SEDAR

Southeast Data, Assessment, and Review

SEDAR 65

HMS Blacktip Shark

Section III: Assessment Report

October 2020

SEDAR
4055 Faber Place Drive, Suite 201 North Charleston, SC 29405

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1. **Introduction**

1.1. Workshop Time and Place

The SEDAR 65 HMS Blacktip Shark assessment process was held over a series of webinars from February 2020 – August 2020.

1.1.1. Terms of Reference

1. Review any changes in data following the Data Workshop (DW) and any analyses suggested by the DW. Summarize data as used in each assessment model. Provide justification for any deviations from DW recommendations.
2. Develop population assessment models that are compatible with available data and document input data, model assumptions and configuration, and equations (if necessary) for each model considered.
3. Provide estimates of stock population parameters:
    a. Include fishing mortality, abundance, biomass, selectivity, stock-recruitment relationship (if applicable), and other parameters as necessary to describe the population.
    b. Include appropriate measures of precision for parameter estimates.
4. Characterize uncertainty in the assessment and estimated values.
    a. Consider uncertainty in input data, modeling approach, and model configuration.
    b. Consider and include other sources as appropriate for this assessment.
    c. Provide appropriate measures of model performance, reliability, and 'goodness of fit'.
    d. Provide measures of uncertainty for estimated parameters
5. Provide estimates of yield and productivity.
    a. Include yield-per-recruit, spawner-per-recruit, and stock-recruitment models.
6. Provide estimates of population benchmarks or management criteria to include associated uncertainty, with available data, applicable FMPs, proposed FMPs and Amendments, other ongoing or proposed management programs, and National Standards.

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a. Evaluate existing or proposed management criteria as specified in the management summary.

b. Recommend and define proxy values when necessary, and provide appropriate justification.

7. Provide declarations of stock status relative to management benchmarks or alternative data poor approaches if necessary.

8. Provide uncertainty distributions of proposed reference points and stock status metrics that provide the values indicated in the management specifications. Include probability density functions for biological reference point estimates and population metrics (e.g., biomass and exploitation) used to evaluate stock status.

9. Project future stock conditions and develop rebuilding schedules, if warranted. Provide the estimated generation time for the stock. Stock projections shall be developed in accordance with the following:

a. If the stock is overfished, then utilize projections to determine:

i. Year in which F=0 results in a 70% probability of rebuilding (Year F=0p70).

ii. Target rebuilding year (Year-rebuild).

1. Year F=0p70 if Year F=0p70 ≤ 10 years, or

2. Year F=0p70 + 1 generation time if Year F=0p70 > 10 years.

iii. F resulting in 50% and 70% probability of rebuilding by Year-rebuild.

iv. Fixed level of removals allowing rebuilding of stock with 50% and 70% probability.

b. If stock is undergoing overfishing, then utilize projections to determine:

i. F=Freduce (different reductions in F that should end overfishing with a 50% and 70% probability).

c. If stock is neither overfished nor undergoing overfishing, then utilize projections to determine:

i. The F needed and corresponding removals associated with a 70% probability of overfishing not occurring (analogous to a P* = 0.3 approach).

d. If data-limitations preclude classic projections (i.e. a, b, and c above), explore alternate projection models to provide management advice.

10. Provide recommendations for future research and data collection.

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a. Be as specific as practicable in describing sampling design and sampling intensity.

b. Emphasize items that will improve future assessment capabilities and reliability.

c. Consider data, monitoring, and assessment needs.

11. Complete the Assessment Process (AP) Report in accordance with project schedule deadlines (Section III of the SEDAR Stock Assessment Report).

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1.1.2. List of Participants

SEDAR 65 Assessment Panel Appointee	**Function**	**Affiliation**
Dean Courtney	Lead Assessment Scientist	NMFS Panama City
Enric Cortes	Assessment Support Scientist	NMFS Panama City
Xinsheng Zhang	Assessment Support Scientist	NMFS Panama City
Elizabeth Babcock	Panelist	RSMAS
Rob Latour	Panelist	VIMS
Carolyn Belcher	Panelist	GADNR
Robert Hueter	Panelist	Mote Marine Lab.
STAFF		
Kathleen Howington	Coordinator	SEDAR
Heather Balchowsky-Baertlein	Observer	NMFS/HMS
Karyl Brewster-Geisz	HMS: Management	NMFS/HMS
Clifford Hutt	Observer	NMFS/HMS
Other		
Rusty Hudson	Observer	DSF
Bryan Frazier	Observer	SCDNR
Bryan Keller	Observer	NMFS/IA
Cami McCandless	Observer	NMFS/NEFSC
Chip Collier	Observer	SAFMC
Cassidy Peterson	Observer	NMFS/SEFSC
Delisse Ortiz	Observer	NMFS/HMS
Guy Eroh	Observer	NMFS
Guy Dubeck	Observer	NMFS/HMS
Jim Gelsleichter	Observer	UNF
John Carlson	Observer	NMFS Panama City
Kaitlyn O'Brien	Observer	VIMS

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1.1.4. List of Assessment Process Working and Reference Papers

Working Documents prepared for SEDAR 65 Assessment Workshop			
Document #	**Title**	**Author**	**Date Received**
SEDAR65-AW01	Hierarchical analysis of U.S Atlantic blacktip shark recruitment indices.	Cami McCandless	1/9/2020
SEDAR65-AW02	Estimates of vital rates and population dynamics parameters of interest of blacktip sharks (*Carcharhinus limbatus*) in the Atlantic Ocean	Enric Cortés	3/6/2020
SEDAR65-AW03	Reconciling indices of relative abundance of the Atlantic blacktip shark (Carcharhinus limbatus)	Robert Latour	3/6/2020
SEDAR65-AW04	Hierarchical cluster analysis and cross-correlations of selected CPUE indices for the SEDAR 65 assessment	Dean Courtney	3/6/2020
SEDAR65-AW05	Review of available length composition data submitted for use in the SEDAR 65 Atlantic *Carcharhinus limbatus* stock assessment	Andrea Kroetz and Dean Courtney	3/12/2020
SEDAR65-AW06	Improving discard time series for use in assessment sensitivity analyses	Camilla McCandless, John Carlson, Xinsheng Zhang Enric Cortés	3/25/2020

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Reference Documents			
Document #	**Title**	**Author**	**Date Received**
SEDAR65-RD05	Community interactions and density dependence in the southeast United States coastal shark complex	Peterson et.al.	10/30/19
SEDAR65-RD06	Discard mortality of Carcharhinid sharks in the Florida commercial shark fishery	Whitney	11/4/19
SEDAR65-RD07	Survey of the Florida recreational shark fishery utilizing shark tournament and selected longline data	Hueter	11/1/19
SEDAR65 – RD08	Utility of citizen science data: A case study in land-based shark fishing	Kesley J. Gibson, Matthew K. Streich, Tara S. Topping, Gregory W. Stunz	12/20/19
SEDAR 65-RD09	Stock Synthesis model runs conducted for North Atlantic shortfin mako shark	Dean Courtney, Enric Cortés, and Xinsheng Zhang	5/7/2020

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Reference Documents			
Document #	**Title**	**Author**	**Date Received**
SEDAR 65 – RD10	Stock Synthesis model sensitivity to data weighting: an example from preliminary model runs previously conducted for North Atlantic blue shark	Dean Courtney, Enric Cortés, Xinsheng Zhang, and Felipe Carvalho	5/7/2020
SEDAR 65-RD11	Capture stress and post-release mortality of blacktip sharks in recreational charter fisheries of the Gulf of Mexico	John A. Mohan, Elizabeth R. Jones, Jill M. Hendon, Brett Falterman, Kevin M. Boswell, Eric R. Hoffmayer and R.J. David Wells	5/20/2020
SEDAR65-RD12	Proposal of implementation of low-fecundity spawner-recruitment relationship for shortfin mako in the North Atlantic.	Mikihiko Kai and Felipe Carvalho	6/24/2020
SEDAR65-RD13	Examples of Stock Synthesis diagnostic methods and results implemented for previously completed North Atlantic shortfin mako Stock Synthesis model runs.	Courtney, D., Carvalho, F., Winker, H., and L. Kell.	6/24/2020
SEDAR65-RD14	Example of a Stock Synthesis projection approach at alternative fixed total allowable catch (TAC) limits implemented for three previously completed North Atlantic shortfin mako Stock Synthesis model runs	Courtney, D. and J. Rice	6/24/2020

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1.2. Statements Addressing each Term of Reference

Note: Original ToRs are in normal font. Statements addressing ToRs are in italics.

1.2.1. Statements Addressing Term of Reference 1.

Review any changes in data following the Data Workshop (DW) and any analyses suggested by the DW. Summarize data as used in each assessment model. Provide justification for any deviations from DW recommendations.

The SEDAR 65 Assessment Process Schedule of Events (AP timeline) was modified based on consensus comments and recommendations of the AP Panel in order to accommodate the DW decision for the AP Analytical Team to continue analysis of commercial dead discard and commercial post-release live discard mortality during the AP. The AP Panel adopted the following decisions during the Pre-assessment Webinar.

1) *Modify the Assessment Webinar I AP Schedule of Events to include the evaluation of uncertainty in the catch time series as follows. During Assessment Webinar I (week of March 23, 2020), the AP Analytical Team will analyze commercial dead discard and commercial post-release live discard mortality in an AP working paper [Due March 6, 2020] and present results to the AP Panel for their review. In preparation for Assessment Webinar III, the AP Lead Analyst will develop a base model without commercial bycatch discard estimate(s) (dead discards + live discards that subsequently die from post-release mortality), and present preliminary results to the AP Panel for their review. In contrast, the previous Assessment Webinar I Schedule of Events (week of March 23) included the following: Introduce and discuss uncertainty analyses (alternative states of nature) and develop reference case model run(s) which are robust to the major uncertainties identified.*
2) *Modify the Assessment Webinar II AP Schedule of Events to include the evaluation of uncertainty in the catch time series as follows. During Assessment Webinar II (week of April 13, 2020), the AP Analytical Team will develop alternative reference case catch streams (as alternate states of nature) which are robust to the major uncertainties identified in commercial bycatch discard estimation, recreational catch and live discard*

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estimation, and post-release live-discard mortality estimation, and present preliminary results to the AP Group for their review. In contrast, the previous Assessment Webinar II Schedule of Events (week of April 13) included the following: Finalize uncertainty analyses and reference case model run(s).

3) *Move the following tasks to the Assessment Webinar III AP Schedule of Events. The AP Lead Analyst will adapt the base case model to develop reference case model run(s) (as alternate states of nature) which are robust to the major uncertainties identified in commercial bycatch discard estimation (and post-release mortality), and present preliminary results to the AP Panel for their review. In contrast, the previous Assessment Webinar III Schedule of Events (week of May 4) included the following: Introduce and discuss sensitivity analyses (model diagnostics) and projections.*
4) *Move the following tasks to the Assessment Webinar IV AP Schedule of Events. The AP Lead Analyst will finalize reference case model run(s) which are robust to the major uncertainties identified in commercial bycatch discard estimation (and post-release mortality), and present results to the AP Panel for their review. The AP Lead Analyst will introduce sensitivity analyses and model diagnostic methodology and preliminary results for the reference case model run(s). In contrast, the previous Assessment Webinar IV Schedule of Events (week of June 1) included the following: Finalize sensitivity analyses and projections.*
5) *Move the following tasks to the Assessment Webinar V AP Schedule of Events. The AP Lead Analyst will finalize any changes to the model indicated by the sensitivity analyses and diagnostics and will present results of the finalized reference case model run(s) to the AP Group for their review. The AP Lead Analyst will introduce projection methodology to the AP Group for their review. In contrast, the previous Assessment Webinar V Schedule of Events (week of June 22) included the following: Review and finalize any changes to model and projections.*
6) *Add an additional Assessment Webinar to the AP Schedule of Events to include the following tasks. The AP Lead Analyst will present projection results for finalized reference case model run(s) to the AP Group for their review and finalize any changes to the projections.*

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The SEDAR 65 Assessment Process Schedule of Events (AP timeline) was also modified based on consensus comments and recommendations of the AP Panel in order to accommodate the development of sensitivity analyses robust to uncertainty in indices of relative abundance. The AP Panel adopted the following decisions during the Pre-assessment Webinar.

1) *Move the following tasks to the Assessment Webinar II. The AP Lead Analyst will adapt the base case model to develop reference case model run(s) (as alternate states of nature) which are robust to the major uncertainties identified in the indices of relative abundance, and present preliminary results to the AP Group for their review. In contrast, the previous Assessment Webinar I Schedule of Events (week of April 13) included the following. Finalize uncertainty analyses and reference case model run(s).*
2) *Move the following tasks to the Assessment Webinar III (week of May 4, 2020). The AP Lead Analyst will finalize reference case model run(s) which are robust to the indices of abundance and present results to the AP Group for their review. The AP Lead Analyst will introduce sensitivity analyses and model diagnostic methodology and preliminary results for the reference case model run(s). In contrast, the previous Assessment Webinar III Schedule of Events (week of May 4) included the following: Introduce and discuss sensitivity analyses (model diagnostics) and projections.*

1.2.2. Statements Addressing Term of Reference 2.

Develop population assessment models that are compatible with available data and document input data, model assumptions and configuration, and equations for each model considered.

1) *The AP Panel agreed that Stock Synthesis was the most complete modelling platform for the available data, and that it was not necessary to evaluate other stock assessment modelling platforms.*

1.2.3. Statements Addressing Term of Reference 3.

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Provide estimates of stock population parameters: a) Include fishing mortality, abundance, biomass, selectivity, stock-recruitment relationship (if applicable), and other parameters as necessary to describe the population; and b) Include appropriate measures of precision for parameter estimates.

Stock population parameter estimates are provided in Section 3.4. Parameter estimates and their associated measures of asymptotic uncertainty are provided in Section 3.4.1.4. Selectivity methods are provided in Section 3.3.1.6 and selectivity results are reported in Section 3.4.1.5. Predicted log recruitment deviations and predicted age-0 recruits obtained from the stock-recruitment relationship are provided in Section 3.4.1.6. Estimates of annual fishing mortality rates are provided in Section 3.4.2. Estimates of stock biomass, total and spawning stock fecundity (a proxy for female spawning biomass), are provided in Section 3.4.3.

1.2.4. Statements Addressing Term of Reference 4.

Characterize uncertainty in the assessment and estimated values: a) Consider uncertainty in input data, modeling approach, and model configuration; b) Consider and include other sources as appropriate for this assessment; c) Provide appropriate measures of model performance, reliability, and 'goodness of fit'; and d) Provide measures of uncertainty for estimated parameters.

Input data uncertainty tuning methods and results (data weighting) are provided in Section 3.3.1.7. Recruitment deviation variability and the associated recruitment deviation bias adjustment ramp are provided in Section 3.3.1.8. Measures of overall model fit are reported in Section 3.4.1. Model convergence and diagnostics are provided in Section 3.4.1.1. Model fits to abundance indices and the associated catchability estimates are provided in Section 3.4.1.2. Model fits to length composition data are provided in Section 3.4.1.3. Robustness of model results to uncertainty in the input data, the modeling approach, and the model configuration are evaluated with sensitivity analysis in Section 3.4.4. Due to time constraints, only one sensitivity analysis was completed in time for review by the AP panel (logistic selectivity). Results of the

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logistic sensitivity analysis are compared to results of the base model configuration in Section 3.4.4.1.

1.2.5. Statements Addressing Terms of Reference 5.

Provide estimates of yield and productivity: 5.a) Include yield-per-recruit, spawner-per-recruit, and stock-recruitment models.

Stock recruit productivity (Section 3.3.1.3) and natural mortality (Section 3.3.1.5) are input as fixed parameters to take advantage of the biological information available (as described in Section 2.3 above).

1.2.6. Statements Addressing Terms of Reference 6.

Provide estimates of population benchmarks or management criteria to include associated uncertainty, with available data, applicable FMPs, proposed FMPs and Amendments, other ongoing or proposed management programs, and National Standards: a) Evaluate existing or proposed management criteria as specified in the management summary; and b) Recommend and define proxy values when necessary, and provide appropriate justification.

Estimates of benchmark and biological reference points (MSY, MSST, F_{MSY}, SSF_{MSY}, SSF/SSF_{MSY}, F/F_{MSY}) are provided in Section 3.4.5.

1.2.7. Statements Addressing Terms of Reference 7.

Provide declarations of stock status relative to management benchmarks or alternative data poor approaches if necessary.

Stock status based on the status determination criteria is provided in Section 3.4.5.

1.2.8. Statements Addressing Terms of Reference 8.

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Provide uncertainty distributions of proposed reference points and stock status metrics that provide the values indicated in the management specifications. Include probability density functions for biological reference point estimates and population metrics (e.g., biomass and exploitation) used to evaluate stock status.

Time series trajectories of the two stock status metrics (SSF/SSFMSY, F/FMSY) are provided with approximate 95% asymptotic confidence intervals in Section 3.4.5 and associated figures.

Markov Chain Monte Carlo (MCMC) was proposed during the AP for use to obtain MCMC credibility intervals for some estimated and derived parameters. However, MCMC credibility intervals are not available for this report because of time constraints resulting from the 2019 Covid-19 crisis including a lack of IT resources necessary to perform MCMC analyses while on mandatory telework.

1.2.9. Statements Addressing Terms of Reference 9.

Project future stock conditions and develop rebuilding schedules, if warranted. Provide the estimated generation time for the stock.

Projections for the Stock Synthesis base model configuration are provided separately as a Review Workshop document. The projection methods follow those from a previous Atlantic HMS sandbar shark update assessment conducted in Stock Synthesis.

Markov Chain Monte Carlo, MCMC, projections were proposed during the AP. However, MCMC projections are not available for this report because of time constraints resulting from the 2019 Covid-19 crisis including a lack of IT resources necessary to perform MCMC analyses while on mandatory telework.

1.2.10. Statements Addressing Terms of Reference 10.

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Provide recommendations for future research and data collection.

Recommendations for future research and data collection are provided in Section 3.4.8.

1.2.11. Statements Addressing Terms of Reference 11.

Complete the Assessment Process (AP) Report in accordance with project schedule deadlines.
The completed AP Report is provided as Section III of this SEDAR 65 Stock Assessment Report.

1.3. Additional Panel Comments

The AP Panel adopted the following decisions regarding commercial landings (Section 2.1.1) during the Pre-assessment Webinar and assessment Webinar I.

1) *Input commercial landings in the assessment model in their native format (weight).*
2) *Convert commercial landings from pounds dressed weight (lb. dw) to kilograms whole weight using the conversion ratio for dressed weight (dw) to whole weight (ww) of ww = 1.39*dw for use in the assessment model.*
3) *Aggregate commercial catch data into fleets for use in Stock Synthesis based on a review of the available length composition data.*

The AP Panel adopted the following decisions regarding recreational catch (section 2.1.2) during the Pre-assessment Webinar and Assessment Webinar I.

1) *Input recreational catch and discards in the assessment model in their native format (numbers).*
2) *Aggregate recreational catch and discard time series into "fleets" for input in the stock assessment model based on a review of the available length composition data.*

The AP Panel adopted the following decisions regarding commercial discards (Section 2.1.3) during the Pre-assessment Webinar and Assessment Webinar I.

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1) *The AP Analytical Team will implement the DW recommendations for continued analyses of commercial dead discard and commercial live discard mortality, present results in an AP working paper, and present results to the AP Group for their review during Assessment Webinar I.*
2) *Input commercial discards in the stock assessment model in their native format (numbers).*
3) *Aggregate commercial discard time series into "fleets" for input in the stock assessment model sensitivity analyses based on a review of the available length composition data.*

   F5 (Com-LL Discard) = Bottom longlines,
   F6 (Com-GN Discard) = Gillnets.
4) *Use multi-year block averaging of the discard ratios to create discard estimates for commercial gillnet and bottom longline fisheries (McCandless 2020, their Table 1) for use in Stock Synthesis model sensitivity analyses.*

The AP Panel adopted the following decisions regarding commercial Low Catch and High Catch scenarios (Sections 2.1.4 and 3.2.4) during Assessment Webinars II and V.

1) *Evaluate the low and high catch scenarios presented during Assessment Webinars II and V as sensitivity analyses.*

The AP Panel adopted the following decisions regarding indices of abundance (Section 2.2.1) during the Pre-assessment Webinar.

1) *Include only the VIMS robust series (1990 – 2018) in the base model. Evaluate the remaining series within sensitivity analyses, if time permits.*
2) *Include the COASTSPAN Longline series All-ages (age-0 and juveniles combined) in the base model as an index of relative abundance. Evaluate the age-0 series as a hierarchical recruitment index in sensitivity analyses. Do not include both the age-0 series and the all-ages series (age-0 and juveniles combined) in a model at the same time, because they are not independent.*

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3) *Include the COASTSPAN long gillnet and short gillnet series All-ages (age-0 and juveniles combined) in the base model as indices of relative abundance. Evaluate the age-0 series as a hierarchical recruitment index in sensitivity analyses, as discussed below. Do not include both the age-0 series and the all-ages series (age-0 and juveniles combined) in a model at the same time, because they are not independent.*

The AP Panel adopted the following decisions regarding sensitivity analyses to alternative index of abundance groupings (Section 2.2.2) during the Pre-assessment Webinar and Assessment Webinar I.

1) *Develop combined indices of abundance with Bayesian hierarchical models and with DFA (separately for age-0 and for all ages) in AP working papers. Review combined indices of abundance during Assessment Webinar I.*
2) *Evaluate the combined age-0 series as recruitment indices in sensitivity analyses. Do not include the combined age-0 series in a model with the individual age-0 series at the same time.*
3) *Bayesian hierarchical models and DFA models produced similar combined index results. Include only DFA combined indices in Stock Synthesis model sensitivity analyses due to time constraints*
4) *Include the DFA age-0 combined index in Stock Synthesis model sensitivity analyses.*
5) *Include the DFA all-ages combined index in Stock Synthesis model sensitivity analyses.*
6) *Include hierarchical cluster analysis and cross-correlations proposed groupings in Stock Synthesis model sensitivity analyses.*

The AP Panel adopted the following decisions regarding sensitivity analyses to alternative index of abundance groupings (Section 3.2.6) during Assessment Webinar V.

1) *Preliminary model fits to the DFA age-0 index (presented during Assessment Webinar V) resulted in a good fit to the index, but the model failed to converge within reasonable parameter bounds. Preliminary model fits to the DFA all-age index (presented during Assessment Webinar V) resulted in a poor fit to the index and also included the same*

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length data within multiple fleets. Consequently, a recommendation was made in coordination with the AP Panel during Assessment Webinar V to exclude DFA from further sensitivity analyses within this assessment.

2) *A pragmatic decision was made in coordination with the AP Panel during Assessment Webinar V to conduct a single abundance index sensitivity analysis that removed the two relative abundance indices S4 (NEFSC-BLL) and S7 (SCDNR-DL), which had a relatively poor fit in preliminary runs of the Stock Synthesis reference case model (as described in the stock assessment results Section 3.4.1.2 below).*

The AP Panel adopted the following decisions regarding life history inputs (Sections 2.3 and 3.2.7) during the Pre-assessment Webinar and Assessment Webinar I.

1) *The AP Panel agreed that stock recruit steepness and natural mortality for use in the stock assessment model will be based on demographic analyses developed from the life history data presented during the DW as summarized in the DW report. The demographic analyses will be provided in an AP working paper, and presented to the combined DW Panel and AP Panel for their review during Assessment Webinar I.*
2) *The combined DW and AP Panels discussed the need to look at Stock Synthesis model sensitivity to different scenarios for steepness but noted that the mean steepness value of 0.4 obtained from the deterministic methods is justified for the reference case.*
3) *The combined DW and AP Panels discussed that the lower and upper values of the range of steepness obtained with the deterministic methods (0.32 and 0.52) are empirically justifiable but that there is still a need to double check the credibility of the different scenarios after implementation within a Stock Synthesis population dynamics model sensitivity analysis.*

The AP Panel adopted the following decisions regarding length composition (Section 2.4) during the Pre-assessment Webinar and assessment Webinar I.

1) *Evaluate stock assessment model sensitivity to alternative length based selectivity for catch and discards, based on the available length compositions.*

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2) *Evaluate stock assessment model sensitivity to alternative measures of length frequency sample size for input in the stock assessment model such as number of unique sets/trips/hauls/tows etc. with a length measurement in addition to the total number of lengths measured.*
3) *Develop sensitivity analyses of commercial bottom longline length composition to the relatively smaller length composition observed in the size composition of discarded versus kept sharks.*
4) *Evaluate the large length composition data set of unknown measurement type (n = 1,353) available for commercial gillnet catch.*
5) *Develop sensitivity analyses of recreational length composition to the significantly smaller mean length observed in the MRIP and SRHS survey inshore area and shore-based fishing mode, e.g., as described above.*

The AP Panel adopted the following decisions regarding the stock assessment modelling platform (Section 3) during the Pre-assessment Webinar and Assessment Webinar I.

1) *An integrated modeling approach, Stock Synthesis, will be implemented to utilize the available data, which include catch, CPUE, length composition, and life history.*

The AP Panel adopted the following decisions regarding selectivity (Section 3.3.1.6) during the Pre-assessment Webinar and Assessment Webinar II.

1) *Fit an asymptotic selectivity curve to commercial catch length composition obtained from the BLLOP (both UF and SEFSC). E.g., using the double normal selectivity function in Stock Synthesis, fix initial selectivity (the smallest length bin) equal to zero, fix final selectivity (the largest length bin) equal to one, and estimate the peak and ascending width.*
2) *Allow for the possibility of dome-shaped selectivity for commercial catch length composition obtained from the GNOP. E.g., using the double normal selectivity function in Stock Synthesis, fix (or estimate) initial selectivity slightly larger than zero, estimate the peak, ascending width, descending width, and final selectivity.*

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3) *Allow for the possibility of dome-shaped selectivity for recreational catch length composition obtained from MRIP and SRHS. E.g., using the double normal selectivity function in Stock Synthesis, fix (or estimate) initial and final selectivity slightly above zero, and estimate the peak, ascending width, and descending width and final selectivity.*
4) *Fit an asymptotic selectivity curve to recreational catch length composition obtained for SCDNR Shore sensitivity analysis (if included in a sensitivity analysis). E.g., using the double normal selectivity function in Stock Synthesis, fix (or estimate) initial selectivity slightly above zero, fix final selectivity equal one, and estimate the peak and ascending width.*
5) *Fit an asymptotic selectivity curve for survey length composition obtained from NEFSC BLL and SCDNR DL. E.g., as described above.*
6) *Allow for the possibility of dome-shaped selectivity for survey length composition obtained from VIMS BLL, SEAMAP BLL, SCDNR-RD BLL, COAST BLL (All-age and Age-0), COAST GNL (All-age and Age-0), and COAST GNS (Age-0). E.g., as described above.*
7) *Calculate preliminary selectivity curve for the DFA combined indices (both All-ages and Age-0) as a weighted average of selectivity obtained for each survey, with weights equal to the factor loadings obtained from the DFA analysis.*
8) *Calculate preliminary selectivity curve for the hierarchical Age-0 combined index as average of selectivity obtained each survey*

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2. Data Review and Update

2.1. Catches

2.1.1. Commercial Landings

Commercial landings of blacktip sharks in the U.S. Atlantic were obtained from the DW for the period 1983 – 2018 in weight (pounds dressed weight; lb. dw; **Table 2.1**). Commercial landings of blacktip sharks in the U.S. Atlantic were converted to kilograms whole weight (kg ww) using a conversion ratio for dressed weight (dw) to whole weight (ww) of ww = 1.39*dw (**Table 2.2**). The commercial landings time series (**Table 2.2**) were kept in their native format (weight), converted to units of metric tons (1 mt = 1,000 kg), and aggregated into three fleets (F1 – F3) for use in the stock assessment model:

F1 (Com-LL Kept) = Bottom longlines;
F2 (Com-GN Kept) = Gillnets; and
F3 (Com-Other Kept) = Other gears + Unreported commercial catches.

The total proportions of landings in weight for bottom longline, gillnets, and other gears were 24%, 19%, and 4%, respectively (**Tables 2.1** and **2.2)**.

2.1.2. Recreational Catch

Recreational catches of blacktip sharks in the U.S. Atlantic were obtained from the DW for the period 1981 – 2018 in numbers (**Table 2.3**). The smoothed annual recreational catch estimates of blacktip sharks in the Atlantic were computed as the sum of type A (number of fish killed or kept seen by the interviewer), type B1 (number of fish killed or kept reported to the interviewer by the angler), and type B2 (number of fish released alive reported by the fisher; B2-Live). The data

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were smoothed as described in DW recommendations and decisions regarding blacktip shark recreational catch estimation as summarized in the DW report.

Annual recreational type B2 catch estimates of blacktip sharks in the Atlantic were multiplied by an overall post-release mortality rate of 18.5% for hook and line recreational fisheries to obtain the number of fish released alive, reported by the fisher, that were estimated to have died (B2-Dead; **Table 2.3**). The post-release mortality rate was obtained from the DW recommendations and decisions regarding blacktip shark recreational catch post release mortality estimation as summarized in the DW report.

	Estimate	Lower 95% CI	Upper 95% CI
Recreational	18.5%	10.8%	28.7%

The recreational catch time series (**Table 2.3**) were kept in their native format (numbers), converted to units of thousands, and aggregated into one fleet (F4) for use in the stock assessment model:

F4 (Recreational) = Recreational (A+B1) + Recreational (B2-dead).

The total proportions of landings in numbers for types A + B1 recreational catch and type B2-dead recreational catch were 31% and 53%, respectively (**Table 2.3**).

2.1.3. Commercial Discards

Commercial discards were not included in the reference case model because of uncertainty in bycatch estimation, as described below. Commercial discards were included within proposed sensitivity analyses, as described below.

Bycatch estimation of commercial dead and live discards of blacktip sharks in the U.S. Atlantic was considered to be unreliable during the DW, and the DW recommended against using the bycatch estimates in the base model. The DW recommendations and decisions regarding blacktip shark commercial bycatch estimation (dead and live discards) are summarized below.

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1) *Do not include the three estimates of dead discards (southeast longline, southeast gillnet, and northeast gillnet) in the base run. Include all three estimates of dead discards in a sensitivity run.*
2) *Do not include the three estimates of live discards (southeast longline, southeast gillnet, and northeast gillnet) in the base run. Include all three estimates of live discards in a sensitivity run.*
3) *Use a post-release live discard mortality rate of 31% for commercial gillnets (with a 95% CI of 8.7%-44.4%) and 44.2% for bottom longlines (with a binomial 95% CI of 34.0%-54.8%)*

	Estimate	*Lower 95% CL*	*Upper 95% CL*
Gillnet	*31%*	*8.7%*	*44.4%*
Demersal Longline	*44.2%*	*34.0%*	*54.8%*

The following alternative scenarios were identified during the DW as possible examples for the use of the uncertain bycatch estimation in sensitivity model runs.

1) *Use running average to smooth annual bycatch estimates.*
2) *Use multi-year-block average bycatch estimates to replace annual bycatch estimates. The defined multi-year-block should be consistent with major management changes.*
3) *Use multi-year-block average estimated CPUEs, but using censored annual logbook data or dealer landing data to estimate bycatch. In this case, the interannual variability of bycatch estimates is driven by interannual variability in effort from the logbook data, or in landing data from dealers.*

The AP Analytical Team implemented the DW recommendations for continued analyses of commercial discard estimates (both live and dead) from commercial gillnet and longline fisheries. Results were presented to the Assessment Webinar I Panel in SEDAR65-AW06 (McCandless et al. 2020). The working document authors recommended the use of multi-year block averaging of the discard ratios to create discard estimates (McCandless et al. 2020, their Tables 1 – 3; **Table 2.4**). The estimated annual number of live shark discards in commercial gillnet and bottom longline fisheries was multiplied by the DW recommended post release live-

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discard mortality rate estimates of 31% and 44.2%, respectively, in order to obtain post release mortality (PRM) estimates for live discards in the commercial gillnet and bottom longline fisheries (**Table 2.4**) for use in Stock Synthesis sensitivity model runs.

2.1.4. Low and High Catch Scenarios

The following changes were made to the base input data (**Tables 2.2** and **2.3**) in order to achieve the Low Catch scenario and the High Catch scenario. The changes were presented to the AP Panel during Assessment Webinar II and are summarized in **Table 2.5**. The low catch scenario (**Table 2.5**) used the annual percent standard error estimates (-1PSEs) available for both the A+B1 and B2 recreational time series for the years 1981 – 2018. The recreational post-release mortality rate lower 95% CL of 10.8% (vs. 18.5% in reference case) was applied to the -1PSE of B2. The resulting values used in the Low Catch scenario are provided in **Table 2.6**.

In contrast, the high catch scenario (**Table 2.5**) used the annual +1PSEs available for both the A+B1 and B2 recreational time series for the years 1981 – 2018. The recreational post-release mortality rate upper 95% CL of 28.7% (vs. 18.5% in reference case) was applied to the +1PSE of B2. The high catch scenario also included estimates of both commercial dead discards and commercial live discard post-release mortality (**Table 2.4)** (converted to annual discard weight vs. no discards in reference case). The high catch scenario included a post-release mortality rate of 54.8% for bottom longline (vs. 44.2% in **Table 2.4**) and 44.4% for gillnets (vs. 31% in **Table 2.4**). The high catch scenario also used a dressed weight to whole weight conversion ratio of 2.0 (vs. 1.39 in reference case). The resulting values used in the High Catch scenario are provided in **Table 2.7**.

2.2. Indices of Abundance

2.2.1. Indices of Abundance Recommended by the DW

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All indices of abundance recommended by the DW for use in the stock assessment model are described in the DW report and the associated DW working papers and are summarized here in **Table 2.8**. Unless noted otherwise below, all indices were standardized using generalized linear models in a two-step delta-lognormal approach that modeled the proportion of positive catch with a binomial error distribution separately from the positive catch, which was modeled using a lognormal distribution as described in the associated DW working papers identified below. The SEDAR65-DW papers identified below are referenced in section 1.4 of the DW (List of Data Workshop Working Papers).

Two fishery-dependent series were recommended by the DW from the Southeast Fisheries Science Center (SEFSC) Shark Bottom Longline Observer Program (SEDAR65-DW17). The first was obtained from the shark bottom longline fishery (1994 – 2007). The second was obtained from the shark research fishery (2008 – 2018).

Three fishery-independent series were recommended by the DW from the Virginia Shark Monitoring and Assessment Program (SEDAR65-DW05). The DW recommended that three alternative time series be developed from this data for potential use in the stock assessment: 1) the entire time series regardless of sample size (1974 – 2018); 2) a truncated time series to match the year when the catch series begins (1981 – 2018); and 3) the time series which would be considered to be the most robust by the working paper author in regards to sampling (1990 – 2018).

One fishery-independent series was recommended by the DW from the NOAA Fisheries Northeast Fisheries Science Center Bottom Longline Survey (SEDAR65-DW09). The series occurred intermittently between the years 1996 – 2018.

Two series were recommended by the DW from fishery-independent longline surveys conducted by the South Carolina Department of Natural Resources (SCDNR) (SEDAR65-DW11). The first series was obtained from the SCDNR Southeast Area Monitoring and Assessment Program (SEAMAP) Longline Survey (2007 – 2018). The second series was obtained from the SCDNR

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Red Drum Longline Survey (1996 – 2006). The SEAMAP survey replaced the prior red drum survey and was developed to increase the geographical and seasonal coverage and move from a fixed-station single species survey to a random-stratified multispecies survey.

One series was recommended by the DW from the fishery-independent drumline survey conducted by SCDNR (SEDAR65-DW21). The survey occurred during the years 2013 – 2018 and sampled mostly large juveniles and adults. The series was standardized using only a binomial model of standardized presence/absence because of the use of a single hook fished on each drum line.

Two series were recommended by the DW from the fishery-independent Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) longline survey (SEDAR65-DW08). The survey occurred during the years 2005 – 2018 and sampled mostly age-0 and some juveniles in state estuaries and nearshore waters. The first series included only age-0 sharks, based on an assumed cutoff length at age-0. The second series included all-ages sampled (age-0 and juveniles combined). The DW noted that the age-0 series could be used as a recruitment index for the stock assessment. The DW noted that both the age-0 and all-ages (age-0 and juveniles combined) time series should not be included in a model at the same time because they are based on the same data set and would therefore not be independent.

Three series were recommended by the DW from the fishery-independent COASTSPAN Long and Short Gillnet Surveys (SEDAR65-DW07 and SEDAR65-DW10). Two series were obtained from the long gillnet survey (230 m x 3 m net with 10.3 cm stretched mesh) during the years 2001 – 2018, which sampled mostly age-0 and some juveniles in several estuaries within South Carolina. The first series included only age-0 sharks, based on an assumed cutoff length at age-0. The second included all-ages sampled (age-0 and juveniles combined). The DW noted a peak in 2013 in the standardized indices obtained from the long gillnet survey that was also seen in the SCDNR SEAMAP longline survey (SEDAR65-WP11), and, although not as pronounced, in the COASTSPAN longline survey (SEDAR65-WP08). A small gillnet survey (45 m x 3 m with 10.3 cm stretched mesh) was added in 2006 to supplement large gillnet sampling and facilitate

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sampling in geographically restricted areas that were too small for the large gillnet. One series (age-0) was obtained from the short gillnet survey during the years 2006 – 2018.

2.2.2. Sensitivity Analyses to Alternative Index of Abundance Groupings

Combined indices of abundance were developed for use in stock assessment model sensitivity analyses during the AP using both Bayesian hierarchical models and Dynamic Factor Analysis (DFA) separately for age-0 and for All-ages. Indices of abundance for sensitivity analyses were developed based on DW recommendations and decisions regarding alternative groupings of blacktip shark indices of abundance for use in stock assessment model (Stock Synthesis) sensitivity analyses, as summarized below. The DW recommended breaking the indices of abundance into two groups and then exploring the utility of combining multiple indices within each group separately using both a Bayesian hierarchical model (Conn 2010) and DFA (Peterson et al. 2017). The first group included indices predominantly composed of age-0 (recruits) (**Table 2.8,** R1-R3): R1 is the COASTSPAN Longline Age-0 index (SEDAR65-DW08); R2 is the COASTSPAN Gillnet Long Net Age-0 index (SEDAR65-DW07); and R3 is the SCDNR Gillnet Short Net Age-0 index (SEDAR65-DW10). The second group included indices composed primarily of age-0 but also included some older individuals (All-ages; **Table 2.8**, S1-S6): S1 is the Shark Bottom Longline Fishery index (SEDAR65-DW17); S2 is the Shark Research Fishery index (SEDAR65-DW17); S3 is the VIMS Robust Series index (SEDAR65-DW05); S4 is the NEFSC Bottom Longline index (SEDAR65-DW09); S5 is the SCDNR SEAMAP Longline Survey index (SEDAR65-DW11); and S6 is the SCDNR Red Drum Survey index (SEDAR65-DW11). The All-ages group excluded drumline (SEDAR65-DW21; **Table 2.8)**, which was standardized using a different approach from the other indices.

In response to DW recommendations, several AP working documents were produced that analyzed alternative abundance index groupings for use in sensitivity analyses. A combined hierarchical age-0 index and associated coefficient of variation (CV) were provided in SEDAR65-AW01 (McCandless 2020). A combined DFA age-0 index and a combined DFA all-age index along with associated measures of uncertainty were provided in SEDAR65-AW03

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(Latour and Peterson 2020). Additionally, hierarchical cluster analysis and cross-correlations were evaluated in SEDAR65-AW04 (Courtney 2020) in order to identify potential abundance index groupings for use in sensitivity analyses. The alternative abundance index groupings identified using these methods are summarized below.

Both the hierarchical and DFA analyses of age-0 indices produced similar results, as discussed below. Consequently, a decision was made in coordination with the AP Panel that sensitivity analysis to the hierarchical analysis of age-0 indices would not be implemented in the Stock Assessment. In addition, index groupings identified in the hierarchical cluster analysis and cross-correlations of accepted indices were not implemented in sensitivity analyses due to time constraints of the AP. Instead, a pragmatic decision was made in coordination with the AP Panel to conduct a single abundance index sensitivity analysis which removed two indices (S4-NEFSC BLL and S7-SCDNR Drumline) which had a relatively poor fit in preliminary runs of the Stock Synthesis reference case model (as described in the Stock Assessment section below).

Hierarchical Analysis of Age-0 Indices (SEDAR65-AW01)

McCandless (2020) analyzed the U.S. Atlantic blacktip shark age-0 indices of abundance recommended for use during the SEDAR 65 DW (**Table 2.8**) for a hierarchical trend. Results were presented during Assessment Webinar I with both the DW panel and AP in attendance. The age-0 indices (standardized to their means) and coefficients of variation were used in hierarchical analysis to estimate individual index process error, assuming a lognormal error structure, and a hierarchical index of abundance. Hierarchical analysis of the Atlantic blacktip shark recruitment indices resulted in a slight increasing trend in abundance across years with a notable peak in 2013 and little variation in process error across the individual surveys. The combined hierarchical age-0 index and associated CV are provided in McCandless (2020, their Table 2 and Figures 1 and 2) and reproduced here in **Table 2.9**. More details of the methods and results are provided in McCandless (2020).

DFA of Age-0 Indices (SEDAR65-AW03)

Latour and Peterson (2020) analyzed the combined trend for U.S. Atlantic blacktip shark age-0 indices of abundance recommended for use during the SEDAR 65 DW (**Table 2.8**) with DFA.

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Results were presented during Assessment Webinar I with both the DW panel and AP in attendance. A single common trend was estimated and each time-series, assumed to be independent. The COASTPAN longline survey index was relatively more influential than either the SCDNR COASTPAN long or short gillnet indices in the resulting combined DFA index. The DFA age-0 combined model converged successfully and resulted in a common trend that generally increased from 2001 – 2010, but decreased thereafter (Latour and Peterson 2020, their Figure 2a) in a pattern similar to that resulting from the hierarchical analysis described above. The back-transformed common trend resulting from the DFA model fitted to the age-0 Atlantic blacktip shark time-series of relative abundance along with associated uncertainty is provided in Latour and Peterson (2020, their Figure 3) and reproduced here in **Table 2.10.** More details of the DFA methods and results are provided in Latour and Peterson (2020).

DFA of All-ages Indices (SEDAR65-AW03)

Latour and Peterson (2020) analyzed the combined trend for U.S. Atlantic blacktip shark all-ages indices of abundance recommended for use during the SEDAR 65 DW (**Table 2.8**) with DFA, excluding drumline. Results were presented during Assessment Webinar I with both the DW panel and AP in attendance. A single common trend was estimated and each time-series was assumed to be independent. The DFA all-ages combined model converged successfully and resulted in a common trend that generally increased but fluctuated (Latour and Peterson 2020, their Figure 4). In general, the SEAMAP Longline and Shark Bottom Longline Observer indices, as described above, were relatively more influential than the other indices in the resulting DFA all-ages combined index, however factor loadings (a measure of relative influence) were low for all indices and fits of the common trend to the most influential indices were marginal. The back-transformed common trend resulting from the DFA model fitted to the all-ages Atlantic blacktip shark time-series of relative abundance along with associated uncertainty are provided in Latour and Peterson (2020, their Figure 5) and reproduced here in **Table 2.11.** More details of the methods and results are provided in Latour and Peterson (2020).

Hierarchical Cluster Analysis and Cross-correlations of Accepted Indices (SEDAR65-AW04)

Courtney (2020) analyzed the U.S. Atlantic blacktip shark indices of abundance recommended for use during the SEDAR 65 DW with hierarchical cluster analysis and cross-correlations.

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Results were presented during Assessment Webinar I with both the DW panel and AP in attendance. Indices with conflicting information were identified. Consequently, it may be reasonable to assume that the conflicting indices reflect alternative hypotheses about states of nature and to run separate stock assessment model sensitivity analyses for single or sets of indices identified that represent a common hypothesis. However, some index groupings identified with hierarchical cluster analysis and cross-correlations were suspect because they may have been influenced by highly positively and negatively correlated series with low sample size (n=2), even after adjusting the data set to remove some series with low sample size and to remove outliers. Similarly, the groupings identified for age-0 indices were sensitive to removal of the outlier year 2013. Consequently, the following index groupings were recommended based on robust Spearman's correlation and associated hierarchical cluster analyses: 1) The series S4 on its own; 2) series S1-S10 without S4**;** 3) Series S1, S3; and 4) Series (S6, S7, S2, S5). More details of the methods and results are provided in Courtney (2020).

2.3. Life History Inputs

Life history data used in the stock assessment model were obtained directly from the DW report (reproduced here in **Table 2.12**) and were unchanged for use in the stock assessment unless noted otherwise below.

Estimates of Vital Rates (SEDAR65-AW02)

Cortés (2020) estimated vital rates and population dynamics parameters including Beverton-Holt stock-recruitment steepness (*h*) for the North Atlantic population of blacktip sharks based on biological information provided in the SEDAR 65 Data Workshop Report for use as inputs into Stock Synthesis. Results were presented during Assessment Webinar I with both the DW Panel and the AP Panel in attendance. Four age-aggregated and two age-structured methods (Euler-Lotka equation and Leslie matrix) were used to obtain deterministic parameter values and their plausible range. Additionally, Monte Carlo simulation of the Leslie matrix approach was used to characterize parameter value uncertainty. The author noted that parameter values obtained from the uncertainty analysis were likely to have been underestimated because the life history data

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used in the simulation were obtained under stock conditions not likely to be reflective of ideal conditions needed for estimation of maximum stock productivity (i.e., very low population size after exploitation has ceased). In contrast, the author noted that the mean steepness value of 0.4 inferred from the deterministic methods using the theoretical longevity was similar to that obtained from published values of the maximum lifetime reproductive rate for 33 shark stock assessments, which corresponded to steepness values ranging from 0.20 to 0.83 with a mean of 0.46 (SD = 0.20). The author noted that the lower and upper values of the range obtained with the deterministic methods (0.32 and 0.52) could be useful to inform plausible low and high productivity states of nature, respectively. The author suggested that the minimum estimates of instantaneous natural mortality rates corresponding to the deterministic age-structured Euler-Lotka/Leslie Matrix approaches be used as inputs for the Stock Synthesis reference case, reproduced here in **Table 2.13** separately for females and males using the same methods. Additionally, the author noted that the estimates of generation time obtained (median, LCL, and UCL of 12.5, 11.2, and 20.1, respectively) could be useful to inform the time horizon for projections. More details of the methods and results are provided in Cortés (2020).

The author also provided the AP Analytical Team with mean estimates of instantaneous natural mortality rates corresponding to the deterministic age-structured Euler-Lotka/Leslie Matrix approaches for use in Stock Synthesis model sensitivity analyses (**Table 2.14)** separately for females and males using the same methods.

2.4. Length Composition Data

Atlantic blacktip shark length composition data submitted for use in the SEDAR 65 stock assessment were reviewed in SEDAR65-AW05 (Kroetz and Courtney 2020) and SEDAR65-AW07 (Courtney et al. 2020) and presented during Assessment Webinars I and IV. Detailed methods and results are provided in Kroetz and Courtney (2020) and Courtney et al. (2020). Length composition data available for commercial and recreational gear types were aggregated into 'fleets' with similar length composition based on a review of the available length

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compositions, as described below. Fits to length composition data by fleet are provided separately in the Stock Assessment section of the report.

2.4.1. Commercial Bottom Longline Length Composition

Length composition data available for the commercial bottom longline gear type were aggregated into a single fleet, which was assumed to capture predominantly mature blacktip sharks. Commercial bottom longline length composition was obtained from the Shark Bottom Longline Observer Program (SBLOP) conducted by the University of Florida (UF 1994-2005, n = 1,699) and the Southeast Fisheries Science Center (SEFSC) Panama City Lab (2005-2018, n = 3,708) (Kroetz and Courtney 2020, their Table 1). Predominantly mature sharks were observed in the fishery-dependent bottom longline length composition data obtained from both UF (1994-2005) and SEFSC (2005-2018) (Kroetz and Courtney 2020, their Appendix A).

During Assessment Webinar I, a potential sensitivity analysis was identified, but not implemented, to evaluate the relatively smaller size of discarded versus kept Atlantic blacktip sharks observed in the SBLOP length composition data. As noted above, predominantly mature sharks were observed in the SBLOP length composition data. However, an examination of the SBLOP length composition data by fate (kept versus discarded) resulted in a different distribution in length for sharks discarded dead (relatively smaller) compared to the sharks that were kept (predominantly mature) (Kroetz and Courtney 2020, their Appendix C). A plausible hypothesis based on this result is that kept vs discarded blacktip sharks may have a different length composition. However, the potential sensitivity analysis was not implemented due to time constraints of the AP.

2.4.2. Commercial Gillnet Length Composition

Length composition data available for the commercial gillnet gear type were aggregated into a single fleet, which was assumed to capture predominantly mature blacktip sharks prior to 2006

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and predominantly immature blacktip sharks after 2006. Commercial gillnet length composition data were obtained from the SEFSC Panama City Lab Gillnet Observer Program (GNOP) 1999-2018. However, the SEFSC-GNOP length composition sample size was very low (n = 124; Kroetz and Courtney 2020, their Table 1 and Appendix A). Consequently, a second data set (n = 1,353) was examined of unknown measurement type observed in fishery-dependent sampling of the gillnet fishery available from the GNOP (Kroetz and Courtney 2020, their Appendix B). These data were not included in the original analyses because the measurement type (direct or estimated) was not specified. The size composition of unknown measurement type (Kroetz and Courtney 2020, their Appendix B) spanned a relatively wider range than those directly measured for fork length (GNOP 1999-2018, n = 124; Kroetz and Courtney 2020, their Appendix A). The size composition of unknown measurement type also differed for males and females.

Atlantic blacktip shark fork length (FL cm straight) data obtained from the SEFSC-GNOP 1999-2018 (n = 1477) were updated in SEDAR65-AW07 (Courtney et al. 2020) to include measured lengths, FL cm straight, previously excluded as 'unknown' measurements (Kroetz and Courtney 2020) due to exclusion of a field in the database. This field describes the length measurement taken as directed or estimated, which was added to the database beginning 2010. Before this year, directed lengths were taken and present in the database, however the field describing the length type did not exist.

Inter-annual variation was identified in both gillnet gear type and mean length within the updated length composition data available from SEFSC-GNOP 1999-2018 in SEDAR65-AW07 (Courtney et al. 2020). The largest inter-annual variation occurred after the year 2006 when the proportion of measured lengths obtained from the GNOP gear type(s) recorded in the database as "GILL NETS, DRIFT, RUNAROUND" decreased and the proportion of measured lengths obtained from GNOP gear type(s) recorded in the database as "GILL NETS, SINK/ANCHOR, OTHER" increased. An examination of binned length-frequency data provided for use in the SEDAR 65 stock assessment identified that the gillnet gear type "GILL NETS, DRIFT, RUNAROUND" captured predominantly mature blacktip sharks while the gillnet gear type "GILL NETS, SINK/ANCHOR, OTHER" captured predominantly immature blacktip sharks.

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2.4.3. Recreational Length Composition

Length composition data available for the recreational gear type were aggregated into a single fleet, which was assumed to capture predominantly immature blacktip sharks. Recreational data were obtained from the recreational (A+B1) length composition data described in SEDAR65-DW19 (Cortés and Balchowsky-Baertlein 2019) and SEDAR65-AW05 (Kroetz and Courtney 2020). Predominantly immature sharks were observed in the recreational (A+B1) sampling conducted by both the Marine Recreational Information Program (MRIP 1981-2018, n = 781) and the Southeast Region Head Boat Survey (SRHS 1989-2018, n = 107) (Cortés and Balchowsky-Baertlein 2019, their Figure 8; Kroetz and Courtney 2020, their Appendix A).

During Assessment Webinars I and III, differences in the mean size at capture by recreational fishing mode were identified and discussed. However, potential sensitivity analyses identified to evaluate the effect of the observed differences in size at capture by fishing mode were not implemented due to both limitations in the recreational length composition data, as described below, and time constraints of the AP.

During Assessment Webinar I, differences in the recreational Atlantic blacktip shark mean size at capture by fishing mode were identified and discussed. The differences in size were identified in a review of the available recreational (A + B1) catch length composition data described in SEDAR65-DW19 (Cortés and Balchowsky-Baertlein 2019) and SEDAR65-AW05 (Kroetz and Courtney 2020). Fork length of Atlantic blacktip shark recreational (A + B1) catch from the MRIP and SRHS surveys differed significantly both by fishing mode ($P = 0.0001$; Cortés and Balchowsky-Baertlein 2019, their Figure 9) and by fishing area ($P < 0.0001$; Cortés and Balchowsky-Baertlein 2019, their Figure 10). Mean fork length was smaller for the shore-based fishing mode and the inshore fishing area than for other fishing modes and fishing areas. During the DW, it was noted that age-0 Atlantic blacktip sharks occur in estuaries. Consequently, a plausible hypothesis to explain the observed differences in mean size at capture by fishing mode may be that age-0 Atlantic blacktip sharks are captured more frequently in estuaries compared to other locations.

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In contrast, during Assessment Webinar I, the capture of relatively large Atlantic blacktip sharks by some shore-based anglers was also identified and discussed. The relatively large sharks were identified in a review of the shore-based recreational catch sampling (A + B1 + B2-Released Alive) conducted by South Carolina Department of Natural Resources (SCDNR 2013-2018, n = 166) (Kroetz and Courtney 2020, their Appendix A). During the DW, it was noted that mature Atlantic blacktip sharks occur along coastal beaches and that shore-based anglers participating in the SCDNR logbook sampling program were fishing along coastal beaches. Consequently, a plausible hypothesis to explain the relatively large Atlantic blacktip sharks observed in SCDNR shore-based fishing mode may be that some shore-based fishing is targeting mature Atlantic blacktip sharks along coastal beaches.

During Assessment Webinar III, Atlantic HMS staff presented a review of the available length composition data for Atlantic blacktip sharks sampled from recreational catch and identified a small (10 cm) but significant ($t = -3.62$, $p < 0.001$) difference in blacktip shark average size between targeted recreational shark trips and recreational trips that did not indicate they were targeting sharks (incidental). However, it was noted during the webinar that the length distributions of recreationally caught blacktip sharks on targeted and incidental trips largely overlapped, except that targeted trips captured proportionally fewer blacktip sharks at smaller sizes. The number of recreational trips landing large coastal sharks (LCS) increased over time, but the number of recreational trips targeting LCS remained relatively stable. It was also noted during the webinar that there has been an increase in the number of serious shore-based anglers targeting large sharks. However, these data may not be represented in the recreational sampling data because fishing occurs primarily at night and it is primarily catch and release.

A potential sensitivity analysis was identified, but not implemented, to evaluate the effect of the capture of smaller Atlantic blacktip sharks in the inshore area and shore-based fishing mode by apportioning total recreational catch (A + B1 and B2-Dead) into two fleets. The first fleet would include the capture of smaller Atlantic blacktip sharks in the inshore area and shore-based fishing mode based on the five-year moving average of the observed proportion of Atlantic blacktip shark recreational (A + B1) catch from the inshore area (42%; calculated from Cortés and Balchowsky-Baertlein 2019, their Table 6) and shore-based fishing mode (49%; calculated from

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Cortés and Balchowsky-Baertlein 2019, their Table 5). The second fleet would exclude the observed proportion of Atlantic blacktip shark recreational (A + B1) catch in the inshore area and the shore-based fishing mode, based on the proportions described above.

The potential sensitivity analysis was not implemented due to the limitations in the recreational catch length composition data, as described above, which may not accurately reflect that some shore-based anglers target relatively large sharks. In addition, time constraints of the AP precluded further analysis of the potential effect of Federal actions such as the implementation of a minimum size limit or the implementation of Federal bag limits on the resulting recreational length composition data.

2.5. References

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2.6. Tables

Table 2.1. Commercial landings of blacktip sharks in the U.S. Atlantic for the period 1983 – 2018 in weight (pounds dressed weight; lb. dw)[1] (as described in Section 2.1.1 above).

Year	Unreported commercial catches	Bottom longlines	Gillnets	Other gears
1983		117654	156572	13927
1984		235309	313144	27854
1985		352963	469716	41781
1986		546144	352931	41781
1987		175361	632155	41781
1988	95172	337384	424063	41781
1989	80892	370196	359204	41781
1990		283349	375659	41781
1991		212125	354837	491096
1992		756923	87757	234581
1993		807599	335794	99764
1994		396013	20022	33314
1995		573084	62577	41805
1996		231129	404648	24586
1997		123687	112990	11594
1998		117429	68892	9432
1999		128348	83778	9297
2000		188258	96767	7682
2001		109355	156606	5082
2002		200569	270521	13940
2003		225246	235939	12878
2004		97734	176299	11657
2005		107426	109778	5810
2006		117754	219294	4751
2007		30858	48869	2155
2008		118901	159135	4434
2009		171886	30113	38086
2010		164057	89956	17814
2011		143771	38845	7655
2012		106103	68209	40171
2013		156418	81966	25843
2014		206387	65028	10592
2015		193274	36023	528
2016		175635	70933	1907
2017		175775	42433	1753
2018		93515	29955	1661

[1] SEDAR 65 DW Report (their Table 1)

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Table 2.2. Commercial landings of blacktip sharks in the U.S. Atlantic in kilograms whole weight (kg ww) obtained using a conversion ratio for dressed weight (dw) to whole weight (ww) of ww = 1.39*dw[1] (as described in Section 2.1.1 above).

Year	Unreported commercial catches	Bottom longlines	Gillnets	Other gears
1983		74180	98718	8781
1984		148361	197436	17562
1985		222541	296153	26343
1986		344341	222521	26343
1987		110564	398570	26343
1988	60005	212719	267369	26343
1989	51002	233406	226476	26343
1990		178650	236851	26343
1991		133744	223723	309633
1992		477236	55330	147902
1993		509186	211716	62901
1994		249684	12624	21004
1995		361326	39454	26358
1996		145725	255128	15502
1997		77984	71239	7310
1998		74038	43436	5947
1999		80922	52822	5862
2000		118695	61011	4843
2001		68948	98739	3204
2002		126458	170562	8789
2003		142016	148758	8119
2004		61621	111155	7349
2005		67731	69214	3663
2006		74243	138264	2995
2007		19456	30812	1359
2008		74967	100333	2795
2009		108373	18986	24013
2010		103437	56717	11232
2011		90647	24491	4826
2012		66897	43006	25328
2013		98621	51679	16294
2014		130126	41000	6678
2015		121858	22712	333
2016		110737	44723	1202
2017		110825	26754	1105
2018		58961	18886	1047

[1] Pers. Comm. Enric Cortés

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Table 2.3. Smoothed annual recreational catch estimates of blacktip sharks in the Atlantic obtained from the DW for the period 1981 – 2018 in numbers (as described in Section 2.1.2 above): Type A (number of fish killed or kept seen by the interviewer), type B1 (number of fish killed or kept reported to the interviewer by the angler), type B2 (number of fish released alive reported by the fisher; B2-Live), and type B2 multiplied by a post-release mortality rate of 18.5% for hook and line recreational fisheries to obtain the number of fish released alive that were estimated to have died (B2-Dead).

