose-Atlantic	Metric Tons Dressed Weight	A5a,A6	21.2
Blacknose-GOM[37]	Metric Tons Dressed Weight	A5a,A6	34.9
Small Coastal-Atlantic	Metric Tons Dressed Weight	A6	489.3
Small Coastal-GOM	Metric Tons Dressed Weight	A6	999.0
Prohibited Species	Number of Individuals	A5b	0.0
Dusky	Number of Individuals	A5b	0.0
Pelagic Shark Complex	Metric Tons Dressed Weight	A2	488.0
Porbeagle	Metric Tons Dressed Weight	A2	11.3
Blue Shark	Metric Tons Dressed Weight	1999 FMP; A2	273.0
Smooth Dogfish-Atlantic	Metric Tons Dressed Weight	A9	1430.6
Smooth Dogfish-GOM	Metric Tons Dressed Weight	A9	509.6

[36] The amendments listed in Table E.1 can be found online at https://www.fisheries.noaa.gov/atlantic-highly-migratory-species/atlantic-hms-fishery-management-plans-and-amendments (Accessed November, 2021).

[37] NMFS (2021, their Table 5.13) notes that blacknose shark are prohibited in the Gulf of Mexico, however some landings do exist likely due to misidentification problems or lack of awareness of shark fishing regulations.

APPENDIX F. Status Quo TAC and Commercial Quota Calculations for an Example Atlantic HMS Domestic Shark Stock not on a Rebuilding Plan (Atlantic Smooth Dogfish)

F.1. Status Quo Sustainable Removals Obtained From Projection Results

Sustainable fixed annual removals determined for the base model run with projections.— Projections were provided for the SEDAR 39 Atlantic smooth dogfish Stock Synthesis base model configuration (Courtney 2015) in response to the SEDAR 39 Atlantic smooth dogfish Term of Reference (TOR) 9: Project future stock conditions (NMFS 2015). Status quo projections were implemented externally to the Stock Synthesis model in R statistical software as a proxy to a typical P* approach based on a pre-specified acceptable probability of overfishing (e.g., P* = 0.3; < 0.5) (Courtney et al. 2014). Projections utilized 10,000 Monte Carlo simulations drawn from a bivariate normal distribution for unexploited equilibrium recruitment (SS3_R_0) and the terminal fishing mortality (SS3_F_{2012}) obtained from the Stock Synthesis v3 (SS3) assessment model. Short term projections were implemented for 10 years (t = 2013 – 2022) with lognormal variability in the Beverton-Holt stock-recruitment relationship based on the standard deviation of recruitment in log space (SS3_σ_R) obtained from the SS3 assessment model. Simulations were conducted for 21 alternative fixed levels of total annual removals due to fishing (thousands of sharks) ranging from zero to 1,000 in increments of 50 (Table F.1). Projection results from 10,000 Monte Carlo simulations over the range of fixed annual removals evaluated indicated that levels of fixed annual removals less than or equal to 550 (thousands of sharks) resulted in at least a 70% probability of maintaining spawning stock fecundity in year t (SSF_t) above SSF_{MSY} during the years 2013 – 2022 (Table F.2 and Figure F.1).

Sensitivity analyses and states of nature model runs implemented with projections.—A summary of status quo projection model results for model sensitivity analyses and states of nature model runs associated with the base model configuration were provided during the SEDAR 39 Review Workshop and included as an addendum to the SEDAR 39 Stock Assessment Report (NMFS 2015, their Section VI Addenda and Post-Review Documentation Table 7). Status quo projection methods and results for the base model configuration (ATL Base Sel-2) were provided during the SEDAR 39 Review Workshop (Courtney 2015). The Stock

Assessment Report (NMFS 2015, their Section 3.7 and Table 4.13**)** provides a description of the model sensitivities and model states of nature associated with the base model configuration (Sel-2), which were used for projections: MS-9 Start Year 1972 (Sel-2), MS-10 Ranked CPUE (Sel-2), MS-11 Low Catch (Sel-2), MS-12 High Catch (Sel-2), MS-13 Low Productivity (Sel-2), MS-14 High Productivity (Sel-2), and MS-15 Hierarchical (Sel-2).

The projection methods used for sensitivity analyses and states of nature model runs followed those described above for the base model run. The sustainable TAC levels determined for sensitivity model runs are provided below in Table F.3.