	Recreational catch		
Year	**A + B1**	**B2-Live**	**B2-Dead**
1981	32377	240928	44572
1982	32377	240928	44572
1983	39732	139260	25763
1984	66390	131616	24349
1985	61982	75572	13981
1986	65904	34550	6392
1987	27389	32797	6068
1988	29796	29377	5435
1989	20287	20039	3707
1990	45243	23435	4335
1991	46337	132935	24593
1992	50757	158291	29284
1993	28802	405933	75098
1994	25981	328840	60835
1995	38205	353537	65404
1996	38119	141069	26098
1997	68601	273974	50685
1998	64371	258944	47905
1999	63178	327078	60509
2000	31807	315514	58370
2001	18503	383689	70982
2002	20187	415925	76946
2003	15755	463246	85700
2004	41753	565189	104560
2005	34576	495741	91712
2006	38439	364531	67438
2007	11675	468508	86674
2008	9179	496267	91809
2009	4081	502764	93011
2010	2377	233131	43129
2011	3395	163427	30234
2012	3542	184878	34202
2013	3617	279714	51747
2014	3437	442217	81810
2015	4701	368883	68243
2016	4451	280471	51887
2017	2849	185768	34367
2018	2849	185768	34367

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Table 2.4. Commercial discard estimates (both live and dead numbers of sharks) obtained from commercial gillnet and longline fisheries using multi-year block averaging of the discard ratios obtained from SEDAR65-AW06 (McCandless et al. 2020, their Tables 1 – 3). The estimated annual number of live discards in commercial gillnet and bottom longline fisheries was multiplied by the DW recommended post release live-discard mortality rate estimates of 31% and 44.2% (as described in Section 2.1.3 above) to obtain post release mortality (PRM) estimates for live discards in the commercial gillnet and bottom longline fisheries, respectively.

	Northeast Gillnet			Southeast Gillnet			Bottom Longline		
Yr	Live discard	Live discard PRM	Dead discard	Live discard	Live discard PRM	Dead discard	Live discard	Live discard PRM	Dead discard
1981									
1982									
1983	2	0.5	1						
1984	2	0.5	1						
1985	2	0.7	2						
1986	3	0.8	2						
1987	4	1.4	3						
1988	2	0.6	1						
1989	12	3.7	8						
1990	9	2.8	6						
1991	18	5.6	13						
1992	26	8.0	18						
1993	38	11.7	27				116	51.3	2499
1994	41	12.8	29				239	105.5	5139
1995	45	14.0	32				91	40.4	1966
1996	57	17.7	41				266	117.4	5716
1997	63	19.5	45				122	54.1	2634
1998	444	137.8	543	1277	395.7	4052	143	63.1	3071
1999	376	116.7	460	989	306.5	3139	131	57.8	2814
2000	340	105.5	415	1037	321.4	3291	124	54.8	2666
2001	5	1.7	6	3018	935.5	5345	96	42.5	2076
2002	5	1.6	6	3021	936.5	5350	130	57.5	2803
2003	5	1.6	6	1792	555.4	7684	131	57.8	2817
2004	4	1.4	5	1779	551.5	7630	102	44.9	2187
2005	3	0.8	3	2084	646.0	8937	86	38.1	1854
2006	3	0.8	3	542	168.1	629	86	38.1	1854
2007	5	1.6	6	834	258.5	968	46	20.5	996
2008	5	1.4	5	249	77.0	158	44	19.2	893
2009	6	1.7	6	283	87.9	181	97	43.0	1994
2010	3	1.0	4	187	58.1	119	81	35.7	1656
2011	6	1.9	7	239	74.2	153	58	25.6	1188
2012	5	1.5	6	244	75.7	156	34	15.1	702
2013	5	1.5	6	129	40.1	83	49	21.6	1003
2014	7	2.1	8	231	71.7	148	67	29.5	1369
2015	3	1.1	4	215	66.8	137	60	26.6	1232
2016	4	1.1	4	197	60.9	125	36	15.8	734
2017	3	1.0	4	148	45.8	94	38	16.6	770
2018	3	1.0	4	195	60.6	125	28	12.2	565

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Table 2.5. Changes made to the commercial catch (**Panel A**) and recreational catch (**Panel B**) in order to achieve the Low Catch and High Catch scenarios (as described in section 2.1.4 above). "Base" indicates the catch data used in the Reference Case (**Tables 2.2** and **2.3**).

Panel A.
Commercial Catch (weight)

Scenario	Gear	Landings	Dead discards	Released alive that die	PRM of commercial released alive	DW to WW ratio
Reference Case	Longlines	Base	No	No	n/a	1.39
	Gillnets	Base	No	No	n/a	1.39
	Other gear	Base	No	No	n/a	1.39
Low Catch	Longlines	Base	No	No	n/a	1.39
	Gillnets	Base	No	No	n/a	1.39
	Other gear	Base	No	No	n/a	1.39
High Catch	Longlines	Base	Yes	Yes	54.8%	2.00
	Gillnets	Base	Yes	Yes	44.4%	2.00
	Other gear	Base	No	No	n/a	2.00

Panel B.
Recreational (numbers)

Scenario	AB1	B2 that die	PRM of recreational released alive
Reference Case	Base	Base	18.50%
Low Catch	-1PSE	-1PSE	10.80%
High Catch	+1PSE	+1PSE	28.70%

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Table 2.6. Low Catch scenario (sensitivity analysis) of Atlantic blacktip sharks in weight (kg ww) and numbers as described in section 2.1.4 above. Commercial landings are in weight; recreational catches are in numbers and smoothed. The conversion ratio for dw to ww is ww=1.39dw.

Year	Unreported commercial catches	Bottom longlines	Gillnets	Other gears	Recreational catches (A+B1)	Recreational catches (B2)	Recreational catches (B2) that die
1981					17642	33318	3598
1982					17642	33318	3598
1983		74181	98719	8781	20022	35404	3824
1984		148362	197437	17562	33998	31187	3368
1985		222543	296156	26343	33617	20503	2214
1986		344344	222523	26343	40279	18628	2012
1987		110565	398574	26343	16788	18765	2027
1988	60006	212721	267372	26343	18256	17084	1845
1989	51002	233409	226478	26343	10980	11040	1192
1990		178652	236853	26343	19420	14701	1588
1991		133745	223725	309636	19856	67751	7317
1992		477240	55331	147904	23082	85598	9245
1993		509191	211718	62901	19350	228517	24680
1994		249686	12624	21004	16920	201586	21771
1995		361329	39455	26358	25121	224411	24236
1996		145727	255130	15502	23632	103900	11221
1997		77984	71240	7310	36298	186246	20115
1998		74039	43436	5947	33389	172354	18614
1999		80923	52822	5862	30664	214572	23174
2000		118696	61012	4843	17663	229873	24826
2001		68948	98740	3204	9285	288422	31150
2002		126459	170563	8789	9416	314005	33913
2003		142017	148760	8119	6590	307841	33247
2004		61621	111156	7349	16518	372158	40193
2005		67732	69215	3663	14665	333113	35976
2006		74244	138265	2995	17042	264714	28589
2007		19456	30812	1359	6401	294514	31808
2008		74967	100334	2795	5418	301112	32520
2009		108374	18987	24013	2226	307921	33255
2010		103438	56717	11232	918	147109	15888
2011		90648	24492	4826	1084	100898	10897
2012		66898	43006	25328	1043	110975	11985
2013		98622	51679	16294	1526	162551	17556
2014		130127	41000	6678	1817	295201	31882
2015		121859	22712	333	1987	248974	26889
2016		110738	44723	1202	1501	216032	23331
2017		110826	26754	1105	804	134107	14484
2018		58961	18887	1047	804	134107	14484

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Table 2.7. High Catch scenario (sensitivity analysis) of Atlantic blacktip sharks in weight (kg ww) and numbers as described in section 2.1.4 above. Commercial landings are in weight; recreational catches are in numbers and smoothed. The conversion ratio for dw to ww is ww=2.0dw.

Year	Unreported commercial catches	Bottom longlines	Gillnets	Other gears	Recreational catches (A+B1)	Recreational catches (B2)	Recreational catches (B2) that die
1981					47111	448538	128730
1982					47111	448538	128730
1983		106735	142116	12634	59443	243116	69774
1984		213471	284158	25269	98783	232045	66597
1985		320206	426239	37903	90348	130641	37494
1986		495459	320310	37903	91653	50472	14486
1987		159086	573677	37903	38136	46830	13440
1988	86339	306073	384783	37903	41805	41670	11959
1989	73385	335840	326398	37903	30163	29039	8334
1990		257053	341194	37903	72339	32169	9232
1991		192439	322742	445519	74614	198120	56860
1992		686676	80788	212811	80449	230984	66292
1993		808861	306377	90505	39917	583349	167421
1994		460316	20043	30222	36020	456094	130899
1995		562547	58838	37925	51968	482663	138524
1996		345330	369733	22305	53257	178238	51154
1997		187034	105408	10518	101800	361701	103808
1998		199731	275825	8556	96397	345534	99168
1999		198570	211974	8435	96643	439585	126161
2000		252080	187564	6969	46771	401155	115132
2001		164085	513961	4610	28620	478956	137460
2002		256197	531883	12647	31626	517845	148622
2003		282773	598122	11682	25629	619125	177689
2004		148971	465069	10575	67861	759363	217937
2005		145259	470766	5271	55556	659916	189396
2006		151260	229869	4310	60861	466088	133767
2007		48139	49541	1955	17570	644190	184883
2008		134400	150643	4022	13522	693437	199016
2009		226437	34957	34552	6616	699727	200822
2010		204046	87003	16161	4504	321436	92252
2011		158702	39896	6944	6355	228638	65619
2012		112787	66203	36443	6711	261769	75128
2013		168721	76512	23445	6317	399850	114757
2014		218724	63410	9609	5551	591445	169745
2015		211231	35213	479	7585	490756	140847
2016		179550	75466	1730	7560	346820	99537
2017		178016	39461	1590	5072	240395	68993
2018		102037	30197	1507	5072	240395	68993

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Table 2.8. Indices of relative abundance recommended by the Index Working Group of the SEDAR 65 Data Workshop for the Atlantic stock of blacktip shark (see SEDAR 65 Data Workshop report). The CV is the coefficient of variation for the annual index value. The SEDAR 65 DW report number is identified for each series.

	S1		S2						S3	
Year	**Shark Bottom Longline Fishery (DW-17)**	**CV**	**Shark Research Fishery (DW-17)**	**CV**	**VIMS Original (DW-05)**	**CV**	**VIMS Catch Series (DW-05)**	**CV**	**VIMS Robust Series (DW-05)**	**CV**
1974					0.747	0.639				
1975					1.176	0.646				
1976										
1977										
1978										
1979										
1980					0.094	0.647				
1981					0.050	0.573	0.050	0.571		
1982										
1983					0.117	0.897	0.115	0.900		
1984										
1985										
1986										
1987					0.160	0.934	0.156	0.939		
1988					0.171	1.161	0.157	1.168		
1989										
1990					0.027	0.763	0.027	0.761	0.026	0.767
1991					0.012	0.785	0.012	0.785	0.012	0.790
1992					0.022	0.780	0.022	0.779	0.021	0.784
1993										
1994	19.410	0.710								
1995	46.050	0.440			0.061	1.008	0.060	1.010	0.058	1.012
1996	28.030	0.490			0.037	1.005	0.037	1.006	0.035	1.008
1997	2.580	0.930			0.071	0.667	0.070	0.666	0.069	0.672
1998	34.630	0.580			0.004	1.010	0.005	1.010	0.004	1.012
1999	93.870	0.350			0.211	0.451	0.219	0.447	0.218	0.455
2000	132.340	0.430			0.011	1.012	0.010	1.012	0.010	1.014
2001	46.570	0.510			0.032	0.569	0.032	0.569	0.031	0.576
2002	190.210	0.260			0.109	0.575	0.106	0.577	0.102	0.584
2003	18.290	0.640								
2004	52.600	0.400			0.040	0.648	0.040	0.648	0.038	0.654
2005	106.580	0.460								
2006	91.350	0.540			0.066	0.573	0.063	0.574	0.063	0.580
2007	27.480	0.680			0.044	0.649	0.044	0.649	0.042	0.655
2008			94.600	0.580	0.277	0.322	0.279	0.321	0.277	0.328
2009			108.410	0.350	0.093	0.625	0.090	0.629	0.086	0.640
2010			69.950	0.260	0.084	0.516	0.083	0.516	0.082	0.523
2011			74.770	0.260	0.050	0.763	0.051	0.761	0.051	0.767
2012			176.650	0.420	0.033	0.652	0.032	0.654	0.031	0.661
2013			100.090	0.510	0.226	0.527	0.221	0.525	0.224	0.533
2014			213.370	0.240	0.076	0.393	0.076	0.393	0.074	0.401
2015			144.800	0.300	0.028	0.484	0.028	0.482	0.028	0.488
2016			124.360	0.370	0.084	0.296	0.084	0.296	0.082	0.304
2017			266.440	0.320	0.094	0.461	0.095	0.461	0.092	0.468
2018			42.130	0.500	0.124	0.359	0.123	0.359	0.121	0.367

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Table 2.8. Continued.

	S4		S5		S6		S7		S8	
Year	NMFS-NEFSC Bottom Longline (DW-09)	CV	SCDNR SEAMAP Longline Survey (DW-11)	CV	SCDNR Red Drum Survey (DW-11)	CV	SCDNR Drumline Survey (DW-21)	CV	COASTSPAN Longline All-age (DW-08)	CV
1974										
1975										
1976										
1977										
1978										
1979										
1980										
1981										
1982										
1983										
1984										
1985										
1986										
1987										
1988										
1989										
1990										
1991										
1992										
1993										
1994										
1995										
1996	0.003	1.017			1.227	0.640				
1997					1.273	0.604				
1998	0.031	0.483			0.458	0.610				
1999					0.394	0.865				
2000					1.359	0.441				
2001	0.013	0.561			0.349	1.270				
2002					0.589	0.720				
2003					1.019	0.554				
2004	0.031	0.484			0.459	0.792				
2005					0.310	0.904			3.023	0.286
2006					1.316	0.432			1.522	0.380
2007	0.001	1.901	1.721	0.353					1.205	0.542
2008			0.838	0.510					3.441	0.380
2009	0.026	0.606	1.220	0.357					1.943	0.276
2010			0.899	0.289					2.005	0.249
2011			1.534	0.286					1.602	0.264
2012	0.122	0.384	1.543	0.256					2.690	0.234
2013			2.707	0.211			0.166	0.225	3.696	0.205
2014			1.766	0.201			0.206	0.161	1.974	0.296
2015	0.148	0.351	1.983	0.207			0.174	0.180	1.466	0.299
2016			0.974	0.269			0.136	0.180	1.769	0.246
2017			1.124	0.234			0.185	0.165	1.585	0.282
2018	0.318	0.247	1.464	0.219			0.207	0.186	1.025	0.306

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Table 2.8. Continued.

	R1		S9		R2		S10 (and R3)	
Year	COASTSPAN Longline Age-0 (DW-08)	CV	COASTSPAN Gillnet Long Net All-age (DW-07)	CV	COASTSPAN Gillnet Long Net Age-0 (DW-07)	CV	SCDNR Gillnet Short Net Age-0 (DW-10)	CV
1974								
1975								
1976								
1977								
1978								
1979								
1980								
1981								
1982								
1983								
1984								
1985								
1986								
1987								
1988								
1989								
1990								
1991								
1992								
1993								
1994								
1995								
1996								
1997								
1998								
1999								
2000								
2001			0.798	0.283	0.700	0.336		
2002			0.309	0.430	0.223	0.654		
2003			0.901	0.318	0.815	0.372		
2004			0.150	1.176	0.145	1.333		
2005	2.819	0.304	0.836	0.402	0.906	0.463		
2006	1.413	0.403	1.139	0.369	1.023	0.370	0.498	0.452
2007	1.214	0.552	0.486	0.422	0.490	0.585	1.493	0.519
2008	2.883	0.389	0.552	0.452	0.564	0.538	0.301	1.163
2009	1.882	0.307	1.072	0.363	0.749	0.479	0.309	1.124
2010	1.753	0.286	1.056	0.418	0.615	0.584	0.565	0.476
2011	1.597	0.283	0.726	0.475	0.275	0.755	0.601	0.485
2012	2.656	0.246	0.927	0.776	0.847	0.903	1.068	0.288
2013	3.440	0.217	3.684	0.359	3.845	0.417	0.827	0.426
2014	1.892	0.318	1.277	0.461	0.892	0.535	0.250	0.694
2015	0.897	0.392	0.707	0.301	0.400	0.524	0.540	0.459
2016	1.670	0.270	0.607	0.517	0.118	0.899	0.296	0.526
2017	1.607	0.294	1.320	0.421	1.356	0.495	0.688	0.406
2018	1.031	0.319	1.420	0.315	0.967	0.456	1.217	0.311

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Table 2.9. Hierarchical analysis of the Atlantic blacktip shark recruitment indices (age-0) and associated coefficient of variation (CV) obtained from SEDAR65-AW01 (McCandless 2020, their Table 2 and Figures 1), as described above in Section 2.2.2.

Year	Hierarchical (Age-0)	CV
2001	0.993	0.545
2002	0.494	0.705
2003	1.121	0.536
2004	0.566	0.859
2005	1.376	0.379
2006	0.938	0.356
2007	1.013	0.410
2008	1.079	0.400
2009	0.952	0.365
2010	0.909	0.347
2011	0.792	0.354
2012	1.430	0.335
2013	2.064	0.344
2014	0.910	0.368
2015	0.612	0.370
2016	0.649	0.373
2017	1.076	0.351
2018	1.026	0.371

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Table 2.10. The back-transformed common trend resulting from the DFA model fitted to the age-0 Atlantic blacktip shark time-series of relative abundance along with associated uncertainty (**Panel A**; Latour and Peterson 2020, their Figure 3) along with DFA factor loadings by fleet (**Panel B**), provided from the authors of SEDAR65-AW03 (Latour and Peterson 2020), as described above in Section 2.2.2. Fleets as defined in **Table 2.8**.

Panel A

Year	Index	SE	CV
2001	0.895	0.3074	0.3436
2002	0.820	0.2815	0.3433
2003	0.902	0.2648	0.2937
2004	0.895	0.2365	0.2643
2005	1.212	0.1384	0.1142
2006	0.930	0.1324	0.1423
2007	0.839	0.1321	0.1575
2008	1.237	0.1321	0.1068
2009	1.096	0.1321	0.1205
2010	1.006	0.1321	0.1313
2011	0.967	0.1321	0.1367
2012	1.299	0.1321	0.1017
2013	1.556	0.1321	0.0849
2014	1.088	0.1321	0.1215
2015	0.709	0.1321	0.1863
2016	0.838	0.1321	0.1578
2017	0.897	0.1327	0.1479
2018	0.723	0.1448	0.2002

Panel B

Fleet	Factor loadings
COASTSPAN Longline Age-0 (DW-08)	0.964
COASTSPAN Gillnet Long Net Age-0 (DW-07)	0.414
SCDNR Gillnet Short Net Age-0 (DW-10)	-0.13

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Table 2.11. The back-transformed common trend resulting from the DFA model fitted to the all-ages Atlantic blacktip shark time-series of relative abundance along with associated uncertainty (**Panel A**; Latour and Peterson 2020, their Figure 5) along with DFA factor loadings by fleet (**Panel B**), provided from the authors of SEDAR65-AW03 (Latour and Peterson 2020), as described above in Section 2.2.2. Fleets as defined in **Table 2.8**.

Panel A

Year	Index	SE	CV
1990	0.306	0.9465	3.0895
1991	0.267	0.9139	3.4206
1992	0.276	0.8644	3.1266
1993	0.312	0.7876	2.5209
1994	0.353	0.6343	1.7963
1995	0.407	0.5596	1.3748
1996	0.321	0.4982	1.5538
1997	0.281	0.5001	1.7788
1998	0.607	0.4848	0.7992
1999	1.246	0.5007	0.4018
2000	1.257	0.5008	0.3986
2001	1.428	0.4852	0.3399
2002	1.727	0.5021	0.2907
2003	1.154	0.5061	0.4385
2004	1.440	0.4856	0.3372
2005	1.744	0.4986	0.2859
2006	1.264	0.4700	0.3720
2007	0.925	0.3373	0.3648
2008	0.503	0.3345	0.6651
2009	0.614	0.3282	0.5343
2010	0.478	0.3342	0.6985
2011	0.930	0.3342	0.3592
2012	1.660	0.3281	0.1977
2013	2.976	0.3342	0.1123
2014	2.404	0.3342	0.1390
2015	1.888	0.3282	0.1738
2016	0.812	0.3345	0.4118
2017	0.928	0.3374	0.3634
2018	0.869	0.3684	0.4240

Panel B

Fleet	Factor loadings
Shark Bottom Longline Fishery (DW-17)	0.416
Shark Research Fishery (DW-17)	0.325
VIMS Robust Series (DW-05)	0.145
NMFS-NEFSC Bottom Longline (DW-09)	0.304
SCDNR SEAMAP Longline Survey (DW-11)	0.674
SCDNR Red Drum Survey (DW-11)	-0.292

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Table 2.12. Life history data obtained from the SEDAR65 DW report (their Table 1). Values in parentheses represent standard error unless otherwise noted. References are as listed within the SEDAR65 DW.

Parameter(s)	Value(s)	Reference(s)
Growth relationships	Female / Male / Sexes combined	
L_∞ (cm)	166.23 (2.47)/ 145.03 (1.82) / 159.30 (1.87)	SEDAR65-DW-02
K	0.16 (0.01) / 0.23 (0.02) / 0.17 (0.01)	SEDAR65-DW-02
t_o (years)	-2.59 (0.16) / -1.97 (0.16) / -2.51 (0.13)	SEDAR65-DW-02
Maximum observed age (years)	17.5 / 13.5	SEDAR65-DW-02
Sample size	269 / 278 / 547	SEDAR65-DW-02
Length-weight relationships		
PCL (cm)	PCL = 1.92990 + 0.885043*FL	SEDAR65-DW-15
NTL (cm)	NTL = 4.89349 + 1.15734*FL	SEDAR65-DW-15
STL (cm)	STL = 9.00754 + 1.16776*FL	SEDAR65-DW-15
Wt (kg)	Wt = $(4.63\text{x}10^{-6})FL^{3.21575}$	SEDAR65-DW-15
Age at 50% maturity		
Female	t_{mat}= 6.69 years a = -12.07 (2.52) b = 1.80 (0.35)	SEDAR65-DW-01
Male	t_{mat}= 5.34 years a = -9.09 (1.72) b = 1.70 (0.29)	SEDAR65-DW-01
Size at 50% maturity		
Female	FL_{mat}= 123.05 cm FL a = -30.09 (4.66) b = 0.24 (0.04)	SEDAR65-DW-01
Male	FL_{mat}= 115.15 cm FL a =-31.41 (5.34) b = 0.27 (0.04)	SEDAR65-DW-01
Reproductive cycle	Biennial	Castro 1996, Gelsleichter pers. comm.
Fecundity	4.09 (SD = 0.13) pups per brood	SEDAR65-DW-01
Maternal age/fecundity relationship	Brood size = -0.04078 + 0.38445*Age	SEDAR65-DW-01
Maternal size/fecundity relationship	Brood size = -5.82556+0.06857*FL	SEDAR65-DW-01
Gestation	11 months	Castro 1996, Ulrich et al. 2007
Pupping month	late May / June	Castro 1996, Ulrich et al. 2007, Frazier pers. comm.

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Table 2.13. Minimum estimates of instantaneous natural mortality rates (yr^{-1}) for use in the reference case Stock Synthesis model obtained with six life-history invariant estimators used in the Euler-Lotka and Leslie matrix approaches in SEDAR65-DW19 (Cortés 2020, his Table 2) separately for females and males using the same methods, as described above in Section 2.3.

Females		Males	
Age	M	Age	M
0	0.198	0	0.273
1	0.198	1	0.237
2	0.198	2	0.203
3	0.185	3	0.183
4	0.171	4	0.170
5	0.161	5	0.161
6	0.153	6	0.155
7	0.147	7	0.150
8	0.143	8	0.147
9	0.139	9	0.144
10	0.136	10	0.142
11	0.133	11	0.140
12	0.131	12	0.139
13	0.130	13	0.138
14	0.128	14	0.137
15	0.127	15	0.137
16	0.126	16	0.136
17	0.125	17	0.136
18	0.125	18	0.136
19	0.124	19	0.136
20	0.123	20	0.135
21	0.123	21	0.135
22	0.123		
23	0.122		
24	0.122		
25	0.122		
26	0.122		
27	0.122		
28	0.121		
29	0.121		
30	0.121		
31	0.121		
Average	0.139	Average	0.158

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Table 2.14. Mean estimates of instantaneous natural mortality rates (yr^{-1}) for use in Stock Synthesis model sensitivity analyses obtained with six life-history invariant estimators used in the Euler-Lotka and Leslie matrix approaches in SEDAR65-DW19 (Cortés 2020) separately for females and males, as described above in Section 2.3.

Females		Males	
Age	M	Age	M
0	0.261	0	0.340
1	0.252	1	0.328
2	0.247	2	0.322
3	0.244	3	0.318
4	0.241	4	0.315
5	0.239	5	0.314
6	0.238	6	0.312
7	0.237	7	0.311
8	0.236	8	0.311
9	0.235	9	0.310
10	0.235	10	0.310
11	0.234	11	0.309
12	0.234	12	0.309
13	0.234	13	0.309
14	0.233	14	0.309
15	0.233		
16	0.233		
17	0.233		
18	0.233		
Average	0.239	Average	0.315

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Table 2.15 Commercial and recreational gear types were aggregated into four 'fleets' (F1, F2, F3, and F4) with similar length composition based on a review of the available length composition data cited in the footnotes (**Panel A**); Length composition data provided for fisheries-independent scientific surveys is identified in **Panel B**.

Panel A

Data source	Years of coverage	Sample size (number of sharks)	Fleet	Survey
Fishery dependent				
University of Florida Longline[1]	1994 – 2005	1,699	F1 (Com-BLL-Kept)	S1 (Shark-BLL-Obs)
Southeast Fisheries Science Center (SEFSC) Panama City Lab Shark Bottom Longline Observer Program (SBLOP)[1]	2005 – 2018	3,708	F1 (Com-BLL-Kept)	S2 (Shark-BLL-Res)
Southeast Fisheries Science Center (SEFSC) Panama City Lab Gillnet Observer Program (GNOP)[2]	1999 – 2018	1,477	F2 (Com-GN-Kept)	
Marine Recreational Information Program (MRIP)[1]	1981 – 2018	781	F4 (Recreational)	
Southeast Region Head Boat Survey (SRHS)[1]	1989 – 2018	107	F4 (Recreational)	
South Carolina Department of Natural Resources (SCDNR) Shore Fishing[1]	2013 – 2018	166	Recommended for use in stock assessment model sensitivity analyses during the AP	
	Total	**7,938**		

[1] SEDAR65-AW05 (Kroetz and Courtney 2020).
[2] SEDAR65-AW07 (Courtney et al. 2020).

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Table 2.15. Continued

Panel B

Data source	Years of coverage	Sample size (number of sharks)		Survey
Fishery independent				
Virginia Shark Monitoring and Assessment Program (VASMAP)[1]	1990 – 2018	324		S3 (VIMS-BLL-Robust)
Southeast Fisheries Science Center (SEFSC) Bottom Longline[1]	1996 – 2018	19	Survey not recommended for use in the stock assessment model during the DW	
Northeast Fisheries Science Center (NEFSC) Bottom Longline[1]	1996 – 2018	638		S4 (NEFSC-BLL)
Southeast Area Monitoring and Assessment Program (SEAMAP) Longline (Georgia-University of North Florida)[1]	2007 – 2018	218	Survey not recommended for use in the stock assessment model during the DW	
South Carolina Department of Natural Resources (SCDNR) SEAMAP Longline[1]	2007 – 2018	1,032		S5 (SCDNR-SEAMAP-BLL)
South Carolina Department of Natural Resources (SCDNR) Red Drum longline[1]	1994 – 2008	301		S6 (SCDNR_Red_Drum_BLL)
South Carolina Department of Natural Resources (SCDNR) Drumline[1]	2013 – 2019	302		S7 (SCDNR-DL)
Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) Longline[1]	1999 – 2019	641		S8 (COASTSPAN-BLL-All-ages)
Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) Gillnet[1]	1999 – 2019	487		S9 (COASTSPAN-GNL-All-ages)
Florida Atlantic University Drumline/Longline[1]	2014 – 2019	123	Survey not recommended for use in the stock assessment model during the DW	
South Carolina Department of Natural Resources (SCDNR) Small Gillnet Survey[1]	2006 – 2019	275		S10 (COASTSPAN-GNS-Age-0)
	Total	**4,360**		

[1] SEDAR65-AW05 (Kroetz and Courtney 2020).

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3. Stock Assessment Models and Results

The analytical approach implemented in this assessment is a length-based age-structured statistical model implemented within Stock Synthesis (Methot and Wetzel 2013; e.g., Wetzel and Punt 2011a, 2011b). Stock Synthesis utilizes an integrated modeling approach (Maunder and Punt 2013) to take advantage of the many data sources available.

3.1. Overview

Stock Synthesis (version 3.30.15.00, released 03/26/2020; Methot et al. 2020) was implemented here using an areas as fleets approach by including multiple fleets within a spatially-aggregated assessment model (e.g., Hurtado-Ferro et al. 2014; Punt et al. 2014). In the areas as fleets approach, each fleet is assigned its own size selectivity pattern. Size selectivity is the probability of a fleet capturing a shark of a given size relative to the probability of that fleet capturing a shark of a different size (here the size at which the probability of capture is highest). Size selectivity for each fleet is either fixed or estimated within the assessment model based on the available size composition data. The resulting size selectivity for each fleet is interpreted as the combined effect of availability to the fishing gear (i.e., a shark of a given size is in the fishing area when fishing occurs and is available to be captured) and size selectivity of the fishing gear. Stock Synthesis has previously been implemented utilizing the areas as fleets approach for Atlantic HMS domestic shark stock assessments conducted within the SEDAR process (Anon. 2015, 2017a, 2018) and for Atlantic HMS international shark stock assessments conducted within the ICCAT process (Anon. 2016, 2017b; Courtney 2016; Courtney et al. 2017a, 2017b).

3.2. Data Sources

Commercial landings, recreational catch, indices of abundance, life history, and length composition used in this assessment were obtained as described in the Data Workshop (DW) and

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Assessment Process (AP) working documents summarized in Section 2 above and summarized here in **Table 3.1**.

3.2.1. Commercial Landings

Commercial landings were entered in Stock Synthesis in metric tons (one mt = 1,000 kg) aggregated into three "fleets" (F1 – F3) (**Table 3.1**):

F1 (Com-BLL-Kept) = Bottom longline (1983 – 2018);

F2 (Com-GN-Kept) = Gillnets (1983 – 2018); and

F3 (Com-Other-Kept) = Other gears + Unreported commercial catches (1983 – 2018).

Annual commercial landings of blacktip sharks in the U.S. Atlantic during the years 1983 – 2018 were obtained from the DW (lb. dressed weight; **Table 2.1**), converted to kilograms whole weight (kg ww; **Table 2.2**).

3.2.2. Recreational Catch

Recreational catch was entered in Stock Synthesis in numbers (thousands) aggregated into one fleet (F4):

F4 (Recreational) = Recreational A+B1+B2-Dead (1981 – 2018), as defined below.

Annual recreational catch of blacktip sharks in the U.S. Atlantic during the years 1981 – 2018 was obtained from the DW (numbers of sharks; **Tables 2.3**). The data were smoothed as described in DW recommendations and decisions summarized in the DW report. The smoothed annual recreational catch estimates of blacktip sharks in the Atlantic were computed as the sum of type A (number of fish killed or kept seen by the interviewer), type B1 (number of fish killed or kept reported to the interviewer by the angler), and type B2 (number of fish released alive reported by the fisher; B2-Live). Annual recreational type B2 catch estimates of blacktip sharks in the Atlantic were multiplied by an overall post-release mortality rate of 18.5% for hook and line recreational fisheries to obtain the number of fish released alive, that were estimated to have

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died (B2-Dead; **Table 2.3**) as described in DW recommendations and decisions summarized in the DW report.

3.2.3. Commercial Discards

Commercial discard estimates were not included in the base case model because of uncertainty in bycatch estimation as described in DW recommendations and decisions summarized in the DW report. Instead, commercial discard estimates were developed during the AP for use within sensitivity analyses, as described in Section 2.1.3 above, and summarized here. The AP Analytical Team implemented the DW recommendations for continued analyses of commercial discard estimates (both live and dead) from commercial gillnet and longline fisheries using multi-year block averaging of the discard ratios to create discard estimates (**Table 2.4**). The estimated annual number of live shark discards in commercial gillnet and bottom longline fisheries was multiplied by the DW recommended post release live-discard mortality rate estimates of 31% and 44.2%, respectively. The resulting post release mortality (PRM) estimates for live discards in the commercial gillnet and bottom longline fisheries were provided in **Table 2.4** for use in Stock Synthesis sensitivity model runs.

3.2.4. Low and High Catch Scenarios

Based on the DW recommendations, low and high catch scenarios were developed during the AP for use in sensitivity analyses, as described in Section 2.1.4 above, and summarized here. The AP Analytical Team made several changes to the base case input data (**Tables 2.5**) in order to develop the low and high catch scenarios. The Low Catch scenario (**Table 2.6**) used the annual percent standard error estimates (-1PSEs) available for both the A+B1 and B2 recreational time series for the years 1981-2018. The recreational post-release mortality rate lower 95% CL of 10.8% (vs. 18.5% in reference case) was applied to the -1PSE of B2. In contrast, the high catch scenario (**Table 2.7**) used the annual +1PSEs available for both the A+B1 and B2 recreational time series for the years 1981-2018. The recreational post-release mortality rate upper 95% CL of 28.7% (vs. 18.5% in reference case) was applied to the +1PSE of B2. The high catch scenario

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also included estimates of both commercial dead discards and commercial live discard post release mortality (**Table 2.4)** (converted to annual discard weight vs. no discards in reference case). The high catch scenario included a post-release mortality rate of 54.8% for bottom longline (vs. 44.2% in **Table 2.4**) and 44.4% for gillnets (vs. 31% in **Table 2.4**). The high catch scenario also used a dressed weight to whole weight conversion ratio of 2.0 (vs. 1.39 in reference case).

3.2.5. Indices of Abundance and Catchability

Ten indices of relative abundance (**Table 3.1**) were input in Stock Synthesis as "surveys" S1 – S10:
S1 (Shark-BLL-Obs) = Shark Bottom Longline Fishery (1994 – 2007);
S2 (Shark-BLL-Res) = Shark Bottom Longline Research Fishery (2008 – 2018);
S3 (VIMS-BLL-Robust) = VIMS Bottom Longline Robust Series (1990 – 2018);
S4 (NEFSC-BLL) = NMFS-NEFSC Bottom Longline (1996 – 2018);
S5 (SCDNR-SEAMAP-BLL) = SCDNR SEAMAP Bottom Longline Survey (2007 – 2018);
S6 (SCDNR-Red-Drum-BLL) = SCDNR Red Drum Bottom Longline Survey (1996 – 2006);
S7 (SCDNR-DL) = SCDNR Drumline Survey (2013 – 2018);
S8 (COASTSPAN-BLL-All-ages) = COASTSPAN Bottom Longline All-age (2005 – 2018);
S9 (COASTSPAN-GNL-All-ages) = COASTSPAN Gillnet Long Net All-age (2001 – 2018);
and S10 (COASTSPAN-GNS-Age-0) = SCDNR Gillnet Short Net Age-0 (2006 – 2018) as described below.

The ten indices of relative abundance were recommended by the Index Working Group of the Data Workshop for use in the base model configuration. The indices of relative abundance and the associated annual coefficients of variation (CVs) were obtained from both fisheries-dependent observer programs (S1 and S2) and fisheries-independent scientific surveys (S3 – S10), as described in Section 2.2.1 and **Table 2.8**.

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Indices were input in the base model configurations with inverse CV weighting. Indices were treated as relative abundance and assumed to have log-normally distributed error. Inverse CV weighting was calculated as sqrt(ln(1+CV^2)), which is approximated by the CV. Annual CVs for each index were obtained from the DW (**Table 2.8**) and modified by data weighting as described below.

Indices of relative abundance were assumed to be proportional to available biomass at the middle of the calendar year, with constant catchability (q) (Methot and Wetzel 2013). Catchability, q, was estimated for index S1 with time blocks (1981 – 1996, 1997 – 2004, 2005 – 2007) and for index S2 with time blocks (2008 – 2017, 2018). Time blocks were obtained based on the model fit to available length composition data for each survey, as described below. In contrast, time-blocks were not required to fit the available length composition data for the remaining surveys S3 – S10. Consequently, the median unbiased analytical solution for q was obtained from Stock Synthesis for these surveys by setting q equal to a constant scaling factor (Methot et al. 2020).

3.2.6. Alternative Index of Abundance Groupings

In response to DW recommendations, several AP working documents were produced that analyzed alternative abundance index groupings for use in sensitivity analyses, as described in Section 2.2.2 above, and summarized here. Combined indices included a Bayesian hierarchical age-0 index (**Table 2.9**), a combined Dynamic Factor Analysis (DFA) age-0 index (**Table 2.10**), and a combined DFA all-age index (**Table 2.11**) along with associated measures of uncertainty. Potential abundance index groupings for use in sensitivity analyses were also identified with hierarchical cluster analysis and cross-correlations.

However, both the Bayesian hierarchical and DFA analyses of age-0 indices produced similar results. Consequently, a decision was made in coordination with the AP Panel that sensitivity analysis to the Bayesian hierarchical analysis of age-0 indices would not implemented in the Stock Assessment. Preliminary model fits to the DFA age-0 index (Assessment Webinar V) resulted in a good fit to the index, but the model failed to converge within reasonable parameter

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bounds. Preliminary model fits to the DFA all-age index (Assessment Webinar V) resulted in a poor fit to the index and also included the same length data within multiple fleets. Consequently, a recommendation was made (Assessment Webinar V) to exclude DFA from further sensitivity analyses within this assessment, and to limit DFA analysis to fishery independent data in future assessments. In addition, alternative index groupings identified in the hierarchical cluster analysis and cross-correlations of accepted indices were not implemented in sensitivity analyses due to time constraints of the AP.

Consequently, a pragmatic decision was made in coordination with the AP Panel to conduct a single abundance index sensitivity analysis that removed the two relative abundance indices S4 (NEFSC-BLL) and S7 (SCDNR-DL), which had a relatively poor fit in preliminary runs of the Stock Synthesis reference case model (as described in the stock assessment results Section 3.4.1.2 below).

3.2.7. Life History Data

Life history data used in the stock assessment model were obtained directly from the DW report, and reproduced in **Table 2.12**, as described in Section 2.3 above. In addition, an AP working document developed vital rates and population dynamics parameters including Beverton-Holt stock-recruitment steepness (*h*) and natural mortality based on biological information provided in the DW report, as described in Section 2.3 above, and summarized here. The mean steepness value of 0.4 inferred from the deterministic methods using the theoretical longevity was recommended during the AP for use in the base case Stock Synthesis model. The minimum estimates of instantaneous natural mortality rates (**Table 2.13**) corresponding to the deterministic age-structured Euler-Lotka/Leslie Matrix approaches were recommended during the AP for use in the base case Stock Synthesis model. In addition, the lower and upper values of the range of steepness values obtained with the deterministic methods (0.32 and 0.52) were recommended during the AP for use in Stock Synthesis model low and high productivity states of nature sensitivity analyses. The mean estimates of instantaneous natural mortality rates (**Table 2.14**)

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corresponding to the deterministic age-structured Euler-Lotka/Leslie Matrix approaches were also provided during the AP for use in Stock Synthesis model sensitivity analyses.

3.2.8. Length Composition Data

The commercial and recreational gear types were aggregated into 'fleets' (F1, F2, F3, and F4) with similar length composition based on a review of the available length composition data, as described above in Section 2.4 (**Table 2.15)**, and summarized in **Tables 3.1** and **3.2**. This approach is consistent with the previous Atlantic HMS SEDAR benchmark stock assessment conducted in Stock Synthesis for Atlantic smooth dogfish (Anon. 2015). Fishery-independent length composition data were also provided for many of the fishery independent scientific survey indices of relative abundance as described above in Section 2.4 (**Table 2.15)**, and summarized in **Tables 3.1** and **3.2**.

A minimum annual sample size of 30 was established for the base model configuration (**Table 3.2**) in an effort to insure that the annual length composition data entered in the stock assessment model were representative of the annual distributions in length captured by each fleet and survey. This approach is consistent with the previous Atlantic HMS SEDAR benchmark stock assessment conducted in Stock Synthesis for Atlantic smooth dogfish (Anon. 2015). However, the minimum annual sample size was reduced from 30 to 20 for fleet F4 in an effort to increase the number of years with recreational length composition data within selectivity time-blocks, as described below. Total sample size differs in some cases between **Table 2.15** and **Table 3.2** because sex specific data are included in **Table 3.2**. Length data in **Table 3.2** were also limited to the years with catch and survey data included in the base model configuration (**Table 3.1)**. Fits to length composition data by fleet and survey are provided below in the assessment model results section.

3.3. Model Configuration and Equations

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The Stock Synthesis model for the Atlantic population of blacktip sharks is a single stock that encompasses the U.S. East Coast Atlantic waters defined in the DW report. Based on the DW recommendations, the end year of the assessment data included in the model was 2018, and the start year of the base model configurations was 1981, based on the availability of catch data.

3.3.1. Base Model Configuration

A two sex model was implemented in the base model configuration to account for sexually dimorphic growth (Natanson et al. 2019). Recruitment was assumed to occur at age-0 in order to accommodate the high proportion of sharks captured at small sizes in many of the length composition data sources (Courtney et al. 2020; Kroetz and Courtney 2020). The maximum age in Stock Synthesis is modeled as a "plus" group that accumulates ages greater than or equal to the maximum age by assuming constant natural mortality at age and constant fishing mortality at age above the maximum age (Methot and Wetzel 2013; Methot et al. 2020). The maximum age in the base model configuration was set equal to 30 years for both sexes, which is consistent with the theoretical maximum age of females (31 years) and above that of males (21 years) obtained from the estimation of vital rates for the North Atlantic population of blacktip sharks (Cortés 2020). The theoretical maximum ages are well above the observed maximum age for females (17.5 yr) and males (13.5 yr) provided in the SEDAR 65 Data Workshop Report and reproduced here in **Table 2.12**.

3.3.1.1. Length at Age and Weight at Length

Growth in length at age for the base model configuration was assumed to follow the separate von Bertalanffy growth (VBG) relationships recommended in the DW report for females and males (**Table 2.12**). The VBG length at age-0 (LAmin = L_0 cm FL), VBG length at age-infinity (LAmax = L_{inf} cm FL), and VBG growth coefficient (k) were input in the assessment base model configurations as fixed parameters separately for males and females (**Table 3.3**).

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In Stock Synthesis (version 3.30.15.00; Methot et al. 2020), fish recruit at the real age of 0.0 with a body size equal to the lower edge of the first population size bin. Fish then grow linearly until they reach the real age associated with LAmin and have a size equal to the parameter value for LAmin. As fish continue to age, they grow according to the VBG relationship. The growth curve is calibrated to go through the size equal to the parameter value for LAmax when they reach the age associated with LAmax.

In the base model configuration, the lower edge of the first population size bin was defined as 40 cm FL. The parameter for LAmin was defined as the length at age-0 and was fixed at 56.4 and 52.8 cm FL for females and males, respectively, following the VBG relationships described above. The parameter for LAmax was defined as the length at age-infinity (L_{inf}) and set equal to 166.2 and 145.0 cm FL for females and males, respectively, following the VBG relationships described above.

The VBG relationship implemented in the base model configuration resulted in a relatively larger length at age-0 (LAmin) for females and males (56.4 and 52.8 cm FL, respectively) than the approximate size at birth (c. 45 cm FL) obtained from the scientific literature. The approximate size at birth, c. 45 cm FL, was based on the midpoint of the range given in Castro (1996), which was 55-60 cm TL. Using the TL to FL relationship given in **Table 2.12** (NTL = 4.89349 + 1.15734 FL) resulted in 45 cm FL. Consequently, an attempt was made to account for growth from the approximate observed size at birth, c. 45 cm FL, by fixing the lower edge of the first population size bin equal to 40 cm FL in the base model configuration. The same approach was used in the SEDAR 39 Stock Synthesis model developed for Atlantic smooth dogfish (Anon. 2015) to address a similar discrepancy between the VBG relationship and the observed size at birth in that assessment.

Uncertainty, in the distribution of mean length at each age was modeled as a normal distribution and the CV in mean length at age was modeled as a linear function of length. In the base model configuration, the CVs for LAmin and LAmax were fixed at 0.1 for both females and males (**Figure 3.1**). The CV values were obtained from a recent Stock Synthesis assessment model developed for North Atlantic shortfin mako (Courtney et al. 2017a; Anon. 2017b). In that

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assessment, the CV values in length for each observed age were approximated from the sample distribution of the pooled length-at-age data. Consequently, for the base model configuration, the uncertainty in length at each age was assumed to be equal to that of North Atlantic shortfin mako and was not analyzed further because of time constraints and the limited sex specific length composition data available for Atlantic blacktip shark available in this assessment. However, stock assessment model sensitivity to the assumed uncertainty in length at age was evaluated by estimating the CVs for L_{Amin} and L_{Amax} within the logistic model sensitivity analysis, as described below.

Sex-specific weight (kg) at length (cm FL) was assumed to follow the sex-combined weight-at-length relationship recommended in the DW report $Wt = (4.63x10^{-6})FL^{3.21575}$ (**Table 2.12**). The two weight-at-length relationship parameters were input in the base model configuration as fixed parameters separately for males and females.

3.3.1.2. Annual Pup Production at Age

Annual pup production at age in the Stock Synthesis base model configuration (**Table 3.4**) was calculated as follows. Litter size (LS) was obtained as -0.04078 + 0.38445*Age (**Table 2.12)**, while imposing a minimum litter size of one and a maximum litter size of seven obtained from SEDAR65-DW-01 (Natanson et al. 2019, their Figure 1). Female fraction mature at age was obtained from the DW report (DW Section II, their Table 3; e.g., see equations in **Table 2.12**). Female fraction maternal at age was obtained from the fraction mature at age by assuming an 11 month gestation period (**Table 2.12**), approximated by 1-year from maturity to maternity. Pup production at age was obtained as (LS at age)* (Fraction Maternal at age). Annual pup production at age was obtained by assuming a two year reproductive cycle (**Table 2.12**) and calculated as [(LS at age)* (Fraction Maternal at age)]/two.

3.3.1.3. Stock Recruit Model and Steepness (*h*)

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A Beverton-Holt (BH) stock-recruitment relationship was assumed and implemented in the base model configuration. In Stock Synthesis, (version 3.30.15.00; Methot et al. 2020), the BH stock-recruitment model is parameterized with three parameters, the natural log (ln) of unexploited equilibrium recruitment (R_0), the steepness parameter (h) and a parameter representing the standard deviation in annual recruitment deviation (σ_R) (Methot and Wetzel 2013; e.g., Wetzel and Punt 2011a, 2011b). Parameter estimation for ln(R_0) utilized a normal prior with a large standard deviation (Pr_SD) along with independent minimum and maximum boundary conditions (Min, Max). Implementation of a normal prior is described in the manual for Stock Synthesis (version 3.30.15.00; Methot et al. 2020). The steepness parameter, h, describes the fraction of the unexploited recruits produced at 20% of the equilibrium spawning stock size. For the base model configuration, the stock-recruit steepness parameter was fixed at a value obtained analytically based on life history, h = 0.40, obtained from the assessment document SEDAR65-AW02 (Cortés 2020), as described in Section 2.3 above. The parameter representing the standard deviation in annual recruitment, σ_R, was fixed initially at a value of 0.283 obtained from a recent Stock Synthesis assessment model developed for North Atlantic shortfin mako (Courtney et al. 2017a). In that assessment, the σ_R value was adjusted one time from an initial value of 0.4 to the value of 0.28 in order match the RMSE of recruitment variability obtained during the main recruitment deviation period (1990 – 2012) from the assessment model (Courtney et al. 2017a). The same uncertainty in annual recruitment deviation was assumed for this assessment. The minimum (-10) and maximum (10) recruitment deviation bounds in the base model configuration were set at relatively large values in an effort not to restrict the estimated recruitment deviation beyond that imposed by the standard deviation in annual recruitment, σ_R.

Spawning stock size within the stock-recruitment relationship was modeled as spawning stock fecundity (SSF), and calculated as the sum of female numbers at age (in 1,000s) multiplied by annual pup production at age at the beginning of each calendar year assuming a 1:1 ratio of male to female pups.

An examination of preliminary base model configuration output with the program r4ss (Taylor et al. 2020) indicated that there was little recruitment information in the data prior to the mid-1990s. There was also a ramp up in recruitment information from about 1994 until the mid-2000s

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consistent with the increasing availability of length composition data during that time period (**Table 3.2**). Consequently, main recruitment deviations were estimated in the base model configuration during the years 1994 – 2012, with early recruitment deviations beginning 10 years prior to the main recruitment (1984 – 1993). Main recruitment deviations are zero centered. The estimation of early recruitment deviations allows for recruitment in early periods without biasing recruitment estimates in the main period.

In Stock Synthesis (version 3.30.15.00; Methot et al. 2020), recruitment deviations are estimated on the natural log scale. Consequently, the expected recruitments require a bias adjustment so that the resulting recruitment level on the standard scale is mean unbiased. The years chosen for bias adjustment, and the maximum bias adjustment parameter value, were obtained from Stock Synthesis output with the program r4ss, as described below in the data weighting section.

3.3.1.4. Reproductive Output Timing

In Stock Synthesis version 3.30 (version 3.30.15.00; Methot et al. 2020), reproductive output has a specified spawning (parturition) timing within the calendar year and an explicit elapsed time between spawning (parturition) and recruitment. In the base model configuration, 'spawning' timing was defined as January 1 and recruitment timing was defined as July 1 (month 7) approximately one month after pupping, which occurs for Atlantic blacktip sharks in late May and June (**Table 2.12**). The timing of reproductive output in the base model configuration is consistent with the previous Atlantic HMS SEDAR benchmark stock assessment conducted in Stock Synthesis v3.24U for Atlantic smooth dogfish (Anon. 2015), which included one spawning season and recruitment event on January 1.

3.3.1.5. Natural Mortality (*M*)

The sex-specific natural mortality rate at each age (M_a) was fixed in the base model configuration at age-specific values, separately for females and males, obtained independently with life history invariant methods in the assessment document SEDAR65-AW02 (Cortés 2020),

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as described above in Section 2.3 and provided in **Table 2.13.** Natural mortality was assumed to occur beginning at age-0 consistent with the previous Atlantic HMS SEDAR benchmark stock assessment conducted in Stock Synthesis v3.24U for Atlantic smooth dogfish (Anon. 2015). In contrast, natural mortality was assumed to occur beginning at age-1 in the State Space Age Structured Production Model (SSASPM) previously used by the SEFSC PCL to conduct Atlantic HMS domestic shark stock assessments (Anon. 2012, 2013a, 2013b).

3.3.1.6. Selectivity

The Stock Synthesis double normal selectivity function (Stock Synthesis selectivity pattern 24; Methot et al. 2020) was implemented (**Table 3.5**) and fit to the available length composition data (40 – 165+ cm FL straight with a 5 cm bin width; Kroetz and Courtney 2020; Courtney et al. 2020). The double normal selectivity function includes six parameters: p1 - Peak value, p2 - Top logistic, p3 - Ascending width, p4 - Descending width, p5 - Selectivity at initial size bin, and p6 - Selectivity at final size bin. Initial selectivity parameter values were obtained by fitting the double normal selectivity curve by eye to the available length composition data (Kroetz and Courtney 2020; Courtney et al. 2020) separately for each fleet with the SELEX24 helper spreadsheet.[1] Selectivity at the first bin (p5) was fixed at the values obtained with the SELEX24 helper spreadsheet, and the remaining parameters were estimated within the base model configuration setting initial values equal to those obtained with the SELEX24 helper spreadsheet. This approach allowed for either asymptotic selectivity or dome-shaped selectivity depending on base model configuration fits to the available length composition data. Parameter estimation for double normal selectivity parameters utilized a diffuse symmetric beta prior (Pr_SD = 0.05) scaled between minimum and maximum parameter bounds (Min, Max). The diffuse symmetric beta prior imposes a relative large penalty near parameter bounds, but is otherwise uninformative (Methot et al. 2020). The symmetric beta prior does not utilize the prior mean (Methot et al. 2020). However, a value for the prior mean is still required and reported, as a placeholder. Because there was no prior information – other than the fit obtained with the SELEX24 helper

[1] (SELEX24 helper spreadsheet available: https://vlab.ncep.noaa.gov/web/stock-synthesis; accessed August 2020)

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spreadsheet, the prior means for the double normal selectivity function were set equal to estimated values obtained from preliminary model runs of the base model configuration.

Sex-specific selectivity was implemented for fleets with sufficient sex-specific length composition data (F1, S3 – S10; **Tables 3.2 and 3.5**). Sex-specific selectivity was implemented as a parameter offset to the double normal selectivity (Methot et al. 2020) and included the estimation of five additional parameters per fleet: p1-offset (peak), p3-offset (ascending width), p4-offset (descending width), p6-offset (selectivity at final size bin), and a scaling parameter representing the sex specific offset (as a fraction) of apical selectivity. Estimation of parameter offsets to double normal selectivity utilized a normal prior with a large standard deviation (Pr_SD) along with independent minimum and maximum parameter offset bounds (Min, Max). Prior mean values were set to zero for parameter offsets and to one for the offset scaling parameter. For each fleet, both male (option 3) and female (option 4) selectivity were evaluated as the offset parameters. The offset option which resulted in maximum selectivity equal to one and the offset scaling parameter as a fraction less than one was chosen. Following this approach, the resulting apical fishing mortality, the maximum continuous *F* obtained for each fleet when multiplied by maximum selectivity (equal to one), was comparable among fleets. Initial values for selectivity offset parameters along with their minimum and maximum parameter offset bounds were adjusted by trial and error in preliminary model runs to insure that parameter estimates were not hitting upper or lower bounds.

Asymptotic selectivity was proposed during Assessment Webinars II and IV for fleets that capture the largest sharks F1 (Com-BLL-Kept), F2 (Com-GN-Kept), S4 (NEFSC-BLL), and S7 (SCDNR-DL) (**Table 3.5**). An assumption was that large sharks would be targeted and retained (kept) by both the commercial bottom longline and gillnet fisheries. An examination of the available fishery-dependent length composition data obtained from observer programs identified predominantly large sharks (> size at maturity) in both F1 (Com-BLL-Kept; Kroetz and Courtney 2020) and F2 (Com-GN-Kept; Courtney et al. 2020). Similarly, an examination of the available fishery-independent length composition data obtained for surveys S4 (NEFSC-BLL) and S7 (SCDNR-DL) identified that they also captured predominantly large sharks (> size at

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maturity) (Kroetz and Courtney 2020). The remaining fleets and surveys all captured relatively smaller sharks (Kroetz and Courtney 2020).

Asymptotic selectivity was implemented with a logistic selectivity curve for F1, F2, S4, and S7 in preliminary model runs. The logistic selectivity function was implemented in Stock Synthesis with selectivity pattern 1 (Methot et al. 2020):

(Eq. 3.1) $$S(l) = \frac{1}{1 + e^{\left(\frac{-\ln(19)(L_l - p1)}{p2}\right)}}$$ (Methot et al. 2020, their equation 21).

The value for L_l is the length bin, p1 is the size at inflection, and p2 is width for 95% selection. A negative width causes a descending curve. However, logistic selectivity resulted in poor fits to length composition data at the largest size bins (not shown). Consequently, the double normal selectivity function was implemented in the base model configuration for F1, F2, S4, and S7 with final selectivity at the largest size bins estimated in the model based on fit to the length composition data, as described above.

Time blocks were added to the estimation of selectivity for F1 (1981 – 1996; 1997 – 2004; 2005 – 2007; 2008 – 2017,2018), F2 (1981 – 2006; 2007 – 2018), and F4 (1981 – 1989; 1990 – 1999; 2000 – 2018) in order to account for observed inter-annual variation observed in Pearson residuals of preliminary model fits to length composition data for these fleets (**Table 3.5**). Corresponding time blocks were also added to the estimation of catchability, *q*, for surveys S1 and S2, as described above, because the surveys S1 and S2 are fit using the length based selectivity obtained for F1 (mirrored F1; **Table 3.5**).

In preliminary model runs, the addition of time blocks resulted in a very large number of poorly estimated selectivity parameters (i.e., CVs > 50%, highly correlated > 0.95, un-correlated < 0.01, or estimated at a boundary condition). Consequently, the number of estimated selectivity parameters was reduced by identifying and removing (or reformulating) the large number of poorly estimated selectivity parameters. Poorly estimated selectivity time block parameters were

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fixed to their estimated values obtained during the time block with the most data. Similarly, poorly estimated sex-specific offset parameter values were fixed to their estimated values obtained for the other sex in the same fleet. If neither of these options were available, poorly estimated parameters were fixed at their initial values obtained as described above. In addition, the minimum sample size was reduced from 30 to 20 for fleet F4, as described above, in order to increase the number of years of length composition data available in each time block. The final year of length composition data for F2 (2018) was removed from the model because of low sample size of females in 2018.

3.3.1.7. Data Weighting

A Francis (2011) two-stage data weighting approach was implemented in the base model configuration. In stage one, a minimum average standard error, SE on the natural log scale, was imposed in Stock Synthesis for each CPUE series. The minimum SE was based on the residual variance obtained from a simple smoother fit to each CPUE series, on the natural log scale, outside the model (Francis 2011; Lee et al. 2014a, 2014b). In stage two, the effective sample size (Effn) of each length composition data set was obtained from the residuals of the Stock Synthesis model fit to each length composition data set using either the Francis (2011) or the McAllister and Ianelli (1997) harmonic mean data weighting methods. The Francis (2011) and McAllister and Ianelli (1997) data weighting methods are reviewed in Francis (2017) and Punt (2017). Data weighting philosophies in fisheries stock assessment models are discussed in Punt et al. (2014).

Stage 1

A LOESS smoother was fit to each CPUE data on the log scale (**Appendix 3.A**). The square root of the residual variance was calculated for each CPUE series based on the fit of the simple smoother to the CPUE series on the log scale as

(Eq. 3.2)
$$\mathrm{RMSE}_{smoother} = \sqrt{\left(\frac{1}{N}\right)\sum_{t=1}^{N}\left(Y_t - \hat{Y}_t\right)^2} \quad .$$

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The value for Y_t is the observed CPUE in year *t* on the log scale, $\hat{Y}_t$ is the predicted CPUE in year *t* obtained from the smoother fit to the data on the log scale, and *N* is the number of CPUE observations (Francis 2011; Lee et al. 2014a, 2014b; e.g., Courtney et al. 2017b). The average annual CV input (SE.in) for each CPUE series in the Stock Synthesis base model configuration was assumed to be equal to the average SE on the log scale. The SE was then adjusted based on the expectation that the stock assessment model would fit each CPUE data **at best** as well as the smoother (Francis 2011; Lee et al. 2014a, 2014b; e.g., Courtney et al. 2017b).

On the one hand, if SE.in for a CPUE series was less than $\mathrm{RMSE}_{smoother}$ for that CPUE series, then the input SE for the CPUE series was adjusted (SE.adj) in Stock Synthesis before running the model so that the new average SE was equal to $\mathrm{RMSE}_{smoother}$ (SE.in + SE.adj = $\mathrm{RMSE}_{smoother}$). On the other hand, if SE.in for a CPUE series was greater than or equal to the $\mathrm{RMSE}_{smoother}$ for that CPUE series, then the SE of the CPUE series was not adjusted in the Stock Synthesis model. All calculations were implemented in R (R Core Team 2020). The resulting variance adjustments for surveys S1 – S10 are provided in **Table 3.6**.

Stage 2

Effn for each length composition data set was estimated using the Francis method (Punt 2017, his equation 1.C "Francis tuning method") for length composition data sets with more than ten years of data. Otherwise, Effn was estimated using the McAllister and Ianelli harmonic mean method (Punt 2017, his equation 1.B "McAllister-Ianelli-2 tuning method"). Sample size for the Francis method is based on the number of years with length composition data (Punt 2017, his Table 2). In contrast, sample size for the McAllister and Ianelli harmonic mean method is based on the number of lengths measured each year (Punt 2017, his Table 2). In preliminary model runs, Effn estimates obtained using the Francis method were larger than those obtained using the McAllister and Ianelli harmonic mean method for data sets with less than 11 years of length composition. Consequently, the McAllister and Ianelli harmonic mean was used for these length composition data. Effn estimates were obtained from the R package r4ss (Taylor et al. 2020) for the Francis method, and from Stock Synthesis output (Methot and Wetzel 2013; Methot et al.

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2020) for the McAllister and Ianelli harmonic mean method. The resulting length composition variance adjustment factors for the base model configuration are provided in **Table 3.6**.

3.3.1.8. Recruitment Deviation Bias Adjustment Ramp

The parameter representing the standard deviation in recruitment, σ_R, was not adjusted from the initial value of 0.28, which was consistent with the RMSE of recruitment variability obtained from the main recruitment deviation period (0.28, 1994 – 2017).

The expected recruitments require a bias adjustment so that the resulting recruitment level on the standard scale is mean unbiased (Methot and Taylor 2011). The years chosen for bias adjustment, and the maximum bias adjustment parameter value were obtained from Stock Synthesis output with the program r4ss from the R package r4ss (Taylor et al. 2020):

```
  1979   #_last_yr_nobias_adj_in_MPD; begin of ramp
  2012   #_first_yr_fullbias_adj_in_MPD; begin of plateau
2018.8   #_last_yr_fullbias_adj_in_MPD
2018.9   #_end_yr_for_ramp_in_MPD
0.6913   #_max_bias_adj_in_MPD
```

3.3.1.9. Initial Population State

The Atlantic blacktip shark population was assumed to be in an unfished state of equilibrium at the start of the model (1981). The population age structure and overall size in the first year was determined as a function of the parameter estimate of the first year recruitment on the natural log scale, $\ln(R_0)$, and the initial equilibrium catch (set to 0.0 mt).

3.3.1.10. Model Convergence and Diagnostics

Model convergence was based on whether or not the Hessian inverted (i.e., the matrix of second derivatives of the likelihood with respect to the parameters, from which the asymptotic standard

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error of the parameter estimates is derived). Other convergence diagnostics were also evaluated. Excessive CVs on estimated quantities (>> 50 %) or a large final gradient (>1.00E-05) were indicative of poorly estimated parameters. The correlation matrix was also examined for highly correlated (> 0.95) and un-correlated (< 0.01) parameters, which were assumed to be non-informative and an indication of over parameterization. Parameters estimated at a bound were a diagnostic for poorly estimated parameters (or poorly specified model structure). Poor fits to CPUE or length composition data along with patterns in Pearson's residuals of fits to CPUE or length composition data were diagnostics for problems with fitting the available data resulting from poorly estimated parameters or poorly specified model structure.

3.3.1.11. Uncertainty and Measures of Precision

Uncertainty in estimated and derived parameters was obtained from Stock Synthesis AD-Model Builder (ADMB) output as the asymptotic parameter standard deviations (SD) at the converged solution (Fournier et al. 2011).

Markov Chain Monte Carlo, MCMC, was proposed during the AP to obtain MCMC credibility intervals for some estimated and derived parameters. However, MCMC credibility intervals are not available for this report because of time constraints resulting from the 2019 Covid-19 crisis including a lack of IT resources necessary to perform MCMC analyses while on mandatory telework.

3.3.1.12. Sensitivity Analyses

The base model configuration sensitivity to selectivity and natural mortality was evaluated with a logistic sensitivity analysis. The logistic sensitivity analysis was implemented by modifying the base model configuration to include asymptotic selection (full selection) at large lengths for fleets and surveys that captured blacktip sharks at relatively large lengths. The logistic sensitivity analysis also implemented mean natural mortality obtained from life history invariant methods

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(Section 3.1.7; **Table 2.14**) and estimated the CVs for L_{Amin} and L_{Amax} (Section 3.3.1.1) within the model. In addition, the CVs of length at age-0 and length at age-Linf were estimated within the length-at-age transition matrix, and the minimum annual length composition sample size was reduced from 30 to 20 for fleet F2, as described in Section 3.4.4.1 below.

Additional sensitivity analyses to the base model configuration were proposed during the AP:

Low Catch scenario (Sections 2.1.4 and 3.2.4; **Tables 2.5** and **2.6**);
High Catch scenario (Sections 2.1.4 and 3.2.4; **Tables 2.5** and **2.6**);
Remove CPUE indices S4 (NEFSC-BLL) and S7 (SCDNR-DL) (Section 3.2.6);
Low Productivity (stock recruit steepness h = 0.32, Sections 2.3 and 3.2.7); and
High Productivity (stock recruit steepness h = 0.52, Sections 2.3 and 3.2.7).

However, the additional sensitivity analyses are not available for this report because of time constraints resulting from the 2019 Covid-19 crisis including a lack of IT resources necessary to perform additional sensitivity analyses while on mandatory telework.

3.3.1.13. Benchmarks and Reference Points

Benchmarks are provided in this assessment for spawning stock fecundity, SSF, and fishing mortality, F, in the terminal year of the assessment, 2018 (SSF_{2018}, and F_{2018}). Benchmarks are reported relative to equilibrium MSY reference points (SSF_{MSY}, and F_{MSY}). Depletion estimates are provided relative to unfished equilibrium levels estimated at the start year of the assessment (1981) for SSF, F and recruitment (SSF_0, F_0, R_0). Trajectories and phase plots are provided for F_Y/F_{MSY} and SSF_Y/SSF_{MSY}.

Stock status definitions are based on the current Atlantic HMS stock status criteria (e.g., NMFS (2019, their Section 2 Status of Stocks) and summarized here: "… a stock is considered "overfished" when the current biomass (B) is less than the biomass for the minimum stock size threshold ($B < B_{MSST}$). The minimum stock size threshold (MSST) is determined based on the natural mortality of the stock and the biomass at maximum sustainable yield (B_{MSY}). Maximum

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sustainable yield (MSY) is the maximum long-term average yield that can be produced by a stock on a continuing basis. The biomass can fall below the B_{MSY} without causing the stock to be declared "overfished" as long as the biomass is above B_{MSST}."

Similarly, stock status determinations are based on the current Atlantic HMS stock status reference point thresholds (e.g., NMFS 2019, their Section 2 Status of Stocks) and summarized here:

> "Maximum Fishing Mortality Threshold (MFMT) = $F_{limit} = F_{MSY}$;
> Overfishing is occurring when $F_{year} > F_{MSY}$;
> Minimum Stock Size Threshold (MSST) = B_{limit} = (1-M)B_{MSY} when M < 0.5 or MSST = 0.5B_{MSY} when M ≥ 0.5, M = natural mortality.
> An overfished status is defined as B_{year} relative to B_{MSST}."

Consequently, for the purposes of this assessment, the Atlantic blacktip shark stock was defined to be in an overfishing condition in year *y* if $F_Y > F_{MSY}$. The fishing mortality rate, *F*, was calculated in Stock Synthesis as the total annual fishing mortality rate experienced by the population (*F=Z-M*) (Methot et al. 2020). The stock was defined to be in an overfished condition in year *y* if $SSF_Y < \left(1-\bar{M}_a\right)$*$SSF_{MSY}$. Spawning stock fecundity, SSF, was used as a proxy for female biomass, *B*, and $\bar{M}_a$ was calculated as the average natural mortality rate at age used in the assessment model configuration. For the base model configuration, $\bar{M}_a$ was calculated as the arithmetic mean of the female age-specific values of *M* used for the baseline run (0.139; **Table 2.13**). Consequently, for the base model configuration $\bar{M}_a < 0.5$ and MSST was defined as $\left(1-\bar{M}_a\right)$*SSF_{MSY}. The MSST reference point threshold defined in NMFS (2019, their Section 2 Status of Stocks) is consistent with recommendations from Restrepo et al. (1998) and Restrepo and Powers (1999).

3.3.1.14. Projection Methods

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Projections for the Stock Synthesis base model configuration are provided separately as a Review Workshop document. The projection methods follow those from a previous Atlantic HMS sandbar shark update assessment conducted in Stock Synthesis version 3.24 (Anon 2017a) and updated to Stock Synthesis version 3.30 (Anon 2017b; Courtney and Rice 2020).

Markov Chain Monte Carlo, MCMC, projections were proposed during the AP. However, MCMC projections are not available for this report because of time constraints resulting from the 2019 Covid-19 crisis including a lack of IT resources necessary to perform MCMC analyses while on mandatory telework.

3.4. Results

3.4.1. Measures of Overall Model Fit

3.4.1.1. Model Convergence and Diagnostics

The Hessian matrix inverted and, consequently, was assumed to be positive definite. The final gradient was reasonably small ($5.49*10^{-5}$) and no parameters were estimated above the maximum correlation threshold *(cormax = 0.95)* or below the minimum correlation threshold (*cormin* = 0.01). No parameters were estimated on a boundary condition, and CVs were less than 0.5 for all estimated parameters excluding recruitment deviations (**Table 3.7**).

3.4.1.2. Indices of Abundance and Catchability

Model fits to indices of abundance included in the base model configuration are provided in **Figure 3.2**. Fits are provided on the nominal scale and on the log scale along with residuals on the log scale. Estimates of catchability, *q*, are provided for indices S1 (with time blocks during the years 1981 – 1996, 1997 – 2004, and 2005 – 2007) and S2 (with time blocks during the years

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2008 – 2017 and 2018) (**Table 3.8; Figure 3.2**). The median unbiased analytical solution for *q*, calculated in Stock Synthesis, is provided for the remaining indices S3 – S10 (**Table 3.8; Figure 3.2**). Fits to the indices of abundance S4 (NEFSC-BLL) and S7 (SCDNR-DL) were poor. Fits to the remaining indices appeared to balance high inter-annual variability within each of the individual indices.

3.4.1.3. Length Composition

Fits to length composition included in the base model configuration are provided in **Figure 3.3**. Observed and predicted annual length compositions are provided along with Pearson residuals. Years with annual length composition sample size less than the minimum input sample size (Min; **Table 3.2)** were excluded from the model fit, and are not plotted. The value "N adj" is the input effective sample size obtained using either the Francis method or the McAllister and Ianelli harmonic mean, as described above. The value "N eff" is an alternative effective sample size estimate (McAllister and Ianelli 1997; Punt 2017, his McAllister-Ianelli-1 in equation 1.A:) that is not implemented in this assessment. The diameter of Pearson residuals indicates relative error; predicted < observed (solid), predicted > observed (transparent) within the length composition data set. The maximum diameter of Pearson residuals indicates relative error among length composition data sets.

Fits to the annual length compositions within each length composition data set were generally poor (**Figure 3.3**). Time-blocks and sex specific selectivity were added in preliminary model runs to improve the fits to fleets F1, F2, and F4. However, after the addition of time-blocks and sex specific selectivity there were few remaining obvious systematic patterns observed in the residuals (e.g., patterns of positive or negative residuals), making it difficult to objectively determine how to improve the fits. The maximum diameter of Pearson residuals was relatively large for F4 (Recreational catch, Max = 10), S7 (SCNDR Drum Line, Max = 8), and S9 (COASTSPAN Gillnet Long, Max = 4) indicating a relatively poorer fit to these length composition data sets than to the others.

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In contrast, fits to aggregate length compositions (**Figure 3.4**) appeared to be reasonably accurate – indicating that the estimated selectivity curves in the base model configuration removed sharks from the modeled population in aggregate at comparable length to that observed in the data for each fleet and survey.

3.4.1.4. Parameter Estimates and Associated Measures of Uncertainty

Parameter estimates along with their priors, asymptotic standard errors, and resulting CVs are provided in **Table 3.7**. Parameters with a negative phase were fixed at their initial value. CVs are calculated as the asymptotic standard error (Parm_StDev) divided by the estimated value (Value).

3.4.1.5. Length Based Selectivity

Estimated selectivity at length (cm FL straight) obtained in the base model configuration is provided in **Figure 3.5.** Selectivity was estimated by implementing the selectivity functions identified in **Table 3.5**. Selectivity parameter estimates and their associated asymptotic standard errors and CVs are provided in **Table 3.7**.

3.4.1.6. Recruitment

The annual numbers of age-0 recruits obtained for the base model configuration are provided in **Table 3.9** and **Figure 3.6**. Estimated log recruitment deviations were estimated for early (1984 – 1993), main (1994 – 2017), late (2018), and forecast (2019) recruitment periods and are plotted with associated 95% asymptotic confidence intervals. Estimated annual age-0 recruits are also plotted with 95% asymptotic confidence intervals. Age-0 recruits follow the assumed stock recruitment relationship exactly in years prior to the early recruitment period (1918 – 1984) and during the forecast period 2019. Expected recruitment from the stock-recruitment relationship

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and the bias adjustment applied to the stock-recruitment relationship (Methot and Taylor 2011) are provided in **Figure 3.7**.

3.4.2. Fishing Mortality

Two calculations of fishing mortality rate were obtained from Stock Synthesis model output for the base model configuration. First, the instantaneous annual fishing mortality rate (Continuous *F*) was obtained from Stock Synthesis output separately for each fleet F1 – F4 (**Figure 3.8**). A plot of total annual landings (mt) by fleet is also provided (**Figure 3.8)** for comparison. Total annual landings include both commercial landings (mt) and recreational catch (A + B1 + B2-Dead), as described above. Recreational catch data were entered in numbers (1,000s) and converted internally within Stock Synthesis to weight (mt) based on the weight at length of recreational fishery (F4) removals obtained from Stock Synthesis.

Second, the total fishing mortality rate across all fleets was obtained from Stock Synthesis output as the total annual fishing mortality rate experienced by the population (F=Z-M) (**Table 3.9**). Total annual F is provided relative to F_{MSY}, F/F_{MSY}, along with the asymptotic standard error of the derived quantity obtained from Stock Synthesis output (**Table 3.10** and **Figures 3.8** and **3.9)**.

3.4.3. Stock Biomass (Total and Spawning Stock)

Annual total biomass, *B*, and annual spawning stock fecundity, SSF, obtained from the base model configuration are provided in **Table 3.9**. Annual SSF is provided relative to SSF_{MSY}, SSF/SSF_{MSY}, along with the asymptotic standard error of the derived quantity obtained from Stock Synthesis output (**Table 3.10)**. Annual SSF is also provided relative to MSST, SSF/MSST, in **Table 3.10.** However, SSF/MSST is not a standard derived quantity in Stock Synthesis, and as a result, the asymptotic standard error of the derived quantity is not available from Stock Synthesis output. Consequently, annual SSF is plotted along with its asymptotic standard error obtained from Stock Synthesis and then compared to MSST (**Figure 3.9)**.

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3.4.4. Sensitivity Analyses

3.4.4.1. Logistic Selectivity

The logistic sensitivity analysis was implemented by modifying the base model configuration to include asymptotic selection with full selection (selectivity equal to 1.0) at large lengths for fleets and surveys that captured blacktip sharks at relatively large lengths. Results of the logistic sensitivity analysis are provided in **Appendix 3.B** and are described below.

The base model configuration was modified to include logistic selectivity with full selection (selectivity equal to 1.0) at large lengths for fleets F1 and F2 and surveys S4 and S7 (**Table 3.B.1)**. Preliminary model runs with this selectivity configuration resulted in poor fits to length composition data sets at the largest sizes for fleets F1 and F2 and surveys S4 and S7 (not shown). Consequently, the following additional modifications from the base model configuration were implemented in the logistic sensitivity analysis in an effort to improve fits to these length composition data sets at the largest sizes. The mean natural mortality at age for females and males obtained from life history invariant methods (**Table 2.14**) was implemented in order to evaluate the effect of natural mortality on the numbers at length at the largest sizes in the modeled population. The CVs of length at age-0 and length at age-Linf within the length-at-age transition matrix were estimated (separately for females and males; **Figure 3.B.1**) in an effort to include additional estimated process in the model fit to length composition data at both the youngest and oldest ages. The minimum annual length composition sample size was reduced from 30 to 20 for fleet F2 (**Table 3.2**) in an effort to include more years of annual length composition data within selectivity time-blocks for F2.

After making the modifications indicated above, the logistic sensitivity analysis was implemented analogously to the base model configuration. Two stage data weighting for the logistic sensitivity analysis is provided in **Table 3.B.2**. Estimated catchability, q, for surveys S1, and S2 along with the median unbiased analytical solution for q obtained for the remaining fleets

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are provided in **Table 3.B.3**. The steepness of the Beverton-Holt stock recruit relationship, h = 0.4, and the parameter representing the standard deviation in recruitment, σ_R = 0.28 for the main recruitment deviation period (1994 – 2017), were unchanged from the base model configuration. The years chosen for bias adjustment, and the maximum bias adjustment parameter value for the logistic sensitivity analysis were obtained analogously to the base model configuration:

```
1977.2   #_last_yr_nobias_adj_in_MPD; begin of ramp
2012.2   #_first_yr_fullbias_adj_in_MPD; begin of plateau
2018.8   #_last_yr_fullbias_adj_in_MPD
  2019   #_end_yr_for_ramp_in_MPD (Stock Synthesis sets bias_adj to 0.0 for fcast yrs)
0.6839   #_max_bias_adj_in_MPD (-1 to override ramp and set biasadj=1.0 for all estimated recdevs)
```

The Hessian matrix for the logistic sensitivity analysis inverted and, consequently, was assumed to be positive definite. No parameters were estimated above the maximum correlation threshold *(cormax = 0.95)* or below the minimum correlation threshold (*cormin* = 0.01). No parameters were estimated on a boundary condition. In contrast to the base model configuration, three estimated parameters in the logistic sensitivity analysis had CVs > 0.5 (excluding recruitment deviations). The final gradient for the logistic sensitivity analysis ($1.03*10^{-4}$) was also relatively larger than that obtained for base model configuration $5.49*10^{-5}$.

Parameter estimates for the logistic sensitivity analysis along with their priors, asymptotic standard errors, and resulting CVs are provided in **Table 3.B.4**.

The estimated CVs in length at age-0 and length at age-Linf obtained in the logistic sensitivity analysis resulted in a narrower distribution of length at age for the oldest ages (**Figure 3.B.1**) compared to the base model configuration (**Figure 3.1**). Fits to the standardized indices of relative abundance in the logistic sensitivity analysis (not shown) were indistinguishable from those obtained for the base model configuration (**Figure 3.2)**. Fits to the annual length compositions for fleets F1 and F2 and surveys S4 and S7 were relatively poor at the largest sizes (**Figures 3.B.2** and **3.B.3**) compared to those obtained for the same fleets in the base model configuration (**Figures 3.3** and **3.4**). As expected, selectivity at length estimated within the logistic sensitivity analysis increased asymptotically (to a maximum of 1.0) at the largest sizes (≥

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150 cm FL straight) for fleets F1 and F2 and surveys S4, and S7, but also for survey S3 (**Figure 3.B.4**). In contrast, selectivity at length estimated within the base case model configuration decreased asymptotically at the large sizes (≥ 150 cm FL straight) with the shape of the descending selectivity curve and its asymptotic value at the large sizes estimated based on model fit to the length composition data (**Figure 3.5**). Males were fully selected for survey S7 in the logistic sensitivity analysis (**Figure 3.B.4**). In contrast, females were fully selected for S7 in the base model configuration (**Figure 3.5**).

The estimated main log recruitment deviations (1994 – 2007) were similar in the logistic sensitivity analysis (**Figure 3.B.5**) and the base model configuration (**Figure 3.6**). However, the base model configuration resulted in increasing recruitment (positive recruitment deviations) for the most recent two years (2017, 2018), while the logistic sensitivity analysis resulted in recruitment deviations closer to zero in 2017 and 2018. The logistic sensitivity analysis also resulted in relatively more recruitment deviations below zero in early years (< 1994). Expected recruitment from the stock-recruitment relationship and the bias adjustment applied to the stock-recruitment relationship were similar for the logistic sensitivity analysis (**Figure 3.B.6**) and the base model configuration (**Figure 3.7**). However, the logistic sensitivity analysis resulted in fewer years with log deviations > 0.5 (2013) compared to the base model configuration (2000, 2001, and 2013).

Annual total biomass, *B*, spawning stock fecundity, SSF, and total fishing mortality (*F=Z-M*) were relatively lower in the logistic sensitivity analysis (**Table 3.B.5**) compared to the base model configuration (**Table 3.9**). In contrast, the annual numbers of age-0 recruits were relatively larger in the logistic sensitivity analysis (**Table 3.B.5 and Figure 3.B.5**) compared to the based model configuration (**Table 3.9** and **Figure 3.6**). Fishing mortality by fleet (Continuous *F*) was dominated by the recreational catch for both the logistic sensitivity analysis (**Figure 3.B.7**) and the base model configuration (**Figure 3.8**).

As described above, recreational catch data were entered in numbers (1,000s) and converted internally within Stock Synthesis to weight (mt) based on the weight at length of recreational fishery (F4) removals obtained from Stock Synthesis. The logistic sensitivity analysis conversion

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in stock Synthesis from numbers to mt resulted in relatively larger recreational catch in weight (A + B1 + B2-Dead) during the years 2000 – 2018 (**Figure 3.B.7**, Upper panel) compared to the base model configuration (**Figure 3.8**, Upper panel). One explanation for this difference is that the double normal selectivity function implemented for fleet F4 resulted in relatively higher selectivity at large size (and, as a result, larger recreational catch in weight) in the logistic sensitivity analysis compared to the base case. The logistic sensitivity analysis resulted in a **fixed** parameter value at a relatively larger final selectivity during the years 2000 – 2018 (Size_DblN_end_logit_F4_Rec_A_B1_B2PRM(4) fixed at a value of -1.20; **Table 3.B.4** and **Figure 3.B.4).** In contrast, the **estimated** parameter value obtained in the base model configuration (Size_DblN_end_logit_F4_Rec_A_B1_B2PRM(4) estimated at a value of -3.21; **Table 3.7** and **Figure 3.5**).

In general, the observed differences in selectivity obtained from each model (when fit to the same observed length composition data) are consistent with the different underlying predicted population numbers at age obtained from each model (**Figure 3.B.9**). In addition, the predicted population numbers at age obtained from each model are also multiplied by different age-length transition matrices in each model (**Figures 3.B.1** and **3.1**) to produce the underlying predicted population numbers at length in each model (**Figure 3.B.10**). The predicted population numbers at length in each model are then multiplied by the different selectivity at length (and different continuous fishing mortality for each fishing fleet) obtained for each model (**Figures 3.B.4** and **3.5**) to produce the predicted proportions at length for each model (**Figures 3.B.2** and **3.3**).

Annual total fishing mortality ($F=Z-M$) relative to MSY (F/F_{MSY}) was lower for the logistic sensitivity analysis (**Table 3.B.6; Figures 3.B.7** and **3.B.8**) compared to the base model configuration (**Table 3.10**; **Figures 3.8** and **3.9**). Annual total F exceeded F_{MSY} during the years 1997 – 2006 for the logistic sensitivity analysis (**Table 3.B.6; Figure 3.B.8)**. In contrast, annual total F exceeded F_{MSY} during the years 1993, 1995, 1997 – 2009, and 2014 for the base model configuration (**Table 3.10; Figure 3.9)**.

Annual spawning stock fecundity, SSF, did not fall below the MSST for either the logistic sensitivity analysis (**Table 3.B.6; Figure 3.B.8**) or the base model configuration (**Table 3.10;**

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Figure 3.9). SSF relative to MSY (SSF/SSF_{MSY}) was similar for the logistic sensitivity analysis (**Table 3.B.6**) compared to the base model configuration (**Table 3.10**). SSF approached SSF_{MSY} and then recovered for both the logistic sensitivity analysis (**Figure 3.B.8**) and the base model configuration (**Figure 3.9**).

SSF approached SSF_{MSY} earlier for the logistic sensitivity analysis (2009 – 2012; **Table 3.B.6** and **Figure 3.B.8**) compared to the base model configuration (2012 – 2015; **Figure 3.9**). SSF also recovered to a relatively higher level in the terminal year of the assessment, 2018, for the logistic sensitivity analysis (SSF_{2018}/SSF_{MSY} = 1.39, SE = 0.286; **Table 3.B.6**; **Figure 3.B.8**) compared to the base model configuration (SSF_{2018}/SSF_{MSY} = 1.16, SE = 0.255; **Table 3.10**; **Figure 3.9**)

3.4.5. Benchmarks and Reference Points

The base model configuration predicted that the stock was not overfished (SSF_{2018} > MSST) and that the stock was not experiencing overfishing ($F_{2018} > F_{MSY}$) in the terminal year of the assessment (**Tables 3.10** and **3.11; Figures 3.9** and **3.10).** In contrast, the base model configuration predicted that the stock had experienced overfishing, annual total $F > F_{MSY}$, during some years of the assessment: 1993, 1995, 1997 – 2009, and 2014 (**Table 3.10**; **Figures 3.9** and **3.10**).

Similarly, the logistic sensitivity analysis also predicted that the stock was not overfished (SSF_{2018} > MSST) and that the stock was not experiencing overfishing ($F_{2018} > F_{MSY}$) in the terminal year of the assessment (**Tables 3.B.6** and **3.11; Figures 3.B.8** and **3.B.11)**. The logistic sensitivity analysis also predicted that the stock had experienced overfishing, annual total $F > F_{MSY}$, during some years of the assessment: 1997 – 2006 (**Table 3.B.6**; **Figures 3.B.8** and **3.B.11**).

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Markov Chain Monte Carlo, MCMC, was proposed during the AP for use to obtain MCMC credibility intervals for benchmarks. However, MCMC credibility intervals are not available for this report because of time constraints resulting from the 2019 Covid-19 crisis including a lack of IT resources necessary to perform MCMC analyses while on mandatory telework.

3.4.6. Projections

Projections results for the Stock Synthesis base model configuration are provided separately in a Review Workshop document.

Markov Chain Monte Carlo, MCMC, was proposed during the AP for use to obtain MCMC credibility intervals for projections. However, MCMC credibility intervals are not available for this report because of time constraints resulting from the 2019 Covid-19 crisis including a lack of IT resources necessary to perform MCMC analyses while on mandatory telework.

3.5. Discussion

Stock status determinations obtained from the base model configuration and the logistic sensitivity analysis were consistent. Both models predicted that the stock was not overfished (SSF_{2018} > MSST) and that overfishing was not occurring ($F_{2018} > F_{MSY}$) in the terminal year of the assessment (**Table 3.11**, **Figures 3.10** and **3.B.11**).

Both the base model configuration and the logistic sensitivity analysis predicted that the stock had experienced overfishing, annual total $F > F_{MSY}$, prior to the terminal year. The base model configuration predicted that the stock had experienced overfishing during the years 1993, 1995, 1997 – 2009, and 2014 (**Table 3.10**; **Figures 3.9** and **3.10**). The logistic sensitivity analysis predicted that the stock had experienced overfishing during the years 1997 – 2006 (**Table 3.B.6**; **Figures 3.B.8** and **3.B.11**).

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SSF declined in response to increased fishing mortality relatively earlier for the logistic sensitivity analysis (2009 – 2012; **Table 3.B.6** and **Figure 3.B.8**) compared to the base model configuration (2012 – 2015; **Figure 3.9**). SSF also recovered in response to reduced fishing mortality relatively more quickly (SSF_{2018}/SSF_{MSY} = 1.39, SE = 0.286; **Table 3.B.6**; **Figure 3.B.8**) compared to the base model configuration (SSF_{2018}/SSF_{MSY} = 1.16, SE = 0.255; **Table 3.10**; **Figure 3.9**)

One explanation for the different trajectories in recovery of SSF relative to SSF_{MSY} may be the higher natural mortality rate imposed in the logistic sensitivity analysis, which resulted in a compressed age structure. The base case model implemented the minimum estimates of instantaneous natural mortality rates obtained from life history invariant methods, as recommended during the AP (**Table 2.13**). In contrast, the logistic sensitivity analysis implemented relatively higher mean estimates of instantaneous natural mortality rates obtained from the same life history invariant methods (**Table 2.14**). The relatively higher natural mortality rates were implemented in an attempt to improve the logistic sensitivity model fit to the largest sharks (> 150 cm FL) by reducing the number of older (and larger) sharks in the underlying modeled population. Implementing the relatively higher natural mortality in the logistic sensitivity analysis had the anticipated effect of reducing the proportion of older (and larger) sharks compared to the base model configuration (**Figures 3.B.9** and **3.B.10**). The compressed age structure resulting from higher natural mortality in the logistic sensitivity analysis may have resulted in a more rapid response in the modeled population to changes in fishing mortality over time.

In addition, the effect of imposing logistic selectivity for fleets F1 and F2 (which capture relatively large sharks > 150 cm FL) also removed large sharks (> 150 cm FL) from the underlying modeled population at proportionally higher rates than smaller sharks. The anticipated effect of the compressed age structure resulting from imposing logistic selectivity is also a more rapid response in the modeled population to changes in fishing mortality over time, as described above.

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In contrast, as described above in Section 3.3.1.6, the implementation of a double normal selectivity function in the base model configuration allowed for either asymptotic selectivity or dome-shaped selectivity to be estimated within the model based on the model fit to the available length composition data. Fits of the base model configuration to the available length composition data resulted in dome-shaped selectivity for fleets F1 and F2 with proportionally fewer large sharks (> 150 cm FL) selected by these fleets.

The anticipated effect of proportionally fewer smaller (immature) sharks in the underlying modeled population under dome-shaped selectivity is a lagged recovery of SSF following a reduction of fishing mortality by approximately one generation (Anon. 2017b). Following a reduction of fishing mortality, mature females alive at the time in the modeled population must first produce pups, the pups must then survive until maturity at higher rates under reduced fishing mortality, and then they must produce pups of their own before contributing to an observed increase in SSF.

This is the first time that Atlantic blacktip sharks have been assessed using Stock Synthesis within SEDAR. An advantage of the integrated modeling approach is that the development of statistical models that combine several sources of information into a single analysis allows for consistency in assumptions and permits the uncertainty associated with all data sources to be propagated to final model outputs (Maunder and Punt 2013).

However, a disadvantage of utilizing a pre-packaged integrated modeling approach is that increased model complexity of the package itself can lead to the possibility of implementation errors when developing a new model. Arguably, the amount of time required by an analyst to detect and correct implementation errors in a new complex integrated stock assessment model can be similar to the amount of time required to program and debug a new tailored stock assessment model (Courtney et al. 2007). In order to accommodate the extended timeline required to implement a new Stock Synthesis model for Atlantic blacktip sharks well as the modified AP time line required to accommodate additional analyses of commercial catch data, additional stock assessment modelling platforms were not evaluated.

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In an attempt to gain efficiencies from previous Stock Synthesis experience within the SEFSC PCL stock assessment enterprise, this implementation of the Atlantic blacktip shark Stock Synthesis model and the format of this assessment report followed a previous Atlantic HMS SEDAR benchmark stock assessment conducted in Stock Synthesis (version 3.24) by the SEFSC PCL for Atlantic smooth dogfish (Anon. 2015). However, two major advancements were made in this integrated Stock Synthesis model.

First, as described above, length based selectivity was estimated internally within Stock Synthesis based on model fits to the available length composition data. The implementation of length based selectivity was adapted from a North Pacific swordfish assessment implemented in Stock Synthesis (Courtney and Piner 2009, 2010). In contrast, the length based selectivity implemented in previous Atlantic HMS domestic shark stock assessments conducted by the SEFSC PCL with both Stock Synthesis (Anon. 2015) and SSASPM (Anon. 2012, 2013a, 2013b) depended upon obtaining selectivity externally to the stock assessment model.

Second, as described above, recreational catch (A + B1 + B2-Dead) was entered in Stock Synthesis in its native format (numbers in 1000s) and then converted within Stock Synthesis to weight (mt) based on the underlying modeled population numbers at age, the modeled length at age relationship along with its uncertainty, and the estimated length based selectivity of the recreational fishery (F4). In contrast, the recreational catch entered in previous Atlantic HMS domestic shark stock assessments conducted by the SEFSC PCL with both Stock Synthesis (Anon. 2015) and SSASPM (Anon. 2012, 2013a, 2013b) depended upon obtaining recreational catch in weight externally to the model using conversion factors.

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3.6. Recommendations for Future Research and Data Collection

Additional research may be needed on the variable effects of Federal and state recreational management actions on the annual length composition of Atlantic blacktip shark recreational catch (A + B1 + B2-Dead). During Assessment Webinars I and III, it was discussed that data limitations resulting from recreational length sampling might not accurately reflect the effect of

Federal management actions on length composition of retained and discarded Atlantic blacktip sharks over time. Federal management actions include implementation of a minimum size limit (54 inches straight fork length) in Federal waters during calendar years 2000 – 2018 and the implementation of Federal bag limits of 4 LCS (Large Coastal Sharks; 1993), 2 LCS (1997) and 1 LCS (2000 – 2018). It was also noted that most Atlantic blacktip sharks are captured recreationally within state waters, and that the Federal management actions identified above may not have been implemented uniformly within state waters.

The selectivity parameterization approach implemented here estimated selectivity parameters where possible and fixed (or reformulated) poorly estimated selectivity parameters where necessary. This pragmatic selectivity parameterization approach is consistent with regularization to reduce over-parameterization in Bayesian stock assessments implemented in AD Model Builder, ADMB, by adding priors and turning off estimation for poorly informed parameters (Monnahan et al. 2019). This pragmatic approach was implemented here in order to remove sharks from the modeled population at the correct aggregate size sampled by each data set (**Figures 3.4 and 3.B.3**), while allowing relatively poorer fits to some poor quality annual length composition data sets (e.g., because of low sample size; **Figures 3.3 and 3.B.2**). An assumption was that poor quality annual length composition data sets were not necessarily representative of annual changes in the length composition sampled in that year (e.g., because of low sample size and observation error). In contrast, the aggregate length composition data obtained from the poor quality data were assumed to be representative of the length composition sampled in that data set (e.g., because of higher sample size and reduced observation error in aggregate). Future research could investigate trade-offs in model fit and uncertainty by evaluating selectivity functions with fewer parameters and developing informed priors for the selectivity parameters.

The observation of proportionally few large sharks in the sampled length composition data compared to that expected based on life history may result for reasons other than dome-shaped selectivity. For example, the spatial distribution of fishing effort for an exploited population that is not well mixed (Sampson 2014) and selection of individuals with relatively faster growth rates (Taylor and Methot 2013) can also produce apparent dome-shaped selectivity patterns if not explicitly accounted for. Alternative modelling approaches for dealing with apparent dome-

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shaped selectivity can result in different underlying population numbers at age predicted over time within the stock assessment model. An attempt was made here to evaluate the effect of uncertainty in selectivity for fleets F1 and F2 and surveys S4 and S7 on the underlying population numbers at age predicted over time within the stock assessment model by implementing logistic selectivity for F1, F2, S4, and S7 within the logistic sensitivity analysis.

A growing number of model diagnostic methods are becoming available for use in integrated stock assessment models such as Stock Synthesis (e.g., Maunder and Piner 2015, 2017; Carvalho et al. 2017). Examples of implementing some of these diagnostic methods were provided as reference document (SEDAR65-RD13; Courtney et al. 2020). However, this set of diagnostics was not implemented within the current assessment due to time constraints. Additional research is also ongoing to improve the interpretation of model diagnostics in both model development and in model selection for use in providing management advice. For example, Maunder et al (2020) describe a risk-based approach based on individual model diagnostic results that assigned different weights to models used for management advice within an ensemble of candidate models.

Reproductive output timing within the Stock Synthesis assessment model is an active area of investigation within the SEFSC PCL stock assessment enterprise. In older versions of Stock Synthesis (< v3.30), implemented for Atlantic HMS SEDAR shark stock assessments, spawning stock size was calculated annually at the beginning of one specified spawning season and this spawning stock size produced one annual total recruitment value. Our intent in Stock Synthesis version 3.30 had been to change both the spawning timing (to June) and recruitment timing (to July). However, preliminary model runs with spawning timing defined as June (month 6) and recruitment timing defined as July (month 7) crashed, and require further evaluation before this setup can be implemented. In addition, recruitment is assumed to occur at age-0 in Stock Synthesis, consistent with previous Atlantic HMS SEDAR domestic shark stock assessments conducted with Stock Synthesis (Anon. 2015, 2017a, 2018). In contrast, recruitment was assumed to occur at age-1 in Atlantic HMS SEDAR domestic shark stock assessments previously conducted with a SSASPM (Anon. 2012, 2013a, 2013b).

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Model sensitivity to reproductive output timing could be investigated in the future assessments. For example, defining the real age associated with L_{Amin} as age-1 and the size at the parameter value for L_{Amin} based on the VBG length at age-1 might be more consistent with previous SSASPM implementations. However, in the length-based Stock Synthesis model implemented here, the recruitment timing and the resulting body size at recruitment also interact with other parameters within the Stock Synthesis model such as the CV in L_{Amin}, as well as with natural mortality and fishing mortality, which occur annually within the calendar year of recruitment. Consequently, an attempt was made here to evaluate model sensitivity to the combined effect of these interactions by estimating the CV in L_{Amin} within the logistic model sensitivity analysis described above.

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3.8. Tables

Table 3.1. Time series of commercial landings, recreational catch, relative abundance, and length composition data used in the Stock Synthesis base model configuration.

Time series	Symbol	Commercial landings, recreational catch (A+B1+B2-Dead) and relative abundance	Name	Definition	Length composition (**see Table 2.15)**
1	F1	Commercial landings (t)	Com-BLL-Kept	Bottom longlines (1983 – 2018)	UF [1] + SBLOP[2] (1994 – 2018)
2	F2	Commercial landings (t)	Com-GN-Kept	Gillnets (1983 – 2018)	GNOP[3] (2000 – 2018)
3	F3	Commercial landings (t)	Com-Other-Kept	Other gears + Unreported commercial landings (1983 – 2018)	Mirror F1
4	F4	Recreational catch (1000s)	Recreational	Recreational (A+B1) + Recreational (B2-dead) (1981 – 2018)	MRIP [4]+ SRHS[5] (1981 – 2018)
5	S1	Relative abundance (numbers)	Shark-BLL-Obs	Bottom Longline Fishery (1994 – 2007)	Mirror F1
6	S2	Relative abundance (numbers)	Shark-BLL-Res	Shark Bottom Longline Research Fishery (2008 – 2018)	Mirror F1
7	S3	Relative abundance (numbers)	VIMS-BLL-Robust	VIMS Bottom Longline Survey Robust Series (1990 – 2018)	1990 – 2018
8	S4	Relative abundance (numbers)	NEFSC-BLL	NMFS-NEFSC Bottom Longline Survey (1996 – 2018)	1996 – 2018
9	S5	Relative abundance (numbers)	SCDNR-SEAMAP-BLL	SCDNR SEAMAP Bottom Longline Survey (2007 – 2018)	2007 – 2018
10	S6	Relative abundance (numbers)	SCDNR-Red-Drum-BLL	SCDNR Red Drum Bottom Longline Survey (1996 – 2006)	1996 – 2006
11	S7	Relative abundance (numbers)	SCDNR-DL	SCDNR Drumline Survey (2013 – 2018)	2013 – 2018
12	S8	Relative abundance (numbers)	COASTSPAN-BLL-All-ages	COASTSPAN Bottom Longline Survey All-age (2005 – 2018)	2005 – 2018
13	S9	Relative abundance (numbers)	COASTSPAN-GNL-All-ages	COASTSPAN Gillnet Long Net Survey All-age (2001 – 2018)	2001 – 2018
14	S10	Relative abundance (numbers)	COASTSPAN-GNS-Age-0	SCDNR Gillnet Short Net Survey Age-0 (2006 – 2018)	2006 – 2018

[1] University of Florida (UF) Longline 1994 – 2005.
[2] Southeast Fisheries Science Center (SEFSC) Panama City Lab Shark Bottom Longline Observer Program (SBLOP) 2005 – 2018.
[3] Southeast Fisheries Science Center (SEFSC) Panama City Lab Gillnet Observer Program (GNOP) 1999 – 2018.
[4] Marine Recreational Information Program (MRIP) 1981 – 2018.
[5] Southeast Region Head Boat Survey (SRHS) 1989 – 2018.

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Table 3.2. Length composition sample size (number of sharks measured) for fleets (F) and surveys (S) included in the Stock Synthesis base model configuration.

	F1 (Com-BLL-Kept) 1994-2018 Min.[1] 30		F2 (Com-GN-Kept) 2000-2018 Min.[2] 30	F4 (Recreational) 1981-2018 Min. 20	S3 (VIMS-BLL-Robust) 1990-2018 Min. 30		S4 (NEFSC-BLL) 1996-2018 Min. 30		S5 (SCDNR-SEAMAP-BLL) 2007-2018 Min. 30	
Year	(♀)	(♂)	(♀,♂,Unknown)[2]	(♀,♂,Unknown)	(♀)	(♂)	(♀)	(♂)	(♀)	(♂)
1981				2						
1982				15						
1983				16						
1984				10						
1985				60						
1986				45						
1987				62						
1988				29						
1989				38						
1990				15	1	1				
1991				31	0	1				
1992				41	2	0				
1993				27	0	0				
1994	46	30		43	0	0				
1995	235	164		38	3	2				
1996	79	108		53	0	3	1	5		
1997	1	2		27	5	7	0	0		
1998	56	14		36	0	1	5	26		
1999	195	55		17	2	14	0	0		
2000	119	113	42	13	0	1	0	0		
2001	54	13	0	14	2	2	0	18		
2002	163	104	265	14	5	11	0	0		
2003	19	18	332	14	0	0	0	0		
2004	43	36	169	11	2	2	2	25		
2005	27	48	181	21	0	0	0	0		
2006	348	86	336	12	3	4	0	0		
2007	59	41	1	14	0	5	0	1	84	56
2008	68	31	6	7	28	26	0	0	106	82
2009	64	27	20	5	0	3	5	22	50	28
2010	84	57	10	10	8	4	0	0	37	19
2011	153	116	18	7	1	3	0	0	33	25
2012	276	271	42	23	5	2	21	77	33	20
2013	61	120	25	1	8	6	0	0	62	35
2014	306	408	10	22	4	5	0	0	44	15
2015	157	80	10	12	18	7	26	114	55	31
2016	185	140	4	9	18	14	0	0	37	14
2017	192	261	2	4	10	6	0	0	32	22
2018	3	39	3	4	6	8	16	266	43	31
Total	2993	2382	1476	822	131	138	76	554	616	378
Proportion (♀,♂)	100%		58%	NA	96%		100%		96%	

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Table 3.2. Continued.

Year	S6 (SCDNR-Red-Drum-BLL) 1996-2006 Min. 30 (♀)	(♂)	S7 (SCDNR-DL) 2013-2018 Min. 30 (♀)	(♂)	S8 (COASTSPAN-BLL-All-ages) 2005-2018 Min. 30 (♀)	(♂)	S9 (COASTSPAN-GNL-All-ages) 2001-2018 Min. 30 (♀)	(♂)	S10 (COASTSPAN-GNS-Age-0) 2006-2018 Min. 30 (♀)	(♂)
1996	8	7								
1997	19	20								
1998	4	7								
1999	1	6								
2000	10	14								
2001	3	1					15	15		
2002	22	16					3	5		
2003	21	37					18	18		
2004	4	4					1	0		
2005	3	2			36	29	10	10		
2006	22	26			7	6	5	6	1	3
2007					3	1	5	6	7	1
2008					4	0	6	1	1	0
2009					1	9	3	5	2	0
2010					34	31	5	3	11	6
2011					19	17	3	3	7	10
2012					49	41	13	2	27	18
2013			16	7	19	13	43	56	15	8
2014			43	15	13	11	21	7	4	4
2015			27	19	13	10	11	12	14	11
2016			23	22	28	23	19	2	7	9
2017			41	21	28	29	31	28	13	9
2018			24	20	23	16	23	11	18	22
Total	117	140	174	104	277	236	235	190	127	101
Proportion (♀,♂)	98%		99%		99%		96%		98%	

[1] Years with less than minimum sample size were excluded from the fit in the model likelihood.
[2] Min = 20 for F2 in the logistic sensitivity analysis.
[3] Sex-combined length composition data (♀, ♂, Unknown) were input for fleets F2 and F4 because the available sex-specific data (♀, ♂) were only a fraction (58%) of the sex-combined data for fleet F2 and were not available for fleet F4. Sex-specific length composition data were input for fleet F1 and for all surveys because sex-specific data made up higher proportions (96-100%) of the sex-combined data.

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Table 3.3. The von Bertalanffy growth (VBG) relationship implemented separately for females and males in the Stock Synthesis base model configuration.

Age (yr.)	Female cm FL predicted from the VBG parameters below	Male cm FL predicted from VBG parameters below
0	56.4	52.8
1	72.6	71.8
2	86.5	86.8
3	98.3	98.8
4	108.3	108.3
5	116.9	115.8
6	124.2	121.8
7	130.4	126.6
8	135.7	130.4
9	140.2	133.4
10	144.1	135.8
11	147.3	137.7
12	150.1	139.2
13	152.5	140.4
14	154.5	141.3
15	156.3	142.1
16	157.7	142.7
17	159.0	143.2
18	160.1	143.6
19	161.0	143.9
20	161.8	144.1
21	162.4	144.3
22	163.0	144.4
23	163.5	144.6
24	163.9	144.7
25	164.2	144.7
26	164.5	144.8
27	164.8	144.8
28	165.0	144.9
29	165.2	144.9
30	165.3	144.9

VBG parameters	Female	Male
L_{inf}	166.2	145.0
k	0.160	0.230
t_0	-2.59	-1.97
CV implemented for L_{Amin}	0.093	0.097
CV implemented for L_{inf}	0.090	0.082

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Table 3.4. Annual pup production at age used in the base model configuration.

Age (yr.)	Litter size (LS) [1]	Fraction mature [2]	Fraction maternal [3]	Pup production [4]	Annual pup production [5]
0	0.00	0.00	0.00	0.0	0.00
1	0.00	0.00	0.00	0.0	0.00
2	0.00	0.00	0.00	0.0	0.00
3	1.11	0.00	0.00	0.0	0.00
4	1.50	0.01	0.00	0.0	0.00
5	1.88	0.05	0.01	0.0	0.01
6	2.27	0.22	0.05	0.1	0.06
7	2.65	0.64	0.22	0.6	0.29
8	3.03	0.91	0.64	1.9	0.97
9	3.42	0.98	0.91	3.1	1.56
10	3.80	1.00	0.98	3.7	1.86
11	4.19	1.00	1.00	4.2	2.09
12	4.57	1.00	1.00	4.6	2.29
13	4.96	1.00	1.00	5.0	2.48
14	5.34	1.00	1.00	5.3	2.67
15	5.73	1.00	1.00	5.7	2.86
16	6.11	1.00	1.00	6.1	3.06
17	6.49	1.00	1.00	6.5	3.25
18	6.88	1.00	1.00	6.9	3.44
19	7.00	1.00	1.00	7.0	3.50
20	7.00	1.00	1.00	7.0	3.50
21	7.00	1.00	1.00	7.0	3.50
22	7.00	1.00	1.00	7.0	3.50
23	7.00	1.00	1.00	7.0	3.50
24	7.00	1.00	1.00	7.0	3.50
25	7.00	1.00	1.00	7.0	3.50
26	7.00	1.00	1.00	7.0	3.50
27	7.00	1.00	1.00	7.0	3.50
28	7.00	1.00	1.00	7.0	3.50
29	7.00	1.00	1.00	7.0	3.50
30	7.00	1.00	1.00	7.0	3.50

[1] Litter size (LS) = -0.04078 + 0.38445*Age (**Table 2.12**); Min LS = 1; Max LS = 7 (SEDAR65-DW-01, their Figure 1).
[2] Fraction mature obtained from the DW report (DW Section II, their Table 3; e.g. see equations in **Table 2.12)**.
[3] Fraction maternal assumed an 11 month gestation period (**Table 2.12)**, approximated here by one year from maturity to maternity.
[4] Pup production was obtained as (LS at age)* (Fraction maternal at age).
[5] Annual pup production was obtained by assuming a two year reproductive cycle (**Table 2.12**) and calculated as [(LS at age)* (Fraction maternal at age)]/2.

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Table 3.5. Selectivity functions and number of estimated parameters in the base model configuration.

Fleet	Fleet name	Proposed selectivity pattern	Implemented selectivity pattern	Sex	Number of parameters	Sub-total
1	F1 (Com-BLL-Kept)	Logistic	Double Normal	Sex specific	17 Selectivity[1]	17
2	F2 (Com-GN-Kept)	Logistic	Double Normal	Combined sex	4 Selectivity[2]	4
3	F3 (Com-Other-Kept)	Mirror Fleet 1	Mirror F1	Combined sex	NA	
4	F4 (Recreational)	Double Normal	Double Normal	Combined sex	7 Selectivity[3]	7
5	S1 (Shark-BLL-Obs)	Mirror Fleet 1	Mirror F1	Combined sex	3 Catchability[4]	3
6	S2 (Shark-BLL-Res)	Mirror Fleet 1	Mirror F1	Combined sex	2 Catchability[5]	2
7	S3 (VIMS-BLL-Robust)	Double Normal	Double Normal	Sex specific	4 Selectivity	4
8	S4 (NEFSC-BLL)	Logistic	Double Normal	Sex specific	5 Selectivity	5
9	S5 (SCDNR-SEAMAP-BLL)	Double Normal	Double Normal	Sex specific	5 Selectivity	5
10	S6 (SCDNR-Red-Drum-BLL)	Double Normal	Double Normal	Sex specific	5 Selectivity	5
11	S7 (SCDNR-DL)	Logistic	Double Normal	Sex specific	6 Selectivity	6
12	S8 (COASTSPAN-BLL-All-ages)	Double Normal	Double Normal	Sex specific	3 Selectivity	3
13	S9 (COASTSPAN-GNL-All-ages)	Double Normal	Double Normal	Sex specific	3 Selectivity	3
14	S10 (COASTSPAN-GNS-Age-0)	Double Normal	Double Normal	Sex specific	4 Selectivity	2
					Total (Selectivity; Catchability)	66
	Other Estimated Parameters					
	ln(R_0)					1
	Recruitment deviations				1984 – 2018	35
					Grand Total	102

[1] Time blocks in selectivity for F1 (1981 – 1996, 1997 – 2004, 2005 – 2007, 2008 – 2017, 2018).
[2] Time blocks in selectivity for F2 (1981 – 2006, 2007 – 2018).
[3] Time blocks in selectivity for F4 (1981 – 1989, 1990 – 1999, 2000 – 2018).
[4] Time blocks in catchability for S1 (1981 – 1996, 1997 – 2004, 2005 – 2007).
[5] Time blocks in catchability for S2 (2008 – 2017, 2018).

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Table 3.6. Two stage data weighting used in the base model configuration, as described above in Section 3.3.1.7; The stage-1 CPUE (survey) variance adjustments are provided along with the mean of input CV and the resulting mean of adjusted input CV obtained after adding the variance adjustment (**Panel A**). The stage-2 length composition Effn adjustments are provided along with the mean input sample size (n) and the resulting mean of the adjusted input sample size, n, obtained after multiplying by the Effn adjustment (**Panel B**).

Panel A

Survey	Mean of input CV	Variance adjustment	Mean of adjusted input CV
S1 (Shark-BLL-Obs)	0.5300	0.3010	0.8310
S2 (Shark-BLL-Res)	0.3736	0.0004	0.3740
S3 (VIMS-BLL-Robust)	0.6417	0.1923	0.8340
S4 (NEFSC-BLL)	0.6704	0.1766	0.8470
S5 (SCDNR-SEAMAP-BLL)	0.2826	0.0000	0.2826
S6 (SCDNR-Red-Drum-BLL)	0.7120	0.0000	0.7120
S7 (SCDNR-DL)	0.1830	0.0000	0.1830
S8 (COASTSPAN-BLL-All-ages)	0.3031	0.0000	0.3031
S9 (COASTSPAN-GNL-All-ages)	0.4588	0.0902	0.5490
S10 (COASTSPAN-GNS-Age-0)	0.5637	0.0000	0.5637

Panel B

Length composition data source	Mean of input n	Adjustment method	Sample size adjustment	Mean of adjusted input n
F1 (Com-BLL-Kept)	231.7	Francis	0.080	18.5
F2 (Com-GN-Kept)	195.3	Harmonic mean	0.198	38.6
F4 (Recreational)	37.3	Francis	0.205	7.6
S3 (VIMS-BLL-Robust)	43.0	Harmonic mean	0.637	27.4
S4 (NEFSC-BLL)	137.8	Harmonic mean	0.269	37.1
S5 (SCDNR-SEAMAP-BLL)	82.8	Francis	0.162	13.5
S6 (SCDNR-Red-Drum-BLL)	45.8	Harmonic mean	0.311	14.2
S7 (SCDNR-DL)	51.0	Harmonic mean	0.784	40.0
S8 (COASTSPAN-BLL-All-ages)	47.0	Harmonic mean	0.269	12.7
S9 (COASTSPAN-GNL-All-ages)	51.6	Harmonic mean	0.416	21.5
S10 (COASTSPAN-GNS-Age-0)	42.5	Harmonic mean	0.368	15.6

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Table 3.7. Base model configuration parameters. Parameters with a negative phase were fixed at their initial value. CV is calculated as the asymptotic standard error (Parm_StDev) divided by the estimated value (Value).

Label	Value	Active_Cnt	Phase	Min	Max	Init	Parm_StDev	Pr_type	Prior	Pr_SD	CV
L_at_Amin_Fem_GP_1	56.40	_	-3	5.00	100.00	56.40	_	Normal	56.40	1000	NA
L_at_Amax_Fem_GP_1	166.23	_	-4	50.00	600.00	166.23	_	Normal	166.23	1000	NA
VonBert_K_Fem_GP_1	0.16	_	-5	0.01	0.65	0.16	_	Normal	0.06	0.2	NA
CV_young_Fem_GP_1	0.09	_	-2	0.01	0.30	0.09	_	Normal	0.09	0.01	NA
CV_old_Fem_GP_1	0.09	_	-3	0.01	0.30	0.09	_	Normal	0.09	0.01	NA
Wtlen_1_Fem_GP_1	0.00	_	-3	-3.00	3.00	0.00	_	Normal	0.00	0.8	NA
Wtlen_2_Fem_GP_1	3.22	_	-3	-3.00	5.00	3.22	_	Normal	3.22	0.8	NA
L_at_Amin_Mal_GP_1	52.84	_	-3	5.00	100.00	52.84	_	Normal	52.84	1000	NA
L_at_Amax_Mal_GP_1	145.03	_	-4	50.00	600.00	145.03	_	Normal	145.03	1000	NA
VonBert_K_Mal_GP_1	0.23	_	-5	0.01	0.65	0.23	_	Normal	0.23	0.2	NA
CV_young_Mal_GP_1	0.10	_	-2	0.01	0.30	0.10	_	Normal	0.10	0.01	NA
CV_old_Mal_GP_1	0.08	_	-3	0.01	0.30	0.08	_	Normal	0.08	0.01	NA
Wtlen_1_Mal_GP_1	0.00	_	-3	-3.00	3.00	0.00	_	Normal	0.00	0.8	NA
Wtlen_2_Mal_GP_1	3.22	_	-3	-3.00	5.00	3.22	_	Normal	3.22	0.8	NA
FracFemale_GP_1	0.50	_	-99	0.00	1.00	0.50	_	No_prior			NA
SR_LN(R0)	6.06	1	1	2.30	13.82	5.40	0.179	Normal	7.04	1000	3%
SR_BH_steep	0.40	_	-2	0.20	0.99	0.40	_	Normal	0.40	1000	NA
SR_sigmaR	0.28	_	-4	0.20	1.90	0.28	_	Normal	0.28	1000	NA
Early_RecrDev_1984	-0.18	2	4	-10.00	10.00	0.00	0.256	dev			
Early_RecrDev_1985	-0.27	3	4	-10.00	10.00	0.00	0.242	dev			
Early_RecrDev_1986	-0.09	4	4	-10.00	10.00	0.00	0.243	dev			
Early_RecrDev_1987	0.07	5	4	-10.00	10.00	0.00	0.241	dev			
Early_RecrDev_1988	-0.11	6	4	-10.00	10.00	0.00	0.250	dev			
Early_RecrDev_1989	-0.01	7	4	-10.00	10.00	0.00	0.252	dev			
Early_RecrDev_1990	-0.02	8	4	-10.00	10.00	0.00	0.261	dev			
Early_RecrDev_1991	0.08	9	4	-10.00	10.00	0.00	0.251	dev			
Early_RecrDev_1992	0.09	10	4	-10.00	10.00	0.00	0.256	dev			
Early_RecrDev_1993	0.28	11	4	-10.00	10.00	0.00	0.262	dev			
Main_RecrDev_1994	0.26	12	3	-10.00	10.00	0.00	0.255	dev			
Main_RecrDev_1995	0.20	13	3	-10.00	10.00	0.00	0.243	dev			
Main_RecrDev_1996	-0.19	14	3	-10.00	10.00	0.00	0.239	dev			
Main_RecrDev_1997	-0.22	15	3	-10.00	10.00	0.00	0.234	dev			
Main_RecrDev_1998	-0.27	16	3	-10.00	10.00	0.00	0.228	dev			
Main_RecrDev_1999	-0.37	17	3	-10.00	10.00	0.00	0.218	dev			

Not Peer Reviewed

Table 3.7. Continued.