F.2. Status Quo TAC and Commercial Quota Calculations

TAC and commercial quota calculations for Atlantic smooth dogfish.—The Atlantic smooth dogfish TAC, 1430.6 mt dw (NMFS 2021) is provided above in Appendix E. A detailed description the Atlantic smooth dogfish (smoothhound) shark commercial quota calculations as implemented in Amendment 9 to the 2006 Consolidated HMS FMP is provided below (Figure F.2; Courtesy of the Atlantic HMS Management Division[38]).

[38] E.g., see https://media.fisheries.noaa.gov/dam-migration/hms-a9-quota-methodology.pdf (Accessed August 2022); Also see https://media.fisheries.noaa.gov/dam-migration/smoothhound-shark-quota-presentation-a9.pdf (Accessed August 2022).

TABLE F.1. Simulations were conducted for 21 alternative fixed levels of total annual removals due to fishing (thousands of sharks) ranging from zero to 1,000 in increments of 50. Adapted from Courtney (2015, his Table 1).

Fixed level of total annual removals due to fishing (thousands of sharks)	Alternative
0	1
50	2
100	3
150	4
200	5
250	6
300	7
350	8
400	9
450	10
500	11
550	12
600	13
650	14
700	15
750	16
800	17
850	18
900	19
950	20
1000	21

TABLE F.2. Projection results from 10,000 Monte Carlo simulations for the SEDAR 39 Atlantic smooth dogfish base model configuration evaluated under a range of fixed annual removals due to fishing (thousands of sharks). Projection results were reported as the proportion of times that spawning stock fecundity in projection year *t* (SSF_t) was above spawning stock fecundity at maximum sustainable yield (SSF_{MSY}), $Pr(SSF_t > SSF_{MSY})$, for a given fixed level of total annual removals due to fishing (thousands of sharks). The $Pr(SSF_t > SSF_{MSY})$ was color coded to represent $Pr \geq 0.70$ (green), $0.50 \leq Pr < 0.70$ (yellow), and $Pr < 0.50$ (red). Adapted from Courtney (2015, his Table 2).

Alternative	Fixed level of total annual removals due to fishing 1000s of sharks	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3	100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4	150	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	200	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6	250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	300	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8	350	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
9	400	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.96
10	450	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.95	0.91
11	500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.90	0.84
12	550	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.83	0.74
13	600	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.88	0.75	0.63
14	650	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.81	0.65	0.51
15	700	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.72	0.54	0.38
16	750	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.64	0.43	0.28
17	800	1.00	1.00	1.00	1.00	1.00	1.00	0.84	0.54	0.34	0.18
18	850	1.00	1.00	1.00	1.00	1.00	1.00	0.77	0.46	0.24	0.10
19	900	1.00	1.00	1.00	1.00	1.00	0.99	0.70	0.37	0.17	0.05
20	950	1.00	1.00	1.00	1.00	1.00	0.98	0.62	0.29	0.10	0.02
21	1000	1.00	1.00	1.00	1.00	1.00	0.96	0.53	0.21	0.06	0.01

TABLE F.3. Projection results for the SEDAR 39 Atlantic smooth dogfish provide examples of a given fixed level of total annual removals due to fishing (thousands of sharks) during the years (2013 – 2022) which resulted in the $Pr(SSF_t > SSF_{MSY}) \geq 70\%$ in the year 2022 from 10,000 Monte Carlo projections. Model configurations as described in the original assessment document (NMFS 2015, their Section VI Addenda and Post-Review Documentation Table 7).

Projection scenario	Model configuration	Example of fixed removals (thousands)
1	Base Model Configuration (Sel-2)	550
2	MS-9 Start Year 1972 (Sel-2)	350
3	MS-10 Ranked CPUE (Sel-2)	650
4	MS-11 Low Catch (Sel-2)	450
5	MS-12 High Catch (Sel-2)	650
6	MS-13 Low Productivity (Sel-2)	850
7	MS-14 High Productivity (Sel-2)	350
8	MS-15 Hierarchical (Sel-2)	500