Label	Value	Active	Cnt	Phase	Min	Max	Init	Parm	StDev	Pr_type	Prior	Pr_SD	CV
Main_RecrDev_2000	-0.55		18	3	-10.00	10.00	0.00		0.210	dev			
Main_RecrDev_2001	-0.53		19	3	-10.00	10.00	0.00		0.184	dev			
Main_RecrDev_2002	-0.29		20	3	-10.00	10.00	0.00		0.179	dev			
Main_RecrDev_2003	-0.10		21	3	-10.00	10.00	0.00		0.175	dev			
Main_RecrDev_2004	0.17		22	3	-10.00	10.00	0.00		0.198	dev			
Main_RecrDev_2005	0.17		23	3	-10.00	10.00	0.00		0.165	dev			
Main_RecrDev_2006	0.01		24	3	-10.00	10.00	0.00		0.170	dev			
Main_RecrDev_2007	0.13		25	3	-10.00	10.00	0.00		0.168	dev			
Main_RecrDev_2008	0.27		26	3	-10.00	10.00	0.00		0.170	dev			
Main_RecrDev_2009	0.25		27	3	-10.00	10.00	0.00		0.170	dev			
Main_RecrDev_2010	0.15		28	3	-10.00	10.00	0.00		0.162	dev			
Main_RecrDev_2011	0.19		29	3	-10.00	10.00	0.00		0.164	dev			
Main_RecrDev_2012	0.42		30	3	-10.00	10.00	0.00		0.143	dev			
Main_RecrDev_2013	0.54		31	3	-10.00	10.00	0.00		0.133	dev			
Main_RecrDev_2014	-0.07		32	3	-10.00	10.00	0.00		0.172	dev			
Main_RecrDev_2015	-0.14		33	3	-10.00	10.00	0.00		0.164	dev			
Main_RecrDev_2016	-0.16		34	3	-10.00	10.00	0.00		0.163	dev			
Main_RecrDev_2017	0.13		35	3	-10.00	10.00	0.00		0.157	dev			
Late_RecrDev_2018	0.09		36	6	-10.00	10.00	0.00		0.162	dev			
ForeRecr_2019[1]	0		37	6	-10	10	0		0.283103	dev			
LnQ_base_S1_Shark_BLL_Obs(5)	-1.69		38	1	-25.00	25.00	3.36		0.421	Sym_Beta	0.00	0.05	25%
LnQ_base_S2_Shark_BLL_Res(6)	-1.08		39	1	-25.00	25.00	-0.76		0.415	Sym_Beta	0.00	0.05	38%
LnQ_base_S3_VIMS_Robust(7)	-8.90	_		-1	-25.00	25.00	-8.72	_		No_prior			NA
LnQ_base_S4_NEFSC_BLL(8)	-8.06	_		-1	-25.00	25.00	-8.60	_		No_prior			NA
LnQ_base_S5_SCDNR_SEAMAP_BLL(9)	-6.33	_		-1	-25.00	25.00	-6.33	_		No_prior			NA
LnQ_base_S6_SCDNR_Red_Drum_BLL(10)	-6.57	_		-1	-25.00	25.00	-6.50	_		No_prior			NA
LnQ_base_S7_SCDNR_Drumline(11)	-7.49	_		-1	-25.00	25.00	-7.62	_		No_prior			NA
LnQ_base_S8_COASTSPAN_BLL_All_ages(12)	-4.44	_		-1	-25.00	25.00	-4.41	_		No_prior			NA
LnQ_base_S9_COASTSPAN_GN_Long_All_ages(13)	-5.37	_		-1	-25.00	25.00	-5.73	_		No_prior			NA
LnQ_base_S10_COASTSPAN_GN_Short_Age_0(14)	-5.20	_		-1	-25.00	25.00	-5.16	_		No_prior			NA
LnQ_base_S1_Shark_BLL_Obs(5)_BLK3repl_1981	-3.11		40	1	-25.00	25.00	-2.94		0.561	Sym_Beta	0.00	0.05	18%
LnQ_base_S1_Shark_BLL_Obs(5)_BLK3repl_2005	-1.60		41	1	-25.00	25.00	-1.37		0.646	Sym_Beta	0.00	0.05	40%
LnQ_base_S2_Shark_BLL_Res(6)_BLK4repl_2018	-2.33		42	1	-25.00	25.00	-1.70		0.640	Sym_Beta	0.00	0.05	27%
Size_DblN_peak_F1_Com_BLL_Kept(1)	144.26		43	2	47.50	162.50	144.30		2.377	Sym_Beta	138.00	0.05	2%
Size_DblN_top_logit_F1_Com_BLL_Kept(1)	-5.36		44	3	-6.00	4.00	-5.40		2.219	Sym_Beta	-6.00	0.05	41%
Size_DblN_ascend_se_F1_Com_BLL_Kept(1)	6.92		45	3	-1.00	9.00	7.00		0.154	Sym_Beta	7.10	0.05	2%
Size_DblN_descend_se_F1_Com_BLL_Kept(1)	3.99		46	3	-1.00	9.00	3.90		0.625	Sym_Beta	4.70	0.05	16%
Size_DblN_start_logit_F1_Com_BLL_Kept(1)	-5.98		47	2	-15.00	9.00	-5.80		1.462	Sym_Beta	-15.00	0.05	24%
Size_DblN_end_logit_F1_Com_BLL_Kept(1)	-3.70		48	2	-15.00	9.00	-3.90		0.888	Sym_Beta	9.00	0.05	24%
SzSel_Male_Peak_F1_Com_BLL_Kept(1)	-11.52		49	4	-50.00	50.00	-11.46		1.574	Normal	0.00	1000	14%
SzSel_Male_Ascend_F1_Com_BLL_Kept(1)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Descend_F1_Com_BLL_Kept(1)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Final_F1_Com_BLL_Kept(1)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA

[1] Forecast recruitment deviation (year 2019) not included in the number of estimated parameters.

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Table 3.7. Continued.

Label	Value	Active	Cnt	Phase	Min	Max	Init	Parm	StDev	Pr type	Prior	Pr SD	CV
SzSel_Male_Scale_F1_Com_BLL_Kept(1)	0.66		50	5	-15.00	15.00	0.69		0.069	Normal	1.00	1000	10%
Size_DblN_peak_F2_Com_GN_Kept(2)	83.78		51	2	47.50	162.50	77.40		11.073	Sym_Beta	121.60	0.05	13%
Size_DblN_top_logit_F2_Com_GN_Kept(2)	-0.20	_		-3	-6.00	4.00	-0.20	_		Sym_Beta	-0.20	0.05	NA
Size_DblN_ascend_se_F2_Com_GN_Kept(2)	6.17		52	3	-1.00	9.00	6.20		0.352	Sym_Beta	6.90	0.05	6%
Size_DblN_descend_se_F2_Com_GN_Kept(2)	4.78		53	3	-1.00	9.00	4.80		0.470	Sym_Beta	5.00	0.05	10%
Size_DblN_start_logit_F2_Com_GN_Kept(2)	-15.00	_		-2	-15.00	9.00	-15.00	_		Sym_Beta	-15.00	0.05	NA
Size_DblN_end_logit_F2_Com_GN_Kept(2)	-999.00	_		-2	-999.00	9.00	-999.00	_		Sym_Beta	-15.00	0.05	NA
Size_DblN_peak_F4_Rec_A_B1_B2PRM(4)	76.95		54	2	47.50	162.50	58.00		10.890	Sym_Beta	64.90	0.05	14%
Size_DblN_top_logit_F4_Rec_A_B1_B2PRM(4)	-6.00	_		-3	-6.00	4.00	-6.00	_		Sym_Beta	-6.00	0.05	NA
Size_DblN_ascend_se_F4_Rec_A_B1_B2PRM(4)	6.60	_		-3	-1.00	9.00	6.60	_		Sym_Beta	6.60	0.05	NA
Size_DblN_descend_se_F4_Rec_A_B1_B2PRM(4)	4.70		55	3	-1.00	9.00	6.20		0.760	Sym_Beta	7.20	0.05	16%
Size_DblN_start_logit_F4_Rec_A_B1_B2PRM(4)	0.00	_		-2	-15.00	9.00	0.00	_		Sym_Beta	0.00	0.05	NA
Size_DblN_end_logit_F4_Rec_A_B1_B2PRM(4)	-3.21		56	2	-15.00	9.00	-2.30		0.753	Sym_Beta	-15.00	0.05	23%
Size_DblN_peak_S3_VIMS_Robust(7)	93.16		57	2	47.50	162.50	93.00		1.934	Sym_Beta	96.40	0.05	2%
Size_DblN_top_logit_S3_VIMS_Robust(7)	-6.00	_		-3	-6.00	4.00	-6.00	_		Sym_Beta	-6.00	0.05	NA
Size_DblN_ascend_se_S3_VIMS_Robust(7)	3.82		58	3	-1.00	9.00	3.90		0.585	Sym_Beta	4.40	0.05	15%
Size_DblN_descend_se_S3_VIMS_Robust(7)	7.31		59	3	-1.00	9.00	7.30		0.292	Sym_Beta	6.50	0.05	4%
Size_DblN_start_logit_S3_VIMS_Robust(7)	-15.00	_		-2	-15.00	9.00	-15.00	_		Sym_Beta	-15.00	0.05	NA
Size_DblN_end_logit_S3_VIMS_Robust(7)	-999.00	_		-2	-15.00	9.00	-999.00	_		Sym_Beta	-15.00	0.05	NA
SzSel_Male_Peak_S3_VIMS_Robust(7)	0.00	_		-4	-50.00	50.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Ascend_S3_VIMS_Robust(7)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Descend_S3_VIMS_Robust(7)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Final_S3_VIMS_Robust(7)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Scale_S3_VIMS_Robust(7)	0.85		60	5	-15.00	15.00	0.86		0.232	Normal	1.00	1000	27%
Size_DblN_peak_S4_NEFSC_BLL(8)	136.09		61	2	47.50	162.50	135.90		2.769	Sym_Beta	135.10	0.05	2%
Size_DblN_top_logit_S4_NEFSC_BLL(8)	-5.10	_		-3	-6.00	4.00	-5.10	_		Sym_Beta	-6.00	0.05	NA
Size_DblN_ascend_se_S4_NEFSC_BLL(8)	5.79		62	3	-1.00	9.00	5.80		0.264	Sym_Beta	5.50	0.05	5%
Size_DblN_descend_se_S4_NEFSC_BLL(8)	5.24		63	3	-1.00	9.00	5.30		0.637	Sym_Beta	4.50	0.05	12%
Size_DblN_start_logit_S4_NEFSC_BLL(8)	-6.10	_		-2	-15.00	9.00	-6.10	_		Sym_Beta	-15.00	0.05	NA
Size_DblN_end_logit_S4_NEFSC_BLL(8)	-3.38		64	2	-15.00	9.00	-3.40		1.087	Sym_Beta	-15.00	0.05	32%
SzSel_Fem_Peak_S4_NEFSC_BLL(8)	0.00	_		-4	-50.00	50.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Ascend_S4_NEFSC_BLL(8)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Descend_S4_NEFSC_BLL(8)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Final_S4_NEFSC_BLL(8)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Scale_S4_NEFSC_BLL(8)	0.13		65	5	-15.00	15.00	0.13		0.036	Normal	1.00	1000	28%
Size_DblN_peak_S5_SCDNR_SEAMAP_BLL(9)	52.64		66	2	47.50	162.50	50.50		1.982	Sym_Beta	55.30	0.05	4%
Size_DblN_top_logit_S5_SCDNR_SEAMAP_BLL(9)	-1.72		67	3	-6.00	4.00	-4.60		0.600	Sym_Beta	-6.00	0.05	35%
Size_DblN_ascend_se_S5_SCDNR_SEAMAP_BLL(9)	3.12		68	3	-1.00	9.00	1.90		0.999	Sym_Beta	3.20	0.05	32%
Size_DblN_descend_se_S5_SCDNR_SEAMAP_BLL(9)	7.39		69	3	-1.00	9.00	8.10		0.464	Sym_Beta	7.20	0.05	6%
Size_DblN_start_logit_S5_SCDNR_SEAMAP_BLL(9)	-999.00	_		-2	-15.00	9.00	-999.00	_		Sym_Beta	-15.00	0.05	NA
Size_DblN_end_logit_S5_SCDNR_SEAMAP_BLL(9)	-3.00	_		-2	-15.00	9.00	-3.00	_		Sym_Beta	-3.00	0.05	NA

Not Peer Reviewed

Table 3.7. Continued.

Label	Value	Active	Cnt	Phase	Min	Max	Init	Parm_StDev	Pr_type	Prior	Pr_SD	CV
SzSel_Male_Peak_S5_SCDNR_SEAMAP_BLL(9)	0.00	_		-4	-50.00	50.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Ascend_S5_SCDNR_SEAMAP_BLL(9)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Descend_S5_SCDNR_SEAMAP_BLL(9)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Final_S5_SCDNR_SEAMAP_BLL(9)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Scale_S5_SCDNR_SEAMAP_BLL(9)	0.68		70	5	-15.00	15.00	0.67	0.113	Normal	1.00	1000	17%
Size_DblN_peak_S6_SCDNR_Red_Drum_BLL(10)	57.89		71	2	47.50	162.50	57.50	1.673	Sym_Beta	57.70	0.05	3%
Size_DblN_top_logit_S6_SCDNR_Red_Drum_BLL(10)	-1.53		72	3	-6.00	4.00	-1.80	0.455	Sym_Beta	-6.00	0.05	30%
Size_DblN_ascend_se_S6_SCDNR_Red_Drum_BLL(10)	3.35		73	3	-1.00	9.00	2.90	0.757	Sym_Beta	3.30	0.05	23%
Size_DblN_descend_se_S6_SCDNR_Red_Drum_BLL(10)	6.56		74	3	-1.00	9.00	6.90	0.561	Sym_Beta	7.20	0.05	9%
Size_DblN_start_logit_S6_SCDNR_Red_Drum_BLL(10)	-999.00	_		-2	-15.00	9.00	-999.00	_	Sym_Beta	-15.00	0.05	NA
Size_DblN_end_logit_S6_SCDNR_Red_Drum_BLL(10)	-3.10	_		-2	-15.00	9.00	-3.10	_	Sym_Beta	-3.10	0.05	NA
SzSel_Fem_Peak_S6_SCDNR_Red_Drum_BLL(10)	0.00	_		-4	-50.00	50.00	0.00	_	Normal	0.00	1000	NA
SzSel_Fem_Ascend_S6_SCDNR_Red_Drum_BLL(10)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Fem_Descend_S6_SCDNR_Red_Drum_BLL(10)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Fem_Final_S6_SCDNR_Red_Drum_BLL(10)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Fem_Scale_S6_SCDNR_Red_Drum_BLL(10)	0.77		75	5	-15.00	15.00	0.76	0.212	Normal	1.00	1000	28%
Size_DblN_peak_S7_SCDNR_Drumline(11)	145.16		76	2	47.50	162.50	143.40	2.539	Sym_Beta	131.70	0.05	2%
Size_DblN_top_logit_S7_SCDNR_Drumline(11)	-6.00	_		-3	-6.00	4.00	-6.00	_	Sym_Beta	-6.00	0.05	NA
Size_DblN_ascend_se_S7_SCDNR_Drumline(11)	6.55		77	3	-1.00	9.00	6.50	0.200	Sym_Beta	5.30	0.05	3%
Size_DblN_descend_se_S7_SCDNR_Drumline(11)	4.21		78	3	-1.00	9.00	4.60	0.424	Sym_Beta	5.50	0.05	10%
Size_DblN_start_logit_S7_SCDNR_Drumline(11)	-15.00	_		-2	-15.00	9.00	-15.00	_	Sym_Beta	-15.00	0.05	NA
Size_DblN_end_logit_S7_SCDNR_Drumline(11)	-15.00	_		-2	-15.00	9.00	-15.00	_	Sym_Beta	-15.00	0.05	NA
SzSel_Male_Peak_S7_SCDNR_Drumline(11)	-12.19		79	4	-50.00	50.00	-9.92	2.338	Normal	0.00	1000	19%
SzSel_Male_Ascend_S7_SCDNR_Drumline(11)	-1.44		80	4	-15.00	15.00	-1.30	0.333	Normal	0.00	1000	23%
SzSel_Male_Descend_S7_SCDNR_Drumline(11)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Final_S7_SCDNR_Drumline(11)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Scale_S7_SCDNR_Drumline(11)	0.76		81	5	-15.00	15.00	0.79	0.130	Normal	1.00	1000	17%
Size_DblN_peak_S8_COASTSPAN_BLL_All_ages(12)	47.50	_		-2	47.50	60.00	47.50	_	Sym_Beta	51.30	0.05	NA
Size_DblN_top_logit_S8_COASTSPAN_BLL_All_ages(12)	-6.00	_		-3	-6.00	4.00	-6.00	_	Sym_Beta	-6.00	0.05	NA
Size_DblN_ascend_se_S8_COASTSPAN_BLL_All_ages(12)	6.60	_		-3	-1.00	9.00	6.60	_	Sym_Beta	6.60	0.05	NA
Size_DblN_descend_se_S8_COASTSPAN_BLL_All_ages(12)	3.14		82	3	-1.00	9.00	3.10	0.221	Sym_Beta	-0.30	0.05	7%
Size_DblN_start_logit_S8_COASTSPAN_BLL_All_ages(12)	0.00	_		-2	-15.00	9.00	0.00	_	Sym_Beta	0.00	0.05	NA
Size_DblN_end_logit_S8_COASTSPAN_BLL_All_ages(12)	-5.33		83	2	-15.00	9.00	-5.70	0.544	Sym_Beta	-15.00	0.05	10%
SzSel_Male_Peak_S8_COASTSPAN_BLL_All_ages(12)	0.00	_		-4	-20.00	20.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Ascend_S8_COASTSPAN_BLL_All_ages(12)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Descend_S8_COASTSPAN_BLL_All_ages(12)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Final_S8_COASTSPAN_BLL_All_ages(12)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Scale_S8_COASTSPAN_BLL_All_ages(12)	0.63		84	5	-15.00	15.00	0.62	0.117	Normal	1.00	1000	19%
Size_DblN_peak_S9_COASTSPAN_GN_Long_All_ages(13)	47.50	_		-2	47.50	60.00	47.50	_	Sym_Beta	49.70	0.05	NA
Size_DblN_top_logit_S9_COASTSPAN_GN_Long_All_ages(13)	-6.00	_		-3	-6.00	4.00	-6.00	_	Sym_Beta	-6.00	0.05	NA
Size_DblN_ascend_se_S9_COASTSPAN_GN_Long_All_ages(13)	6.60	_		-3	-1.00	9.00	6.60	_	Sym_Beta	6.60	0.05	NA
Size_DblN_descend_se_S9_COASTSPAN_GN_Long_All_ages(13)	3.03		85	3	-1.00	9.00	3.30	0.323	Sym_Beta	2.90	0.05	11%
Size_DblN_start_logit_S9_COASTSPAN_GN_Long_All_ages(13)	0.00	_		-2	-15.00	9.00	0.00	_	Sym_Beta	0.00	0.05	NA
Size_DblN_end_logit_S9_COASTSPAN_GN_Long_All_ages(13)	-3.80		86	2	-15.00	9.00	-3.30	0.345	Sym_Beta	-2.00	0.05	9%

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Table 3.7. Continued.

Label	Value	Active	Cnt	Phase	Min	Max	Init	Parm	StDev	Pr type	Prior	Pr SD	CV
SzSel_Male_Peak_S9_COASTSPAN_GN_Long_All_ages(13)	0.00	_		-4	-20.00	20.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Ascend_S9_COASTSPAN_GN_Long_All_ages(13)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Descend_S9_COASTSPAN_GN_Long_All_ages(13)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Final_S9_COASTSPAN_GN_Long_All_ages(13)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Scale_S9_COASTSPAN_GN_Long_All_ages(13)	0.84		87	5	-15.00	15.00	0.92		0.179	Normal	1.00	1000	21%
Size_DblN_peak_S10_COASTSPAN_GN_Short_Age_0(14)	47.50	_		-2	47.50	60.00	47.50	_		Sym_Beta	47.70	0.05	NA
Size_DblN_top_logit_S10_COASTSPAN_GN_Short_Age_0(14)	-6.00	_		-3	-6.00	4.00	-6.00	_		Sym_Beta	-6.00	0.05	NA
Size_DblN_ascend_se_S10_COASTSPAN_GN_Short_Age_0(14)	6.60	_		-3	-1.00	9.00	6.60	_		Sym_Beta	6.60	0.05	NA
Size_DblN_descend_se_S10_COASTSPAN_GN_Short_Age_0(14)	2.55		88	3	-1.00	9.00	2.60		0.326	Sym_Beta	3.30	0.05	13%
Size_DblN_start_logit_S10_COASTSPAN_GN_Short_Age_0(14)	0.00	_		-2	-15.00	9.00	0.00	_		Sym_Beta	0.00	0.05	NA
Size_DblN_end_logit_S10_COASTSPAN_GN_Short_Age_0(14)	-15.00	_		-2	-15.00	9.00	-15.00	_		Sym_Beta	-15.00	0.05	NA
SzSel_Male_Peak_S10_COASTSPAN_GN_Short_Age_0(14)	0.00	_		-4	-20.00	20.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Ascend_S10_COASTSPAN_GN_Short_Age_0(14)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Descend_S10_COASTSPAN_GN_Short_Age_0(14)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Final_S10_COASTSPAN_GN_Short_Age_0(14)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Scale_S10_COASTSPAN_GN_Short_Age_0(14)	0.50		89	5	-15.00	15.00	0.53		0.184	Normal	1.00	1000	37%
Size_DblN_peak_F1_Com_BLL_Kept(1)_BLK2repl_1981	139.45		90	2	47.50	162.50	142.00		5.861	Sym_Beta	144.30	0.05	4%
Size_DblN_peak_F1_Com_BLL_Kept(1)_BLK2repl_1997	136.09		91	2	47.50	162.50	136.09		3.744	Sym_Beta	144.30	0.05	3%
Size_DblN_peak_F1_Com_BLL_Kept(1)_BLK2repl_2005	119.50		92	2	47.50	162.50	123.23		8.492	Sym_Beta	144.30	0.05	7%
Size_DblN_ascend_se_F1_Com_BLL_Kept(1)_BLK2repl_1981	7.57		93	3	-1.00	9.00	7.69		0.354	Sym_Beta	7.00	0.05	5%
Size_DblN_ascend_se_F1_Com_BLL_Kept(1)_BLK2repl_1997	5.51		94	3	-1.00	9.00	5.46		0.475	Sym_Beta	7.00	0.05	9%
Size_DblN_ascend_se_F1_Com_BLL_Kept(1)_BLK2repl_2005	6.19		95	3	-1.00	9.00	6.50		0.625	Sym_Beta	7.00	0.05	10%
Size_DblN_descend_se_F1_Com_BLL_Kept(1)_BLK2repl_1981	4.69		96	3	-1.00	9.00	4.50		1.052	Sym_Beta	3.90	0.05	22%
Size_DblN_descend_se_F1_Com_BLL_Kept(1)_BLK2repl_1997	5.22		97	3	-1.00	9.00	5.30		0.551	Sym_Beta	3.90	0.05	11%
Size_DblN_descend_se_F1_Com_BLL_Kept(1)_BLK2repl_2005	6.65		98	3	-1.00	9.00	6.60		0.653	Sym_Beta	3.90	0.05	10%
Size_DblN_peak_F2_Com_GN_Kept(2)_BLK5repl_1981	99.47		99	2	47.50	162.50	99.90		5.127	Sym_Beta	121.60	0.05	5%
Size_DblN_peak_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1981	68.86		100	2	47.50	162.50	50.90		6.045	Sym_Beta	64.90	0.05	9%
Size_DblN_peak_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1990	84.28		101	2	47.50	162.50	66.10		3.682	Sym_Beta	64.90	0.05	4%
Size_DblN_start_logit_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1981	0.00	_		-2	-15.00	9.00	0.00	_		Sym_Beta	0.00	0.05	NA
Size_DblN_start_logit_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1990	0.00	_		-2	-15.00	9.00	0.00	_		Sym_Beta	0.00	0.05	NA
Size_DblN_end_logit_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1981	-2.99		102	2	-15.00	9.00	-3.10		0.568	Sym_Beta	-15.00	0.05	19%
Size_DblN_end_logit_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1990	-2.53		103	2	-15.00	9.00	-2.80		0.532	Sym_Beta	-15.00	0.05	21%

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Table 3.8. Catchability, *q*, estimated for index S1 with time blocks (1981 – 1996, 1997 – 2004, 2005 – 2007) and for index S2 with time blocks (2008 – 2017, 2018), along with the median unbiased analytical solution for *q* calculated in Stock Synthesis for the remaining indices S3 – S10.

Label	ln(*q*)	*q*
Base years		
S1 (Shark-BLL-Obs; 1997 – 2004)	-1.68974	0.1846
S2 (Shark-BLL-Res; 2008 – 2017)	-1.07833	0.3402
S3 (VIMS-BLL-Robust; 1990 – 2018)	-8.90468	0.0001
S4 (NEFSC-BLL; 1996 – 2018)	-8.05628	0.0003
S5 (SCDNR-SEAMAP-BLL; 2007 – 2018)	-6.32516	0.0018
S6 (SCDNR-Red-Drum-BLL; 1996 – 2006)	-6.57149	0.0014
S7 (SCDNR-DL; 2013 – 2018)	-7.48655	0.0006
S8 (COASTSPAN-BLL-All-ages; 2005 – 2018)	-4.44297	0.0118
S9 (COASTSPAN-GNL-All-ages; 2001 – 2018)	-5.37234	0.0046
S10 (COASTSPAN-GNS-Age-0; 2006 – 2018)	-5.20349	0.0055
Time blocks		
S1 (Shark-BLL-Obs; 1981 – 1996)	-3.10568	0.0448
S1 (Shark-BLL-Obs; 2005 – 2007)	-1.59525	0.2029
S2 (Shark-BLL-Res; 2018)	-2.32934	0.0974

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Table 3.9. Total biomass (*B*), spawning stock fecundity (SSF), recruits (*R*), and total fishing mortality (*F*=*Z*-*M*) obtained from the base model configuration.

	Total biomass *B* (Total, mt)	Female spawning stock fecundity SSF (1,000s pups)	Recruits *R* (1,000s pups)	Total fishing mortality *F*=*Z*-*M*
Virg		1140	427	
Init		1140	427	
1981	56320	1140	427	0.030
1982	55739	1135	426	0.030
1983	55045	1129	426	0.029
1984	54019	1121	353	0.045
1985	52447	1106	321	0.044
1986	50739	1086	382	0.044
1987	49088	1062	441	0.025
1988	47757	1040	365	0.027
1989	46637	1012	399	0.021
1990	45731	984	391	0.032
1991	44864	954	428	0.046
1992	43671	913	423	0.051
1993	42677	871	499	0.063
1994	41514	834	483	0.045
1995	41161	815	447	0.057
1996	40310	793	299	0.041
1997	39706	774	288	0.067
1998	38556	757	269	0.068
1999	37172	742	242	0.082
2000	35338	729	200	0.068
2001	33812	725	203	0.073
2002	32270	720	257	0.084
2003	30657	706	309	0.087
2004	29379	682	398	0.113
2005	28205	654	388	0.095
2006	27315	625	323	0.084
2007	26700	594	353	0.073
2008	26531	564	394	0.076
2009	26361	534	374	0.069
2010	26321	509	330	0.036
2011	26696	494	336	0.025
2012	27469	487	419	0.026
2013	28444	486	472	0.035
2014	29029	485	257	0.055
2015	29354	486	241	0.051
2016	29450	495	239	0.042
2017	29570	506	321	0.028
2018	29725	520	314	0.026

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Table 3.10. Total annual fishing mortality (*F=Z-M*) relative to MSY (F/F_{MSY}), annual spawning stock fecundity relative to MSY (SSF/SSF_{MSY}), and annual SSF relative to MSST (SSF/MSST) obtained from the base model configuration.

Year	F/F_{MSY}	SE	SSF/SSF_{MSY}	SE	SSF/MSST
1981	0.57	0.106	2.54	NA	2.95
1982	0.59	0.111	2.53	0.018	2.93
1983	0.57	0.109	2.51	0.020	2.92
1984	0.87	0.173	2.50	0.024	2.90
1985	0.86	0.176	2.46	0.030	2.86
1986	0.86	0.182	2.42	0.038	2.81
1987	0.48	0.103	2.36	0.047	2.75
1988	0.52	0.112	2.32	0.053	2.69
1989	0.41	0.089	2.25	0.061	2.62
1990	0.62	0.136	2.19	0.069	2.54
1991	0.89	0.201	2.12	0.077	2.47
1992	0.99	0.229	2.03	0.090	2.36
1993	1.23	0.292	1.94	0.105	2.25
1994	0.88	0.218	1.86	0.121	2.16
1995	1.10	0.276	1.81	0.133	2.11
1996	0.80	0.206	1.76	0.145	2.05
1997	1.31	0.347	1.72	0.154	2.00
1998	1.32	0.361	1.68	0.164	1.96
1999	1.59	0.448	1.65	0.174	1.92
2000	1.32	0.385	1.62	0.186	1.88
2001	1.41	0.425	1.61	0.192	1.87
2002	1.64	0.502	1.60	0.200	1.86
2003	1.69	0.528	1.57	0.208	1.83
2004	2.20	0.689	1.52	0.213	1.76
2005	1.85	0.598	1.46	0.214	1.69
2006	1.64	0.542	1.39	0.214	1.62
2007	1.42	0.477	1.32	0.214	1.53
2008	1.47	0.503	1.26	0.211	1.46
2009	1.35	0.471	1.19	0.209	1.38
2010	0.69	0.245	1.13	0.209	1.32
2011	0.49	0.172	1.10	0.212	1.28
2012	0.51	0.178	1.08	0.217	1.26
2013	0.68	0.233	1.08	0.223	1.26
2014	1.08	0.378	1.08	0.229	1.25
2015	0.98	0.353	1.08	0.235	1.26
2016	0.83	0.302	1.10	0.242	1.28
2017	0.55	0.199	1.13	0.249	1.31
2018	0.51	0.183	1.16	0.255	1.34

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Table 3.11. Summary of benchmark and reference point results for the base configuration and logistic sensitivity analysis. Benchmarks are provided for spawning stock fecundity, SSF, and the summary fishing mortality, *F*, calculated as the total fishing mortality rate experienced by the population (*F*=*Z*-*M*) for the terminal year of the assessment (SSF_{2018}, and F_{2018}). Benchmarks are reported relative to equilibrium MSY reference points (SSF_{MSY}, and F_{MSY}) and to the Minimum Stock Size Threshold, MSST = $\left(1-\bar{M}_a\right)$*SSF_{MSY}, with $\bar{M}_a$ calculated as the arithmetic mean of the female age-specific values of *M* used in the assessment model configuration (**Tables 2.13** and **2.14**). Unfished equilibrium levels for SSF and recruitment (SSF_0, R_0) are estimated at the start year of the assessment (1981). Stock and fishery status are summarized relative to the benchmarks and reference points as described above in Sections 3.3.1.13 and 3.4.5.

	Base model configuration		Logistic sensitivity	
Parameters	102		90	
Objective function	553.3		593.0	
Gradient	$5.49*10^{-5}$		$1.03*10^{-4}$	
$\bar{M}_a$	0.139		0.239	
$\left(1-\bar{M}_a\right)$	0.861		0.761	
Steepness	0.4		0.4	
	Est	CV	Est	CV
SSF_{2018}	520	39%	341	39%
F_{2018}	0.026	---	0.019	---
R_{2018}	314	33%	587	34%
SSF_0	1,140	18%	637	19%
R_0	427	18%	785	19%
MSY	471	22%	738	19%
SSF_{MSY}	449	18%	246	19%
F_{MSY}	0.051	9%	0.052	3%
SSF_{2018}/SSF_{MSY}	1.158	22%	1.390	21%
F_{2018}/F_{MSY}	0.509	36%	0.366	34%
MSST	387		187	
SSF_{2018}/MSST	1.344		1.825	
Stock status	SSF_{2018} > MSST		SSF_{2018} > MSST	
Fishery status	$F_{2018} < F_{MSY}$		$F_{2018} < F_{MSY}$	

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3.9. Figures

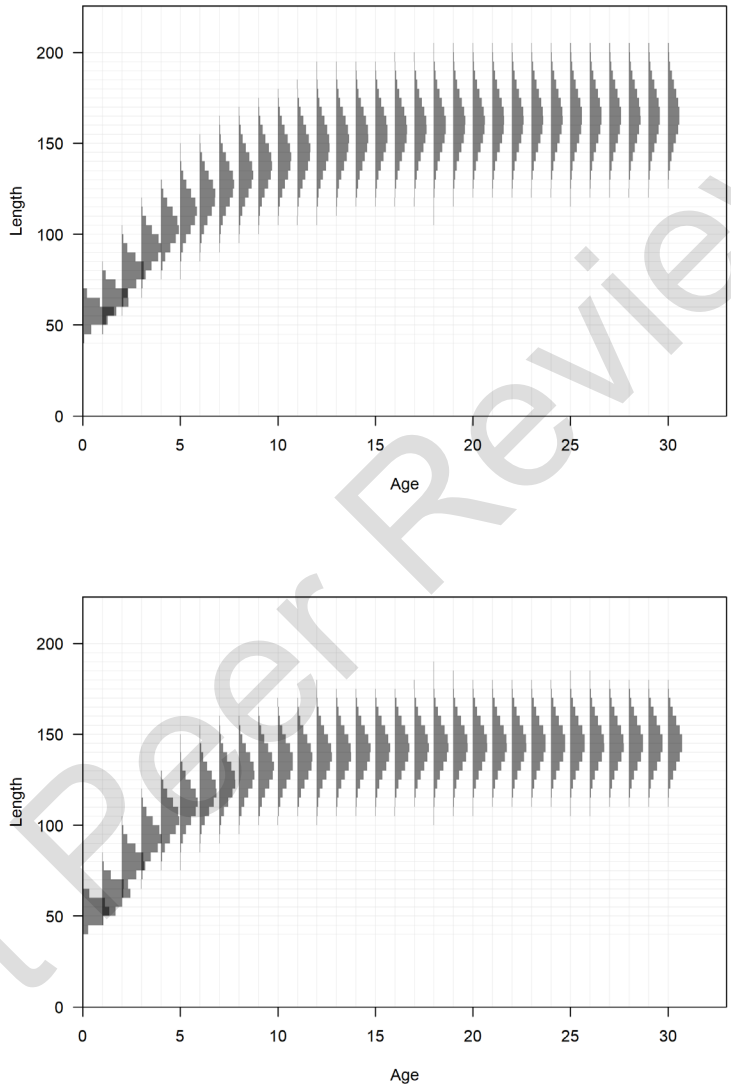

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Figure 3.1. Distribution of mean length (cm FL straight) at each age implemented separately for females (upper panel) and males (lower panel) in the base model configuration.

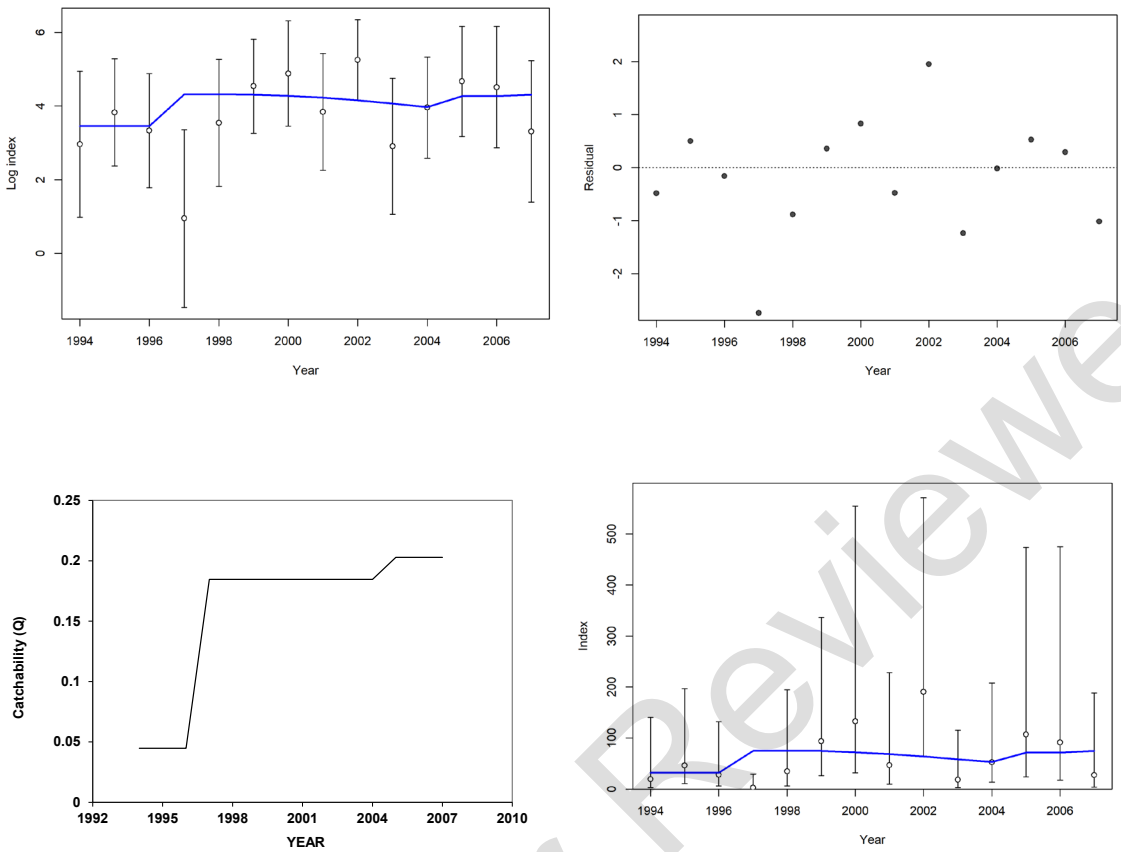

Figure 3.2. Fits to abundance index S1 (Shark-BLL-Obs; 1994 – 2007; **Table 3.1**) in the base model configuration: Upper left panel is predicted (blue line) and observed (open circles with approximate 95% confidence intervals based on the input standard error, SE) on the natural log scale; Upper right panel is residuals on the natural log scale (ln(Obs) - ln(Exp))/(observed SE); Lower left panel is estimated catchability; Lower right panel is observed and predicted on the nominal scale.

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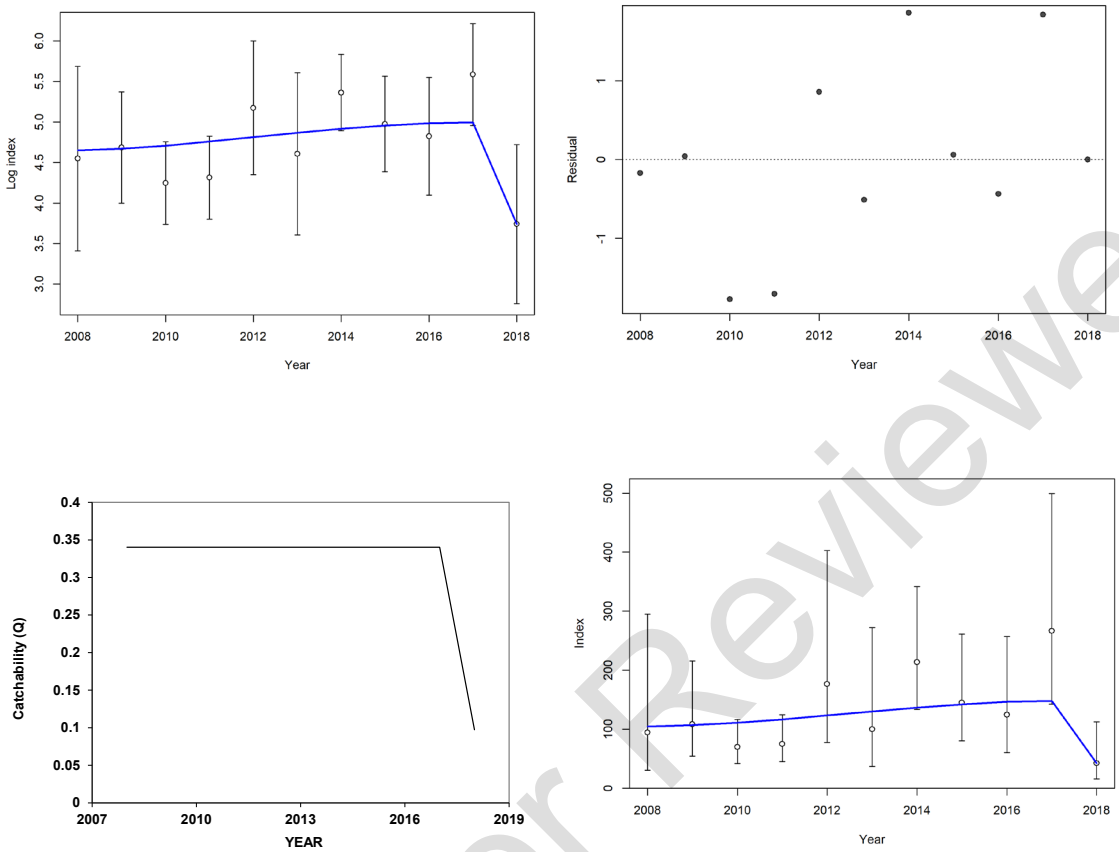

Figure 3.2. Continued: Fits to abundance index S2 (Shark-BLL-Res; 2008 – 2018).

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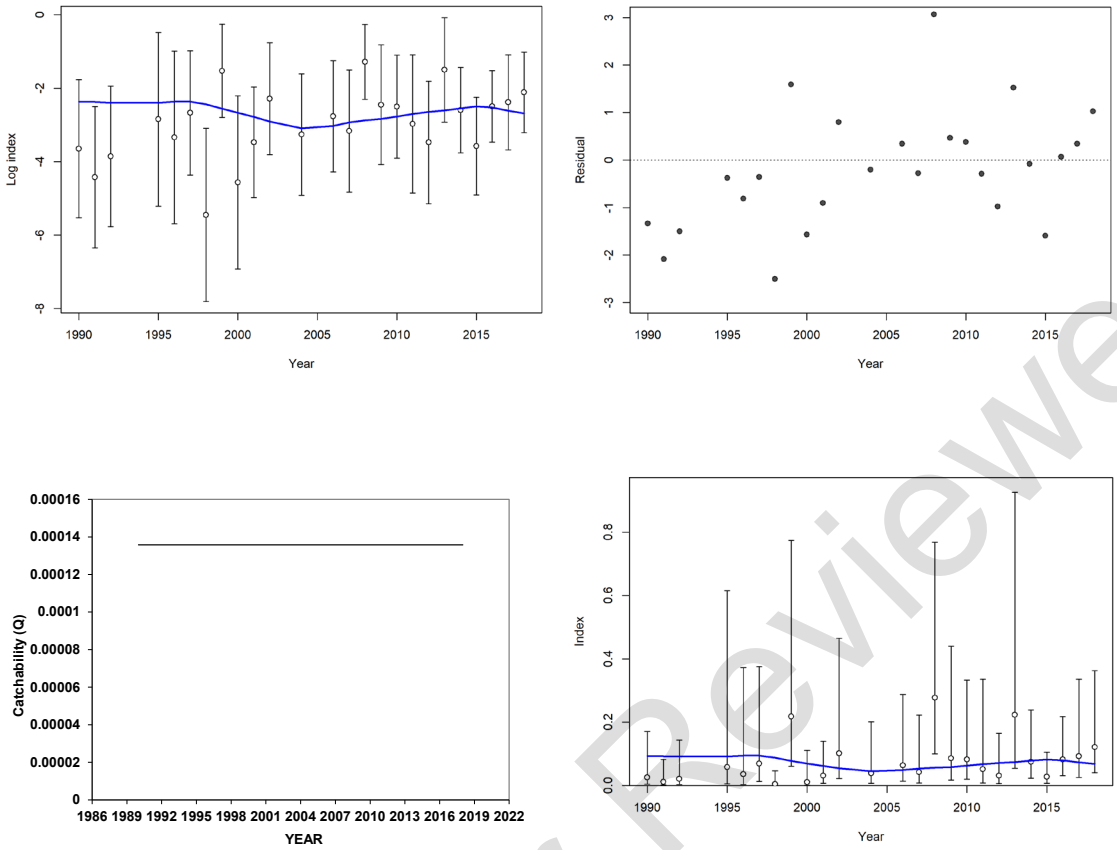

Figure 3.2. Continued: Fits to abundance index S3 (VIMS-BLL-Robust; 1990 – 2018).

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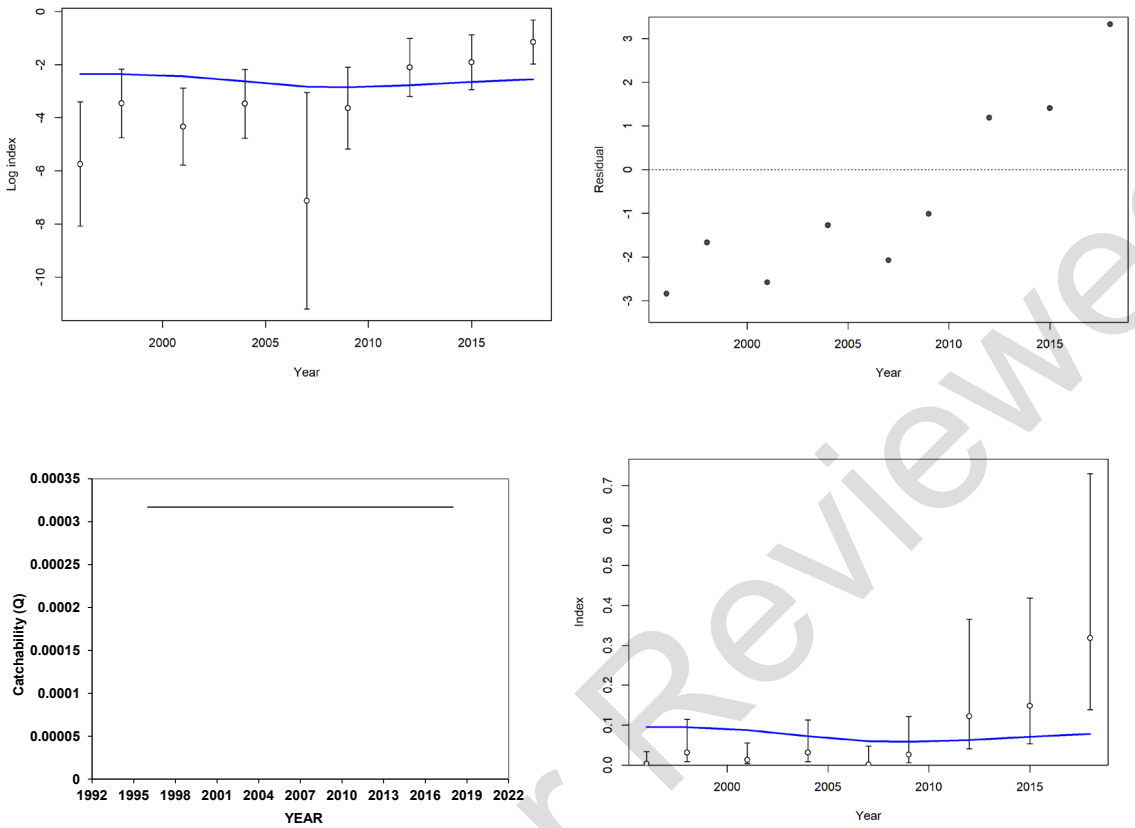

Figure 3.2. Continued: Fits to abundance index S4 (NEFSC-BLL; 1996 – 2018).

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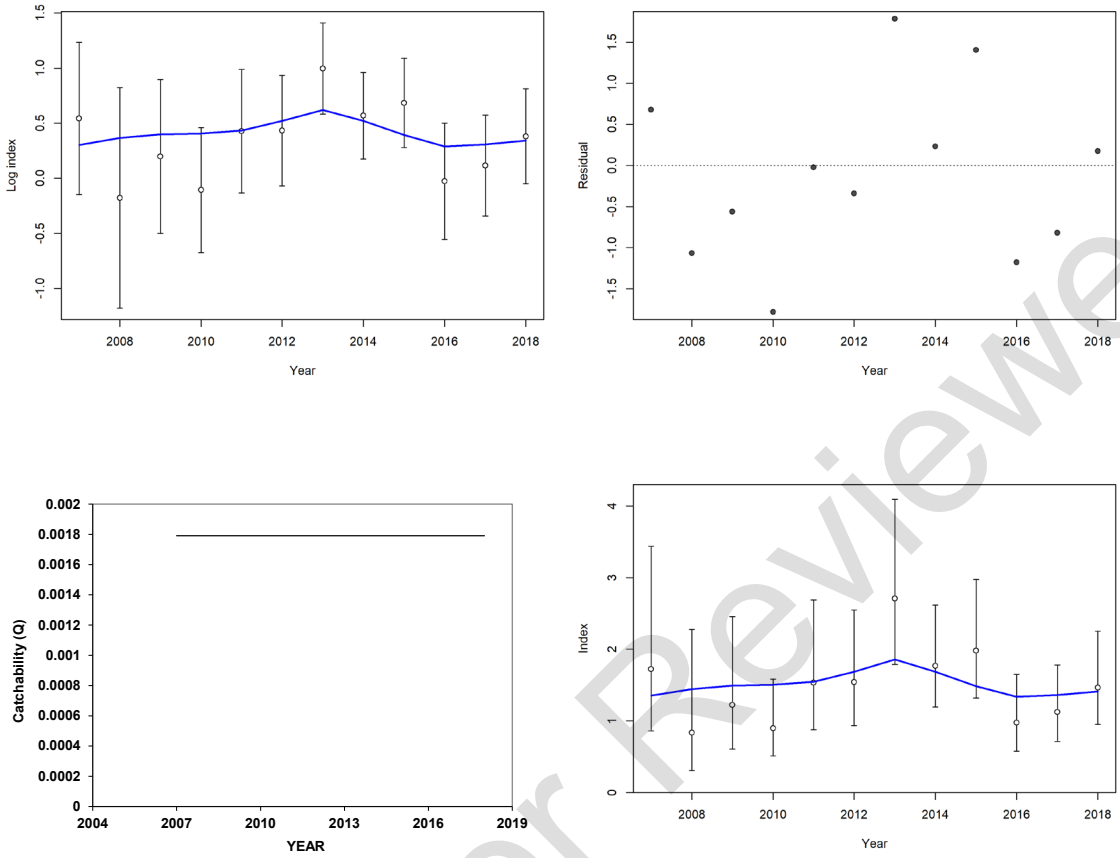

Figure 3.2. Continued: Fits to abundance index S5 (SCDNR-SEAMAP-BLL; 2007 – 2018).

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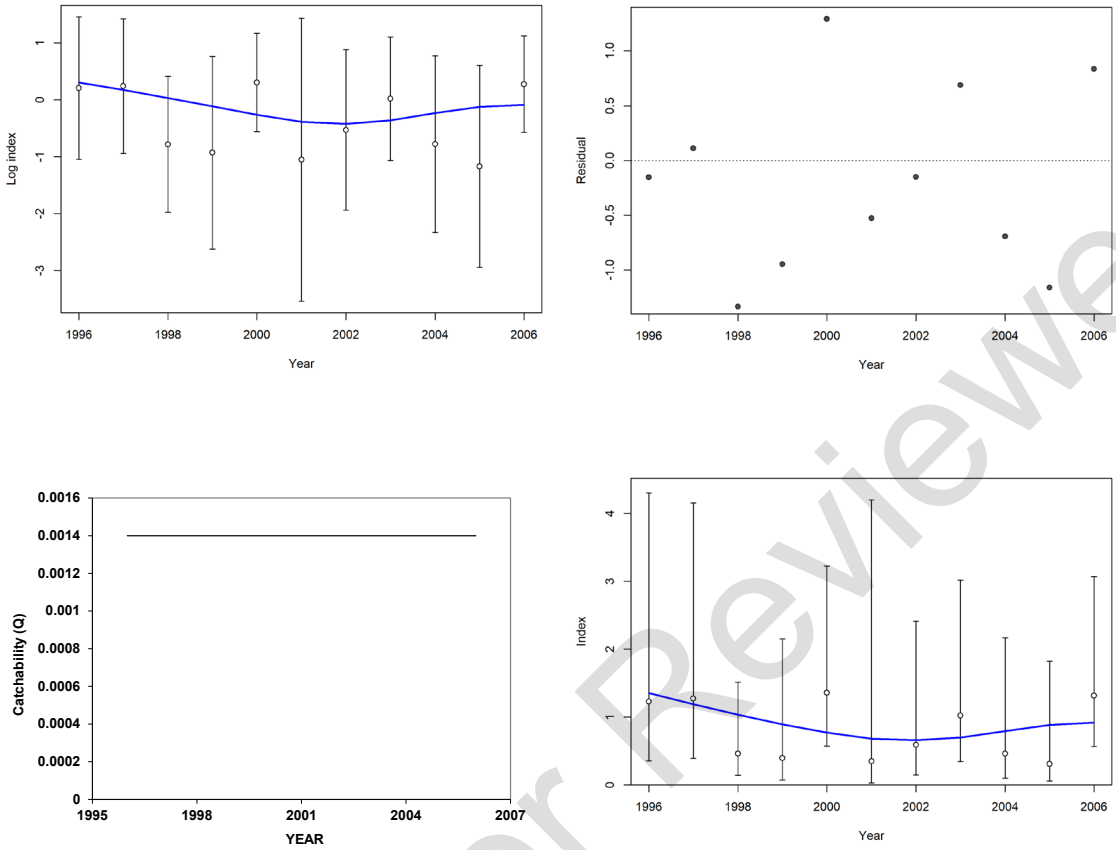

Figure 3.2. Continued: Fits to abundance index S6 (SCDNR-Red-Drum-BLL; 1996 – 2006).

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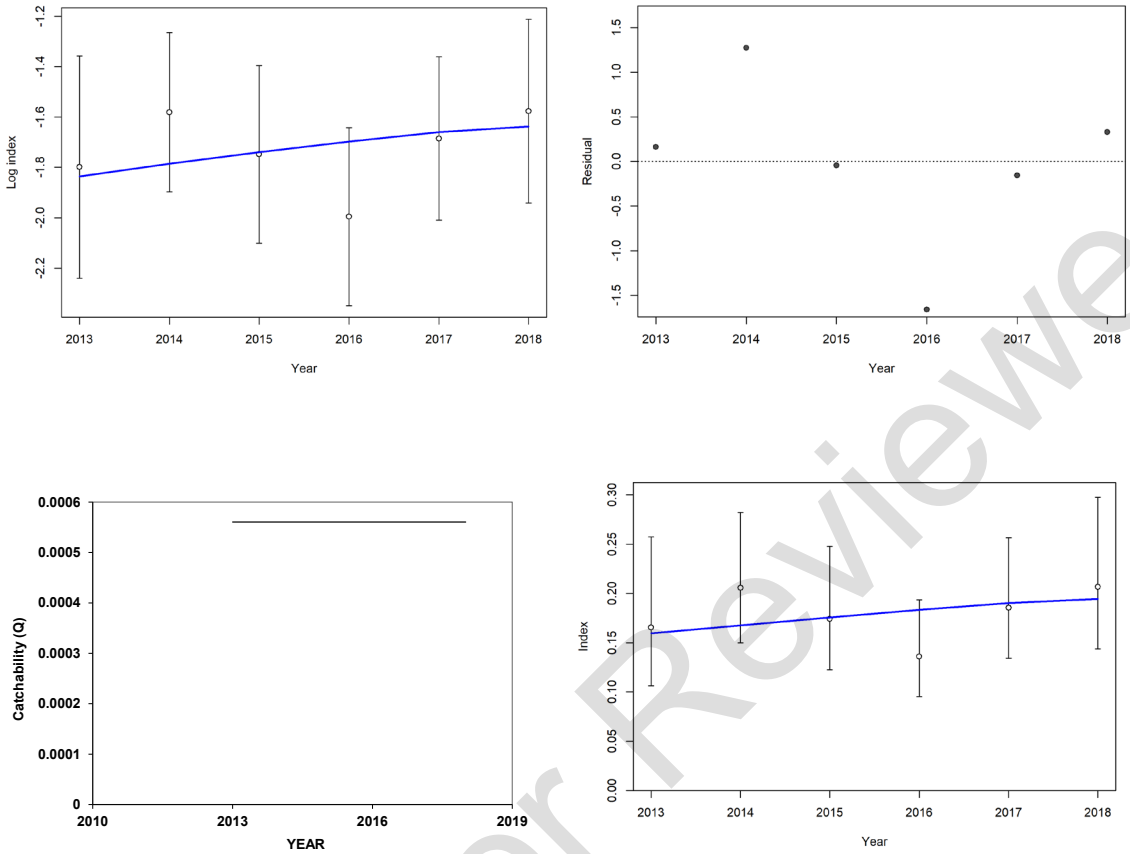

Figure 3.2. Continued: Fits to abundance index S7 (SCDNR-DL; 2013 – 2018).

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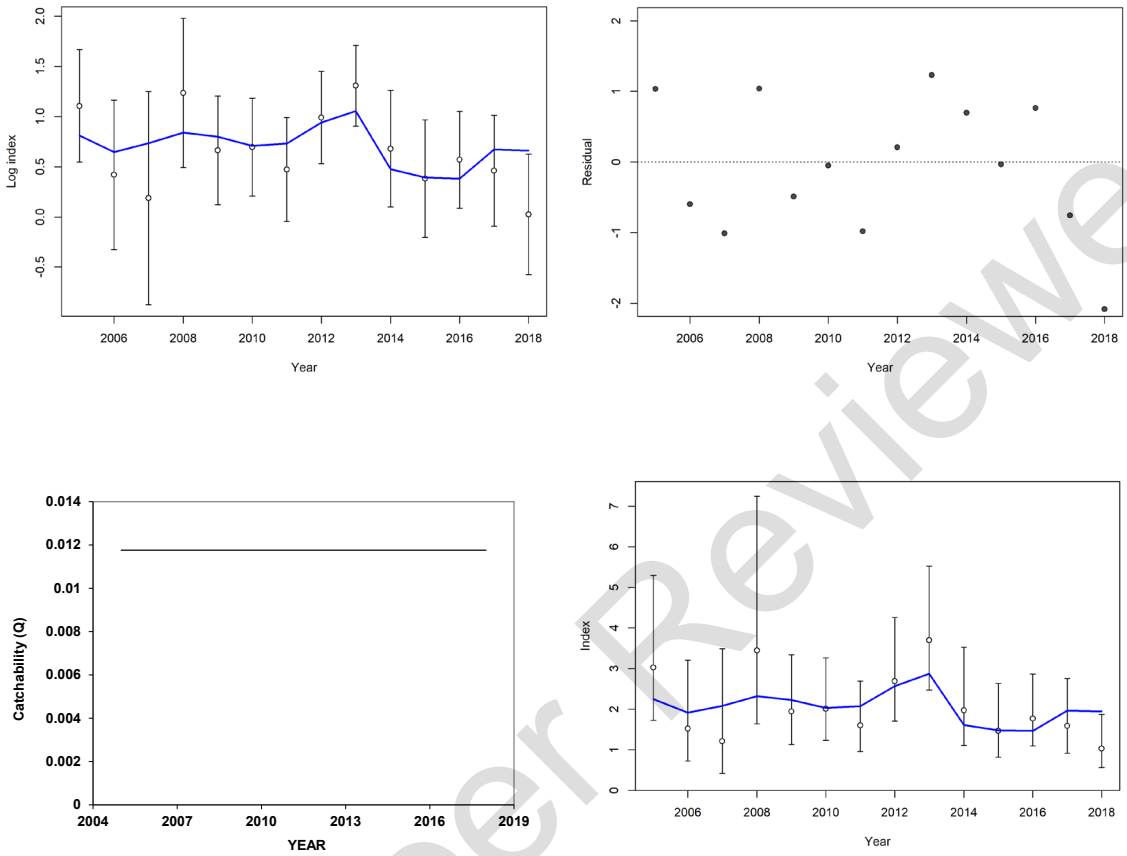

Figure 3.2. Continued: Fits to abundance index S8 (COASTSPAN-BLL-All-ages; 2005 – 2018).

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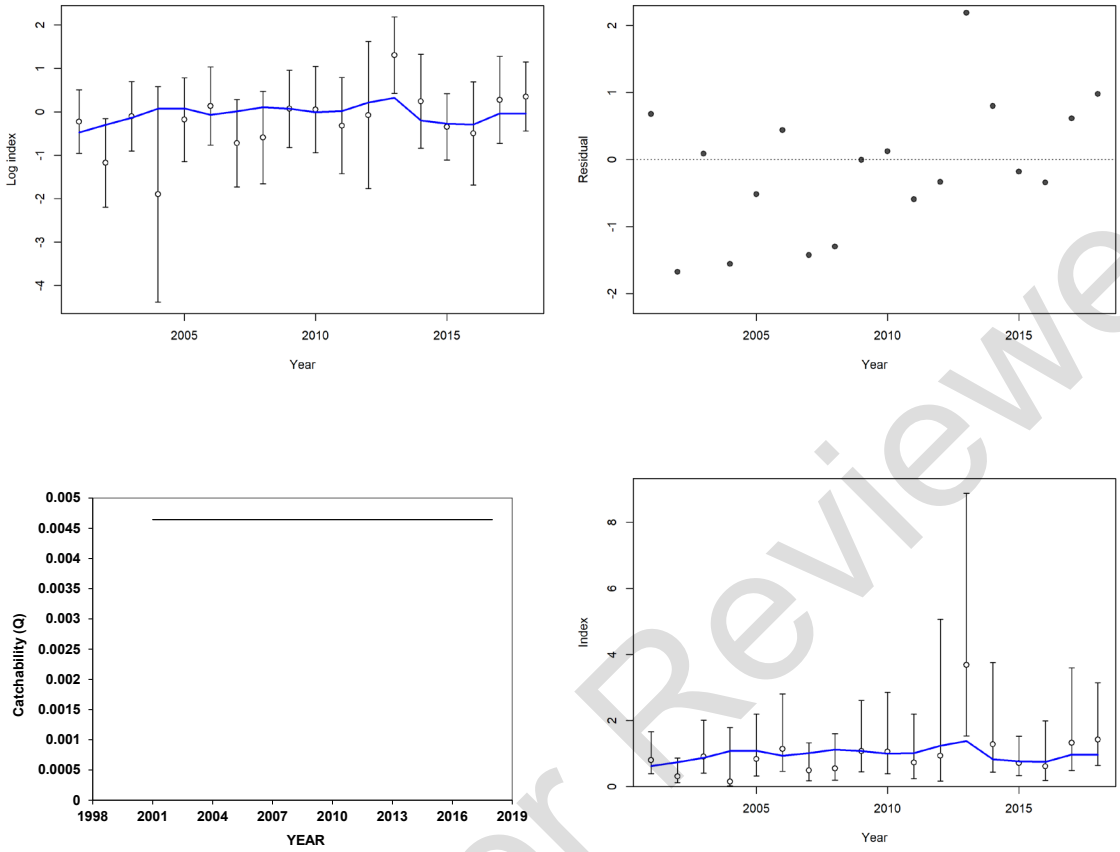

Figure 3.2. Continued: Fits to abundance index S9 (COASTSPAN-GNL-All-ages; 2001 – 2018).

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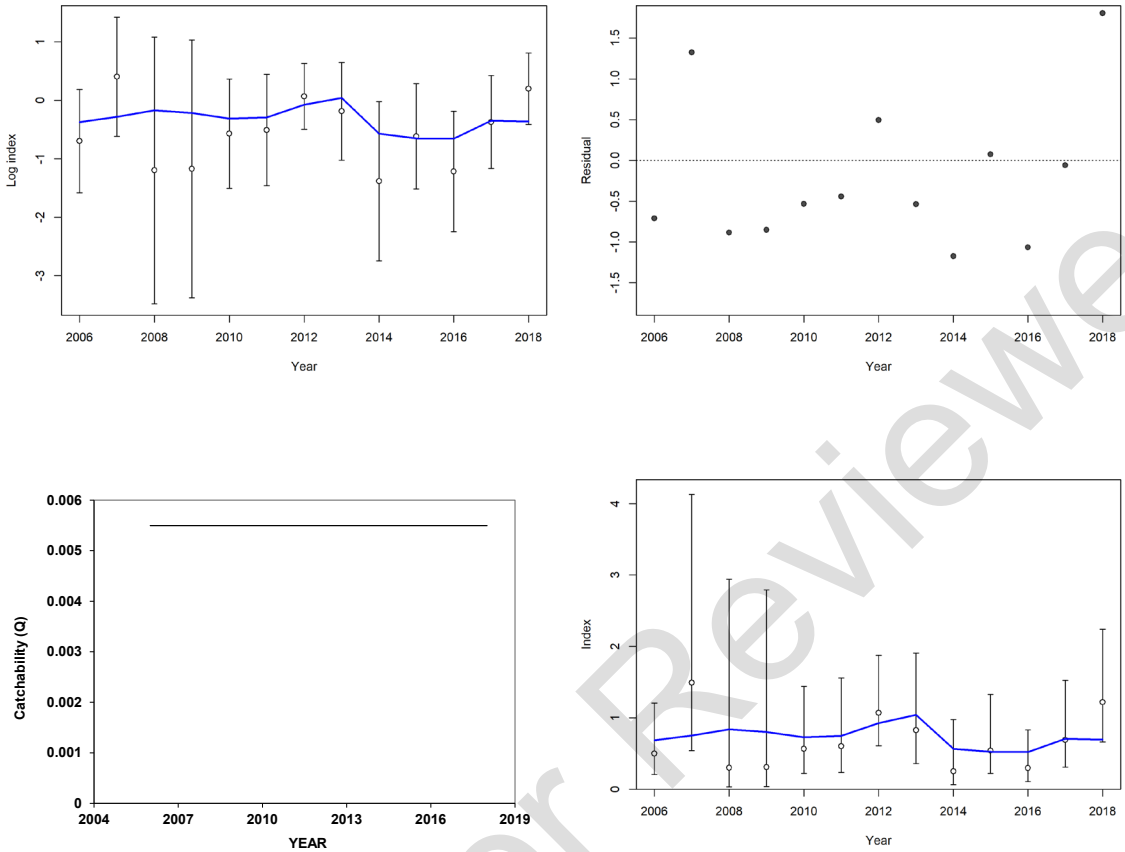

Figure 3.2. Continued: Fits to abundance index S10 (COASTSPAN-GNS-Age-0; 2006 – 2018).

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Figure 3.3. Observed and predicted annual length compositions (Upper panels) and Pearson residuals (Lower panel) in the base model configuration. Years with annual length composition sample size less than the minimum input sample size (Min; **Table 3.2)** were excluded from the model fit, and are not plotted. The value "N adj" is the input effective sample size obtained using either the Francis method or the McAllister and Ianelli harmonic mean, as described above. The value "N eff" is an alternative effective sample size estimate (McAllister and Ianelli 1997; Punt 2017, his McAllister-Ianelli-1 in his equation 1.A:) that is not implemented in this assessment. The diameter of Pearson residuals indicates relative error; predicted < observed (solid), predicted > observed (transparent) within the length composition data set. The maximum diameter of Pearson residuals indicates relative error among length composition data sets.

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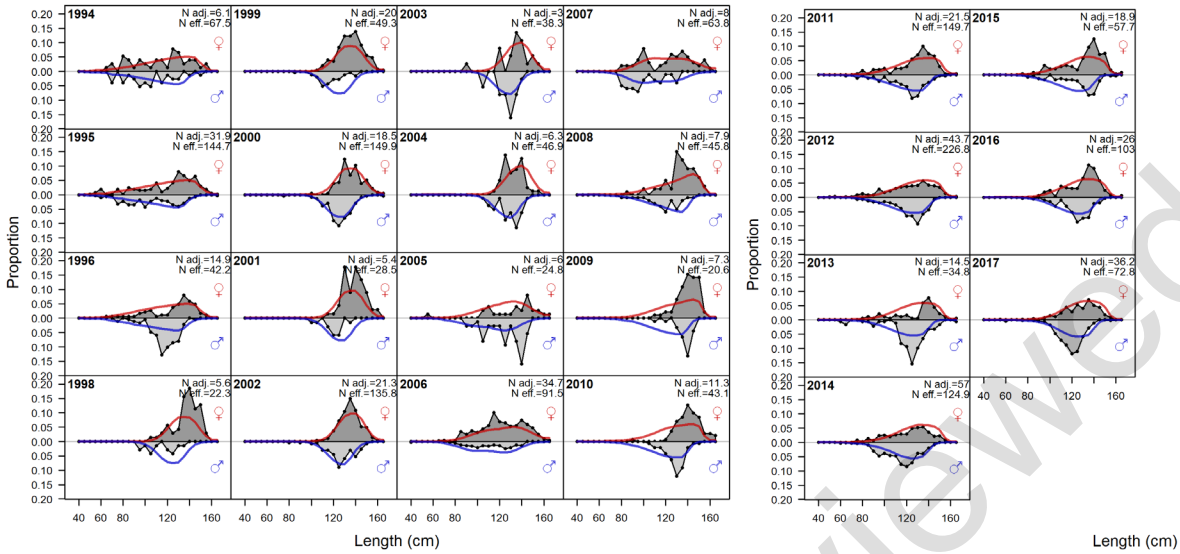

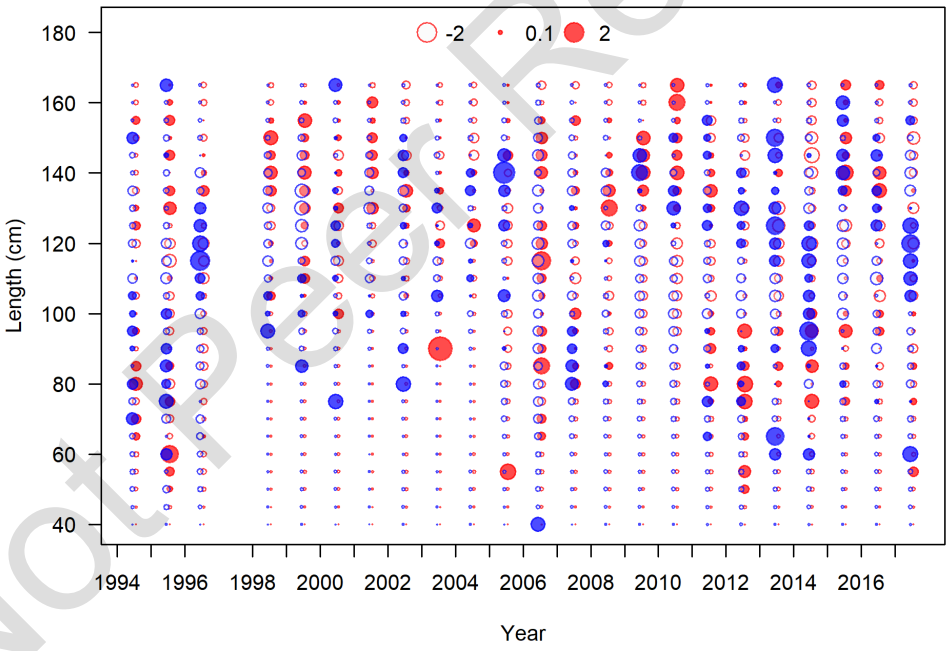

Figure 3.3. Continued. Fits to length composition obtained for F1 (Com-BLL-Kept; 1994 – 2018).

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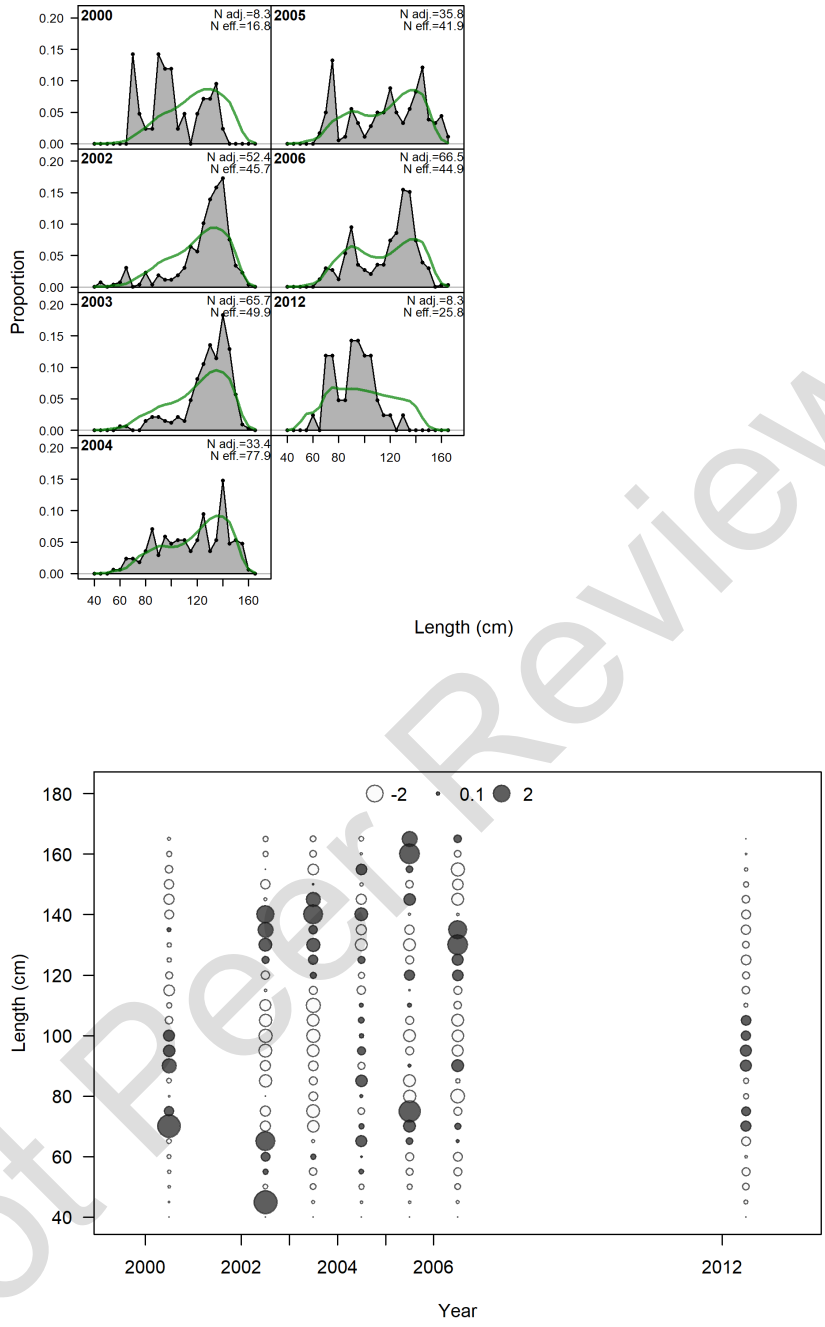

Figure 3.3. Continued. Fits to length composition obtained for F2 (Com-GN-Kept; 2000 – 2018).

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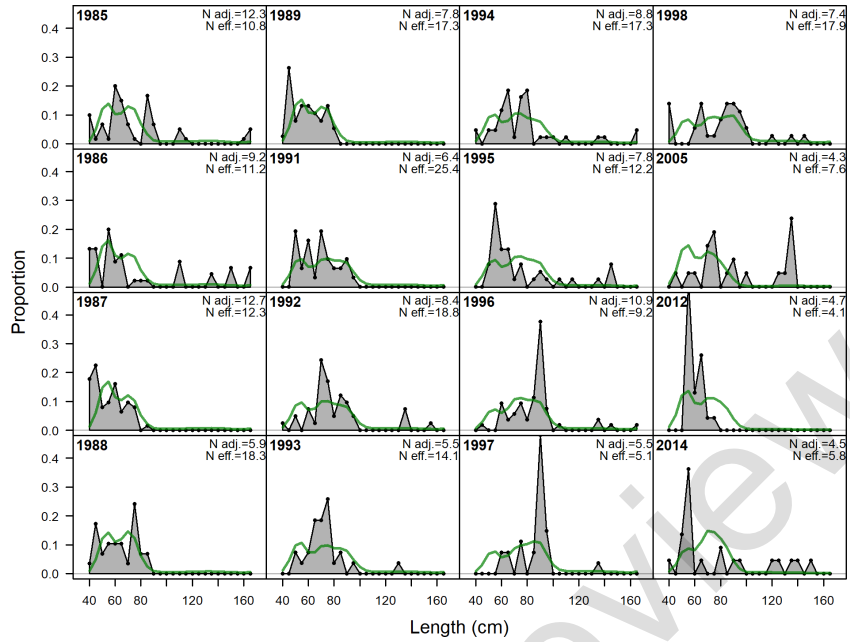

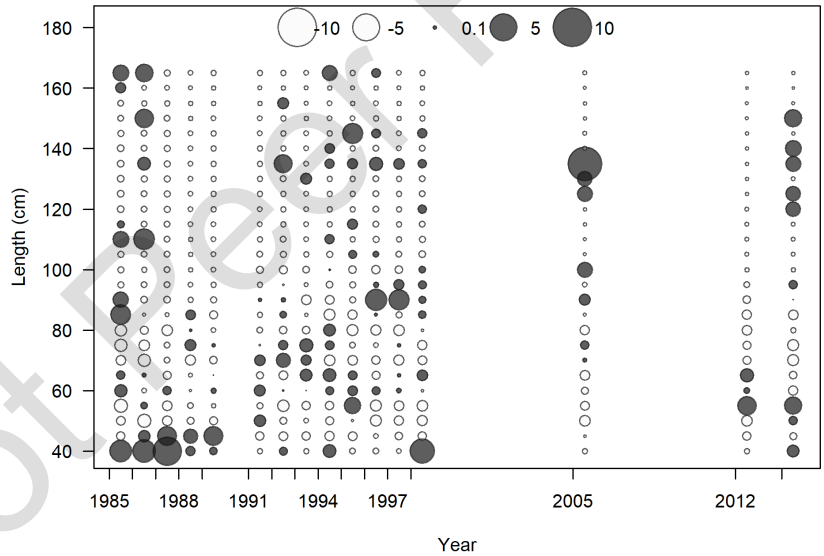

Figure 3.3. Continued. Fits to length composition obtained for F4 (Recreational; 1981 – 2018).

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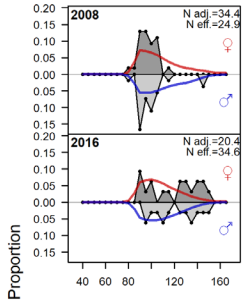

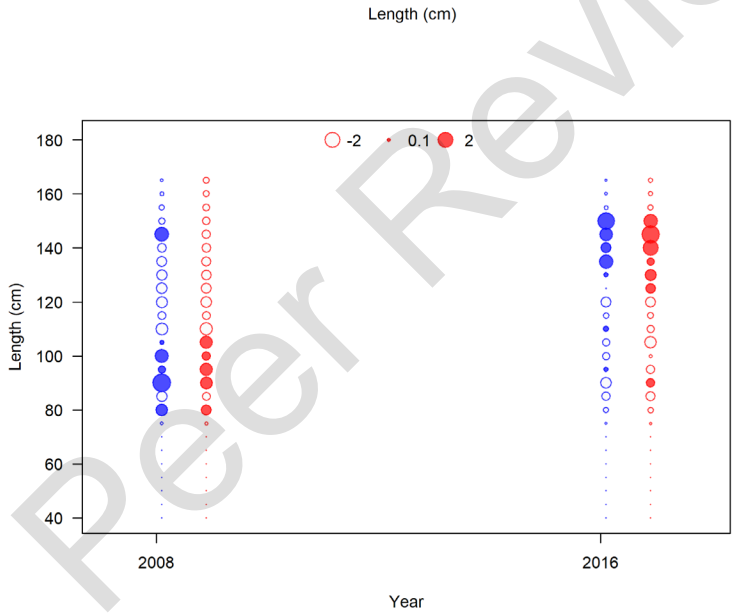

Figure 3.3. Continued. Fits to length composition obtained for S3 (VIMS-BLL-Robust; 1990 – 2018).

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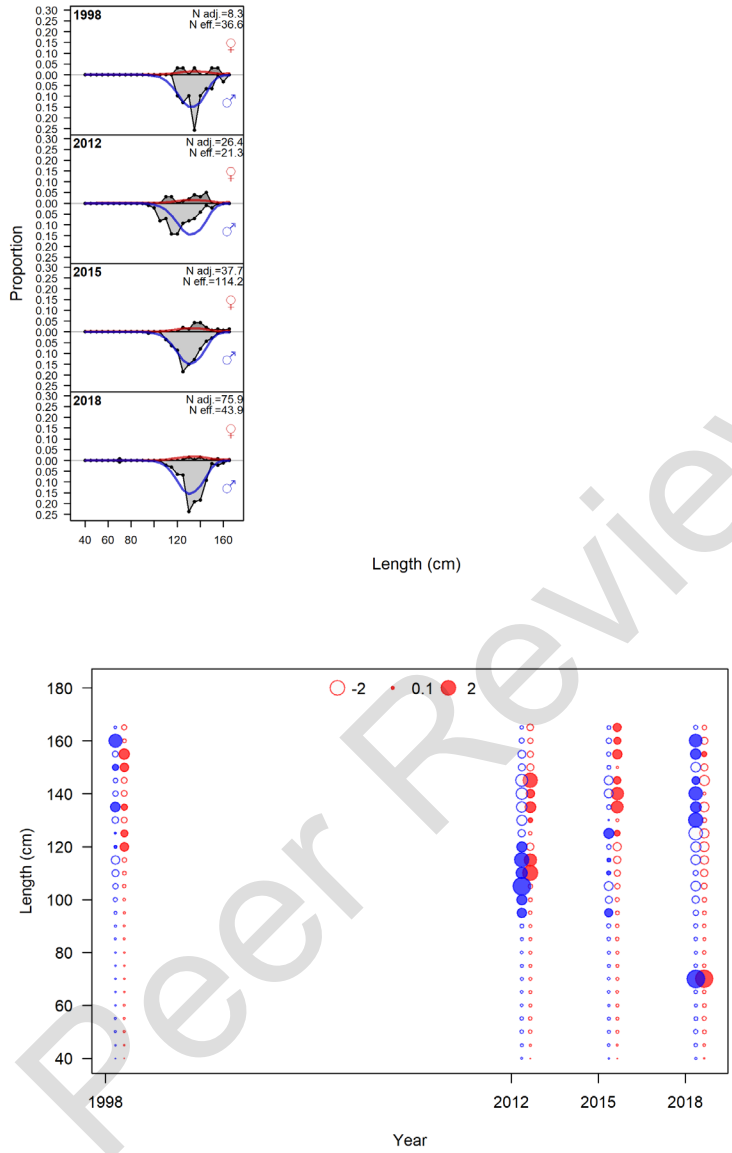

Figure 3.3. Continued. Fits to length composition obtained for S4 (NEFSC-BLL; 1996 – 2018).

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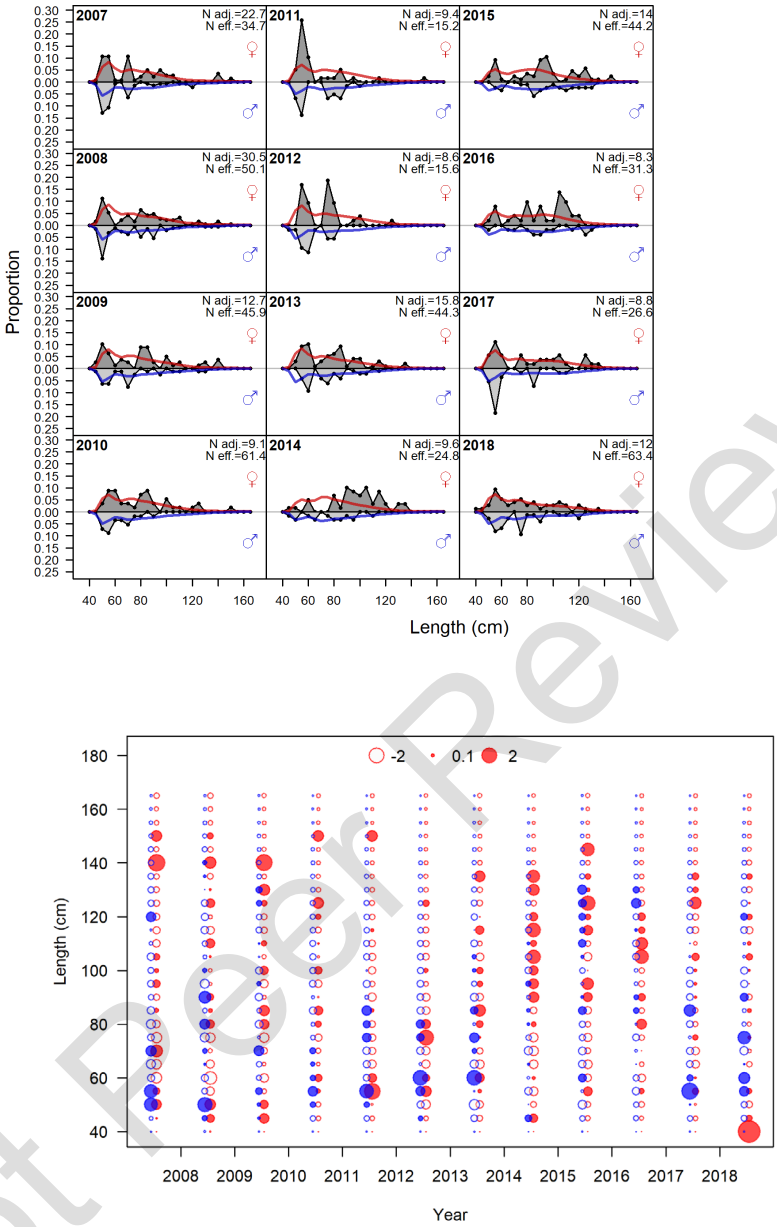

Figure 3.3. Continued. Fits to length composition obtained for S5 (SCDNR-SEAMAP-BLL; 2007 – 2018).

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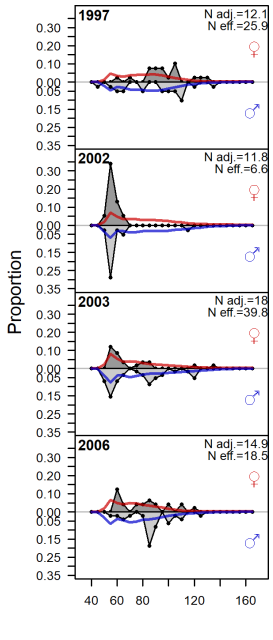

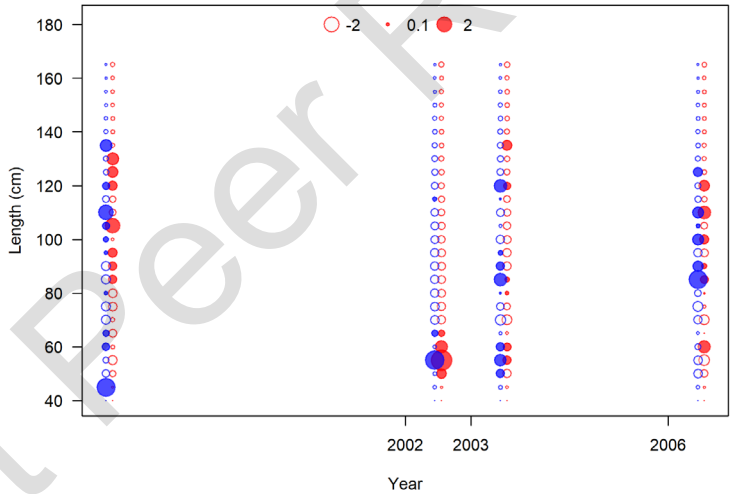

Figure 3.3. Continued. Fits to length composition obtained for S6 (SCDNR-Red-Drum-BLL; 1996 – 2006).

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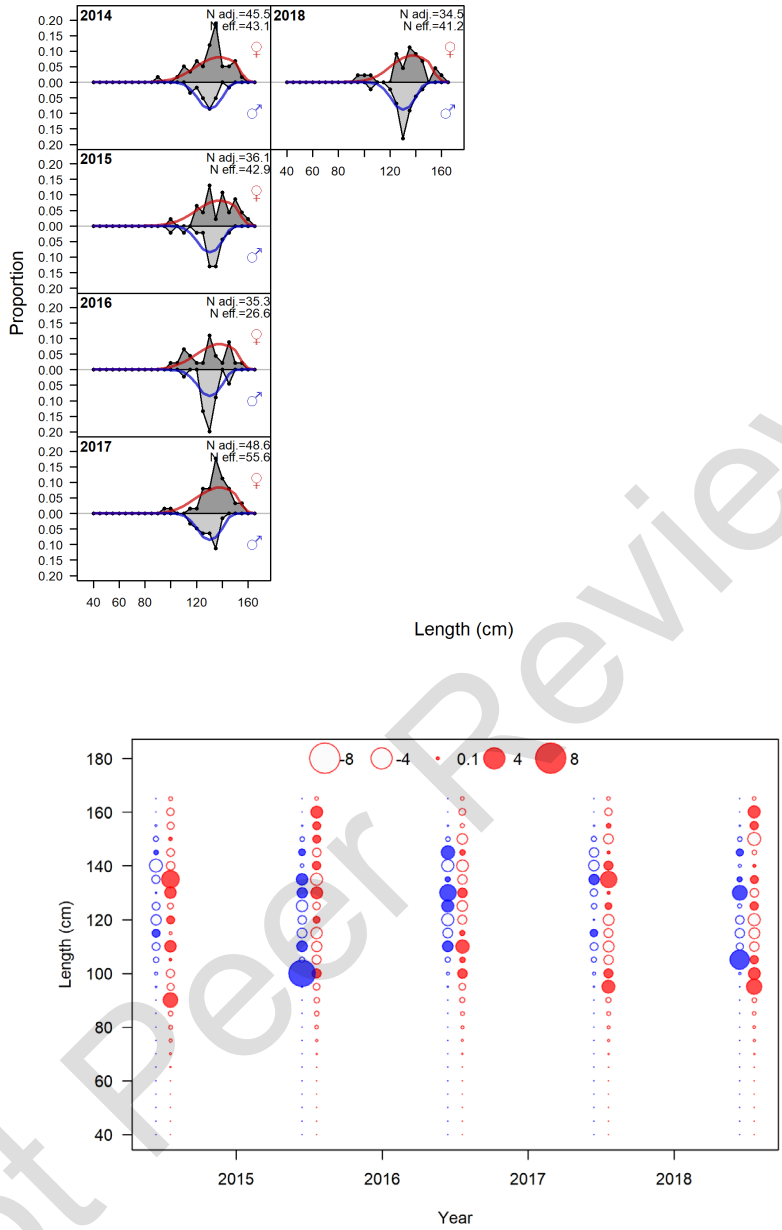

Figure 3.3. Continued. Fits to length composition obtained for S7 (SCDNR-DL; 2013 – 2018).

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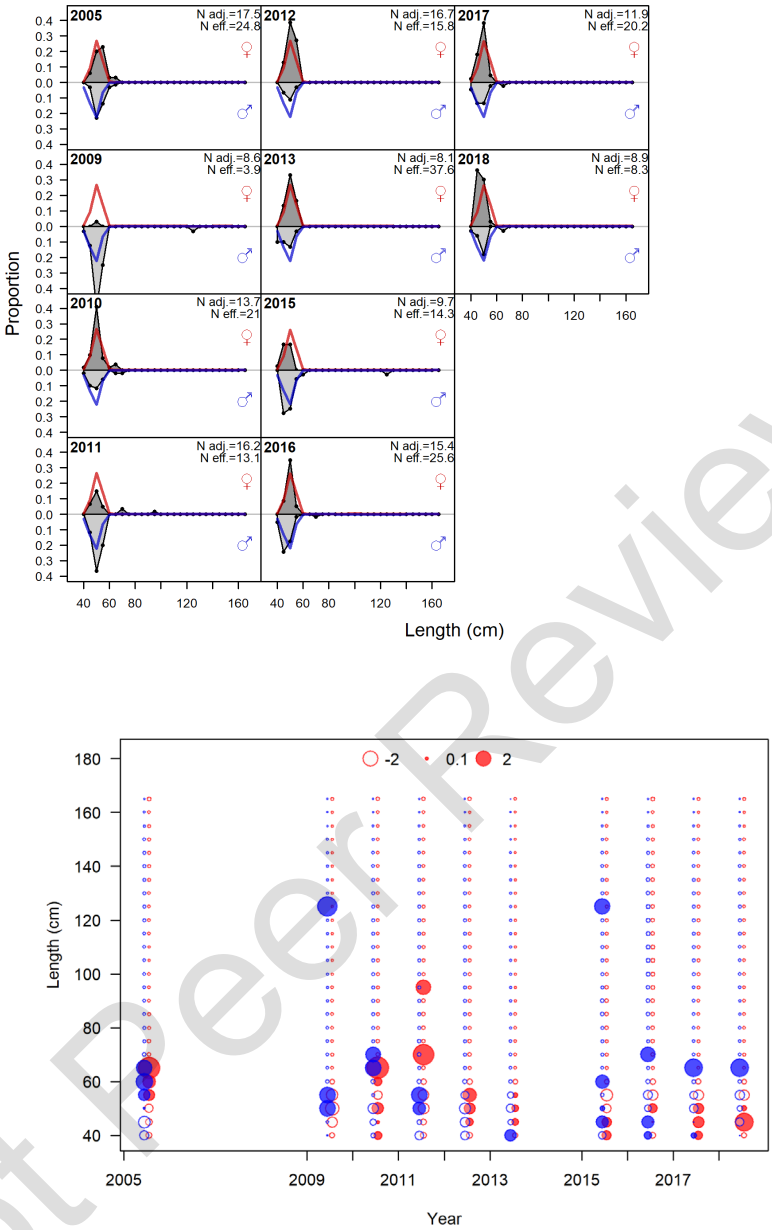

Figure 3.3. Continued. Fits to length composition obtained for S8 (COASTSPAN-BLL-All-ages; 2005 – 2018).

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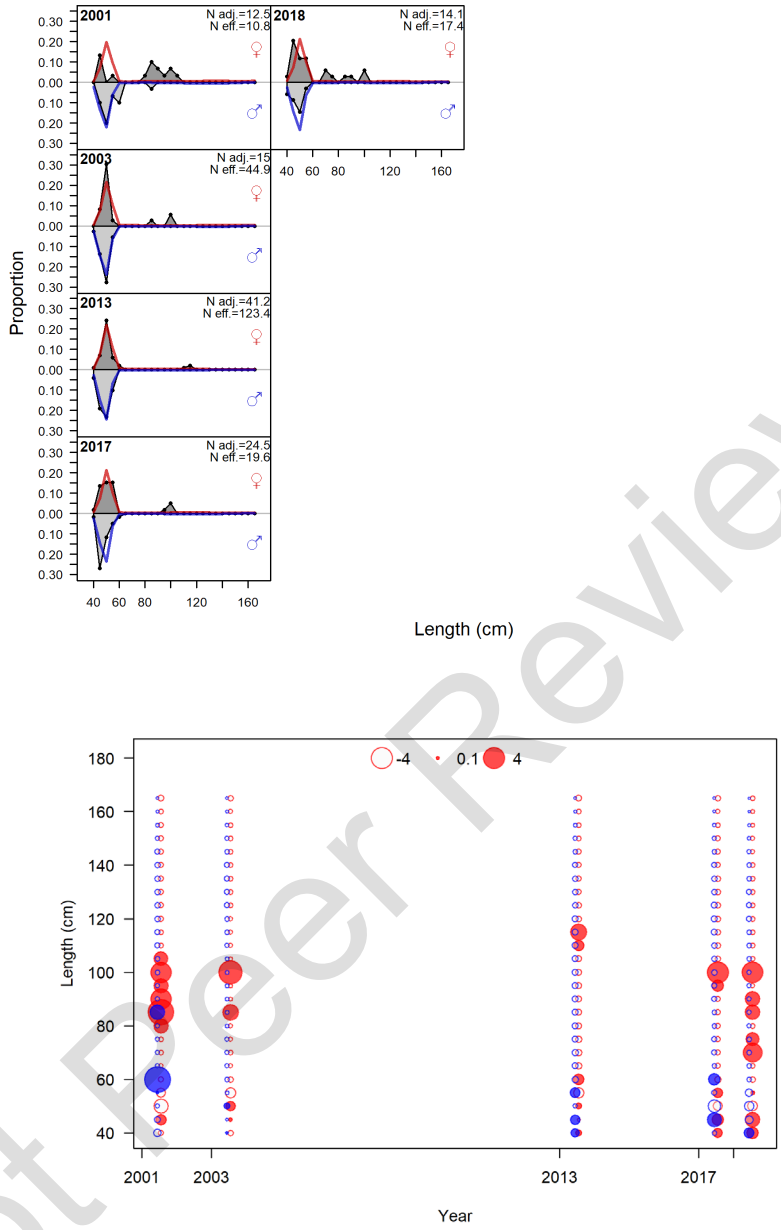

Figure 3.3. Continued. Fits to length composition obtained for S9 (COASTSPAN-GNL-All-ages; 2001 – 2018).

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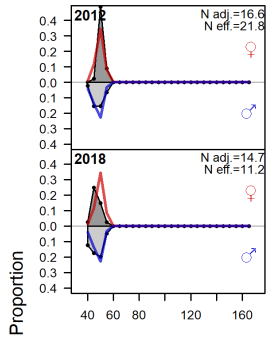

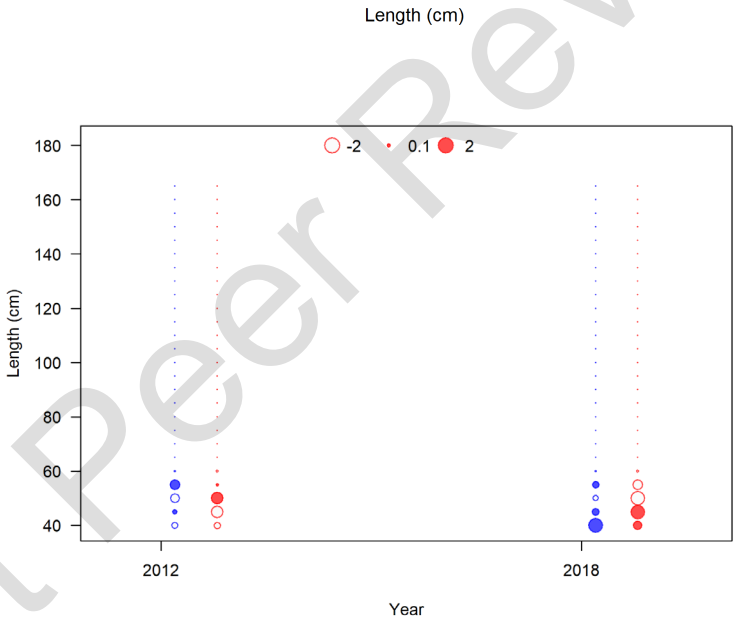

Figure 3.3. Continued. Fits to length composition obtained for S10 (COASTSPAN-GNS-Age-0; 2006 – 2018).

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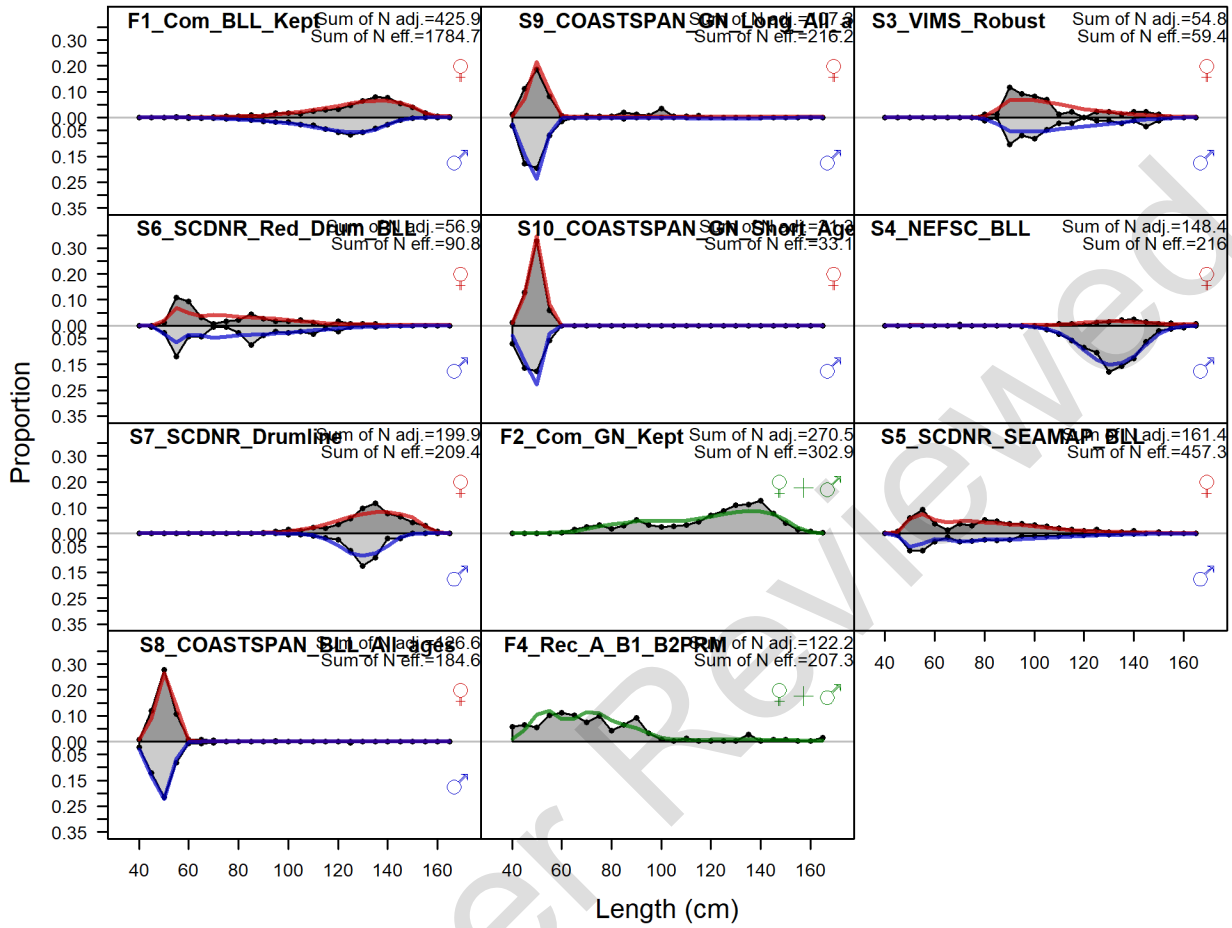

Figure 3.4. Predicted (line) and observed (shaded) aggregated length compositions in the base model configuration model. Years with annual length composition sample size less than the minimum input sample size (Min; **Table 3.2)** were excluded from the model fit, and are not plotted. The value "N adj" is the input effective sample size obtained using either the Francis method or the McAllister and Ianelli harmonic mean, as described above. The value "N eff" is an alternative effective sample size estimate (McAllister and Ianelli 1997; Punt 2017, his McAllister-Ianelli-1 in his equation 1.A:) that is not implemented in this assessment.

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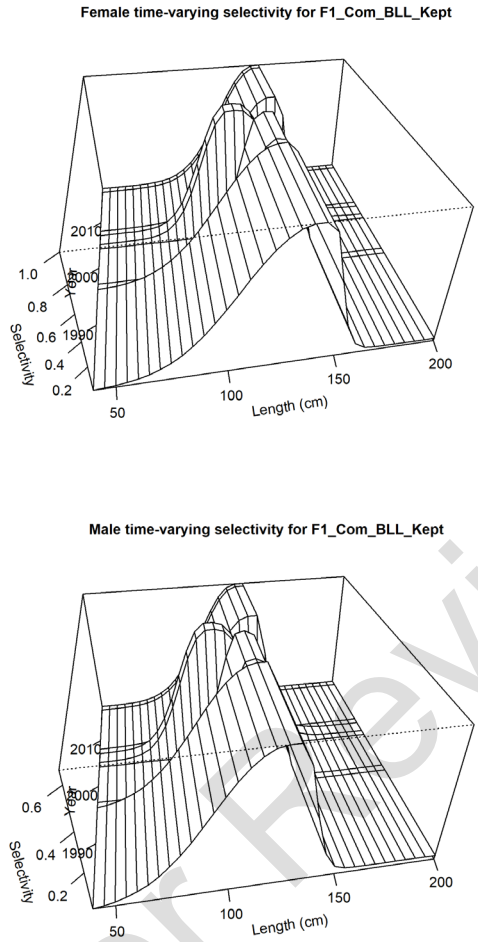

Figure 3.5. Estimated selectivity at length (cm FL straight) obtained in the base model configuration (**Table 3.5)** for F1 (Com-BLL-Kept; 1994 – 2018).

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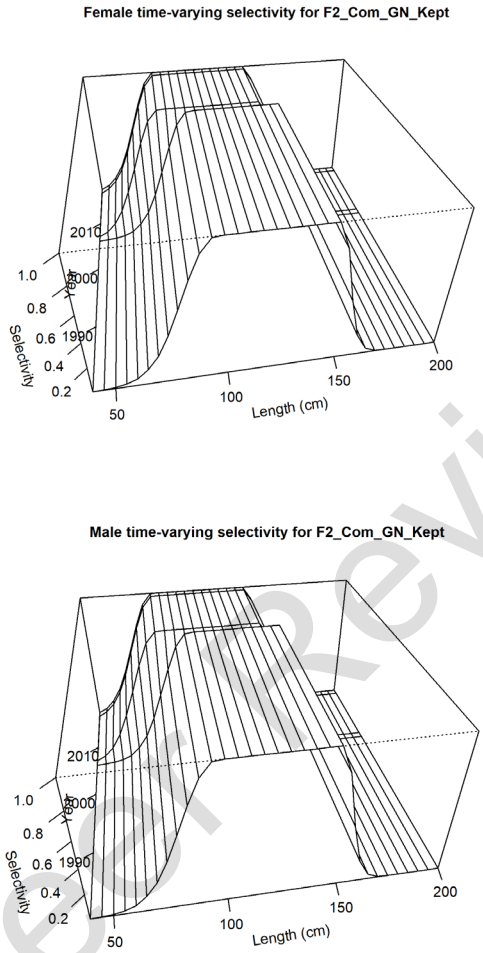

Figure 3.5. Continued. F2 (Com-GN-Kept; 2000 – 2018).

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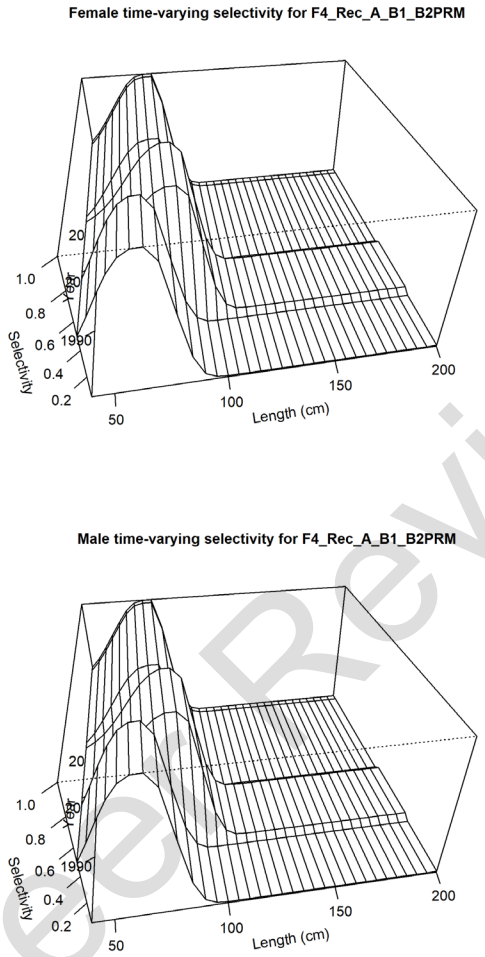

Figure 3.5. Continued. F4 (Recreational; 1981 – 2018).

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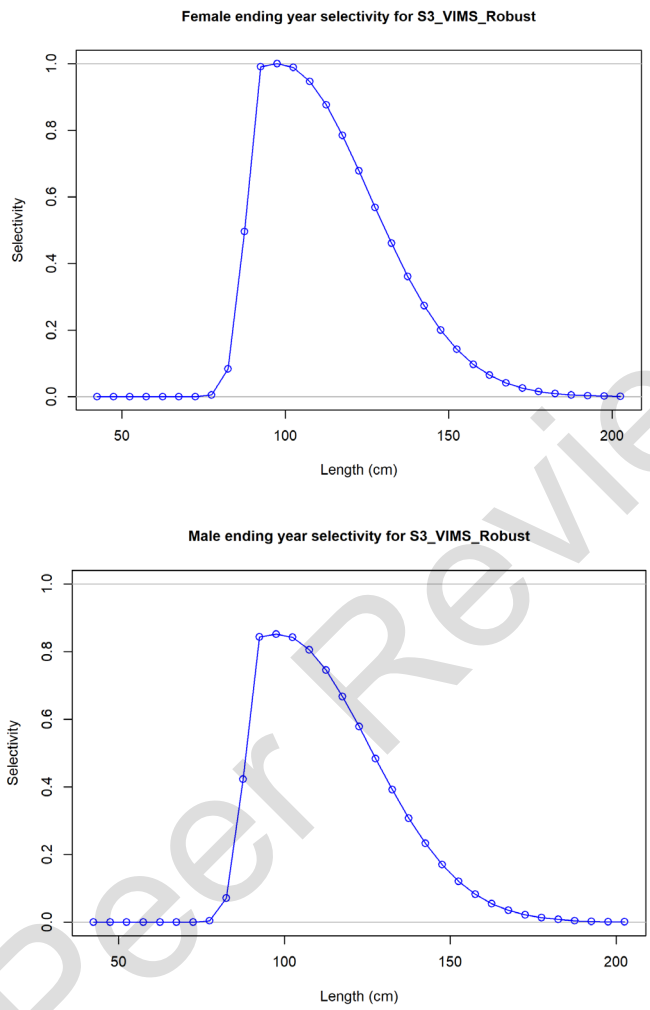

Figure 3.5. Continued. S3 (VIMS-BLL-Robust; 1990 – 2018).

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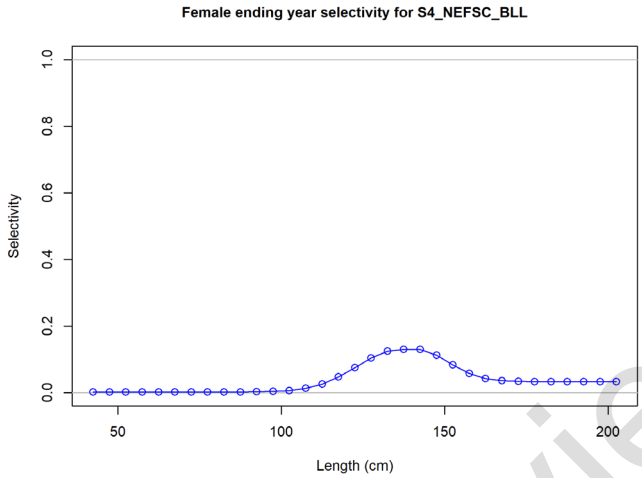

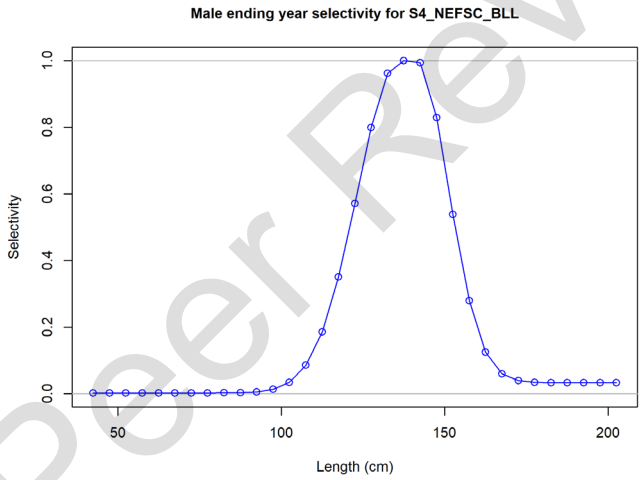

Figure 3.5. Continued. S4 (NEFSC-BLL; 1996 – 2018).

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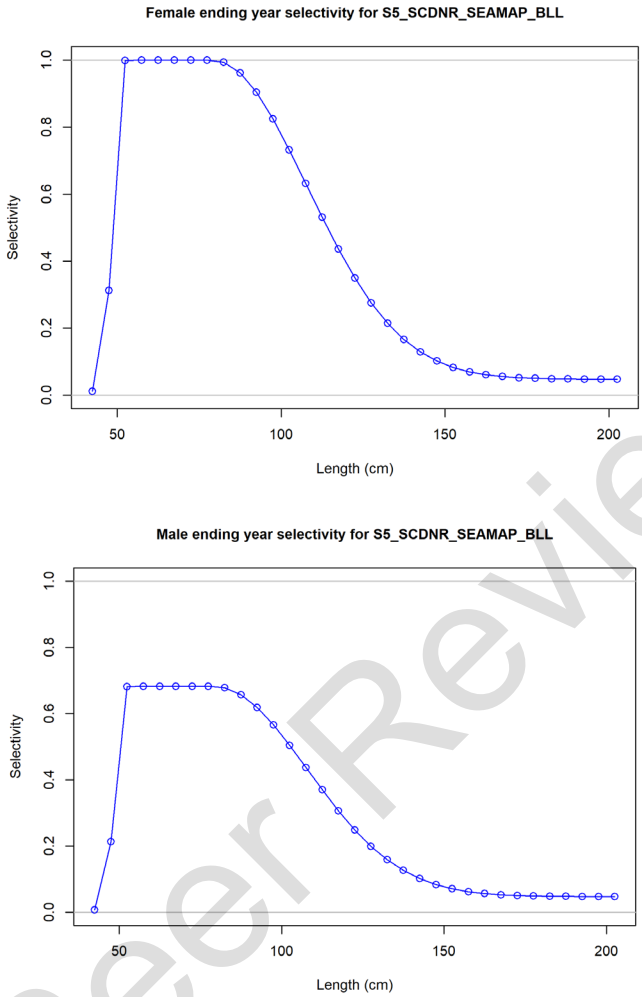

Figure 3.5. Continued. S5 (SCDNR-SEAMAP-BLL; 2007 – 2018).

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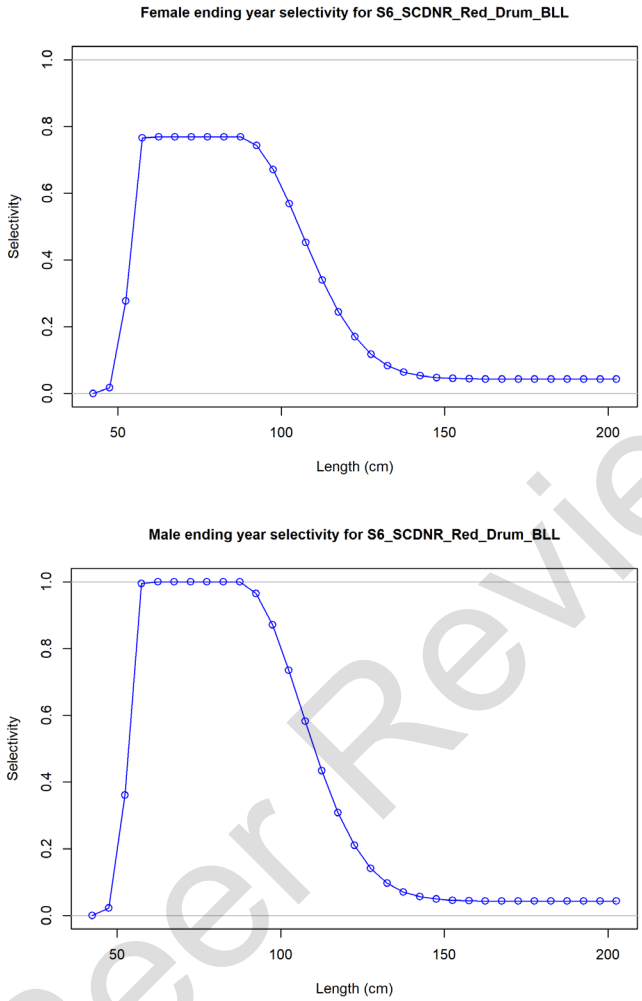

Figure 3.5. Continued. S6 (SCDNR-Red-Drum-BLL; 1996 – 2006).

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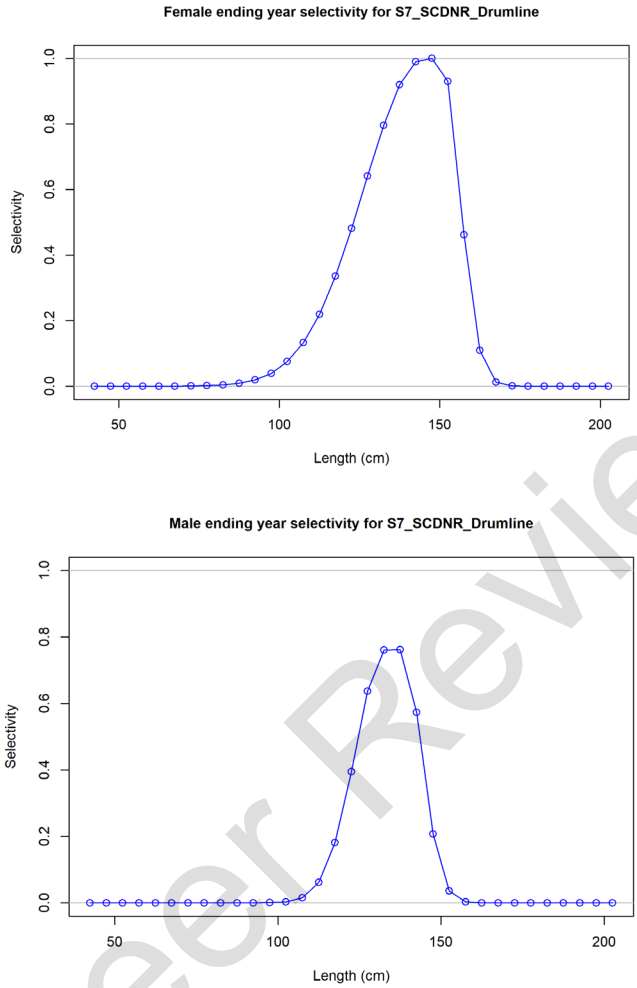

Figure 3.5. Continued. S7 (SCDNR-DL; 2013 – 2018).