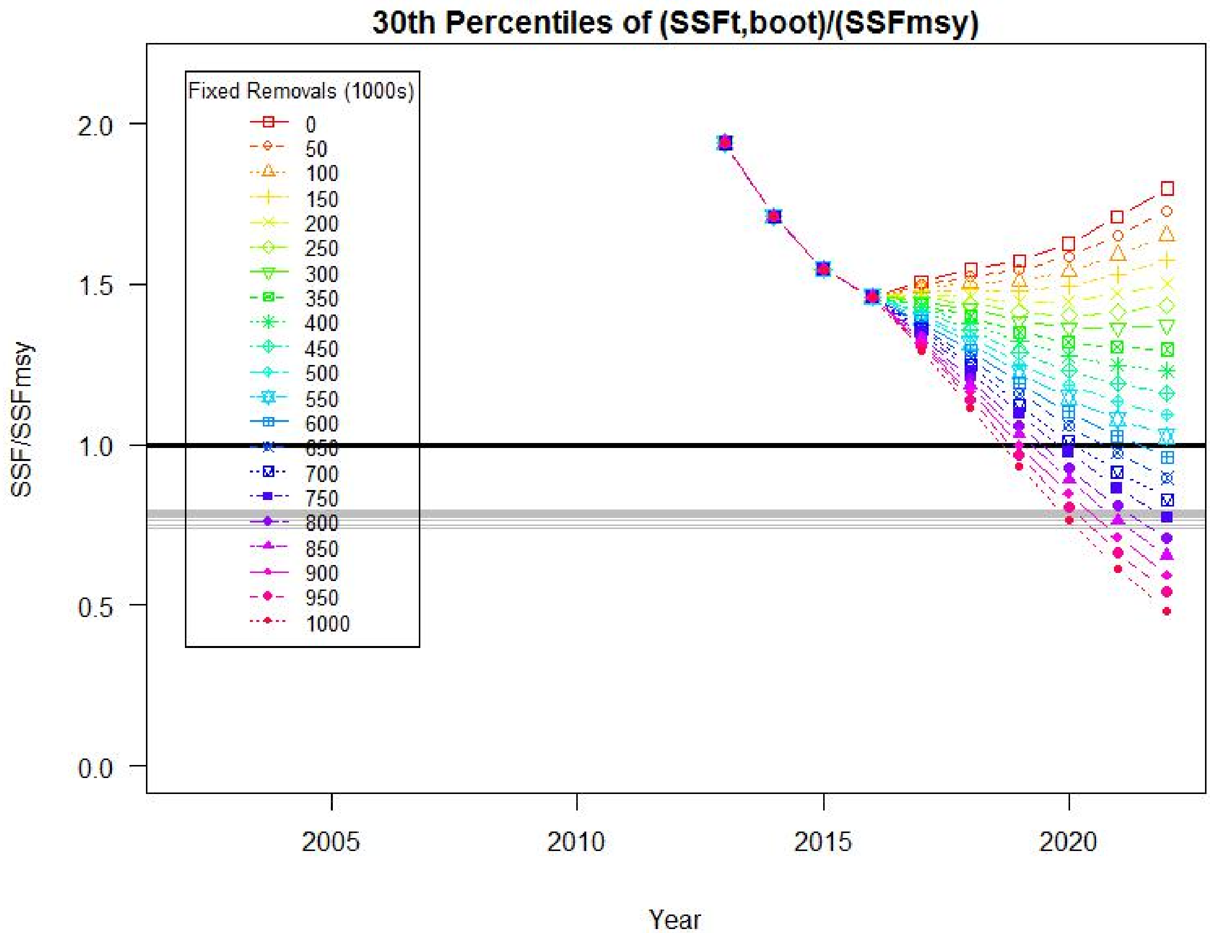

FIGURE F.1. Projection results from 10,000 Monte Carlo simulations for the SEDAR 39 Atlantic smooth dogfish base model configuration under a range of fixed annual removals due to fishing (thousands of sharks). Projection results were summarized as the 30th percentile of $SSF_{t,boot}/SSF_{MSY}$, which represents the 70% probability of maintaining $SSF_{t,}$ above SSF_{MSY} from 10,000 Monte Carlo simulations for a given level of fixed removals (in thousands) (Tables F.1 and F.2) and a given year (2013 – 2022). The shaded thick set of horizontal lines is the approximate location of the minimum stock size threshold (MSST) = $(1-\bar{M}_a)\times SSF_{MSY}$, where ($1-\bar{M}_a$) is one minus the average natural mortality at age obtained from the SEDAR 39 Atlantic smooth dogfish Stock Assessment Report (NMFS 2015, their Table 4.13). Adapted from Courtney (2015, his Figure 1).

Atlantic Smoothhound Shark Commercial Quota Calculation Methodology

November 23, 2015

Amendment 9 to the 2006 Consolidated Highly Migratory Species (HMS) Fishery Management Plan (FMP) implemented, among other things, regional commercial quotas for Atlantic and Gulf of Mexico smoothhound sharks. The commercial quotas were based on results from the Southeast Data, Assessment, and Review (SEDAR) 39 stock assessments. This document focuses on the Atlantic smoothhound shark stock since the primary commercial fishery occurs in that region. All data and calculations can be found in the Amendment 9 and no new information is presented in this document. The Gulf of Mexico commercial quota calculation follows a similar methodology and details can be found in Section 2.2 of the Amendment 9 Environmental Assessment (http://www.nmfs.noaa.gov/sfa/hms/documents/fmp/am9/a9_final_ea.pdf).