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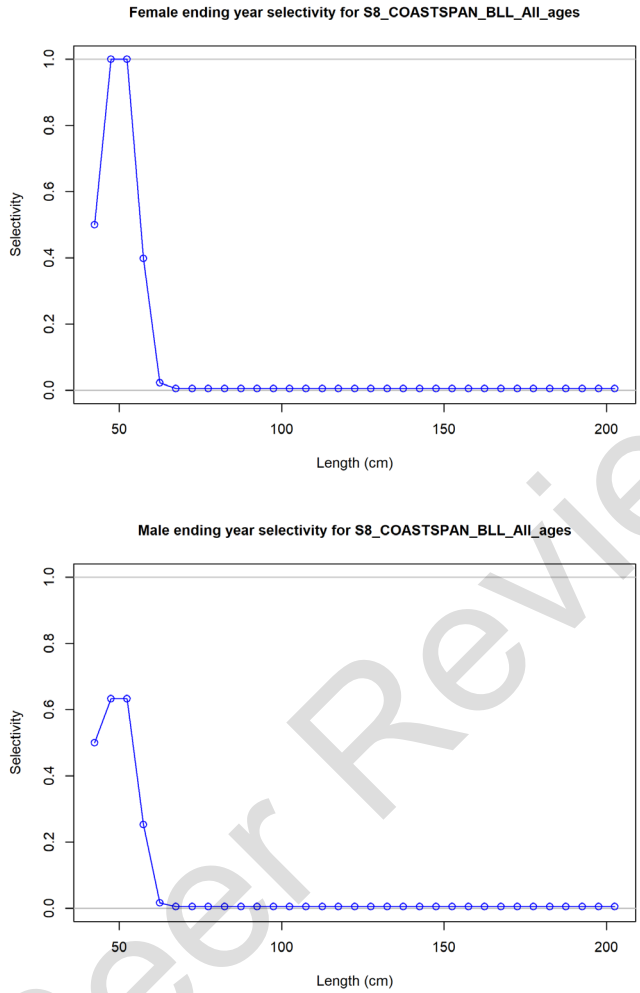

Figure 3.5. Continued. S8 (COASTSPAN-BLL-All-ages; 2005 – 2018).

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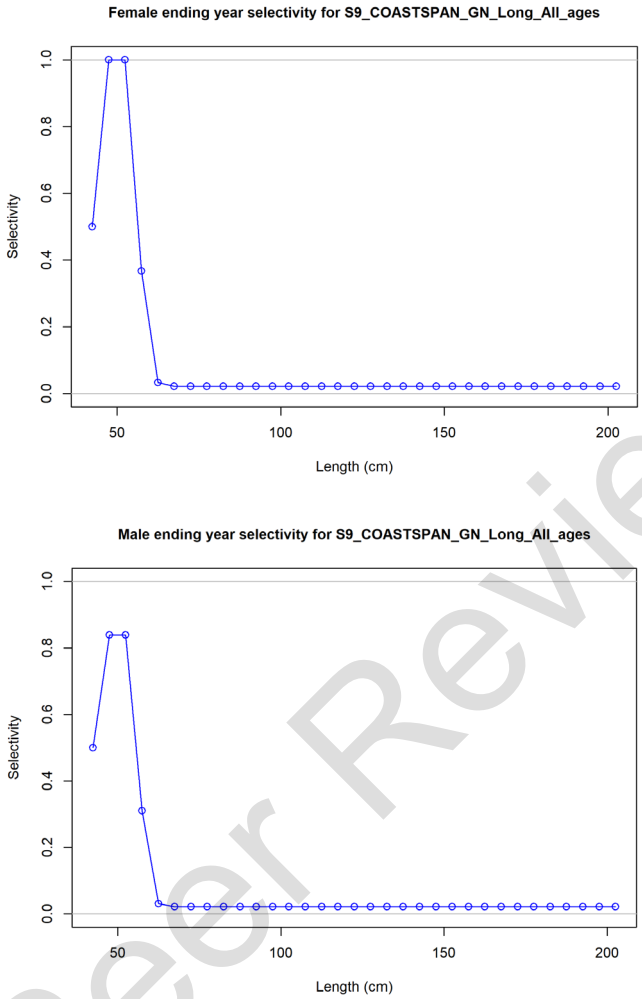

Figure 3.5. Continued. S9 (COASTSPAN-GNL-All-ages; 2001 – 2018).

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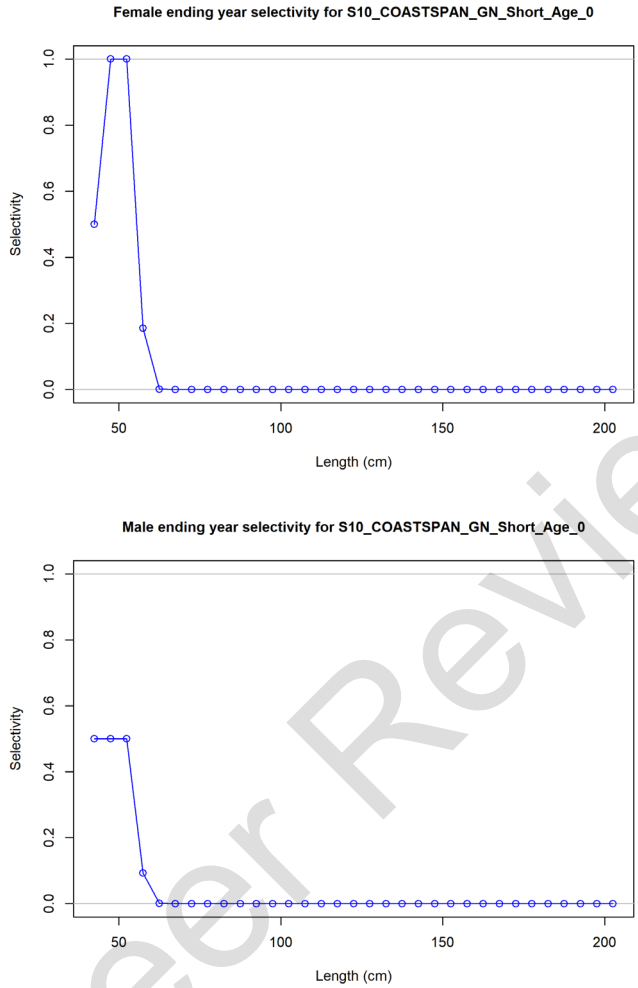

Figure 3.5. Continued. S10 (COASTSPAN-GNS-Age-0; 2006 – 2018).

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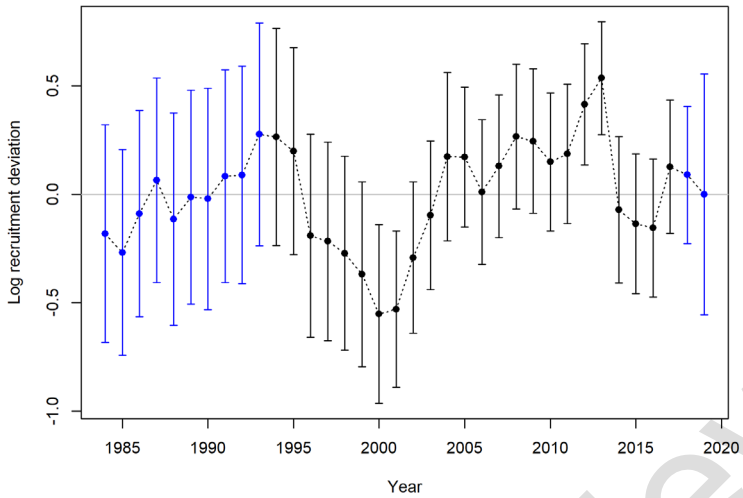

Figure 3.6. Upper panel is the estimated log recruitment deviations for the early (1984 – 1993, blue), main (1994 – 2017, black), late (2018, blue), and forecast (2019, blue) recruitment periods with associated 95% asymptotic confidence intervals in the base model configuration. Lower panel is the estimated annual age-0 recruits (circles) with 95% asymptotic confidence intervals. Age-0 recruits follow the assumed stock recruitment relationship exactly in years prior to 1984 and after 2018.

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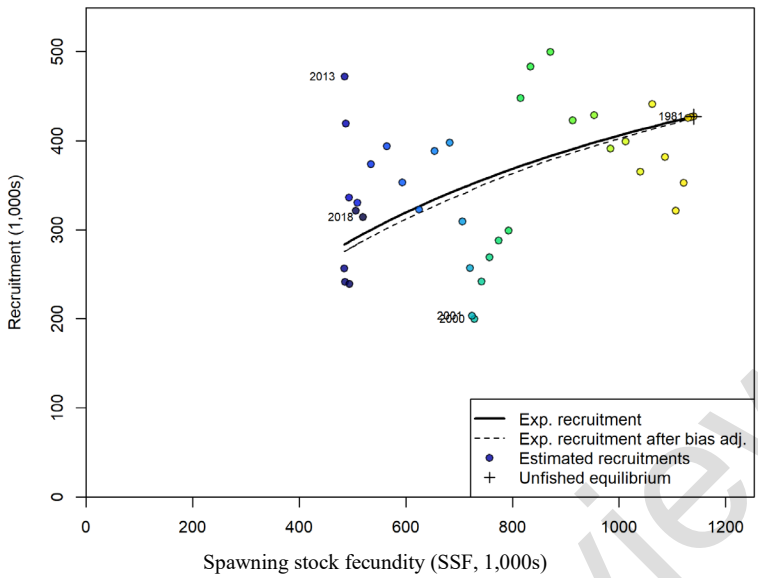

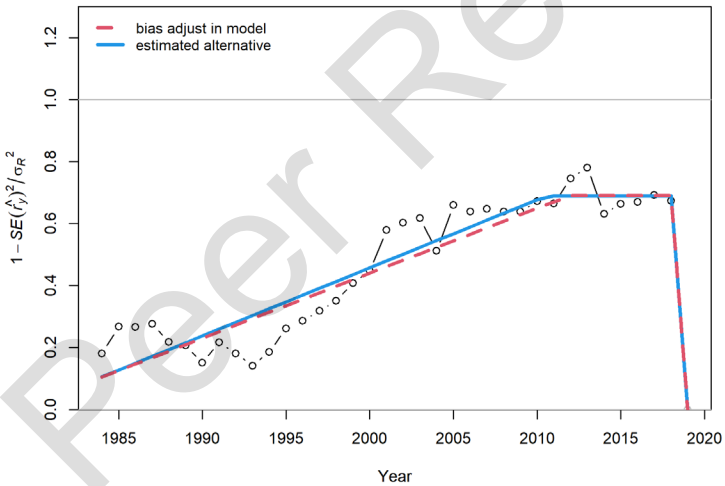

Figure 3.7. Expected recruitment (Upper panel) from the stock-recruitment relationship (solid line), expected recruitment after implementing the bias adjustment correction (dashed line), estimated annual recruitments (circles), unfished equilibrium (plus), and first (1981) and last (2018) years along with years with log deviations > 0.5 (2000, 2001 and 2013) in the base model configuration. Bias adjustment ramp (Lower panel) applied to the stock-recruitment relationship (red stippled line) and the estimated alternative (blue line). The y-axis of the lower panel is the bias adjustment fraction (Methot and Taylor 2011) in the base model configuration.

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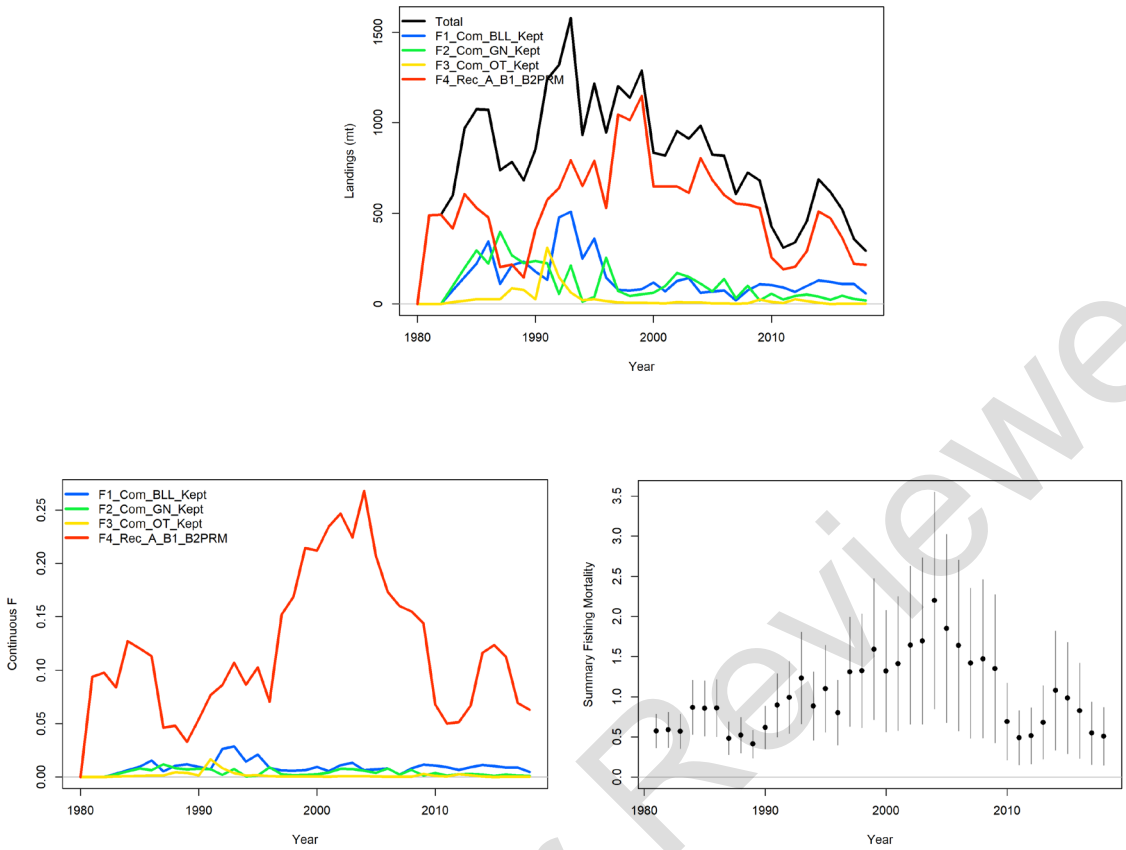

Figure 3.8. Total landings (Upper panel), continuous fishing mortality by fleet (Continuous *F*; Lower left panel), and the summary fishing mortality of all fleets combined (Lower right panel) in the base model configuration. The summary fishing mortality is plotted as a ratio calculated as the total fishing mortality rate experienced by the population (*F*=*Z*-*M*) relative to F_{MSY}. Error bars are the 95% asymptotic standard errors, ± 1.96*SE, obtained from Stock Synthesis output. Total landings include commercial landings (mt) along with recreational catch plus recreational discards assumed to die from post release mortality (A + B1 + B2 dead). Recreational data was entered in numbers (1,000s) and converted internally within Stock Synthesis to weight (mt) based on the weight at length of recreational fishery removals obtained in the Stock Synthesis base model configuration.

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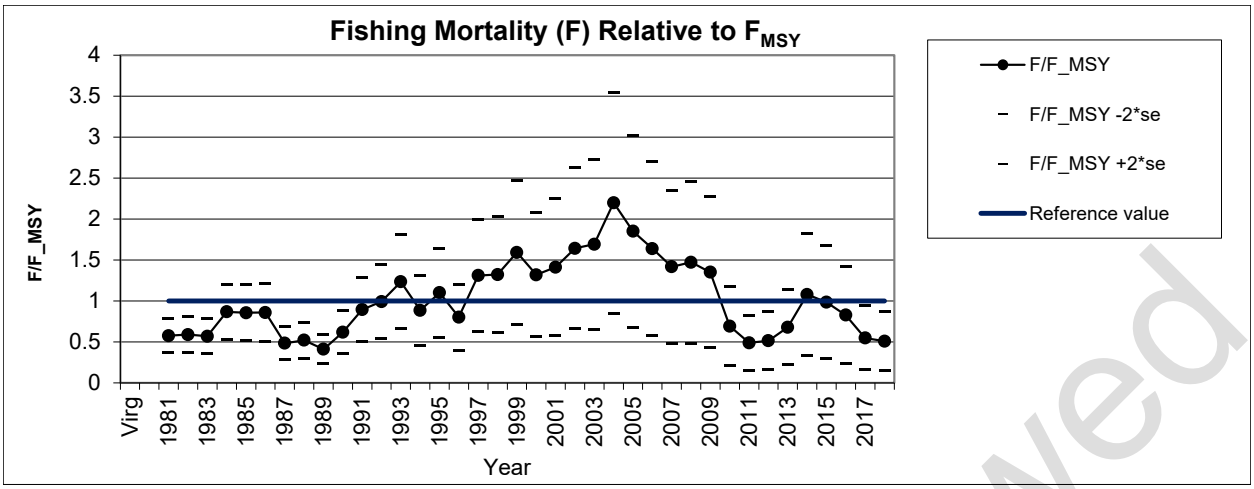

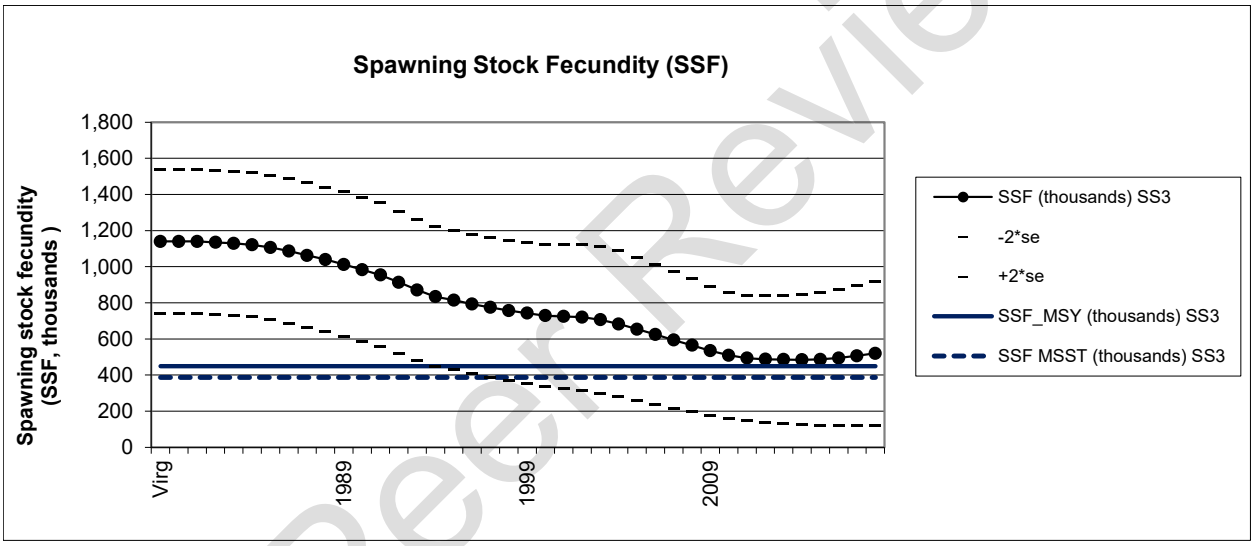

Figure 3.9. Summary fishing mortality (F) relative to F_{MSY} (Upper panel) and spawning stock fecundity (SSF) (Lower Panel) in the base model configuration. Summary fishing mortality, F, is calculated as the total fishing mortality rate experienced by the population (F=Z-M) obtained from Stock Synthesis output. Error bars are the 95% asymptotic standard errors, ± 1.96*SE, for F_Y/F_{MSY} and SSF_Y obtained from Stock Synthesis output. MSST (lower Panel) is $\left(1-\bar{M}_a\right)$ *$\mathrm{SSF}_{\mathrm{MSY}}$, with $\bar{M}_a$ calculated as the arithmetic mean of the female age-specific values of M used in the base model configuration (0.139, **Table 2.13**).

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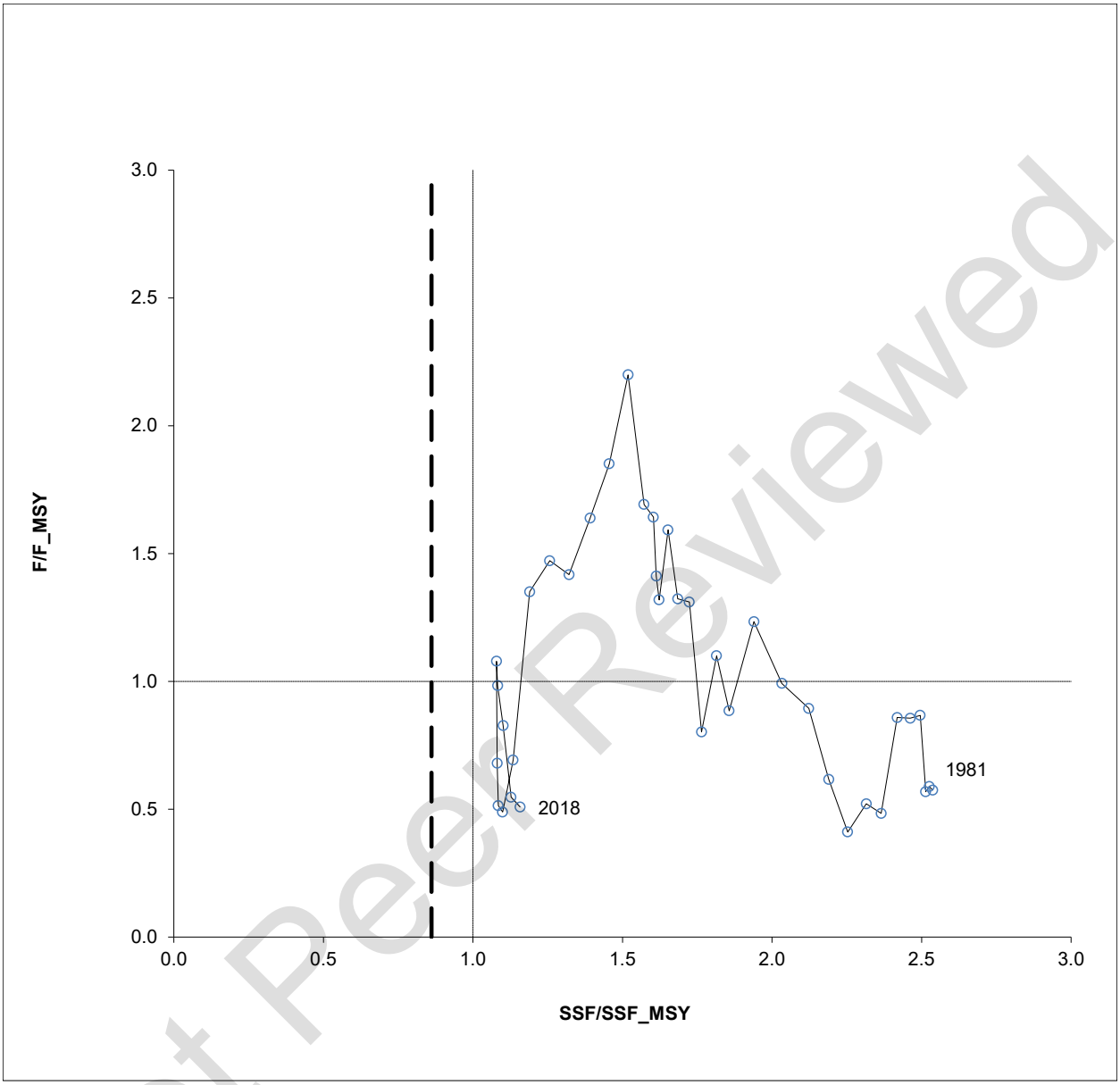

Figure 3.10. Phase plot of the relative spawning stock fecundity (SSF) and relative fishing mortality (F) trajectories by year from 1981 to 2018 for the base model configuration. The dotted horizontal and vertical lines indicate F_{MSY} and $\mathrm{SSF}_{\mathrm{MSY}}$. The dashed vertical line indicates MSST $=\left(1-\bar{M}_a\right)$*$\mathrm{SSF}_{\mathrm{MSY}}$, with $\bar{M}_a$ calculated as the arithmetic mean of the female age-specific values of M used in the base model configuration (0.139, **Table 2.13**).

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Appendix 3.A. Francis (2011) Method (Stage 1) CPUE Variance Adjustments.

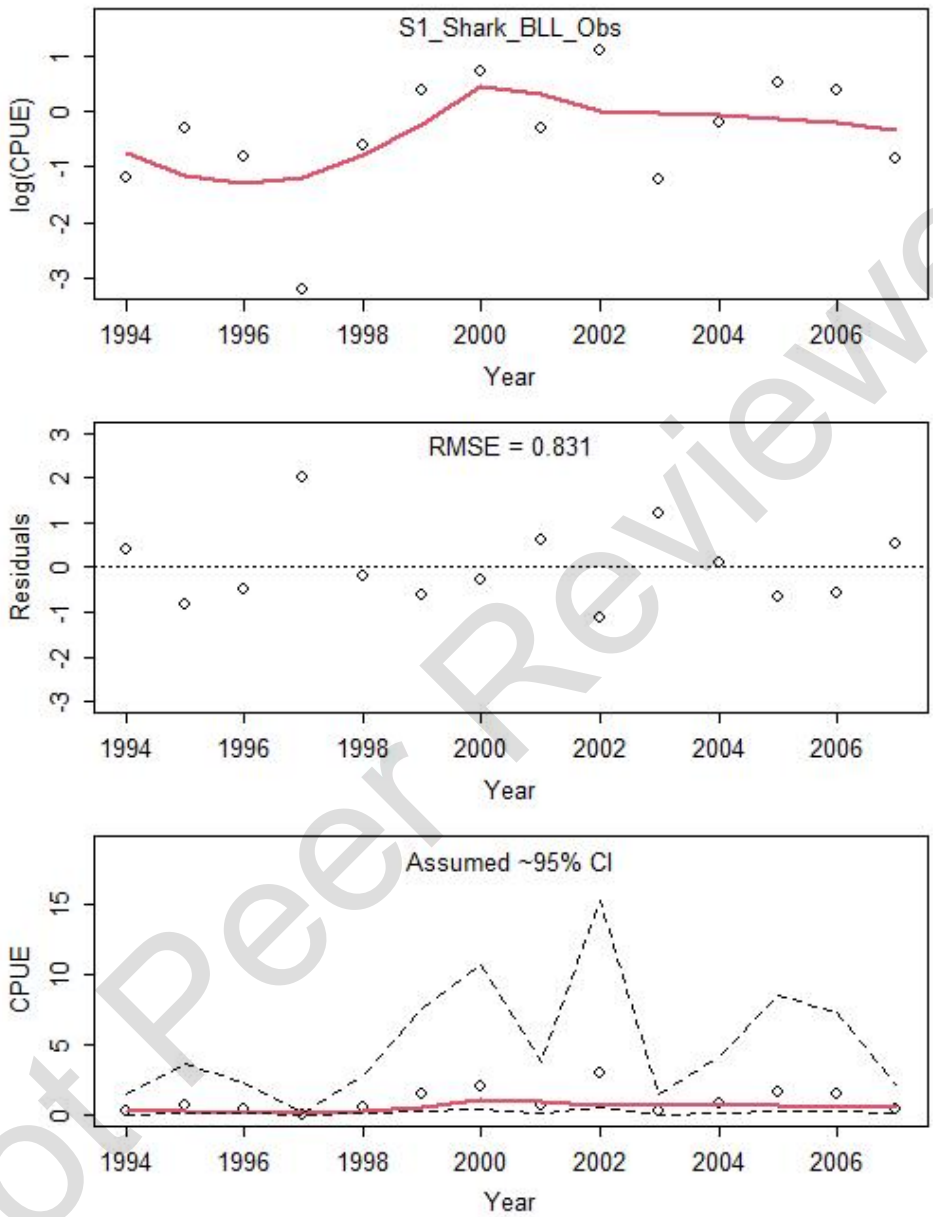

Figure 3.A.1. LOESS smoother fits used to estimate the RMSEsmoother for each CPUE series; Upper panel: Smoother fits to log (CPUE) data; Middle panel: Residual plots and estimated RMSE for each CPUE series; Lower panel: LOESS smoother fits illustrated for CPUE indices along with approximate 95% confidence intervals after applying the variance adjustment.

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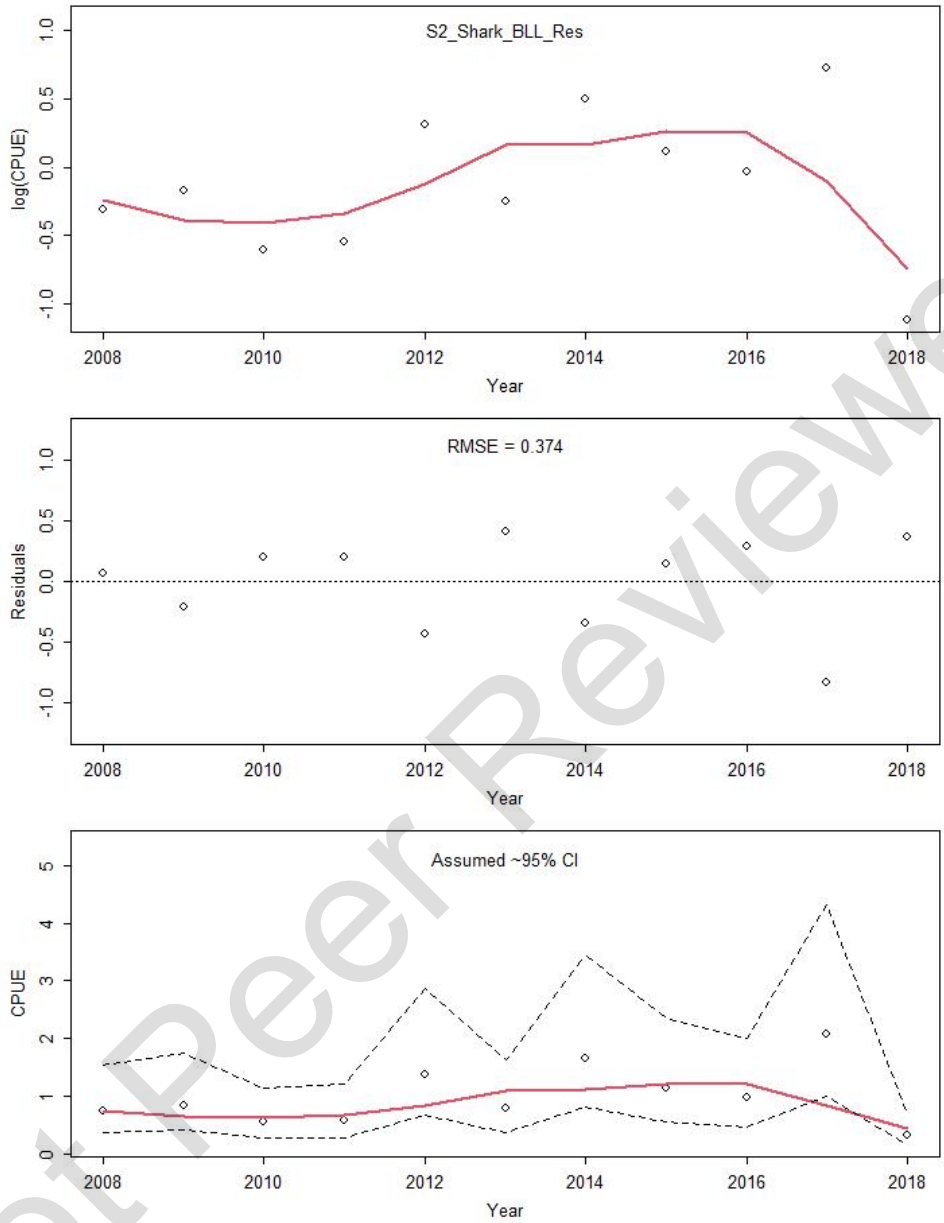

Figure 3.A.1. Continued.

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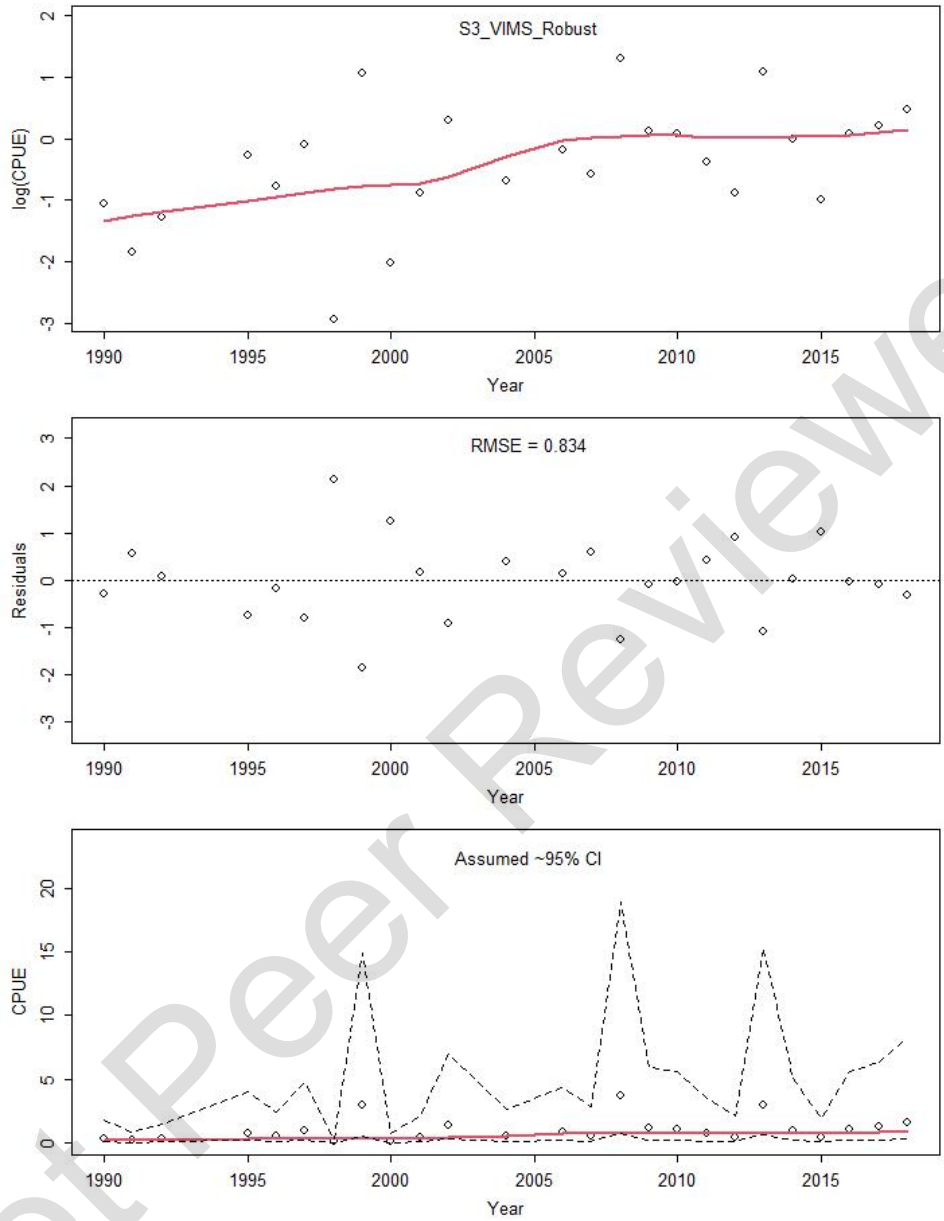

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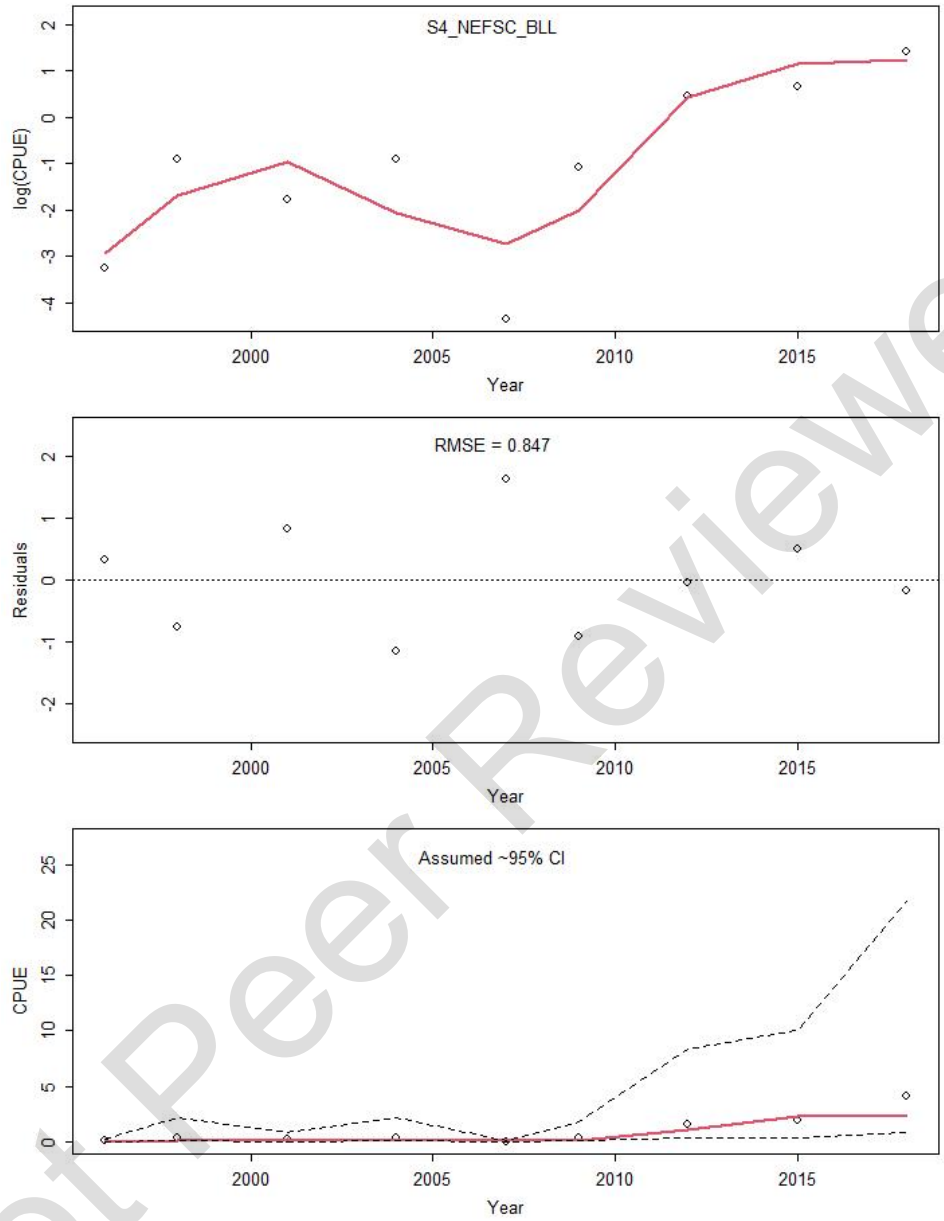

Figure 3.A.1. Continued.

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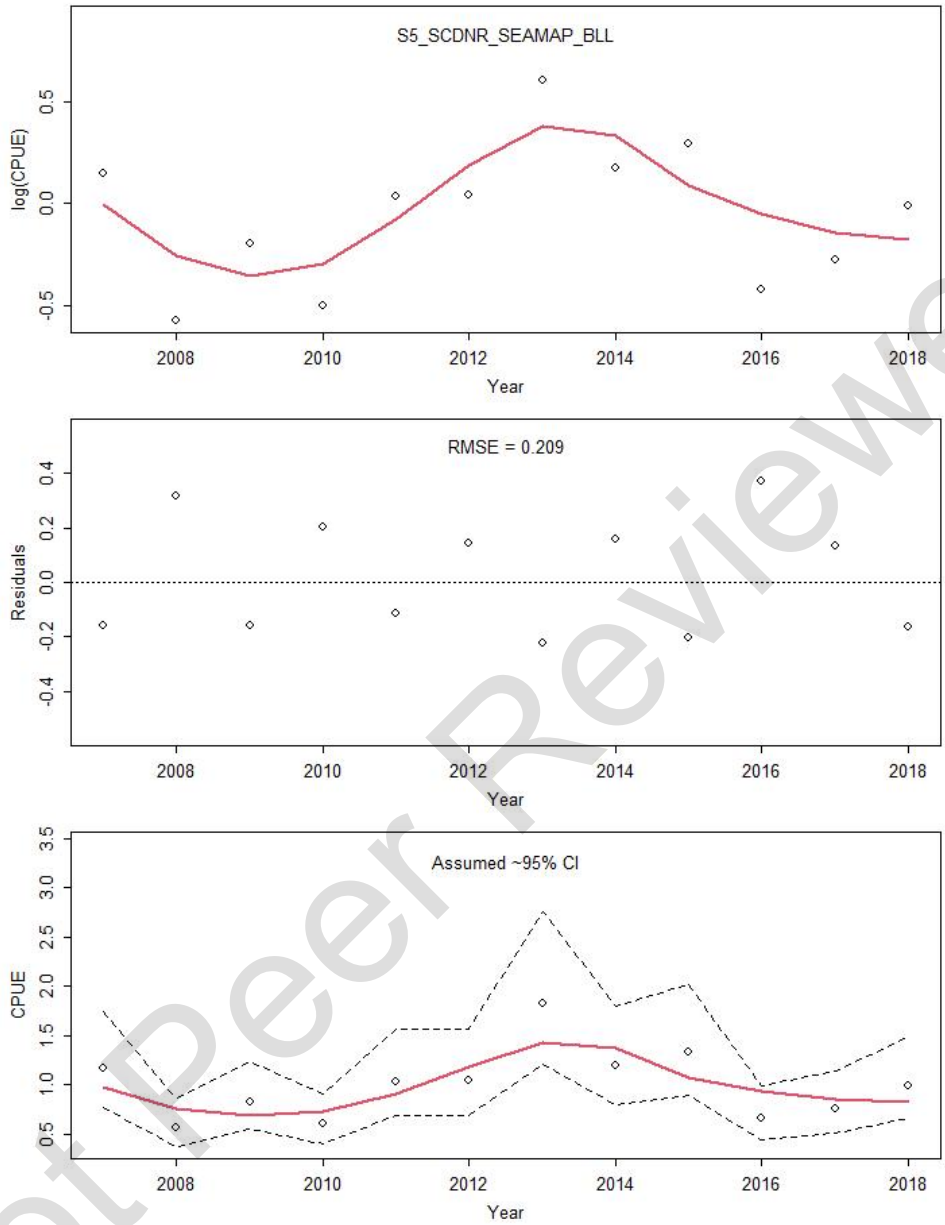

Figure 3.A.1. Continued.

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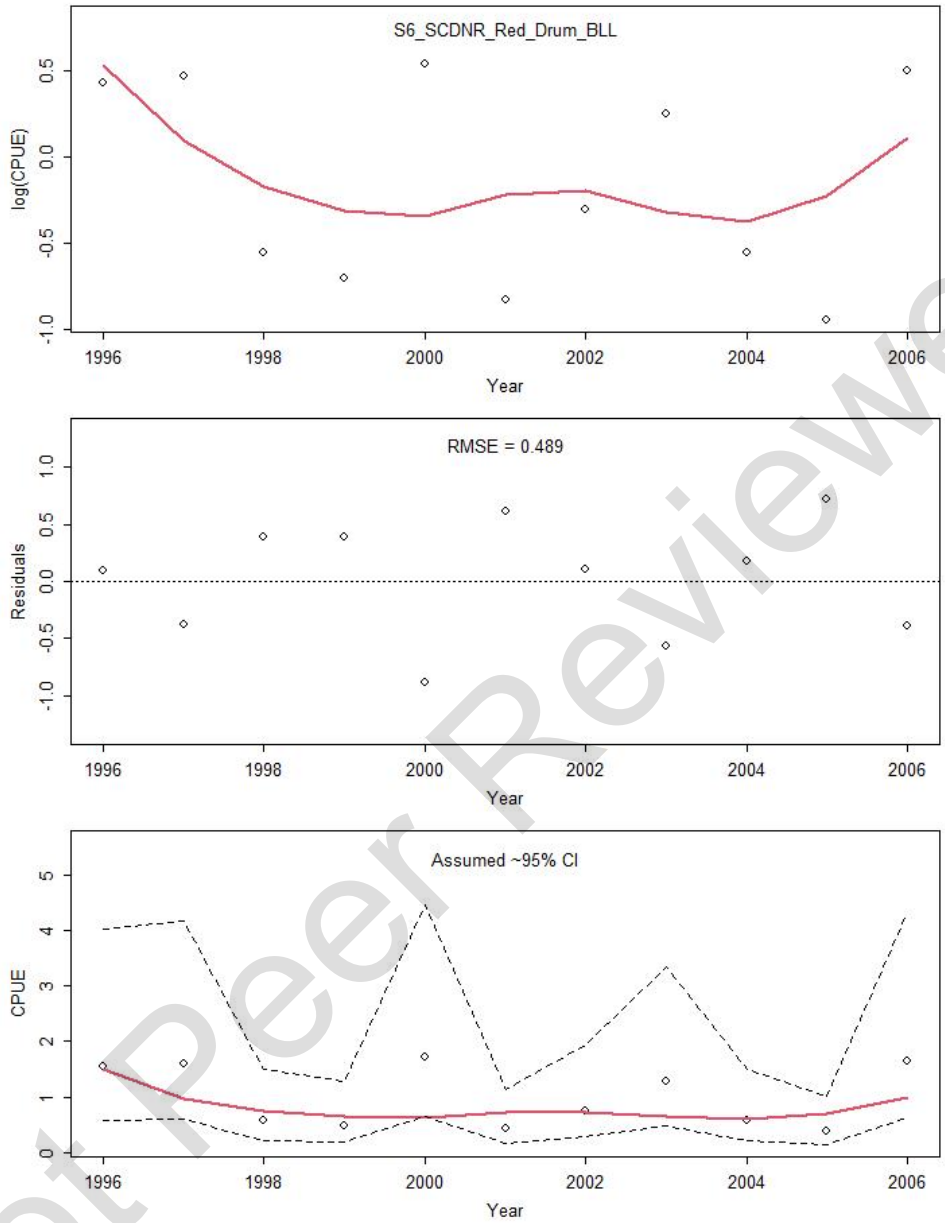

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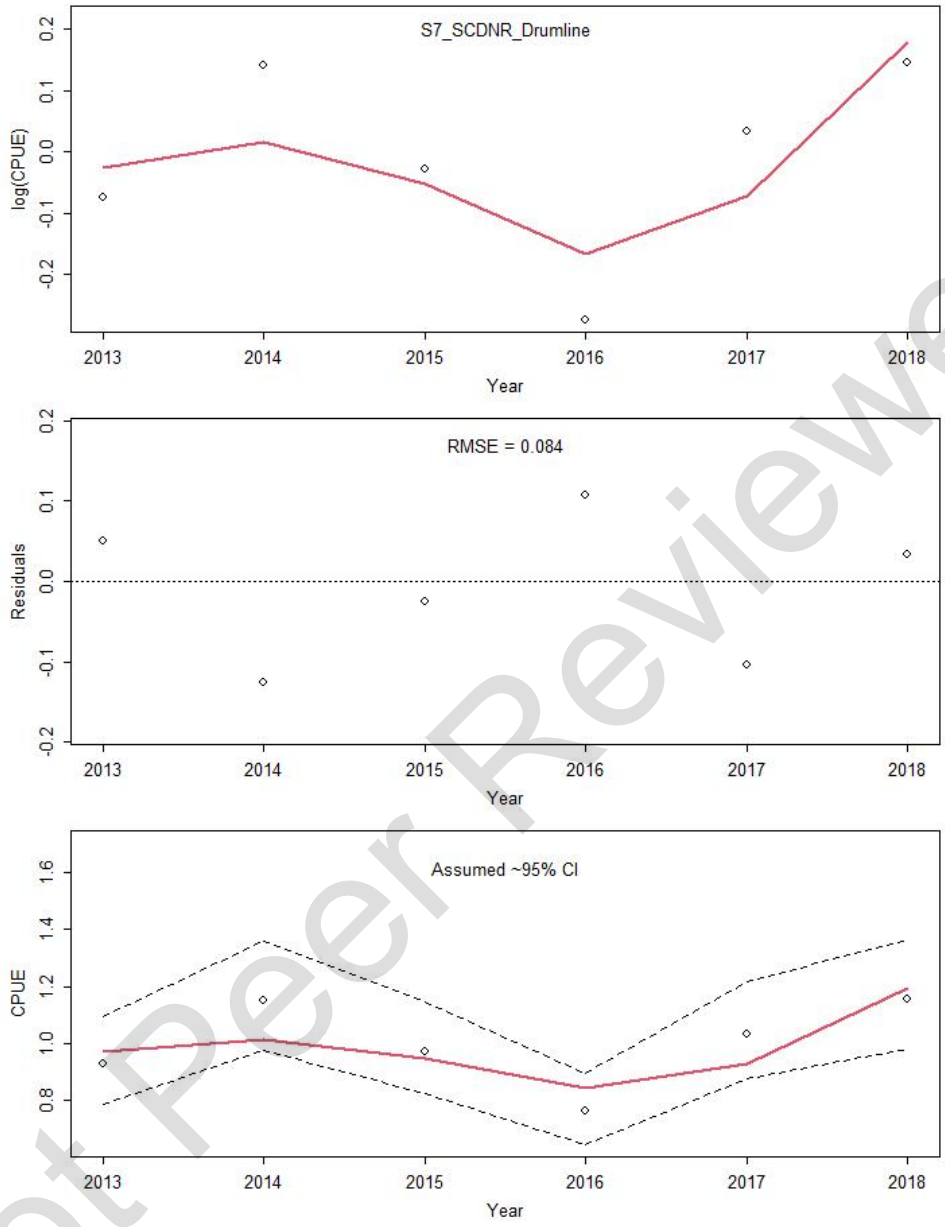

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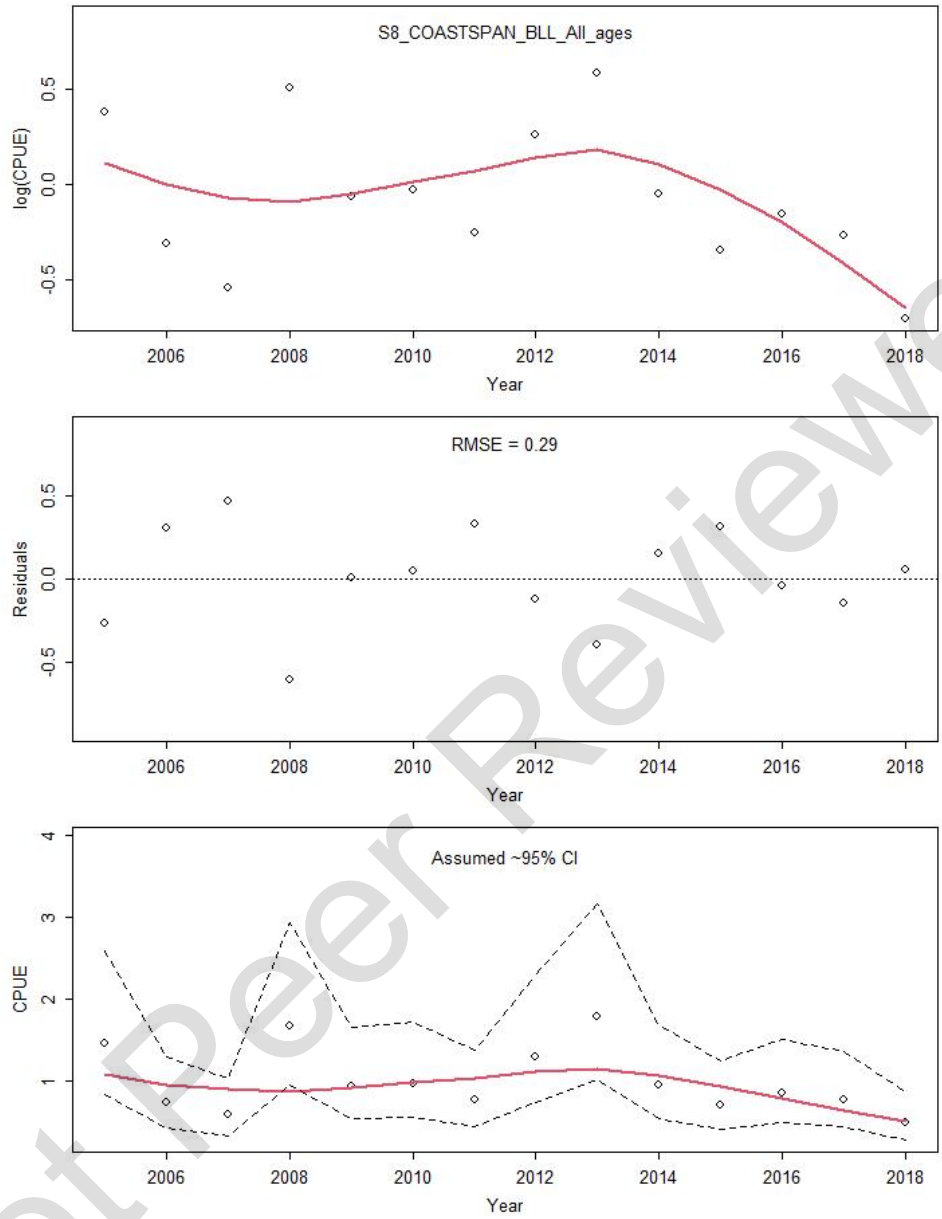

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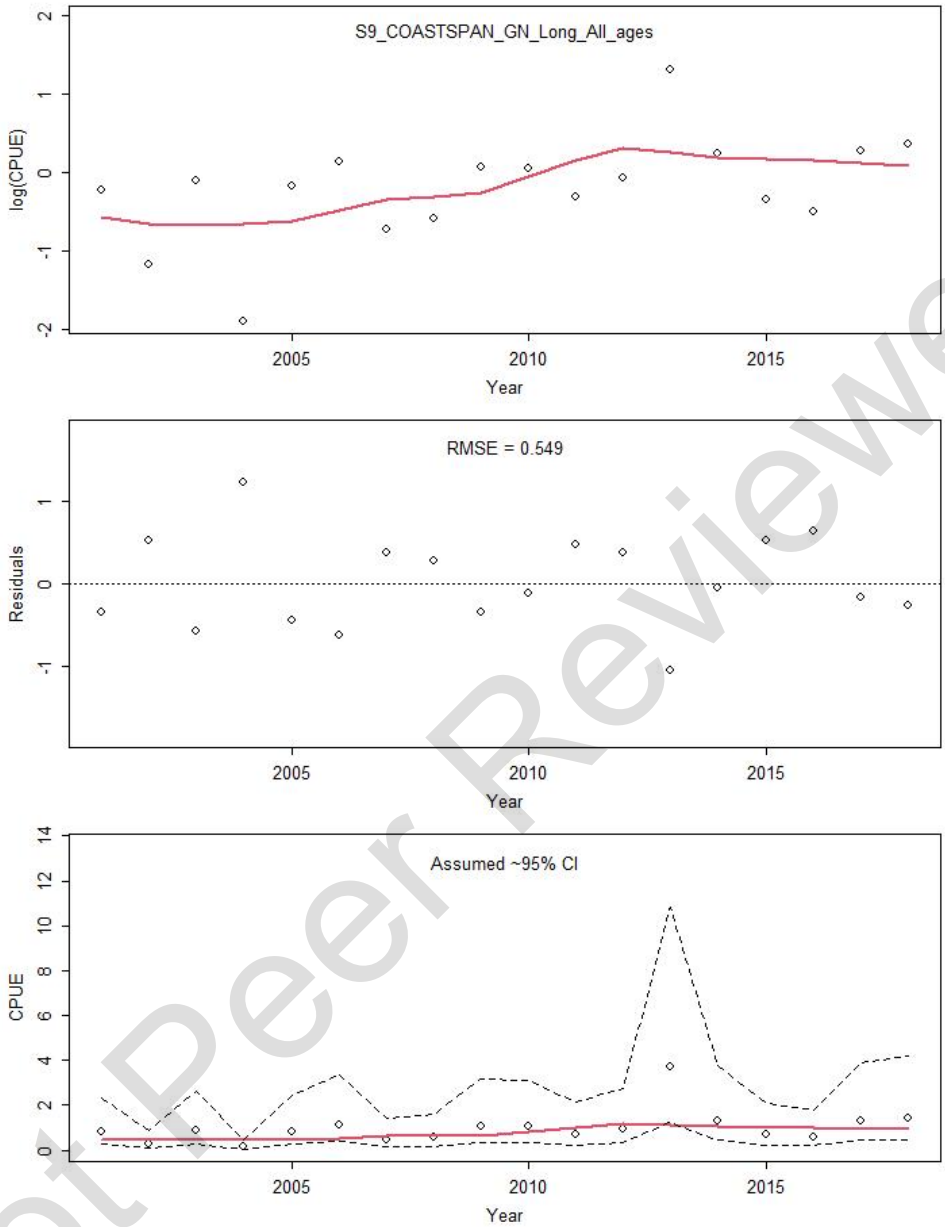

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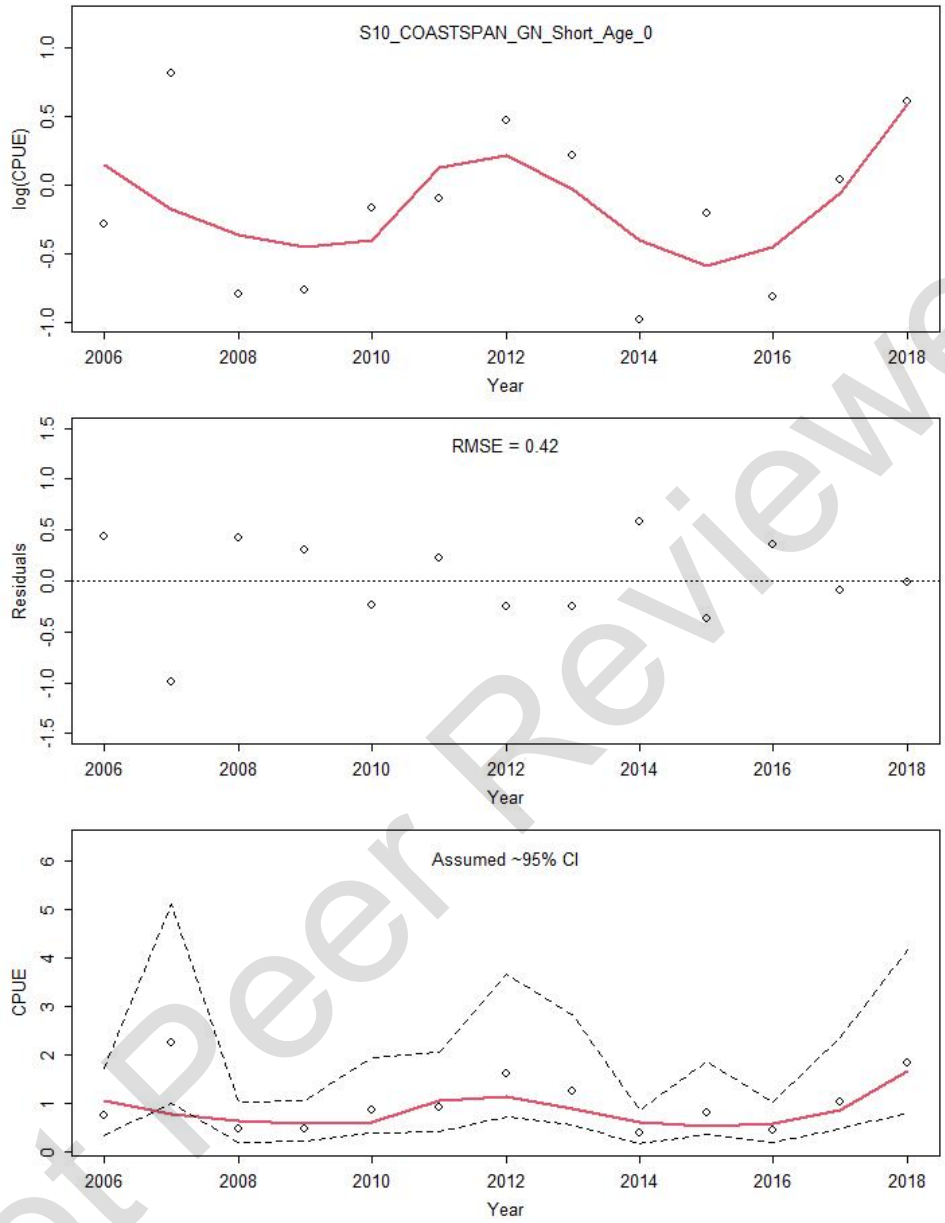

Figure 3.A.1. Continued.

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Appendix 3.B. Logistic Sensitivity Analysis.

Table 3.B.1. Selectivity functions and number of estimated parameters in the logistic model sensitivity analysis.

Fleet	Fleet name	Proposed selectivity pattern	Implemented selectivity pattern	Sex	Number of parameters	Sub-total
1	F1 (Com-BLL-Kept)	Logistic	Logistic	Sex specific	10 Selectivity[1]	10
2	F2 (Com-GN-Kept)	Logistic	Logistic	Combined sex	4 Selectivity[2]	4
3	F3 (Com-Other-Kept)	Mirror Fleet 1	Mirror Fleet 1	Combined sex	NA	
4	F4 (Recreational)	Double Normal	Double Normal	Combined sex	5 Selectivity[3]	5
5	S1 (Shark-BLL-Obs)	Mirror Fleet 1	Mirror Fleet 1	Combined sex	3 Catchability[4]	3
6	S2 (Shark-BLL-Res)	Mirror Fleet 1	Mirror Fleet 1	Combined sex	2 Catchability[5]	2
7	S3 (VIMS-BLL-Robust)	Double Normal	Double Normal	Sex specific	3 Selectivity	3
8	S4 (NEFSC-BLL)	Logistic	Logistic	Sex specific	3 Selectivity	3
9	S5 (SCDNR-SEAMAP-BLL)	Double Normal	Double Normal	Sex specific	4 Selectivity	4
10	S6 (SCDNR-Red-Drum-BLL)	Double Normal	Double Normal	Sex specific	4 Selectivity	4
11	S7 (SCDNR-DL)	Logistic	Logistic	Sex specific	4 Selectivity	4
12	S8 (COASTSPAN-BLL-All-ages)	Double Normal	Double Normal	Sex specific	3 Selectivity	3
13	S9 (COASTSPAN-GNL-All-ages)	Double Normal	Double Normal	Sex specific	3 Selectivity	3
14	S10 (COASTSPAN-GNS-Age-0)	Double Normal	Double Normal	Sex specific	2 Selectivity	2
					Total (Selectivity; Catchability)	50
	Other Estimated Parameters					
	ln(R_0)					1
	CV (Length at Age-0)				2 (male and female)	2
	CV (Length at Age-Linf)				2 (male and female)	2
	Recruitment deviations				1984-2018	35
					Grand Total	90

[1] Time blocks in selectivity for F1 (1981 – 1996, 1997 – 2004, 2005 – 2007, 2008 – 2017, 2018).
[2] Time blocks in selectivity for F2 (1981 – 2006, 2007 – 2018).
[3] Time blocks in selectivity for F4 (1981 – 1989, 1990 – 1999, 2000 – 2018).
[4] Time blocks in catchability for S1 (1981 – 1996, 1997 – 2004, 2005 – 2007).
[5] Time blocks in catchability for S2 (2008 – 2017, 2018).

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Table 3.B.2. Two stage data weighting used in the logistic model sensitivity analysis. The stage-1 CPUE (survey) variance adjustments (**Appendix 3.A**) are provided along with the mean of input CV and the resulting mean of adjusted input CV obtained after adding the variance adjustment (**Panel A**). The stage-2 length composition Effn adjustments are provided along with the mean input sample size (n) and the resulting mean of the adjusted input sample size, n, obtained after multiplying by the Effn adjustment (**Panel B**).

Panel A

Survey	Mean of input CV	Variance adjustment	Mean of adjusted input CV
S1 (Shark-BLL-Obs)	0.5300	0.3010	0.8310
S2 (Shark-BLL-Res)	0.3736	0.0004	0.3740
S3 (VIMS-BLL-Robust)	0.6417	0.1923	0.8340
S4 (NEFSC-BLL)	0.6704	0.1766	0.8470
S5 (SCDNR-SEAMAP-BLL)	0.2826	0.0000	0.2826
S6 (SCDNR-Red-Drum-BLL)	0.7120	0.0000	0.7120
S7 (SCDNR-DL)	0.1830	0.0000	0.1830
S8 (COASTSPAN-BLL-All-ages)	0.3031	0.0000	0.3031
S9 (COASTSPAN-GNL-All-ages)	0.4588	0.0902	0.5490
S10 (COASTSPAN-GNS-Age-0)	0.5637	0.0000	0.5637

Panel B

Length composition data source	Mean of input n	Adjustment method	Sample size adjustment	Mean of adjusted input n
F1 (Com-BLL-Kept)	223.8	Francis	0.081	18.0
F2 (Com-GN-Kept)	156.9	Harmonic mean	0.175	27.5
F4 (Recreational)	37.3	Francis	0.170	6.3
S3 (VIMS-BLL-Robust)	43.0	Harmonic mean	0.669	28.8
S4 (NEFSC-BLL)	137.8	Harmonic mean	0.281	38.7
S5 (SCDNR-SEAMAP-BLL)	82.8	Francis	0.166	13.7
S6 (SCDNR-Red-Drum-BLL)	45.8	Harmonic mean	0.313	14.3
S7 (SCDNR-DL)	51.0	Harmonic mean	0.789	40.3
S8 (COASTSPAN-BLL-All-ages)	47.0	Harmonic mean	0.275	12.9
S9 (COASTSPAN-GNL-All-ages)	51.6	Harmonic mean	0.444	22.9
S10 (COASTSPAN-GNS-Age-0)	42.5	Harmonic mean	0.385	16.4

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Table 3.B.3. Catchability, *q*, estimated for index S1 with time blocks (1981 – 1996, 1997 – 2004, 2005 – 2007) and for index S2 with time blocks (2008 – 2017, 2018), along with the median unbiased analytical solution for *q* calculated in Stock Synthesis for the remaining indices S3 – S10.

Label	ln(*q*)	*q*
Base years		
S1 (Shark-BLL-Obs; 1997 – 2004)	-1.7357	0.1763
S2 (Shark-BLL-Res; 2008 – 2017)	-1.02259	0.3597
S3 (VIMS-BLL-Robust; 1990 – 2018)	-9.4129	0.0001
S4 (NEFSC-BLL; 1996 – 2018)	-6.91941	0.0010
S5 (SCDNR-SEAMAP-BLL; 2007 – 2018)	-6.94236	0.0010
S6 (SCDNR-Red-Drum-BLL; 1996 – 2006)	-7.31933	0.0007
S7 (SCDNR-DL; 2013 – 2018)	-7.03282	0.0009
S8 (COASTSPAN-BLL-All-ages; 2005 – 2018)	-4.99825	0.0067
S9 (COASTSPAN-GNL-All-ages; 2001 – 2018)	-5.92893	0.0027
S10 (COASTSPAN-GNS-Age-0; 2006 – 2018)	-5.77026	0.0031
Time blocks		
S1 (Shark-BLL-Obs; 1981 – 1996)	-2.98926	0.0503
S1 (Shark-BLL-Obs; 2005 – 2007)	-1.96116	0.1407
S2 (Shark-BLL-Res; 2018)	-1.33987	0.2619

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Table 3.B.4. Logistic sensitivity analysis parameters. Parameters with a negative phase were fixed at their initial value. CV is calculated as the asymptotic standard error (Parm_StDev) divided by the estimated value (Value).

Label	Value	Active_Cnt	Phase	Min	Max	Init	Parm_StDev	Pr_type	Prior	Pr_SD	CV
L_at_Amin_Fem_GP_1	56.40	_	-3	5.00	100.00	56.40	_	Normal	56.40	1000	NA
L_at_Amax_Fem_GP_1	166.23	_	-4	50.00	600.00	166.23	_	Normal	166.23	1000	NA
VonBert_K_Fem_GP_1	0.16	_	-5	0.01	0.65	0.16	_	Normal	0.06	0.2	NA
CV_young_Fem_GP_1	0.10	1	2	0.01	0.30	0.10	0.006	Normal	0.09	0.01	6%
CV_old_Fem_GP_1	0.05	2	3	0.01	0.30	0.05	0.008	Normal	0.09	0.01	16%
Wtlen_1_Fem_GP_1	0.00	_	-3	-3.00	3.00	0.00	_	Normal	0.00	0.8	NA
Wtlen_2_Fem_GP_1	3.22	_	-3	-3.00	5.00	3.22	_	Normal	3.22	0.8	NA
L_at_Amin_Mal_GP_1	52.84	_	-3	5.00	100.00	52.84	_	Normal	52.84	1000	NA
L_at_Amax_Mal_GP_1	145.03	_	-4	50.00	600.00	145.03	_	Normal	145.03	1000	NA
VonBert_K_Mal_GP_1	0.23	_	-5	0.01	0.65	0.23	_	Normal	0.23	0.2	NA
CV_young_Mal_GP_1	0.11	3	2	0.01	0.30	0.11	0.007	Normal	0.10	0.01	6%
CV_old_Mal_GP_1	0.06	4	3	0.01	0.30	0.06	0.006	Normal	0.08	0.01	11%
Wtlen_1_Mal_GP_1	0.00	_	-3	-3.00	3.00	0.00	_	Normal	0.00	0.8	NA
Wtlen_2_Mal_GP_1	3.22	_	-3	-3.00	5.00	3.22	_	Normal	3.22	0.8	NA
FracFemale_GP_1	0.50	_	-99	0.00	1.00	0.50	_	No_prior			NA
SR_LN(R0)	6.67	5	1	2.30	13.82	6.73	0.188	Normal	7.04	1000	3%
SR_BH_steep	0.40	_	-2	0.20	0.99	0.40	_	Normal	0.40	1000	NA
SR_sigmaR	0.28	_	-4	0.20	1.90	0.28	_	Normal	0.28	1000	NA
Early_RecrDev_1984	-0.21	6	4	-10.00	10.00	0.00	0.250	dev			
Early_RecrDev_1985	-0.31	7	4	-10.00	10.00	0.00	0.240	dev			
Early_RecrDev_1986	-0.16	8	4	-10.00	10.00	0.00	0.239	dev			
Early_RecrDev_1987	-0.06	9	4	-10.00	10.00	0.00	0.235	dev			
Early_RecrDev_1988	-0.21	10	4	-10.00	10.00	0.00	0.242	dev			
Early_RecrDev_1989	-0.15	11	4	-10.00	10.00	0.00	0.242	dev			
Early_RecrDev_1990	-0.15	12	4	-10.00	10.00	0.00	0.248	dev			
Early_RecrDev_1991	-0.07	13	4	-10.00	10.00	0.00	0.240	dev			
Early_RecrDev_1992	-0.02	14	4	-10.00	10.00	0.00	0.249	dev			
Early_RecrDev_1993	0.24	15	4	-10.00	10.00	0.00	0.257	dev			
Main_RecrDev_1994	0.19	16	3	-10.00	10.00	0.00	0.263	dev			
Main_RecrDev_1995	0.18	17	3	-10.00	10.00	0.00	0.251	dev			
Main_RecrDev_1996	-0.20	18	3	-10.00	10.00	0.00	0.248	dev			
Main_RecrDev_1997	-0.26	19	3	-10.00	10.00	0.00	0.240	dev			
Main_RecrDev_1998	-0.27	20	3	-10.00	10.00	0.00	0.238	dev			
Main_RecrDev_1999	-0.30	21	3	-10.00	10.00	0.00	0.229	dev			

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Table 3.B.4. Continued.

Label	Value	Active	Cnt	Phase	Min	Max	Init	Parm	StDev	Pr type	Prior	Pr SD	CV
Main_RecrDev_2000	-0.41		22	3	-10.00	10.00	0.00		0.225	dev			
Main_RecrDev_2001	-0.44		23	3	-10.00	10.00	0.00		0.195	dev			
Main_RecrDev_2002	-0.28		24	3	-10.00	10.00	0.00		0.188	dev			
Main_RecrDev_2003	-0.13		25	3	-10.00	10.00	0.00		0.185	dev			
Main_RecrDev_2004	0.26		26	3	-10.00	10.00	0.00		0.206	dev			
Main_RecrDev_2005	0.20		27	3	-10.00	10.00	0.00		0.172	dev			
Main_RecrDev_2006	-0.02		28	3	-10.00	10.00	0.00		0.174	dev			
Main_RecrDev_2007	0.16		29	3	-10.00	10.00	0.00		0.172	dev			
Main_RecrDev_2008	0.33		30	3	-10.00	10.00	0.00		0.174	dev			
Main_RecrDev_2009	0.30		31	3	-10.00	10.00	0.00		0.175	dev			
Main_RecrDev_2010	0.21		32	3	-10.00	10.00	0.00		0.166	dev			
Main_RecrDev_2011	0.21		33	3	-10.00	10.00	0.00		0.167	dev			
Main_RecrDev_2012	0.43		34	3	-10.00	10.00	0.00		0.144	dev			
Main_RecrDev_2013	0.52		35	3	-10.00	10.00	0.00		0.133	dev			
Main_RecrDev_2014	-0.16		36	3	-10.00	10.00	0.00		0.175	dev			
Main_RecrDev_2015	-0.23		37	3	-10.00	10.00	0.00		0.165	dev			
Main_RecrDev_2016	-0.28		38	3	-10.00	10.00	0.00		0.163	dev			
Main_RecrDev_2017	0.00		39	3	-10.00	10.00	0.00		0.157	dev			
Late_RecrDev_2018	0.02		40	6	-10.00	10.00	0.00		0.161	dev			
ForeRecr_2019[1]	0		41	6	-10	10	0		0.283103	dev			
LnQ_base_S1_Shark_BLL_Obs(5)	-1.74		42	1	-25.00	25.00	0.00		0.415	Sym_Beta	0.00	0.05	24%
LnQ_base_S2_Shark_BLL_Res(6)	-1.02		43	1	-25.00	25.00	-1.12		0.414	Sym_Beta	0.00	0.05	41%
LnQ_base_S3_VIMS_Robust(7)	-9.41	_		-1	-25.00	25.00	-9.52	_		No_prior			NA
LnQ_base_S4_NEFSC_BLL(8)	-6.92	_		-1	-25.00	25.00	-6.99	_		No_prior			NA
LnQ_base_S5_SCDNR_SEAMAP_BLL(9)	-6.94	_		-1	-25.00	25.00	-6.94	_		No_prior			NA
LnQ_base_S6_SCDNR_Red_Drum_BLL(10)	-7.32	_		-1	-25.00	25.00	-7.04	_		No_prior			NA
LnQ_base_S7_SCDNR_Drumline(11)	-7.03	_		-1	-25.00	25.00	-7.25	_		No_prior			NA
LnQ_base_S8_COASTSPAN_BLL_All_ages(12)	-5.00	_		-1	-25.00	25.00	-5.09	_		No_prior			NA
LnQ_base_S9_COASTSPAN_GN_Long_All_ages(13)	-5.93	_		-1	-25.00	25.00	-6.13	_		No_prior			NA
LnQ_base_S10_COASTSPAN_GN_Short_Age_0(14)	-5.77	_		-1	-25.00	25.00	-5.95	_		No_prior			NA
LnQ_base_S1_Shark_BLL_Obs(5)_BLK3repl_1981	-2.99		44	1	-25.00	25.00	-3.09		0.611	Sym_Beta	0.00	0.05	20%
LnQ_base_S1_Shark_BLL_Obs(5)_BLK3repl_2005	-1.96		45	1	-25.00	25.00	-2.09		0.622	Sym_Beta	0.00	0.05	32%
LnQ_base_S2_Shark_BLL_Res(6)_BLK4repl_2018[2]	-1.34		46	1	-25.00	25.00	-1.55		0.845	Sym_Beta	0.00	0.05	63%
Size_inflection_F1_Com_BLL_Kept(1)	127.23		47	2	5.00	150.00	127.46		3.732	Sym_Beta	105.00	0.05	3%
Size_95%width_F1_Com_BLL_Kept(1)	31.19		48	3	0.01	60.00	31.28		2.995	Sym_Beta	10.00	0.05	10%
SzSel_Male_Infl_F1_Com_BLL_Kept(1)	-8.66		49	4	-50.00	50.00	-8.72		2.001	Normal	0.00	1000	23%
SzSel_Male_Slope_F1_Com_BLL_Kept(1)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Scale_F1_Com_BLL_Kept(1)	1.00	_		-5	-15.00	15.00	1.00	_		Normal	1.00	1000	NA
Size_inflection_F2_Com_GN_Kept(2)	62.63		50	2	5.00	150.00	68.94		5.193	Sym_Beta	102.36	0.05	8%
Size_95%width_F2_Com_GN_Kept(2)[2]	8.50		51	3	0.01	60.00	8.08		7.418	Sym_Beta	23.05	0.05	87%

[1]Forecast recruitment deviation (year 2019) not included in the number of estimated parameters.
[2] CV > 0.5.

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Table 3.B.4. Continued.

Label	Value	Active	Cnt	Phase	Min	Max	Init	Parm	StDev	Pr type	Prior	Pr SD	CV
Size_DblN_peak_F4_Rec_A_B1_B2PRM(4)	50.20		52	2	47.50	162.50	64.90		10.112	Sym_Beta	64.90	0.05	20%
Size_DblN_top_logit_F4_Rec_A_B1_B2PRM(4)[2]	-3.53		53	3	-6.00	4.00	-6.00		2.571	Sym_Beta	-6.00	0.05	73%
Size_DblN_ascend_se_F4_Rec_A_B1_B2PRM(4)	7.00	_		-3	-1.00	9.00	7.00	_		Sym_Beta	7.00	0.05	NA
Size_DblN_descend_se_F4_Rec_A_B1_B2PRM(4)	7.20	_		-3	-1.00	9.00	7.20	_		Sym_Beta	7.20	0.05	NA
Size_DblN_start_logit_F4_Rec_A_B1_B2PRM(4)	-1.10	_		-2	-15.00	9.00	-1.10	_		Sym_Beta	0.00	0.05	NA
Size_DblN_end_logit_F4_Rec_A_B1_B2PRM(4)	-1.20	_		-2	-15.00	9.00	-1.20	_		Sym_Beta	-15.00	0.05	NA
Size_inflection_S3_VIMS_Robust(7)	87.43		54	2	5.00	150.00	89.75		1.988	Sym_Beta	89.75	0.05	2%
Size_95%width_S3_VIMS_Robust(7)	6.23		55	3	0.01	60.00	4.23		2.211	Sym_Beta	4.23	0.05	35%
SzSel_Fem_Infl_S3_VIMS_Robust(7)	0.00	_		-4	-50.00	50.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Slope_S3_VIMS_Robust(7)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Scale_S3_VIMS_Robust(7)	0.79		56	5	-15.00	15.00	0.10		0.209	Normal	1.00	1000	27%
Size_inflection_S4_NEFSC_BLL(8)	131.95		57	2	5.00	150.00	132.41		3.355	Sym_Beta	117.49	0.05	3%
Size_95%width_S4_NEFSC_BLL(8)	19.86		58	3	0.01	60.00	20.11		2.781	Sym_Beta	4.99	0.05	14%
SzSel_Fem_Infl_S4_NEFSC_BLL(8)	0.00	_		-4	-50.00	50.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Slope_S4_NEFSC_BLL(8)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Scale_S4_NEFSC_BLL(8)	0.06		59	5	-15.00	15.00	0.10		0.014	Normal	1.00	1000	26%
Size_DblN_peak_S5_SCDNR_SEAMAP_BLL(9)	56.62		60	2	47.50	162.50	51.90		5.105	Sym_Beta	55.30	0.05	9%
Size_DblN_top_logit_S5_SCDNR_SEAMAP_BLL(9)[2]	-1.88		61	3	-6.00	4.00	-4.40		0.960	Sym_Beta	-6.00	0.05	51%
Size_DblN_ascend_se_S5_SCDNR_SEAMAP_BLL(9)	6.30	_		-3	-1.00	9.00	6.30	_		Sym_Beta	3.20	0.05	NA
Size_DblN_descend_se_S5_SCDNR_SEAMAP_BLL(9)	7.38		62	3	-1.00	9.00	8.70		0.866	Sym_Beta	7.20	0.05	12%
Size_DblN_start_logit_S5_SCDNR_SEAMAP_BLL(9)	-1.20	_		-2	-15.00	9.00	-1.20	_		Sym_Beta	0.00	0.05	NA
Size_DblN_end_logit_S5_SCDNR_SEAMAP_BLL(9)	-1.10	_		-2	-15.00	9.00	-1.10	_		Sym_Beta	-15.00	0.05	NA
SzSel_Male_Peak_S5_SCDNR_SEAMAP_BLL(9)	0.00	_		-4	-50.00	50.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Ascend_S5_SCDNR_SEAMAP_BLL(9)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Descend_S5_SCDNR_SEAMAP_BLL(9)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Final_S5_SCDNR_SEAMAP_BLL(9)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Male_Scale_S5_SCDNR_SEAMAP_BLL(9)	0.76		63	5	-15.00	15.00	0.74		0.130	Normal	1.00	1000	17%
Size_DblN_peak_S6_SCDNR_Red_Drum_BLL(10)	61.75		64	2	47.50	162.50	54.40		5.931	Sym_Beta	57.70	0.05	10%
Size_DblN_top_logit_S6_SCDNR_Red_Drum_BLL(10)	-0.92		65	3	-6.00	4.00	-4.70		0.803	Sym_Beta	-6.00	0.05	88%
Size_DblN_ascend_se_S6_SCDNR_Red_Drum_BLL(10)	6.30	_		-3	-1.00	9.00	6.30	_		Sym_Beta	3.30	0.05	NA
Size_DblN_descend_se_S6_SCDNR_Red_Drum_BLL(10)	5.56		66	3	-1.00	9.00	8.10		2.238	Sym_Beta	7.20	0.05	40%
Size_DblN_start_logit_S6_SCDNR_Red_Drum_BLL(10)	-1.20	_		-2	-15.00	9.00	-1.20	_		Sym_Beta	0.00	0.05	NA
Size_DblN_end_logit_S6_SCDNR_Red_Drum_BLL(10)	-1.10	_		-2	-15.00	9.00	-1.10	_		Sym_Beta	-15.00	0.05	NA
SzSel_Fem_Peak_S6_SCDNR_Red_Drum_BLL(10)	0.00	_		-4	-50.00	50.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Ascend_S6_SCDNR_Red_Drum_BLL(10)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Descend_S6_SCDNR_Red_Drum_BLL(10)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Final_S6_SCDNR_Red_Drum_BLL(10)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Scale_S6_SCDNR_Red_Drum_BLL(10)	0.77		67	5	-15.00	15.00	0.68		0.213	Normal	1.00	1000	27%
Size_inflection_S7_SCDNR_Drumline(11)	129.81		68	2	5.00	150.00	126.96		2.515	Sym_Beta	115.00	0.05	2%
Size_95%width_S7_SCDNR_Drumline(11)	17.92		69	3	0.01	60.00	12.53		2.078	Sym_Beta	8.00	0.05	12%
SzSel_Fem_Infl_S7_SCDNR_Drumline(11)	-6.18		70	4	-50.00	50.00	-0.60		3.046	Normal	0.00	1000	49%
SzSel_Fem_Slope_S7_SCDNR_Drumline(11)	0.00	_		-4	-15.00	15.00	0.00	_		Normal	0.00	1000	NA
SzSel_Fem_Scale_S7_SCDNR_Drumline(11)	0.54		71	5	-15.00	15.00	0.70		0.121	Normal	1.00	1000	22%

[2] CV > 0.5.

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Table 3.B.4. Continued.

Label	Value	Active	Cnt	Phase	Min	Max	Init	Parm_StDev	Pr_type	Prior	Pr_SD	CV
Size_DblN_peak_S8_COASTSPAN_BLL_All_ages(12)	47.50	_		-2	47.50	60.00	47.50	_	Sym_Beta	51.30	0.05	NA
Size_DblN_top_logit_S8_COASTSPAN_BLL_All_ages(12)	-6.00	_		-3	-6.00	4.00	-6.00	_	Sym_Beta	-6.00	0.05	NA
Size_DblN_ascend_se_S8_COASTSPAN_BLL_All_ages(12)	6.30	_		-3	-1.00	9.00	6.30	_	Sym_Beta	2.90	0.05	NA
Size_DblN_descend_se_S8_COASTSPAN_BLL_All_ages(12)	3.10		72	3	-1.00	9.00	3.10	0.217	Sym_Beta	-0.30	0.05	7%
Size_DblN_start_logit_S8_COASTSPAN_BLL_All_ages(12)	-1.20	_		-2	-15.00	9.00	-1.20	_	Sym_Beta	0.00	0.05	NA
Size_DblN_end_logit_S8_COASTSPAN_BLL_All_ages(12)	-5.00		73	2	-15.00	9.00	-5.30	0.523	Sym_Beta	-15.00	0.05	10%
SzSel_Male_Peak_S8_COASTSPAN_BLL_All_ages(12)	0.00	_		-4	-20.00	20.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Ascend_S8_COASTSPAN_BLL_All_ages(12)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Descend_S8_COASTSPAN_BLL_All_ages(12)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Final_S8_COASTSPAN_BLL_All_ages(12)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Scale_S8_COASTSPAN_BLL_All_ages(12)	0.66		74	5	-15.00	15.00	0.65	0.123	Normal	1.00	1000	19%
Size_DblN_peak_S9_COASTSPAN_GN_Long_All_ages(13)	47.50	_		-2	47.50	60.00	47.50	_	Sym_Beta	49.70	0.05	NA
Size_DblN_top_logit_S9_COASTSPAN_GN_Long_All_ages(13)	-6.00	_		-3	-6.00	4.00	-6.00	_	Sym_Beta	-6.00	0.05	NA
Size_DblN_ascend_se_S9_COASTSPAN_GN_Long_All_ages(13)	6.30	_		-3	-1.00	9.00	6.30	_	Sym_Beta	9.00	0.05	NA
Size_DblN_descend_se_S9_COASTSPAN_GN_Long_All_ages(13)	2.92		75	3	-1.00	9.00	3.20	0.278	Sym_Beta	2.90	0.05	10%
Size_DblN_start_logit_S9_COASTSPAN_GN_Long_All_ages(13)	-1.20	_		-2	-15.00	9.00	-1.20	_	Sym_Beta	-15.00	0.05	NA
Size_DblN_end_logit_S9_COASTSPAN_GN_Long_All_ages(13)	-3.42		76	2	-15.00	9.00	-2.90	0.326	Sym_Beta	-2.00	0.05	10%
SzSel_Male_Peak_S9_COASTSPAN_GN_Long_All_ages(13)	0.00	_		-4	-20.00	20.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Ascend_S9_COASTSPAN_GN_Long_All_ages(13)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Descend_S9_COASTSPAN_GN_Long_All_ages(13)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Final_S9_COASTSPAN_GN_Long_All_ages(13)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Scale_S9_COASTSPAN_GN_Long_All_ages(13)	0.87		77	5	-15.00	15.00	0.96	0.183	Normal	1.00	1000	21%
Size_DblN_peak_S10_COASTSPAN_GN_Short_Age_0(14)	47.50	_		-2	47.50	60.00	47.50	_	Sym_Beta	47.70	0.05	NA
Size_DblN_top_logit_S10_COASTSPAN_GN_Short_Age_0(14)	-6.00	_		-3	-6.00	4.00	-6.00	_	Sym_Beta	-6.00	0.05	NA
Size_DblN_ascend_se_S10_COASTSPAN_GN_Short_Age_0(14)	6.30	_		-3	-1.00	9.00	6.30	_	Sym_Beta	9.00	0.05	NA
Size_DblN_descend_se_S10_COASTSPAN_GN_Short_Age_0(14)	2.55		78	3	-1.00	9.00	2.60	0.320	Sym_Beta	3.30	0.05	13%
Size_DblN_start_logit_S10_COASTSPAN_GN_Short_Age_0(14)	-1.20	_		-2	-15.00	9.00	-1.20	_	Sym_Beta	-15.00	0.05	NA
Size_DblN_end_logit_S10_COASTSPAN_GN_Short_Age_0(14)	-15.00	_		-2	-15.00	9.00	-15.00	_	Sym_Beta	-15.00	0.05	NA
SzSel_Male_Peak_S10_COASTSPAN_GN_Short_Age_0(14)	0.00	_		-4	-20.00	20.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Ascend_S10_COASTSPAN_GN_Short_Age_0(14)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Descend_S10_COASTSPAN_GN_Short_Age_0(14)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Final_S10_COASTSPAN_GN_Short_Age_0(14)	0.00	_		-4	-15.00	15.00	0.00	_	Normal	0.00	1000	NA
SzSel_Male_Scale_S10_COASTSPAN_GN_Short_Age_0(14)	0.53		79	5	-15.00	15.00	0.57	0.191	Normal	1.00	1000	36%
Size_inflection_F1_Com_BLL_Kept(1)_BLK2repl_1981	117.73		80	4	5.00	150.00	117.15	11.356	Sym_Beta	105.00	0.05	10%
Size_inflection_F1_Com_BLL_Kept(1)_BLK2repl_1997	124.68		81	4	5.00	150.00	124.84	2.825	Sym_Beta	105.00	0.05	2%
Size_inflection_F1_Com_BLL_Kept(1)_BLK2repl_2005	107.09		82	4	5.00	150.00	106.88	6.652	Sym_Beta	105.00	0.05	6%
Size_inflection_F1_Com_BLL_Kept(1)_BLK2repl_2018	147.29		83	4	5.00	150.00	141.24	10.223	Sym_Beta	105.00	0.05	7%
Size_95%width_F1_Com_BLL_Kept(1)_BLK2repl_1981	43.17		84	4	0.01	60.00	42.42	10.240	Sym_Beta	10.00	0.05	24%
Size_95%width_F1_Com_BLL_Kept(1)_BLK2repl_1997	14.69		85	4	0.01	60.00	14.68	3.675	Sym_Beta	10.00	0.05	25%
Size_95%width_F1_Com_BLL_Kept(1)_BLK2repl_2005	23.86		86	4	0.01	60.00	24.12	7.383	Sym_Beta	10.00	0.05	31%
Size_95%width_F1_Com_BLL_Kept(1)_BLK2repl_2018	31.28	_		-4	0.01	60.00	31.28	_	Sym_Beta	10.00	0.05	NA
Size_inflection_F2_Com_GN_Kept(2)_BLK5repl_1981	120.42		87	4	5.00	150.00	121.28	5.915	Sym_Beta	102.36	0.05	5%
Size_95%width_F2_Com_GN_Kept(2)_BLK5repl_1981	45.08		88	4	0.01	60.00	46.28	4.880	Sym_Beta	23.05	0.05	11%

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Table 3.B.4. Continued.

Label	Value	Active	Cnt	Phase	Min	Max	Init	Parm_StDev	Pr_type	Prior	Pr_SD	CV
Size_DblN_peak_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1981	64.90	_		-2	47.50	162.50	64.90	_	Sym_Beta	64.90	0.05	NA
Size_DblN_peak_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1990	64.90	_		-2	47.50	162.50	64.90	_	Sym_Beta	64.90	0.05	NA
Size_DblN_descend_se_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1981	4.96		89	3	-1.00	9.00	2.90	1.121	Sym_Beta	7.20	0.05	23%
Size_DblN_descend_se_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1990	6.52		90	3	-1.00	9.00	2.90	0.868	Sym_Beta	7.20	0.05	13%
Size_DblN_start_logit_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1981	9.00	_		-2	-15.00	9.00	9.00	_	Sym_Beta	0.00	0.05	NA
Size_DblN_start_logit_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1990	-1.10	_		-2	-15.00	9.00	-1.10	_	Sym_Beta	0.00	0.05	NA
Size_DblN_end_logit_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1981	-2.10		91	2	-15.00	9.00	-1.20	0.661	Sym_Beta	-15.00	0.05	32%
Size_DblN_end_logit_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1990	-1.20	_		-2	-15.00	9.00	-1.20	_	Sym_Beta	-15.00	0.05	NA
Size_DblN_end_logit_F4_Rec_A_B1_B2PRM(4)_BLK6repl_1990	-1.20	_		-2	-15.00	9.00	-1.20	_	Sym_Beta	-15.00	0.05	NA

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Table 3.B.5. Total biomass (*B*), spawning stock fecundity (SSF), recruits (*R*), and total fishing mortality (*F*=*Z*-*M*) obtained from the logistic sensitivity analysis.

	Total biomass *B* (mt)	Female spawning stock fecundity SSF (1,000s pups)	Recruits *R* (1,000s pups)	Total fishing mortality *F*=*Z*-*M*
Virg		637	785	
Init		637	785	
1981	44181	637	785	0.024
1982	43688	634	783	0.024
1983	43128	631	782	0.023
1984	42113	624	627	0.036
1985	40578	611	565	0.036
1986	38971	595	648	0.036
1987	37440	577	705	0.020
1988	36162	561	602	0.022
1989	35134	544	630	0.017
1990	34307	527	623	0.026
1991	33506	508	663	0.038
1992	32477	478	674	0.043
1993	31944	448	851	0.051
1994	31280	420	784	0.037
1995	31527	411	768	0.045
1996	31071	398	516	0.033
1997	30744	386	480	0.056
1998	29748	378	470	0.056
1999	28456	373	450	0.067
2000	26757	370	403	0.055
2001	25250	374	393	0.058
2002	23907	376	462	0.066
2003	22663	367	529	0.067
2004	22203	347	756	0.080
2005	21880	324	686	0.066
2006	21844	305	531	0.059
2007	22186	285	618	0.051
2008	22911	271	708	0.052
2009	23499	257	667	0.047
2010	24085	250	599	0.025
2011	24989	254	602	0.017
2012	26302	268	772	0.018
2013	27775	282	873	0.024
2014	28332	292	450	0.039
2015	28487	301	426	0.037
2016	28146	315	418	0.032
2017	27818	329	566	0.021
2018	27564	341	587	0.019

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Table 3.B.6. Total annual fishing mortality ($F=Z-M$) relative to MSY (F/F_{MSY}), annual spawning stock fecundity relative to MSY (SSF/SSF_{MSY}), and annual SSF relative to MSST (SSF/MSST) obtained from the base model configuration.

Year	F/F_{MSY}	SE	SSF/SSF_{MSY}	SE	SSF/MSST
1981	0.46	0.090	2.59	NA	3.41
1982	0.47	0.093	2.58	0.011	3.39
1983	0.44	0.089	2.57	0.017	3.37
1984	0.68	0.143	2.54	0.025	3.34
1985	0.68	0.146	2.49	0.037	3.27
1986	0.69	0.151	2.42	0.050	3.18
1987	0.38	0.084	2.35	0.064	3.09
1988	0.41	0.093	2.29	0.073	3.00
1989	0.33	0.073	2.21	0.084	2.91
1990	0.50	0.115	2.15	0.093	2.82
1991	0.74	0.171	2.07	0.102	2.72
1992	0.82	0.196	1.95	0.120	2.56
1993	0.98	0.237	1.82	0.138	2.39
1994	0.70	0.177	1.71	0.155	2.25
1995	0.86	0.216	1.67	0.164	2.20
1996	0.62	0.159	1.62	0.172	2.13
1997	1.06	0.277	1.57	0.178	2.06
1998	1.08	0.288	1.54	0.182	2.02
1999	1.29	0.352	1.52	0.187	1.99
2000	1.05	0.294	1.51	0.195	1.98
2001	1.11	0.320	1.52	0.206	2.00
2002	1.26	0.372	1.53	0.217	2.01
2003	1.28	0.387	1.49	0.227	1.96
2004	1.53	0.466	1.41	0.229	1.86
2005	1.26	0.393	1.32	0.227	1.74
2006	1.13	0.363	1.24	0.221	1.63
2007	0.98	0.320	1.16	0.217	1.52
2008	1.00	0.333	1.10	0.210	1.45
2009	0.91	0.305	1.05	0.206	1.38
2010	0.47	0.160	1.02	0.206	1.34
2011	0.33	0.113	1.03	0.212	1.36
2012	0.35	0.117	1.09	0.223	1.43
2013	0.46	0.151	1.15	0.235	1.51
2014	0.75	0.252	1.19	0.244	1.56
2015	0.70	0.239	1.23	0.254	1.61
2016	0.60	0.209	1.28	0.267	1.68
2017	0.40	0.138	1.34	0.278	1.76
2018	0.37	0.125	1.39	0.286	1.83

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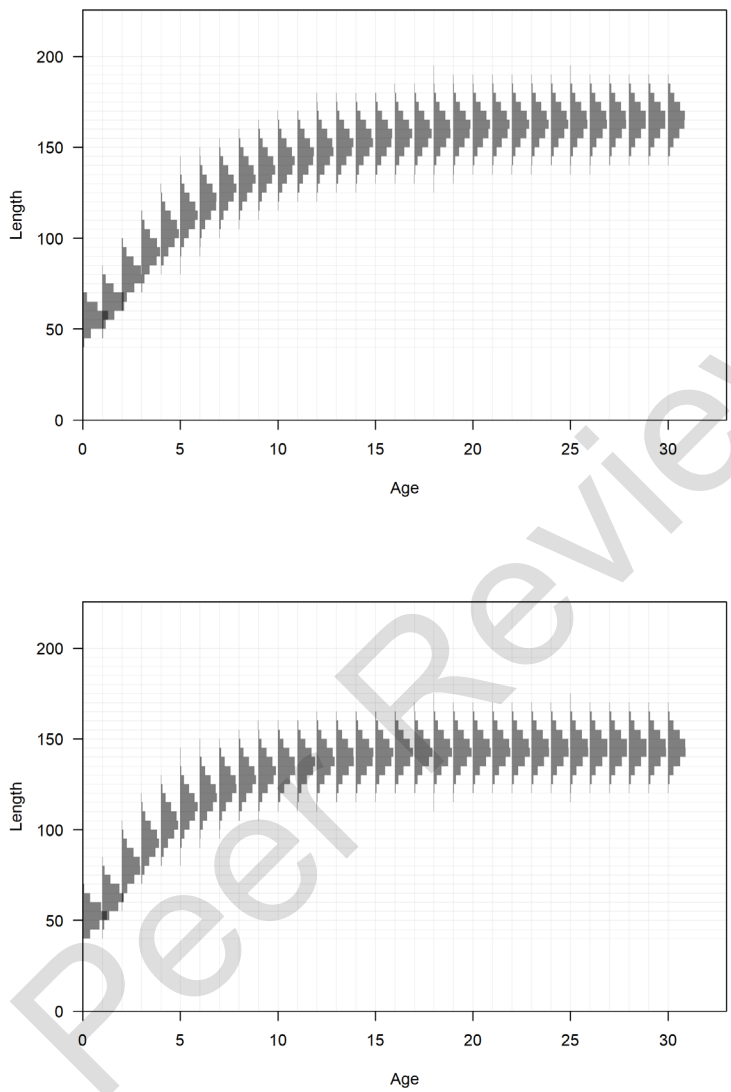

Figure 3.B.1. Distribution of mean length (cm FL straight) at each age implemented separately for females (upper panel) and males (lower panel) in the logistic sensitivity analysis.

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Figure 3.B.2. Observed and predicted annual length compositions (Upper panels) and Pearson residuals (Lower panel) in the logistic sensitivity analysis. Years with annual length composition sample size less than the minimum input sample size (Min; **Table 3.2)** were excluded from the model fit, and are not plotted. The value "N adj" is the input effective sample size obtained using either the Francis method or the McAllister and Ianelli harmonic mean, as described above. The value "N eff" is an alternative effective sample size estimate (McAllister and Ianelli 1997; Punt 2017, his McAllister-Ianelli-1 in his equation 1.A:) that is not implemented in this assessment. The diameter of Pearson residuals indicates relative error; predicted < observed (solid), predicted > observed (transparent) within the length composition data set. The maximum diameter of Pearson residuals indicates relative error among length composition data sets.

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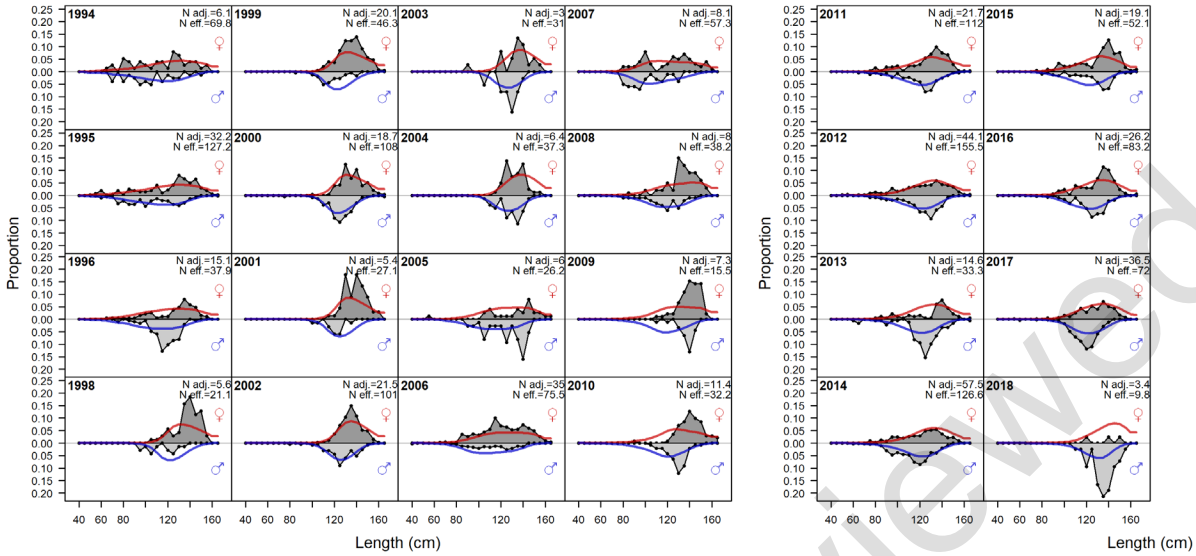

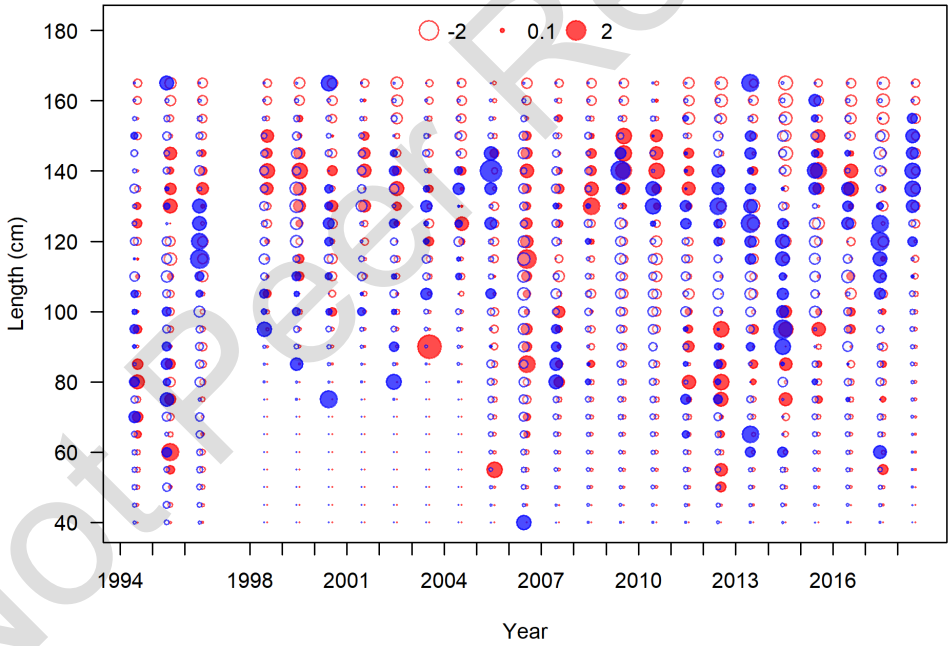

Figure 3.B.2. Continued. F1 (Com-BLL-Kept; 1994 – 2018).

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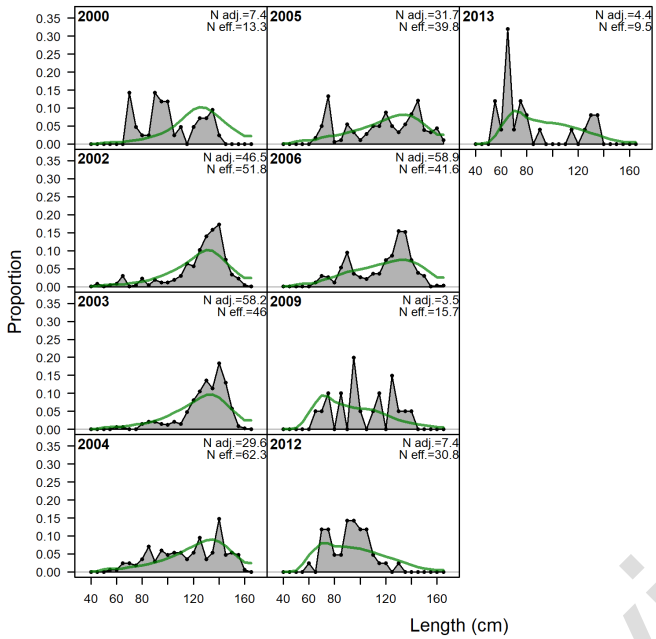

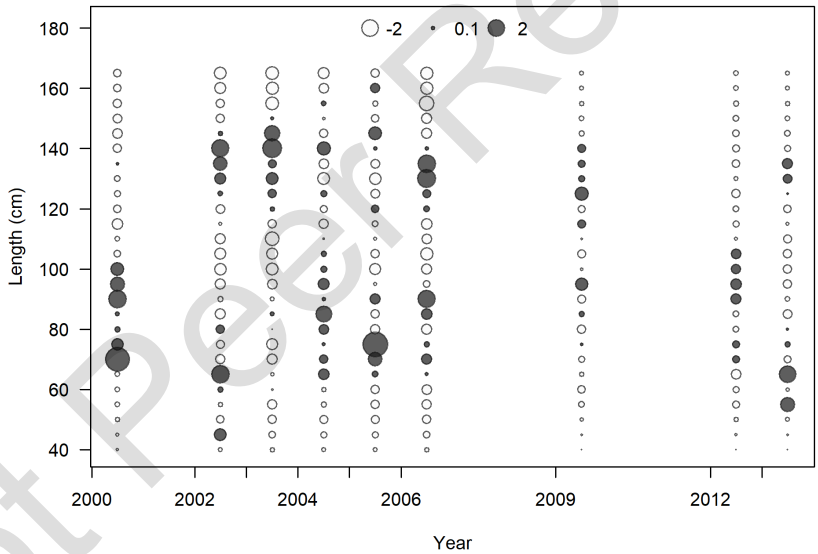

Figure 3.B.2. Continued. F2 (Com-GN-Kept; 2000 – 2018).

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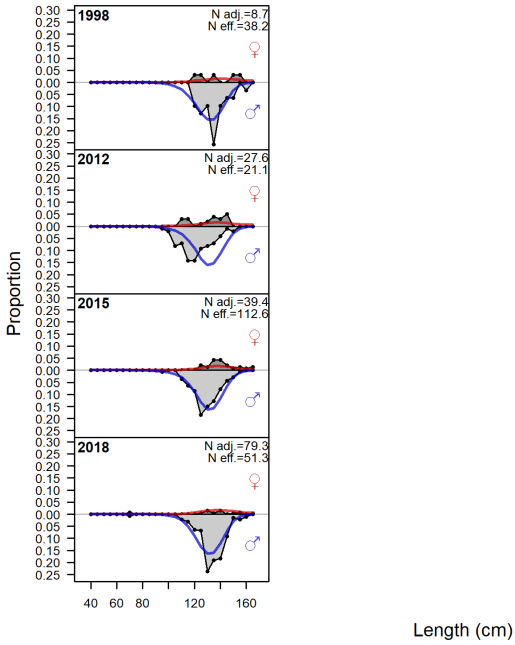

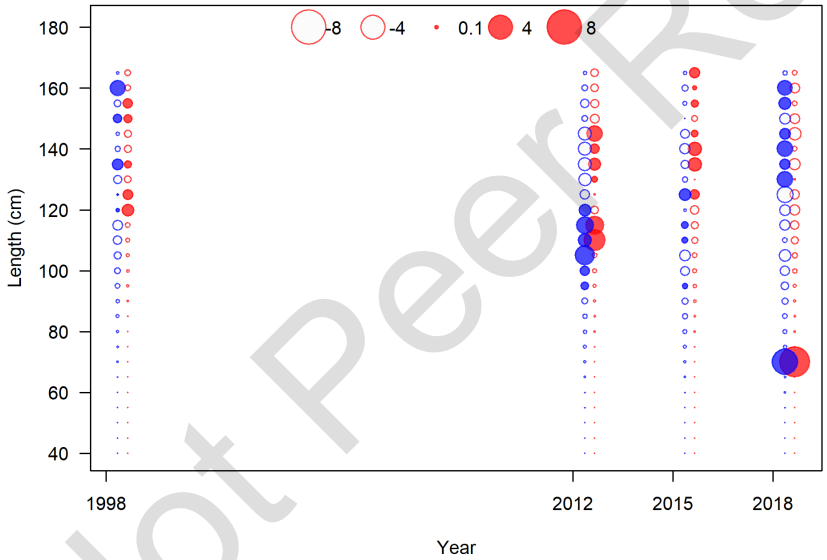

Figure 3.B.2. Continued. S4 (NEFSC-BLL; 1996 – 2018).

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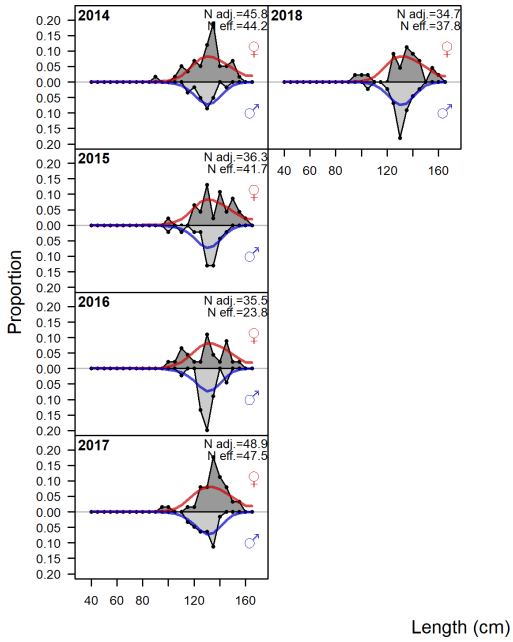

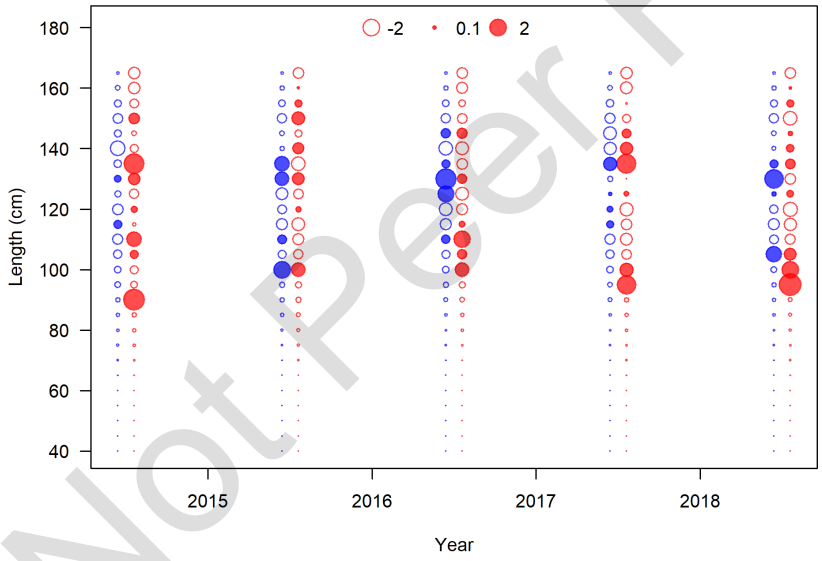

Figure 3.B.2. Continued. S7 (SCDNR-DL; 2013 – 2018).

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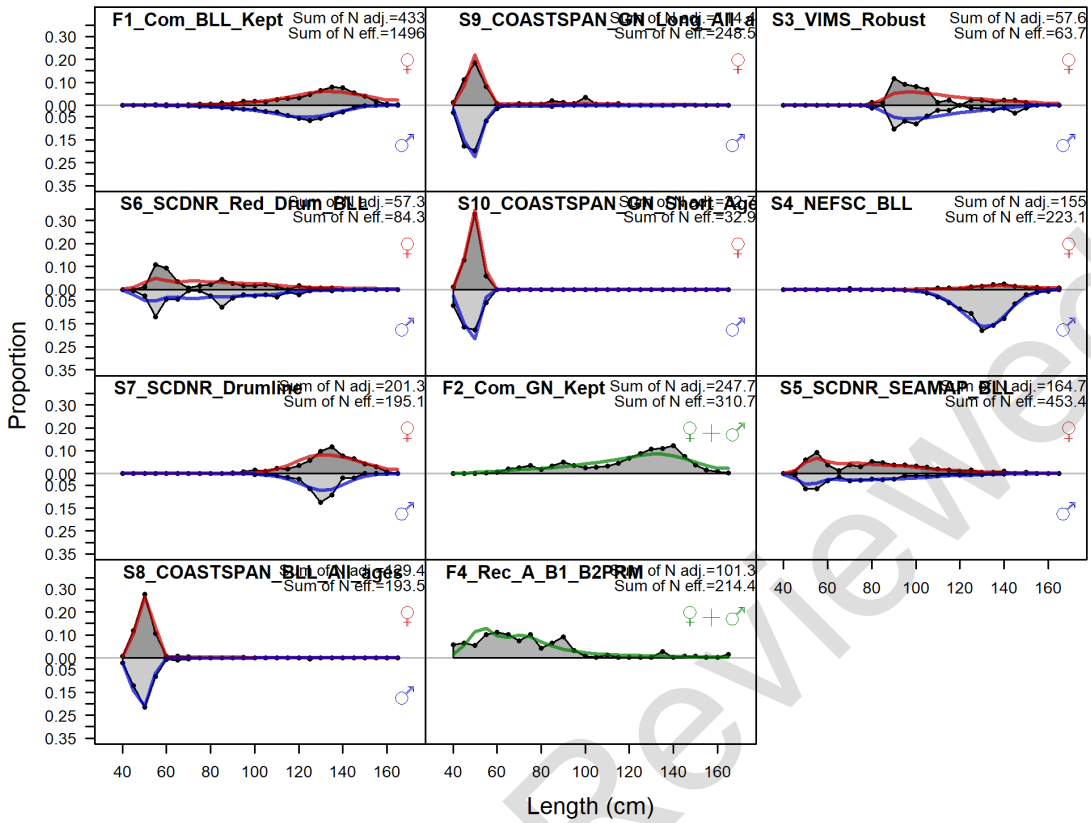

Figure 3.B.3. Predicted (line) and observed (shaded) aggregated length compositions in the logistic sensitivity analysis. Years with annual length composition sample size less than the minimum input sample size (Min; **Table 3.2)** were excluded from the model fit, and are not plotted. The value "N adj" is the input effective sample size obtained using either the Francis method or the McAllister and Ianelli harmonic mean, as described above. The value "N eff" is an alternative effective sample size estimate (McAllister and Ianelli 1997; Punt 2017, his McAllister-Ianelli-1 in his equation 1.A:) that is not implemented in this assessment.

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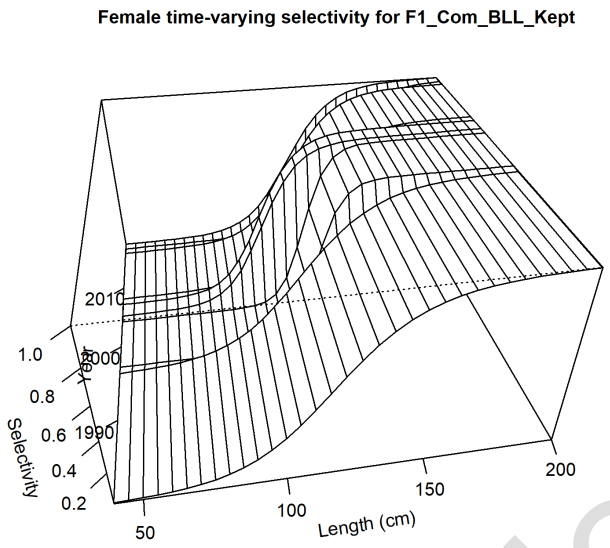

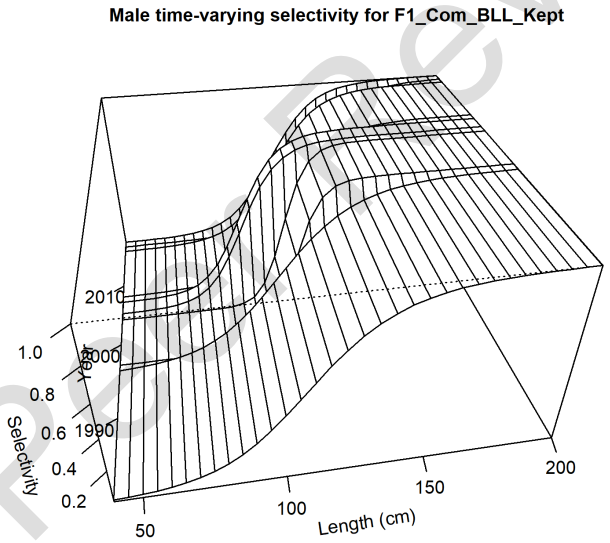

Figure 3.B.4. Selectivity at length (cm FL straight) obtained in the logistic sensitivity analysis (**Table 3.B.1**.) for F1 (Com-BLL-Kept; 1994 – 2018).

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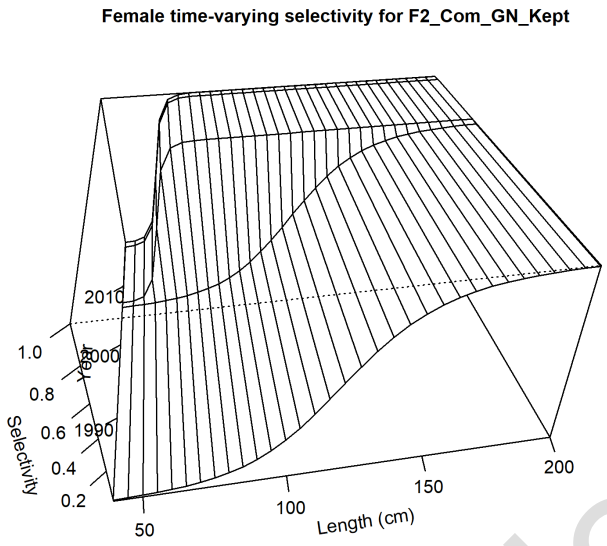

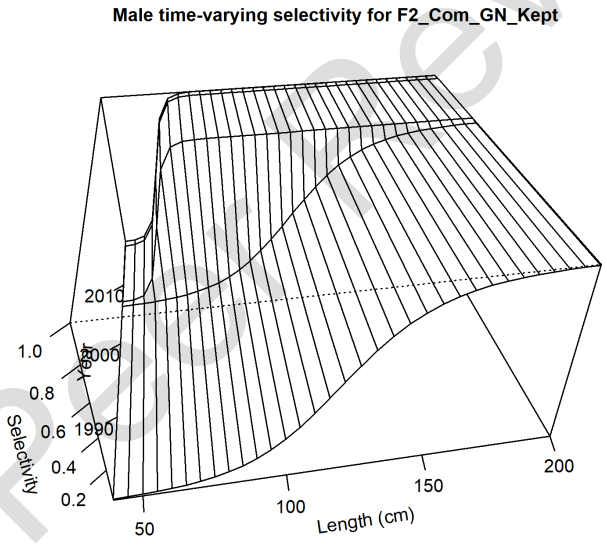

Figure 3.B.4. Continued. F2 (Com-GN-Kept; 2000 – 2018).