How are quotas calculated?

Generally, Atlantic shark commercial quotas, including smoothhound sharks, are calculated the same way for all species assessed through the SEDAR process. First, the stock assessment provides an absolute maximum level of fishing mortality that can occur while still maintaining a sustainable fishery. The maximum level of fishing mortality, or total allowable catch (TAC), is typically presented with a probability of maintaining a healthy stock or rebuilding a depleted one. Thus, multiple TACs are provided in the stock assessment, each with its own probability of maintaining a healthy stock or rebuilding a depleted one. For SEDAR-assessed Atlantic sharks, NMFS typically uses a TAC corresponding to at least a 70 % chance of successfully maintaining a healthy stock. Note that for most Atlantic sharks, including smoothhound sharks, the overall annual catch limit (ACL) is set at a level equal to the TAC, meeting the requirement to establish an ACL. This overall ACL is then split into sector-ACLs (recreational harvest, commercial landings, and commercial dead discards) as described below.

Once a TAC is established, all sources of fishing mortality (excluding commercial landings) provided by the stock assessment are deducted from the TAC. Sources of fishing mortality include recreational landings, research set-aside, and, if available, estimate(s) of the number of fish that die after being released alive (post-release mortality). Once estimates of all sources of fishing mortality (excluding commercial landings) are deducted from the TAC, the remainder becomes the commercial quota. The figure below summarizes this process.

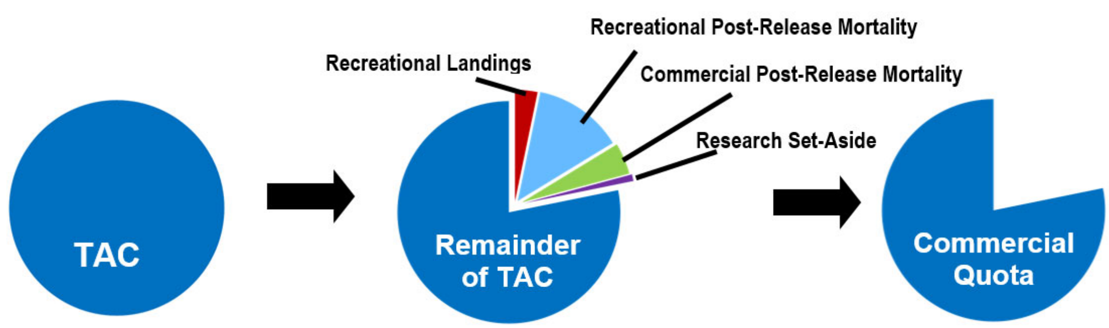

FIGURE F.2. Atlantic smooth dogfish (smoothhound) shark commercial quota methodology provided courtesy of Atlantic HMS Management division.

Atlantic Smoothhound Shark Commercial Quota Calculation Methodology, Continued

Data and sources: All stock assessment documents can be found at: http://sedarweb.org/sedar-39