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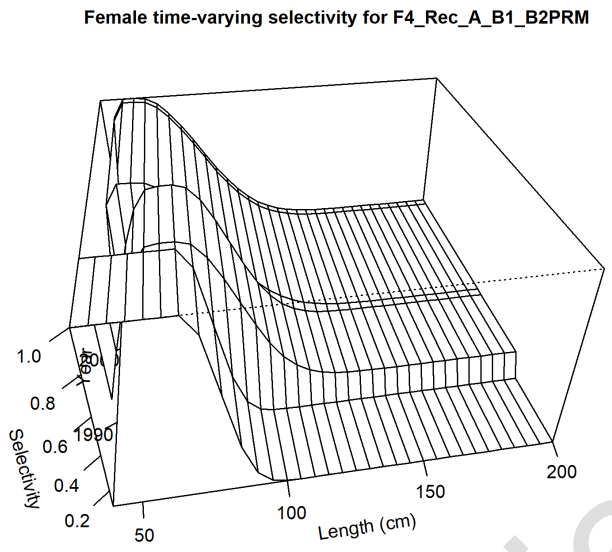

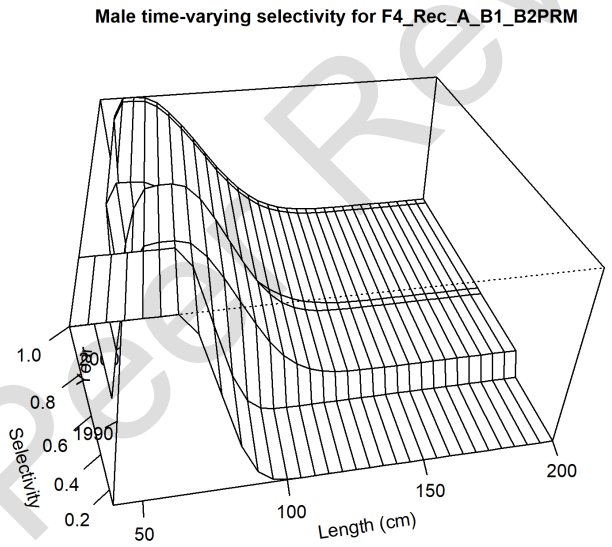

Figure 3.B.4. Continued. F4 (Recreational; 1981 – 2018).

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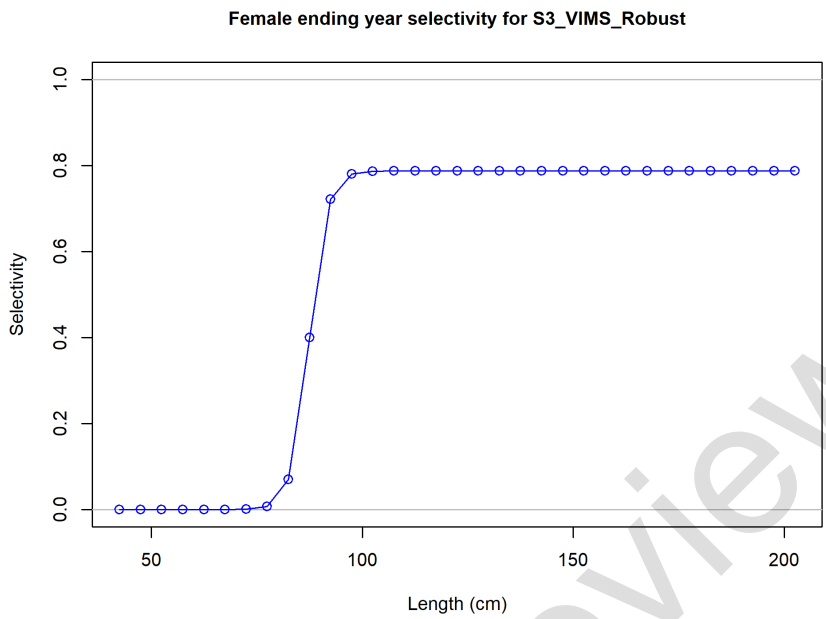

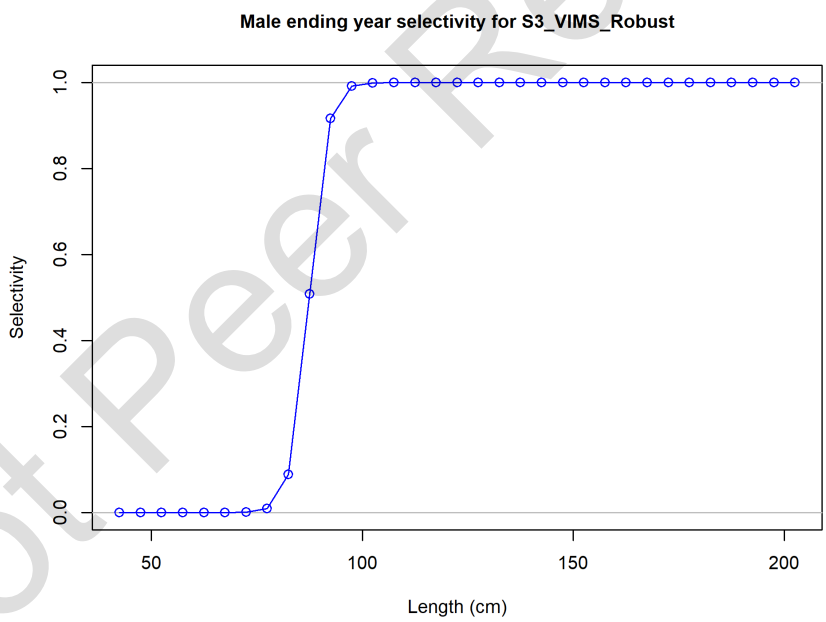

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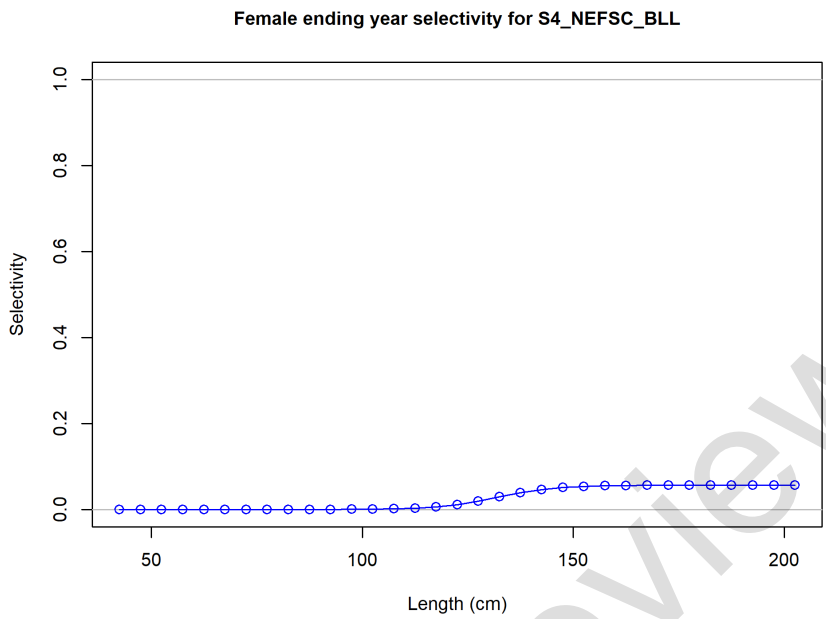
Figure 3.B.4. Continued. S3 (VIMS-BLL-Robust; 1990 – 2018).



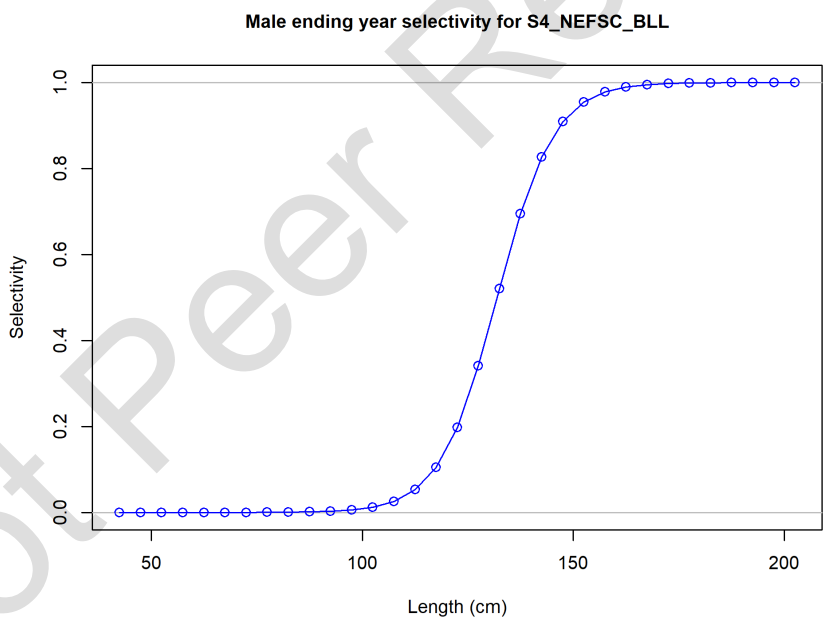


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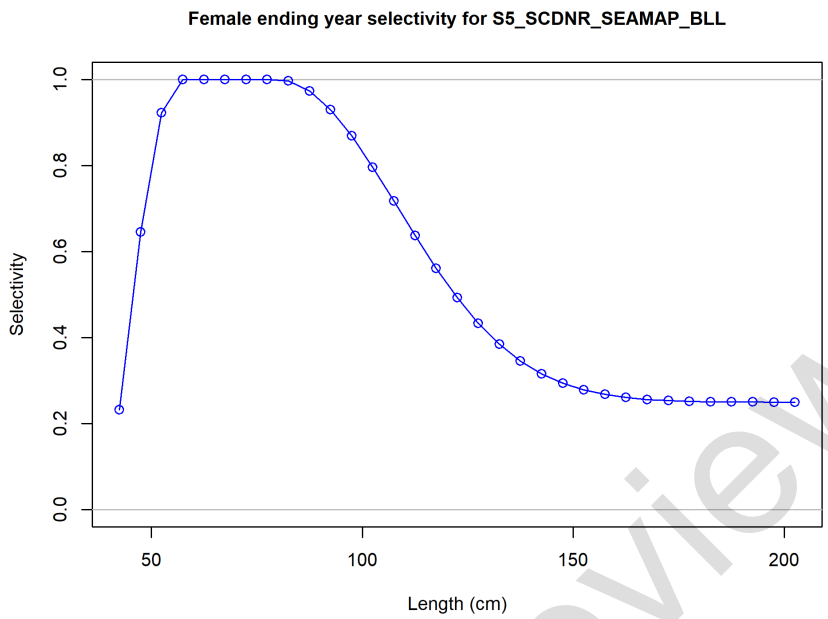
Figure 3.B.4. Continued. S4 (NEFSC-BLL; 1996 – 2018).



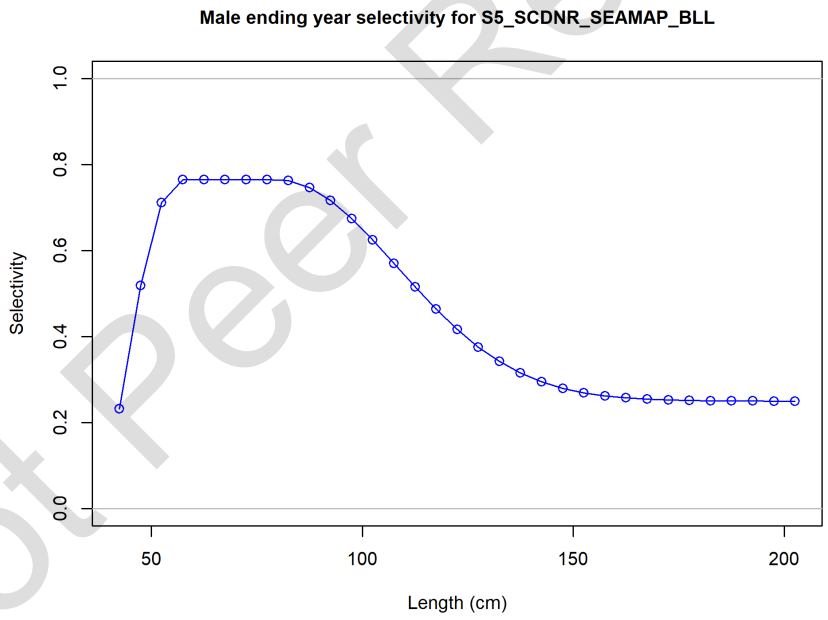


Figure 3.B.4. Continued. S5 (SCDNR-SEAMAP-BLL; 2007 – 2018).

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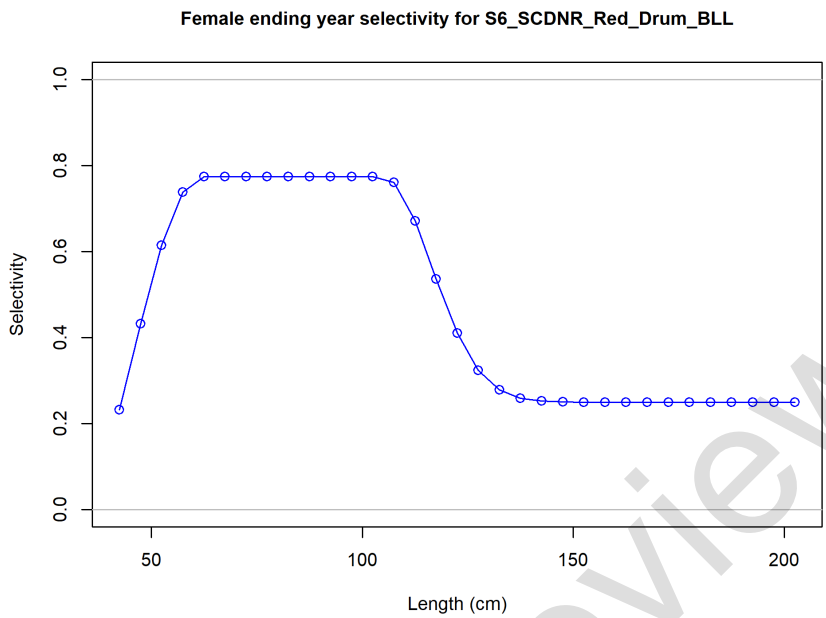

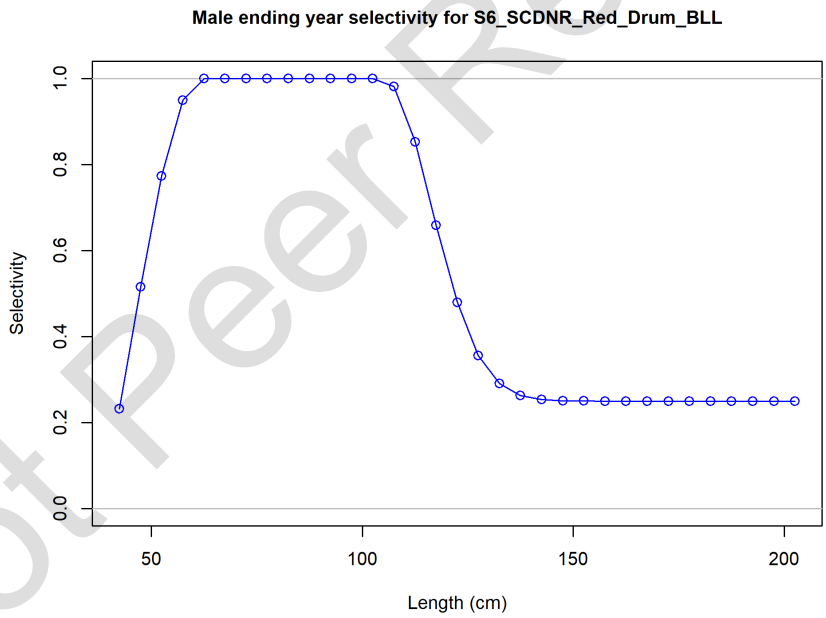

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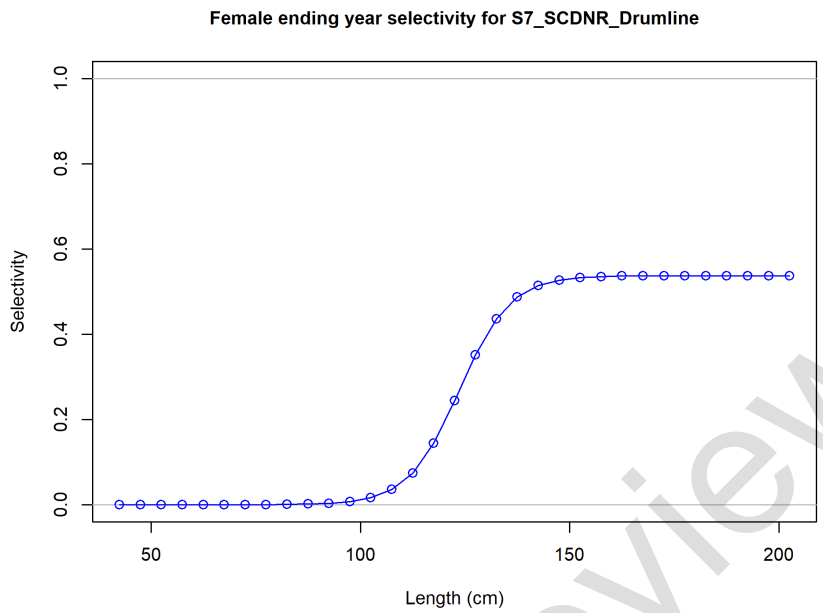
Figure 3.B.4. Continued. S6 (SCDNR-Red-Drum-BLL; 1996 – 2006).



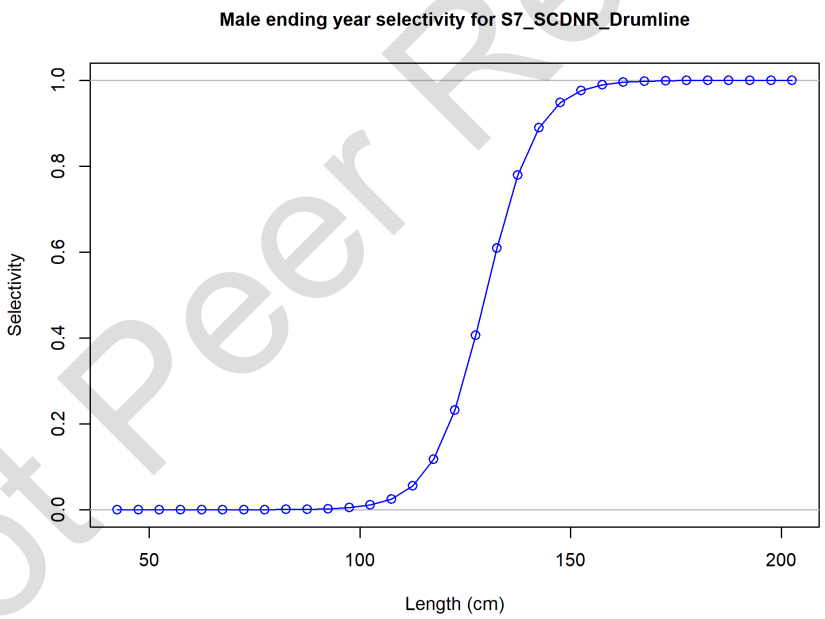


Figure 3.B.4. Continued. S7 (SCDNR-DL; 2013 – 2018).

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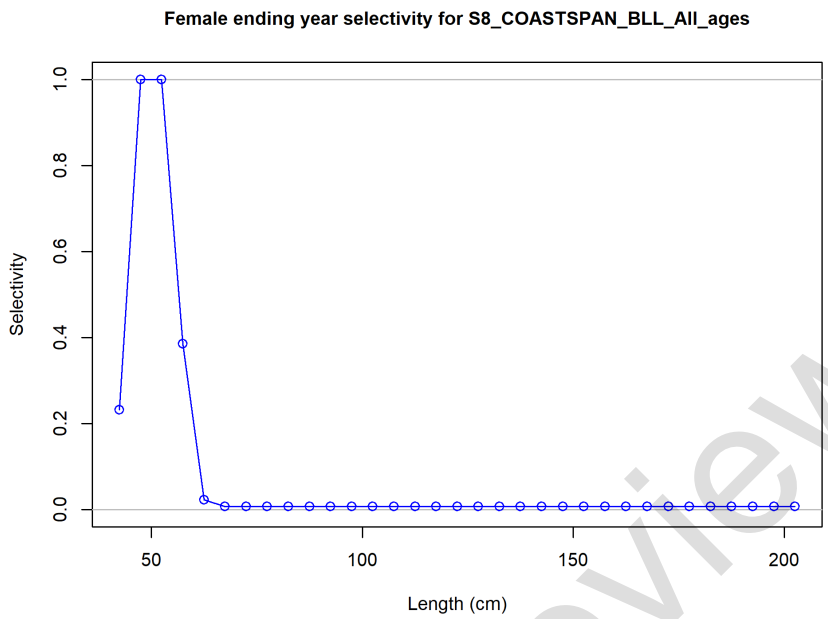

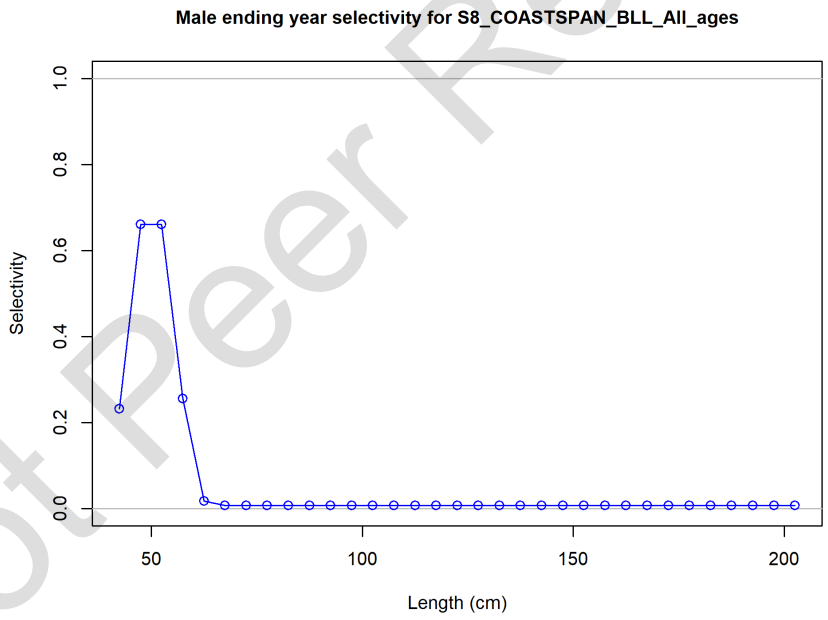

Figure 3.B.4. Continued. S8 (COASTSPAN-BLL-All-ages; 2005 – 2018).

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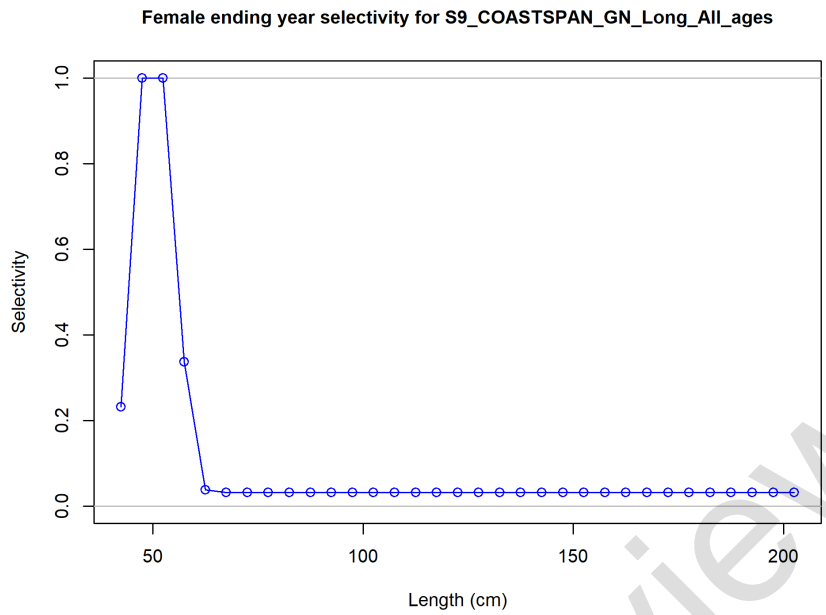

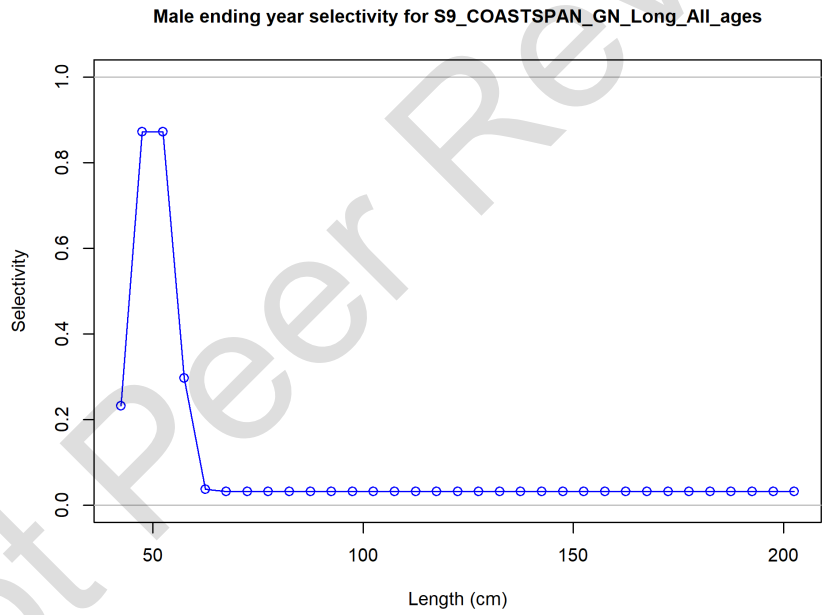

Figure 3.B.4. Continued. S9 (COASTSPAN-GNL-All-ages; 2001 – 2018).

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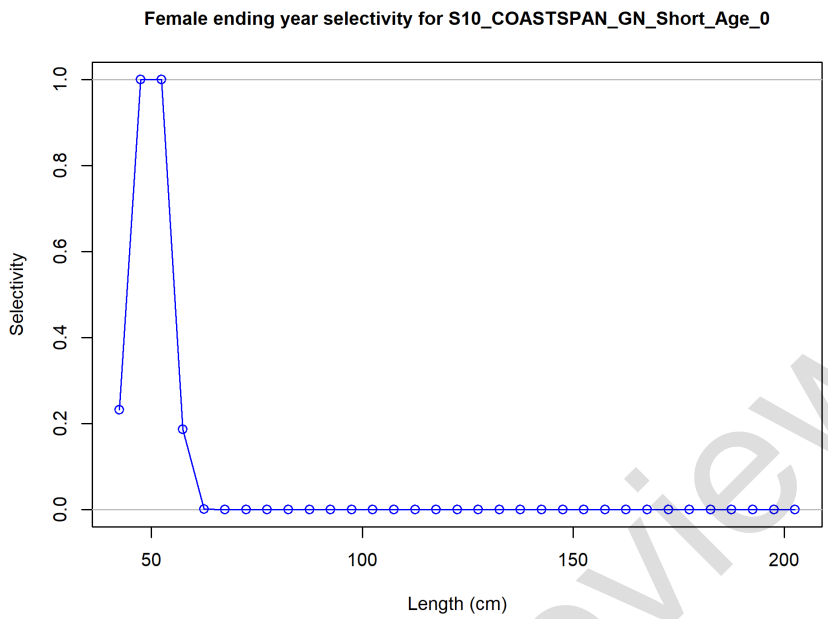

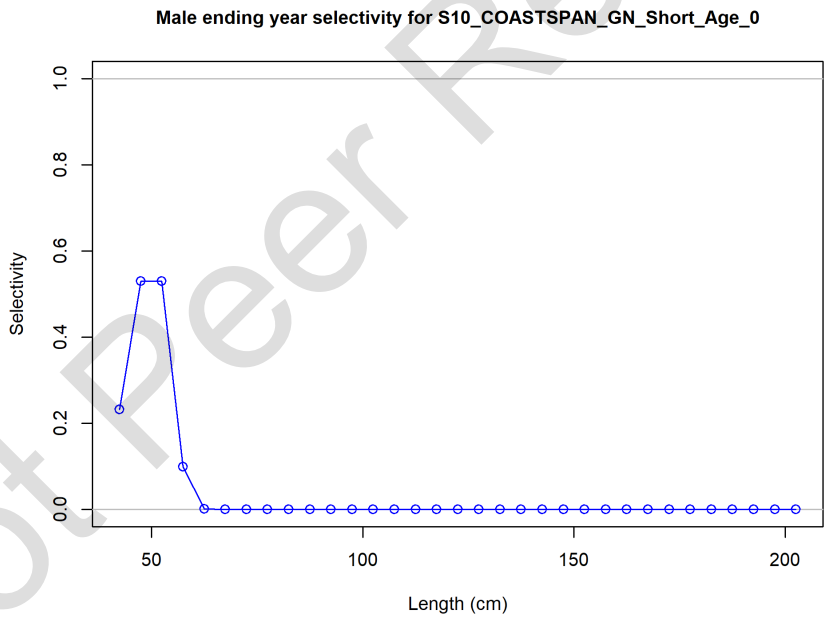

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Figure 3.B.4. Continued. S10 (COASTSPAN-GNS-Age-0; 2006 – 2018).

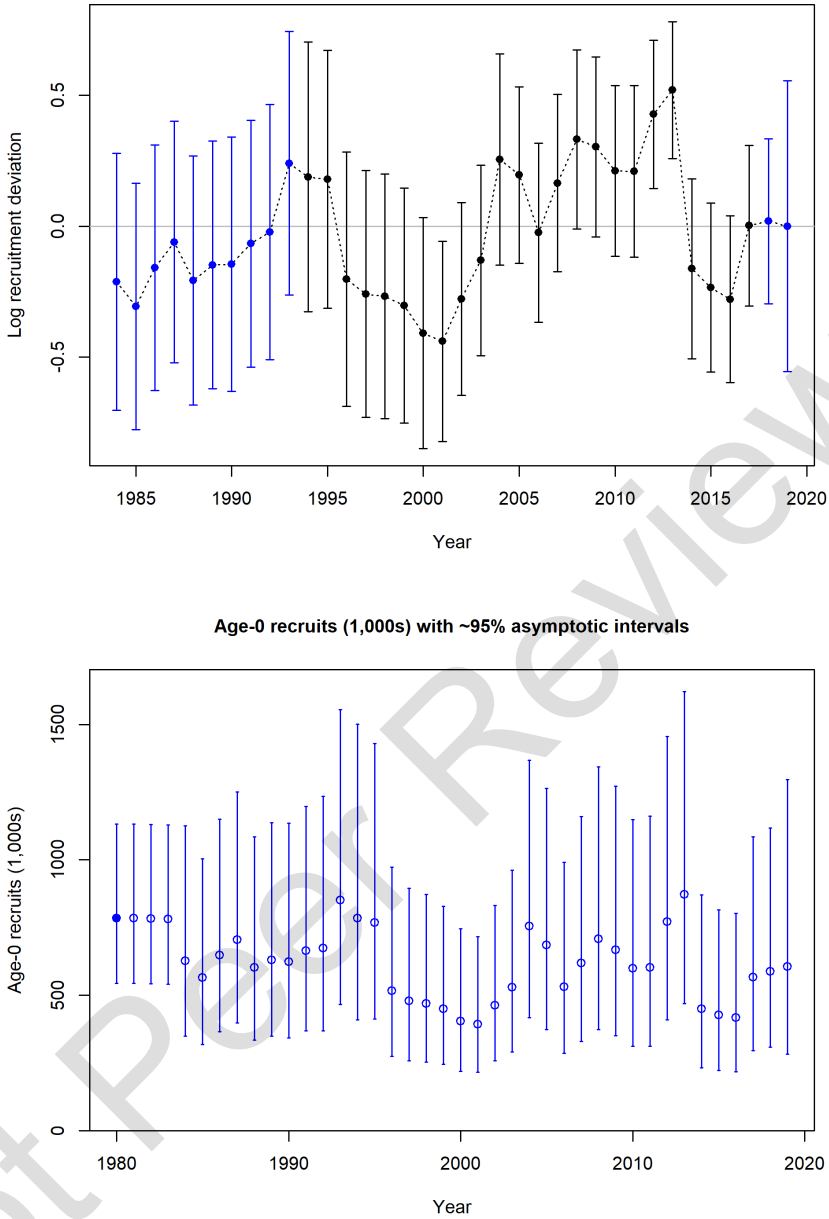

Figure 3.B.5. Upper panel is the estimated log recruitment deviations for the early (1984 – 1993, blue), main (1994 – 2017, black), late (2018, blue), and forecast (2019, blue) recruitment periods with associated 95% asymptotic confidence intervals in the logistic sensitivity analysis. Lower panel is the estimated annual age-0 recruits (circles) with 95% asymptotic confidence intervals. Age-0 recruits follow the assumed stock recruitment relationship exactly in years prior to 1984 and after 2018.

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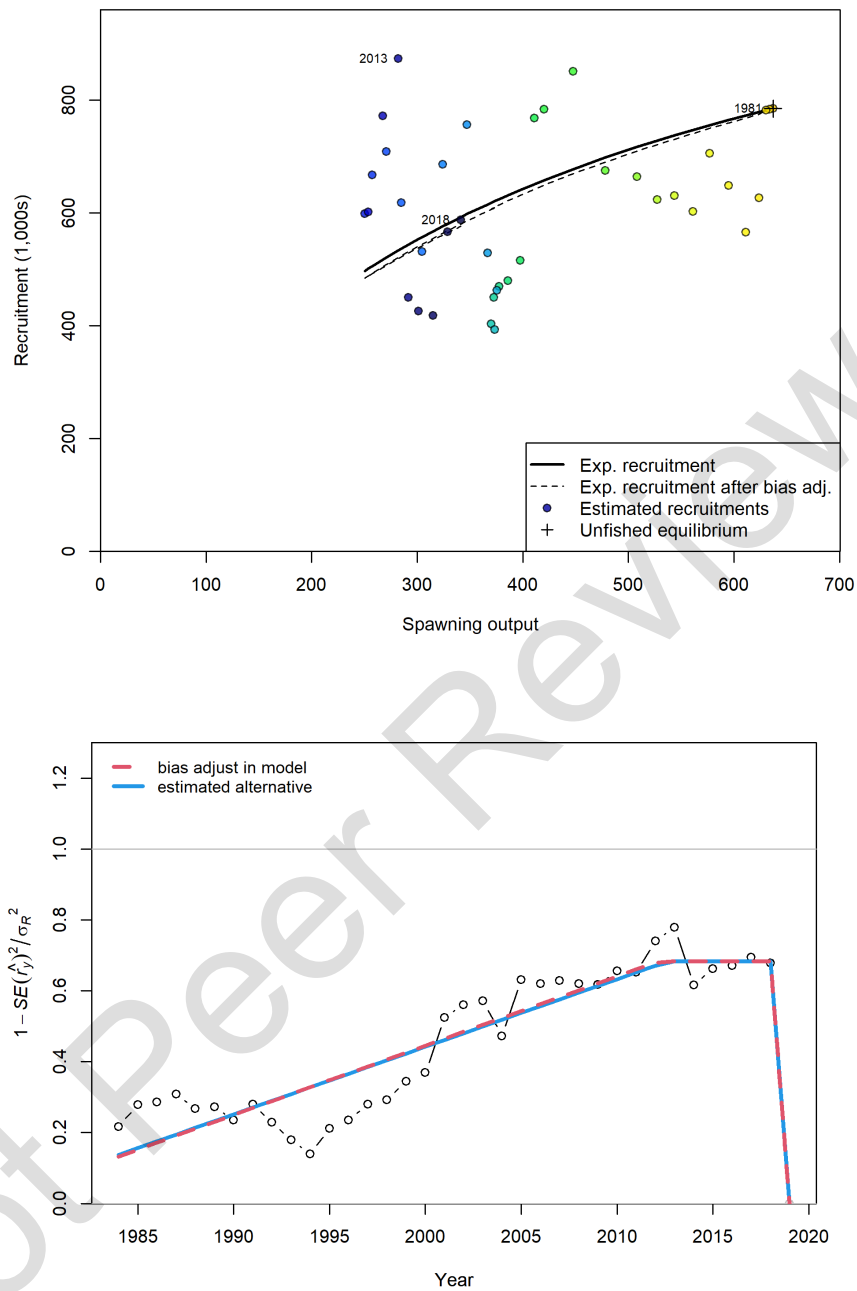

Figure 3.B.6. Expected recruitment (Upper panel) from the stock-recruitment relationship (solid line), expected recruitment after implementing the bias adjustment correction (dashed line), estimated annual recruitments (circles), unfished equilibrium (plus), and first (1981) and last (2018) years along with years with log deviations > 0.5 (2013) in the logistic sensitivity analysis. Bias adjustment ramp (Lower panel) applied to the stock-recruitment relationship (red stippled line) and the estimated alternative (blue line) in the logistic sensitivity analysis. The y-axis of the lower panel is the bias adjustment fraction (Methot and Taylor 2011).

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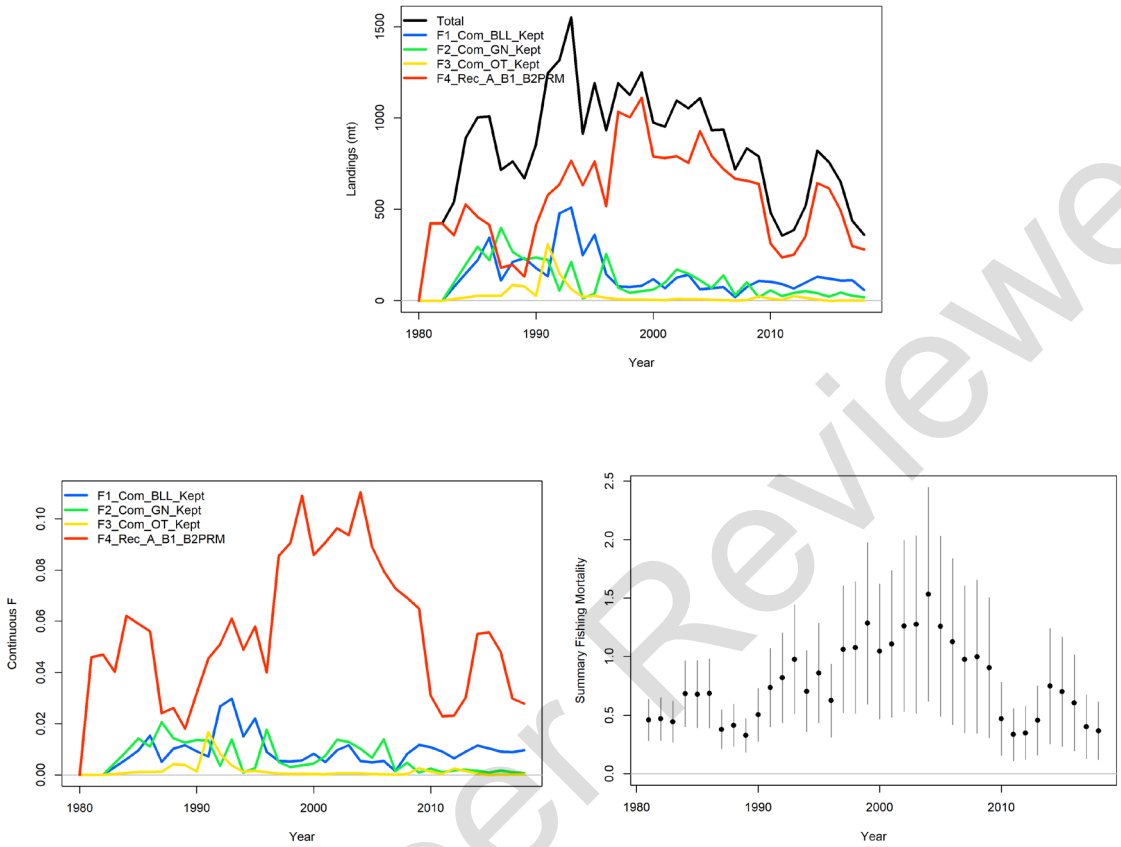

Figure 3.B.7. Total landings (Upper panel), continuous fishing mortality by fleet (Continuous *F*; Lower left panel), and the summary fishing mortality of all fleets combined (Lower right panel) in the logistic sensitivity analysis. The summary fishing mortality is plotted as a ratio calculated as the total fishing mortality rate experienced by the population (*F*=*Z*-*M*) relative to F_{MSY}. Error bars are the 95% asymptotic standard errors, ± 1.96*SE, obtained from Stock Synthesis output. Total landings include commercial landings (mt) along with recreational catch plus recreational discards assumed to die from post release mortality (A + B1 + B2 dead). Recreational data was entered in numbers (1,000s) and converted internally within Stock Synthesis to weight (mt) based on the weight at length of recreational fishery removals obtained in the Stock Synthesis logistic sensitivity analysis.

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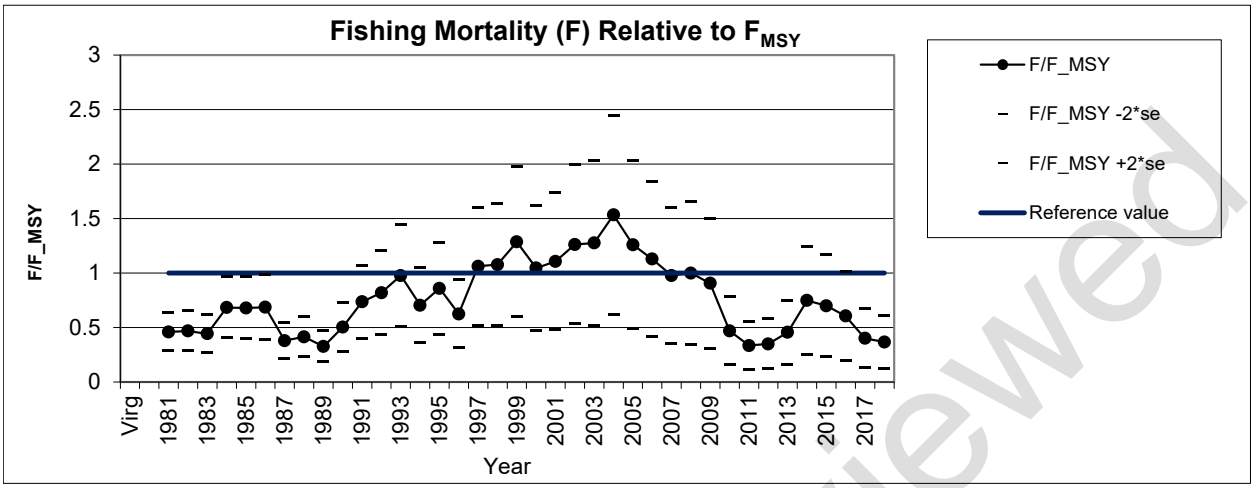

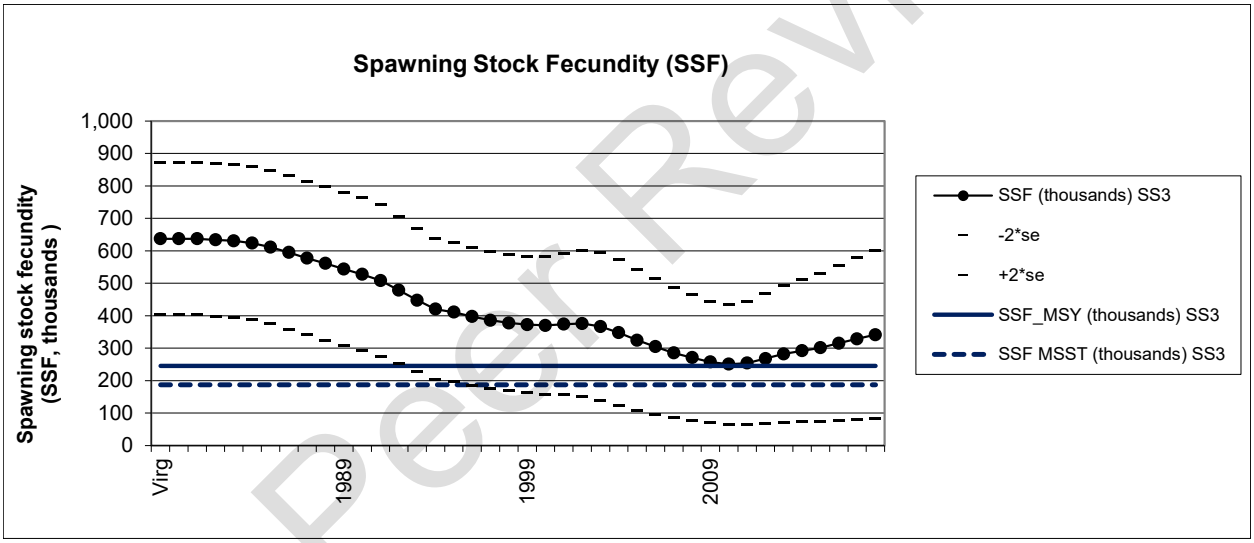

Figure 3.B.8. Summary fishing mortality (F) relative to F_{MSY} (Upper panel) and spawning stock fecundity (SSF) (Lower Panel) in the logistic sensitivity analysis. Summary fishing mortality, F, is calculated as the total fishing mortality rate experienced by the population (F=Z-M) obtained from Stock Synthesis output. Error bars are the 95% asymptotic standard errors, ± 1.96*SE, for F_Y/F_{MSY} and SSF_Y obtained from Stock Synthesis output. MSST (lower Panel) is $\left(1-\bar{M}_a\right)$ *SSF_{MSY}, with $\bar{M}_a$ calculated as the arithmetic mean of the female age-specific values of M used in the logistic sensitivity analysis (0.239, **Table 2.14**).

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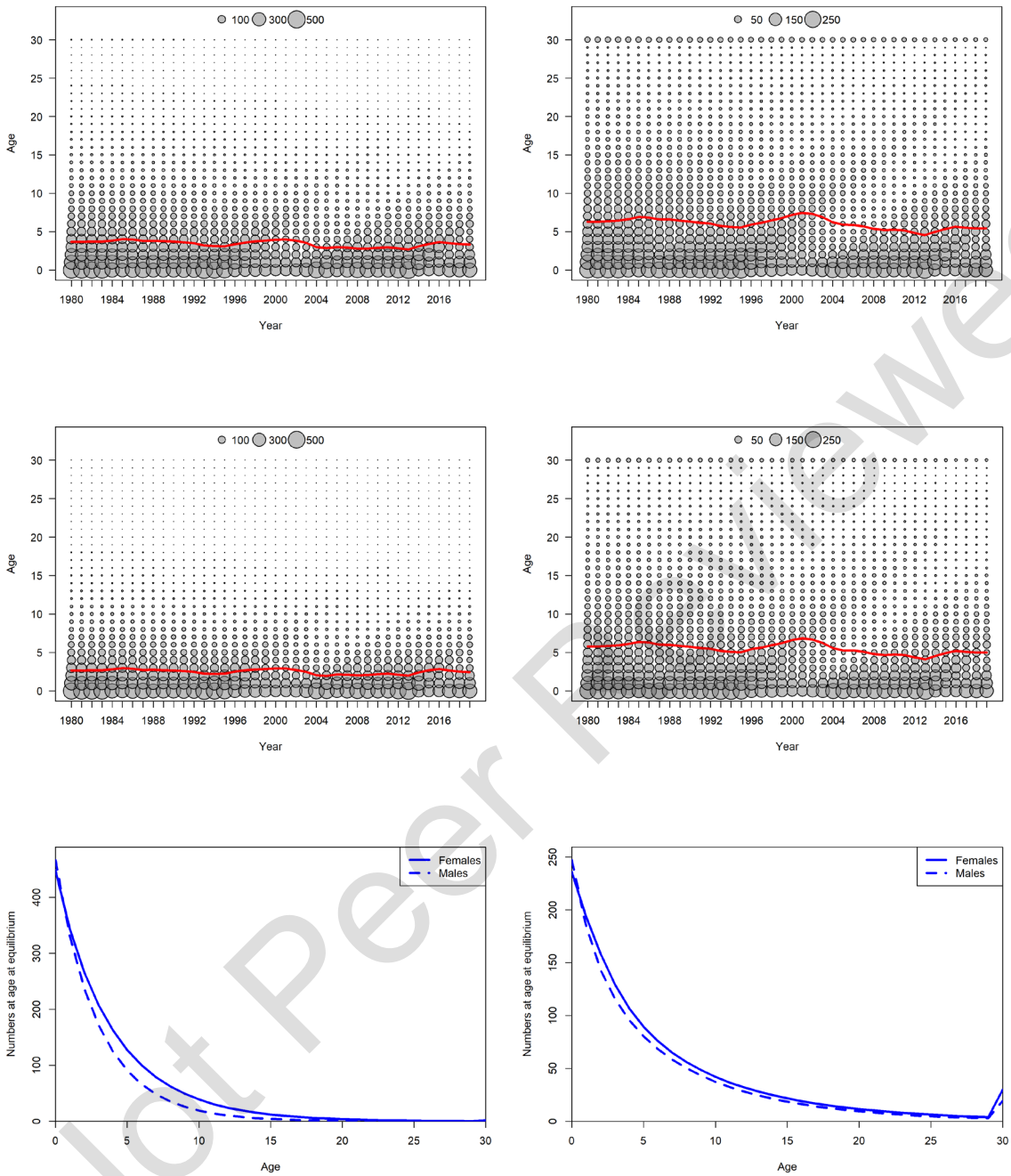

Figure 3.B.9. Beginning of year expected numbers (1000s) at age for females (Upper panels) and males (Middle panels) along with the equilibrium age distribution in the population (Lower panels) for the logistic sensitivity analysis (Left panels) and the base model configuration (Right panels).

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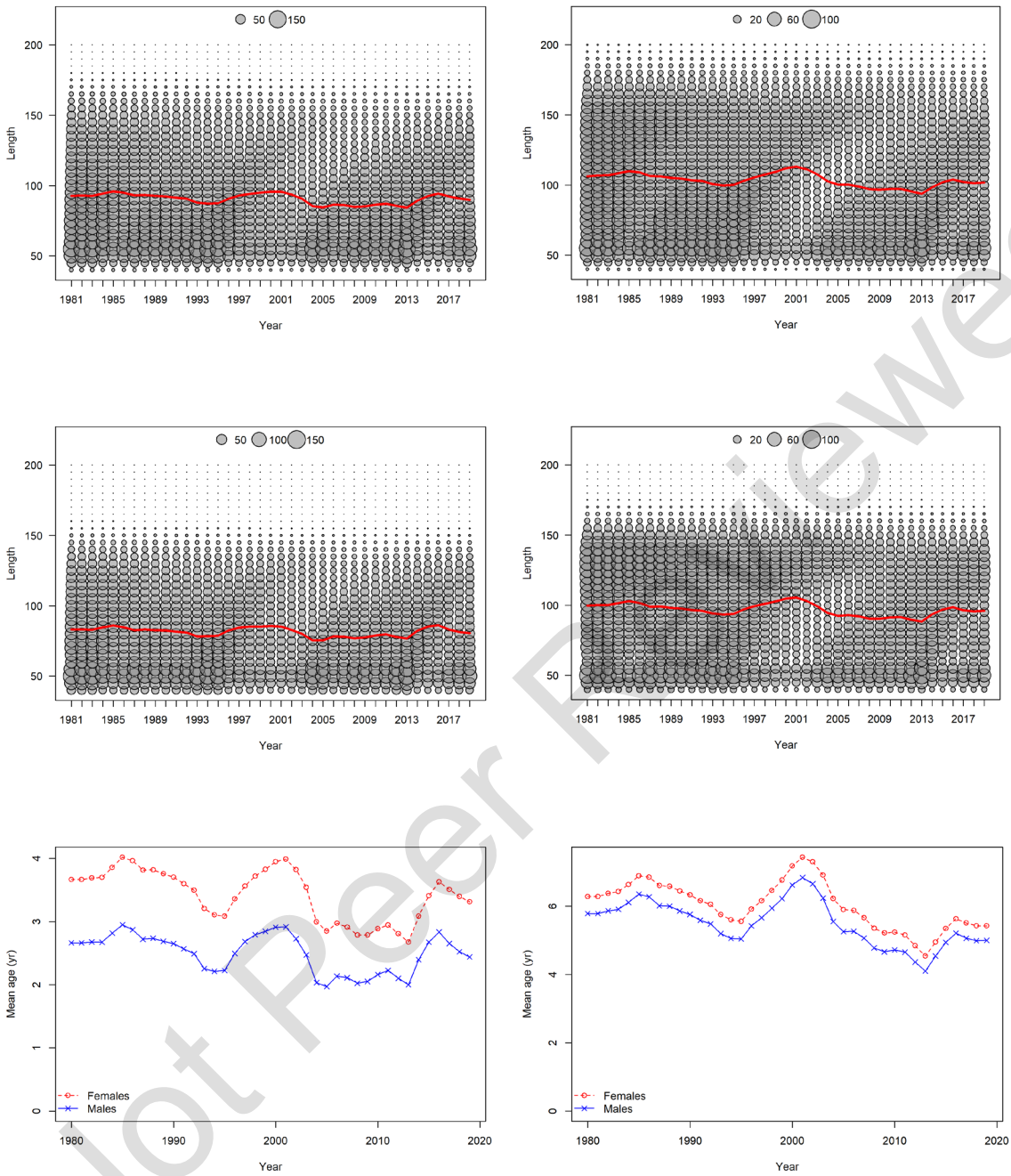

Figure 3.B.10. Beginning of year expected numbers (1000s) at length (cm FL straight) for females (Upper panels) and males (Middle panels) along with beginning of year mean age in the population (Lower panels) for the logistic sensitivity analysis (Left panels) and the base model configuration (Right panels).

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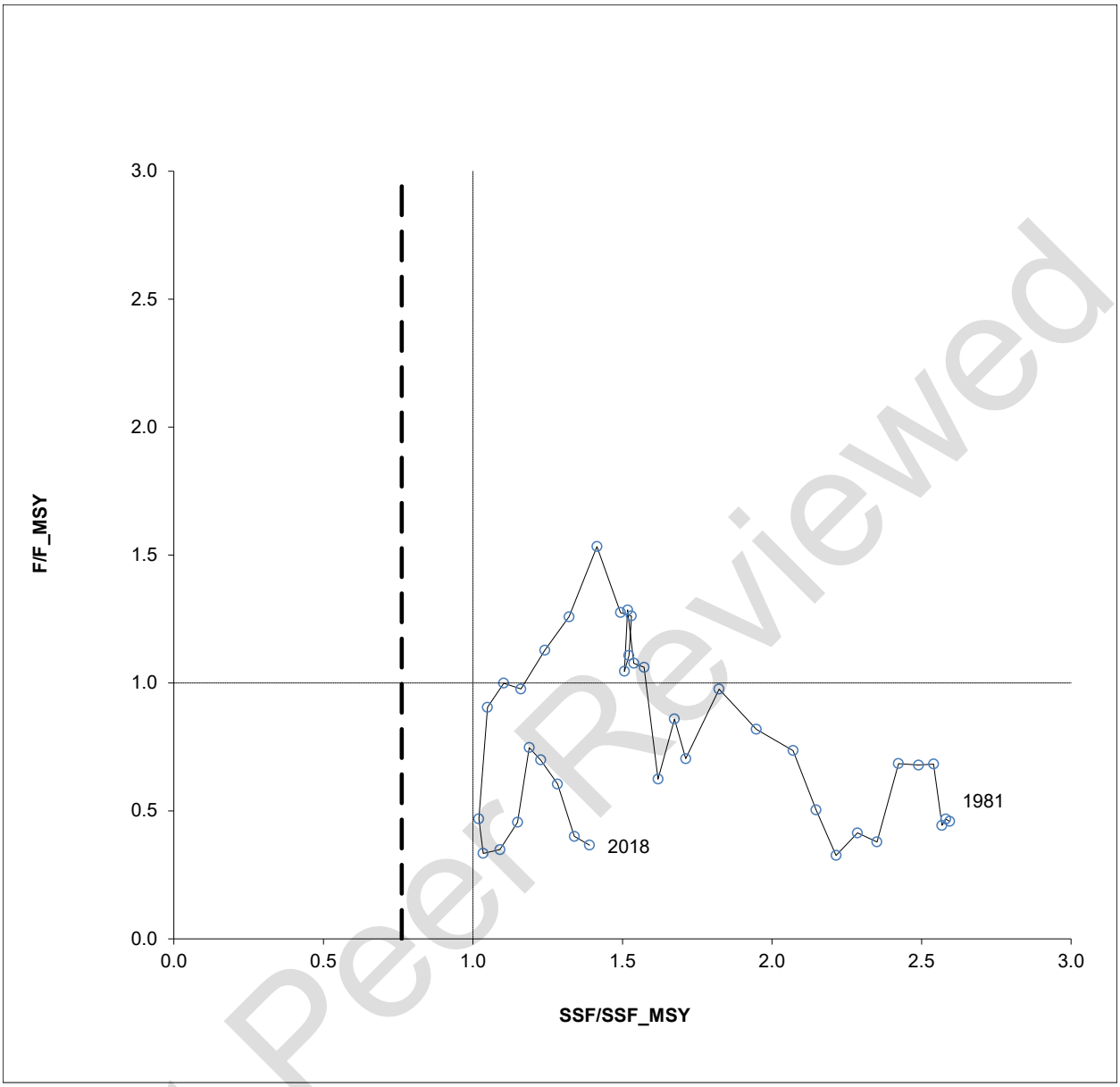

Figure 3.B.11. Phase plot of the relative spawning stock fecundity (SSF) and relative fishing mortality (*F*) trajectories by year from 1981 to 2018 in the logistic sensitivity analysis. The dotted horizontal and vertical lines indicate F_{MSY} and $\mathrm{SSF}_{\mathrm{MSY}}$. The dashed vertical line indicates $\mathrm{MSST} = \left(1 - \bar{M}_a\right) * \mathrm{SSF}_{\mathrm{MSY}}$, with $\bar{M}_a$ calculated as the arithmetic mean of the female age-specific values of *M* used in the logistic sensitivity analysis (0.239, **Table 2.14**).

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