- TAC = **550,000 sharks = 1,430.6 mt dw**
  - TAC associated with 70 % probability of maintaining a healthy stock; Table 2 on Page 17 of the Projections for the SEDAR 39 Atlantic Smooth Dogfish (*Mustelus canis*) Stock Assessment Report Base Model Configuration document. This document was presented at the Review Workshop, and is a separate document from the actual final Stock Assessment Report.
  - Average weight of smooth dogfish sharks = 8.2 lb ww. This is the average weight of smooth dogfish caught in the gillnet fishery. NMFS felt this average weight is appropriate to use because the majority of landings of smooth dogfish are from this fishery.
  - Conversion factor = 1.43. This is the conversion factor ACCSP uses for smooth dogfish to convert whole weight to dressed weight.
  - 550,000 sharks × 8.2 lb ww (average weight) = 4,510,000 lb ww
  - 4,510,000 lb ww/1.43 (conversion factor to dressed weight) = 3,153,846.1 lb dw
  - 3,153,846 lb dw/2204.6 lb/mt = 1,430.6 mt dw
- Commercial post-release mortality = **39.1 mt dw**
  - Average annual estimate from 2008-2012, converted from whole weight to dressed weight using 1.43 conversion factor; Table 2.1 on pages 25 and 26 of Section III (Assessment Process Report) of the SEDAR 39 HMS Atlantic Smooth Dogfish Shark Stock Assessment Report. If you are reading the electronic version of the Stock Assessment Report, these are pdf pages 107 and 108.
- Recreational landings = **23.5 mt dw**
  - Average annual landings from 2008-2012, converted from whole weight to dressed weight using 1.43 conversion factor; Table 2.1 on pages 25 and 26 of Section III (Assessment Process Report) of the SEDAR 39 HMS Atlantic Smooth Dogfish Shark Stock Assessment Report. If you are reading the electronic version of the Stock Assessment Report, these are pdf pages 107 and 108.
- Recreational post-release mortality = **164.9 mt dw**
  - Average annual estimate from 2008-2012, converted from whole weight to dressed weight using 1.43 conversion factor; Table 2.1 on pages 25 and 26 of Section III (Assessment Process Report) of the SEDAR 39 HMS Atlantic Smooth Dogfish Shark Stock Assessment Report. If you are reading the electronic version of the Stock Assessment Report, these are pdf pages 107 and 108.
- Research set-aside = **1.4 mt dw**
  - Amendment 3 to the 2006 Consolidated HMS FMP established a 4.2 mt dw research set aside, covering both the Atlantic and Gulf of Mexico. The Atlantic's share of the research set-aside, 1.4 mt dw, is based on the proportion of mortality occurring under exempted fishing permits in the Atlantic from 2008-2012.

Commercial Quota Calculation Methodology Summary: As described above, NMFS calculated the Atlantic regional smooth dogfish shark commercial quota by subtracting all sources of smoothhound shark mortality. The resulting Atlantic smoothhound shark commercial quota is **1,201.7 mt dw**.

1,430.6 mt dw (Atlantic smoothhound shark TAC)
– 23.5 mt dw (recreational Atlantic smoothhound shark landings)
– 164.9 mt dw (recreational Atlantic smoothhound shark post release mortality)
– 39.1 mt dw (commercial Atlantic smoothhound shark post release mortality)
– 1.4 mt dw (research set-aside)
= **1,201.7 mt dw** (Atlantic commercial smoothhound shark quota)

FIGURE F.2. Continued.

APPENDIX G. Status Quo TAC and Commercial Quota Calculations for an Example Atlantic HMS Domestic Shark Stock on a Rebuilding Plan (Sandbar Shark)

G.1. Status Quo Rebuilding Plan Obtained From Projection Results

The revised National Standard 1, NS1, guidelines (U.S. Office of the Federal Register 2009, 2016)[39] for the MSA note: "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 (i.e., F_{rebuild}) in the rebuilding plan." Consequently, examples of status quo TAC and commercial quota calculations are provided here for the Atlantic HMS domestic sandbar shark stock, which is currently on a rebuilding plan.

Rebuilding TAC determined for the base model run with status quo projections.—The consensus summary report for the SEDAR 11 sandbar shark stock assessment (NMFS 2006) identified the stock status to be overfished with overfishing occurring. A rebuilding timeframe under no fishing was calculated to be 38 years for the base-case model configuration. Adding the estimated generation time (28 years) resulted in the target year for rebuilding of 2070. Projections were implemented to the year 2070 for the base model configuration utilizing the fishing mortality, *F*, obtained in 2004 for the years 2005 – 2007, and constant annual removals applied in years 2008 and beyond. Constant annual removals of 220 mt ww (metric tons whole weight) achieved a 70% probability of rebuilding by 2070, and constant annual removals of 240 mt ww achieved a 50% probability of rebuilding by 2070 for the base model configuration (NMFS 2006, their pdf page 372).

[39] E.g., see NS1 2016 Guidelines (U.S. Office of the Federal Register 2016). Available at https://www.federalregister.gov/documents/2016/10/18/2016-24500/magnuson-stevens-act-provisions-national-standard-guidelines (Accessed August 2022):

> "*…(f) Acceptable biological catch, and annual catch limits (Section 3) Specification of ABC... (ii) 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 (i.e., F_{rebuild}) in the rebuilding plan…"

References to amendments quoted below can be found in NMFS (2021). Amendment 2 to the 2006 Consolidated Atlantic HMS Fishery Management Plan, FMP[40], implemented the constant TAC of 158.3 mt dw (metric tons dressed weight; equivalent to 220 mt ww), which achieved a 70% probability of rebuilding by 2070.

[40] E.g., see the 2008 Amendment 2 to the Atlantic HMS Fishery Management Plan available from the U.S. Office of the Federal Register at https://www.govinfo.gov/content/pkg/FR-2008-07-15/pdf/R8-13961.pdf (Accessed August 2022):

> "… [**Background**] … The 2005/2006 stock assessment for the sandbar shark assumed that sandbar shark fishing mortality from 2005 to 2007 would be maintained at levels similar to 2004 (the last year of data used in the stock assessment was from 2004) and that there would be a constant total allowable catch (TAC) between 2008 and 2070. Using these assumptions, the projections indicated that sandbar sharks would have a 70– percent probability of rebuilding by 2070 with a TAC of 220 mt whole weight (ww) (158 mt dressed weight (dw))/year and a 50–percent probability of rebuilding by 2070 with a TAC of 240 mt ww (172 mt dw)/year. As described in Amendment 2, NMFS used the 70– percent probability of rebuilding to ensure that the intended results of a management action are actually realized given the life history traits of sandbar sharks.
>
> Under the rebuilding plan, sandbar sharks are separated from the LCS complex, and the base commercial sandbar shark quota is established at 116.6 mt dw/year, which results in a total sandbar shark TAC of 158.3 mt dw (220 mt ww) once other sources of sandbar sharks mortality are included. For the first five years of this rebuilding plan (through 2012), to account for 2007 overharvests, the base commercial quota is reduced to 87.9 mt dw. The adjusted base quota through 2012 includes the amount of quota that would have been available in the 1st season of 2008 had NMFS not closed the fishery during that time. In the final rule for the 1st season of 2008, NMFS calculated that 78 mt dw (171,959 lb dw) would have been available (November 29, 2007, 72 FR 67580). However, based on updates to the reported landings, NMFS adjusted the 78 mt dw estimate down to 66.2 mt dw (145,944 lb dw). The actual commercial quota available in any particular year may fluctuate based on overharvests and will be published via appropriate rulemaking in the **Federal Register**. …
>
> … [**Response to Comments**] … The recommended TAC associated with a 50–percent probability of rebuilding by 2070 is 172.7 mt dw (or 240 mt whole weight (ww)). However, given the life history of sharks including slow growth, late age of maturity, and relatively small litter sizes, as described in the 1999 Fishery Management Plan for Atlantic Tunas, Swordfish, and Sharks (1999 FMP), a 50–percent probability of success is minimally acceptable for sharks. Thus, NMFS adopted the TAC corresponding to a 70–percent probability of rebuilding by 2070, or 158.3 mt dw (220 mt ww). …"

Amendment 2 to the 2006 Consolidated HMS FMP also implemented, among other things, a shark research fishery for Atlantic sandbar sharks, which was maintained under Amendment 6[41].

The sandbar shark stock assessment was updated in SEDAR 21 (NMFS 2011). The updated sandbar shark stock assessment estimated that the stock was overfished, but that overfishing was not occurring. Amendment 6 to the 2006 Consolidated HMS FMP (80 FR 50074, published August 18, 2015)[42] determined that an updated rebuilding schedule was not warranted.

The sandbar shark stock assessment was updated again in SEDAR 54 (NMFS 2017, 2018a), which estimated that the stock was overfished, but that overfishing was not occurring. The SEDAR 54 stock assessment results will be further evaluated following Draft Amendment 14 to the Atlantic HMS Fishery Management Plan.

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[41]E.g., see the 2015 Amendment 6 to the Atlantic HMS Fishery Management Plan available from the U.S. Office of the Federal Register at https://www.govinfo.gov/content/pkg/FR-2015-08-18/pdf/2015-19914.pdf (Accessed August 2022):

> " … [**Response to Comments**] … In the Final EA for Amendment 6, NMFS considered the implementation of a sandbar shark commercial quota (Section 2.6, Alternative F) that would allow commercial fishermen to incidentally land a limited number of sandbar sharks outside the Atlantic shark research fishery. NMFS explored several different options of distributing the unused sandbar shark research quota. While some commenters requested a limited number of sandbar sharks (between 1 to 5 per trip), the available sandbar shark quota would only provide between 1 and 7 sandbar sharks per vessel per year, not per trip. Under all options considered, NMFS is concerned about monitoring and enforcing such small individual annual retention limits without the monitoring mechanisms that are possible under a catch share scenario. NMFS is also concerned that changes to the shark research fishery could have negative effects on the status of the sandbar shark stock, which has improved and stabilized since the inception of the research fishery in 2008. In addition, NMFS is concerned about potential identification issues and impacts to dusky sharks if fishermen were allowed to incidentally land sandbar sharks outside the shark research fishery. Thus, due to these concerns and the benefits to the sandbar and dusky sharks of current management measures, NMFS prefers to continue to only allow commercial sandbar shark landings as part of the shark research fishery. NMFS may reexamine the commercial sandbar shark quotas once a new stock assessment has been completed."

[42] E.g., see the 2015 Amendment 6 to the Atlantic HMS Fishery Management Plan available from the U.S. Office of the Federal Register at https://www.govinfo.gov/content/pkg/FR-2015-08-18/pdf/2015-19914.pdf (Accessed August 2022):

> " … [**Response to Comments**] … The SEDAR 21 sandbar shark stock assessment (2011) evaluated the status of the stock based on new landings and biological data, and projected future abundance under a variety of catch levels in the U.S. Atlantic Ocean, Gulf of Mexico, and Caribbean Sea. The base model used in the SEDAR 21 sandbar shark assessment, an age-structured production model, indicated that the stock is overfished (spawning stock fecundity (SSF) 2009/SSFMSY = 0.66), but no longer experiencing overfishing F2009/FMSY=0.62 . According to the SEDAR 21, the sandbar shark stock status is improving, and the current rebuilding timeframe, with the 2008 TAC of 220 mt ww, provides a greater than 70-percent probability of rebuilding by 2070. Having a 70-percent probability of rebuilding is the level of success for rebuilding of sharks that was established in the 1999 FMP for Atlantic Tunas, Swordfish, and Sharks and carried over in the 2006 consolidated HMS FMP. This stock assessment also indicates that reducing the TAC from the current 220 mt ww to 178 mt ww would provide a 70-percent chance of rebuilding the stock by the year 2066, a reduction of 4 years from the current rebuilding timeframe. Because the current TAC already provides a greater than 70-percent probability of rebuilding, and because overfishing is not occurring and the stock status is improving, [Consequently] in Amendment 5a to the 2006 Consolidated HMS FMP, NMFS maintained the current TAC and rebuilding plan, consistent with the Magnuson-Stevens Act requirements and the National Standard Guidelines…"

G.2. Status Quo TAC and Commercial Quota Calculations

TAC and commercial quota calculations for sandbar shark.—The sandbar shark TAC, 158.3 mt dw (NMFS 2021; e.g., Appendix E and Table E.1) was obtained from calculations outlined in the 1999 Atlantic HMS shark FMP and its associated amendments (A1 – A9)[43]. The commercial research quota was based on results from the SEDAR 11 stock assessment. The quota methodology for the Atlantic sandbar shark stock and its chief components, i.e. the scientific and commercial fisheries are provided here courtesy of Atlantic HMS Management Division. All data and calculations can be found in the Amendment 2 and Amendment 6 to the 2006 Consolidated HMS FMP (References to the quoted amendments can be found in NMFS 2021), no new information is presented in this document. The commercial quota methodology for the sandbar shark stock is also summarized in Tables 11 and 12 from the SEDAR 54 stock assessment report (NMFS 2017).

How are quotas calculated?—Generally, Atlantic HMS domestic shark commercial quotas, including sandbar sharks, are calculated the same way for all species assessed through the SEDAR process (e.g., Appendix F and Figure F.2 above). First, the stock assessment provides an absolute maximum level of fishing mortality that can occur while still maintaining a sustainable fishery. The maximum level of fishing mortality, or total allowable catch, TAC, is typically presented with a probability of maintaining a healthy stock or rebuilding a depleted one. Thus, multiple TACs are provided in the stock assessment, each with its own probability of maintaining a healthy stock or rebuilding a depleted one. For SEDAR-assessed Atlantic HMS domestic sharks, the National Marine Fisheries Service (NOAA Fisheries) typically uses a TAC corresponding to at least a 70 percent chance of successfully maintaining a healthy stock. Note that for most Atlantic sharks, including sandbar sharks, the overall annual catch limit, ACL, is set at a level equal to the TAC, meeting the requirement to establish an ACL. This overall ACL is then split into sector-ACLs (recreational harvest, commercial landings, and commercial dead discards) as described below. Once a TAC is established, all sources of fishing mortality (excluding commercial landings) provided by the stock assessment are deducted from the TAC. Sources of fishing mortality include recreational landings, research set-aside, and, if available,

[43] A complete list of the HMS fishery management plan and its amendments can be found online at https://www.fisheries.noaa.gov/atlantic-highly-migratory-species/atlantic-hms-fishery-management-plans-and-amendments (Accessed August 2022).

estimate(s) of the number of fish that die after being released alive (post-release mortality). Once estimates of all sources of fishing mortality (excluding commercial landings) are deducted from the TAC, the remainder becomes the commercial quota.

Status quo sandbar shark quota calculation methodology.—As noted above, the MSA indicates that for an overfished stock the ABC control rule must be consistent with the rebuilding plan. The current commercial quota (90.7 mt dw) was determined starting with the TAC calculated during SEDAR 11 (158.3 mt dw). To determine the proportion of the 158.3 mt dw TAC for sandbar that would be available for the shark research fishery, NOAA Fisheries accounted for mortality of sandbar sharks in all sectors of the recreational and commercial fisheries. As explained in Amendment 2 to the 2006 Consolidated HMS FMP (their Appendix A; References to the quoted amendments can be found in NMFS 2021), NOAA Fisheries first determined the commercial TAC by subtracting the average number of recreational sandbar shark landings (27 mt dw) per year from the 158.3 mt dw TAC, resulting in a commercial TAC of 131.3 mt dw (Table A.1 of Amendment 2). NOAA Fisheries then determined the available commercial quota by subtracting discards across a variety of sources including the HMS pelagic longline (PLL) fishery, and non-HMS fisheries (e.g., the snapper-grouper and tilefish fisheries). NMFS also subtracted the display and research quotas. The resulting commercial quota was 116.6 mt dw (158.3 mt dw TAC subtracting the 27 mt dw recreational harvest and the 14.7 mt dw commercial discards).

As noted above, on August 18, 2015 (80 FR 50074), NOAA Fisheries published the final rule for Amendment 6 to the 2006 Consolidated HMS FMP that, among other things, reduced the commercial sandbar shark research fishery commercial quota to 90.7 mt dw. As described in Amendment 2 and Amendment 6, the retention limit for large coastal sharks (LCS) in the rest of the commercial shark fishery was in part based on how many sandbar sharks would be discarded dead from the number of shark trips that were expected to interact with sandbar sharks. In Amendment 6, NOAA Fisheries used a portion of the unharvested sandbar shark research fishery quota to account for sandbar shark discards that might occur with a higher LCS retention limit and adjusted the sandbar shark research fishery quota accordingly.

As described in Chapter 2 and Table 2.3 of Amendment 6, NOAA Fisheries calculated the number of sandbar sharks that could be discarded dead per trip under the retention limit based on observer data and the average weight of sandbar sharks. These calculations resulted in potential dead discards of sandbar sharks per year of 1,166 sharks (3,696 sandbar sharks discarded per year × 0.315 sandbar sharks observed dead = 1,166 sandbar sharks discarded dead per year). At an average weight of 49.0 lb dw, this results in 57,113 lb dw, or 25.9 mt dw of dead discards of sandbar sharks. This total amount of dead discards was subtracted from the 116.6 mt dw quota resulting in a 90.7 mt dw commercial quota for sandbar sharks in the shark research fishery (116.6 mt dw quota subtracting 25.9 mt dw dead discards).

Summary of quota calculation data sources.—TAC (158.3 mt dw) was obtained from SEDAR 11 (NMFS 2006), as described above. TAC calculation in the assessment used an average weight of sandbar shark sharks = 40.5 lb dw (Cortés and Neer, 2005) and a conversion factor of 1.39 to convert whole weight to dressed weight. Recreational landings were obtained as 27 mt dw, as described in Amendment 2 (e.g., NMFS 2017, their Table 11). Overall commercial discard mortality was obtained as 40.6 mt dw, which is the sum of 14.7 mt dw as described in Amendment 2 (e.g., NMFS 2017, their Table 11) and 25.9 mt dw as described in Amendment 6 e.g., NMFS 2017, their Table 12).

Summary of quota calculation.—As described above, the commercial quota is set by subtracting all sources of sandbar shark mortality. The resulting status quo sandbar shark research fishery quota is equal to 90.7 mt dw:

- **TAC = 158.3 mt dw** is the TAC associated with 70 % probability of rebuilding a healthy stock by 2070. Average weight of sandbar shark sharks = 40.5 lb dw. Conversion factor = 1.39 (conversion factor used to convert whole weight to dressed weight) SEDAR 11 NMFS 2006).
- **Recreational landings** = 27 mt dw based on Amendment 2.
- **Commercial discard mortality** = 40.6 mt dw (14.7 mt dw dead discards based on logbooks + 25.9 mt dw based on potential discards in the shark research fishery) based on Amendments 2 and 6.
- Research fishery commercial landings = 90.7 mt dw.