SEDAR

Southeast Data, Assessment, and Review

SEDAR 84

US Caribbean Yellowtail Snapper – St. Thomas/St. John

SECTION III: Assessment Process Report

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Assessment Process Report Summary

The SEDAR 84 St. Thomas and St. John Yellowtail Snapper (*Ocyurus chrysurus*) stock assessment process consisted of four webinars between April 2024 and October 2024. The data available for the assessment included:

- An annual species-specific catch time series from commercial logbooks
- Fishery-dependent length compositions from commercial port sampling
- Fishery-independent length compositions from two reef fish surveys
- Fishery-independent indices of abundance from two reef fish surveys
- Life history information from otolith analysis and gonad histology

The assessment used Stock Synthesis, a statistical catch-at-age model (Methot et al., 2020). Stock Synthesis V3.30.22 models were initially configured with an annual catch time series, while length composition data from each source were aggregated across all available years. Model development proceeded stepwise from the simplest configuration to those of moderate complexity. Those sequential steps included the inclusion of dome-shaped selectivity, indices of abundance, and annual fishery-independent length compositions. Models were run with and without the estimation of recruitment deviations. Finally, sensitivities of assessment outcomes were investigated using alternative inputs for longevity-informed natural mortality, coefficient of variation on growth, and uncertainty on initial equilibrium catch.

Model diagnostics assessed convergence, fit, and consistency using gradients, residuals, likelihood profiles, hindcast cross-validation, and jitter analyses. Those diagnostics revealed that, although data contrast was limited and recruitment estimates were highly uncertain, the available length and catch data—particularly from fishery-independent sources—provided information that the models can use to determine potential catch advice, particularly in a grid or model ensemble approach that accounts for key model assumptions and data-limited caveats.

Sensitivity analyses evaluated the effects of assumptions about natural mortality, growth variability, and initial equilibrium catch conditions. While these scenarios showed that key uncertainties can influence estimated productivity and biological reference points, nearly all models across the suite supported the conclusion that overfishing is not occurring and the stock is not overfished. A few sensitivity runs did indicate potential concern under specific combinations of assumptions, particularly with lower initial equilibrium catch and higher natural mortality.

1 Introduction

1.1 Workshop Time and Place

The SEDAR 84 Assessment Process was held via webinars from April to November 2024.

1.2 Terms of Reference

1. Develop and apply assessment tools that are compatible with available data and consistent with standard practices. Document input data, model assumptions and configuration, and equations for each approach considered.
2. To the extent possible given data limitations, provide management benchmarks and status determination criteria, including:
    a. Maximum Fishing Mortality Threshold (MFMT) = F_{MSY} or proxy
    b. MSY proxy = yield at MFMT
    c. Minimum Stock Size Threshold (MSST) = SSB_{MSY} or proxy
    d. If alternative status determination criteria are recommended, provide a description of their use and a justification.
3. To the extent possible, develop projections to support estimates of maximum sustainable yield (MSY, the overfishing limit (OFL) and acceptable biological catch (ABC) as described below. If projections are not possible, and alternative management procedures are recommended, provide a description of their use and a justification.
    a. Unless otherwise recommended, use the geometric mean of the three previous years' fishing mortality to determine $F_{Current}$
    b. Project F_{MSY} or proxy
    c. If the stock is overfished:
        i. Project $_{F0}$
        ii. Project $F_{Rebuild}$
4. Provide recommendations for future research and data collection.
5. Provide an Assessment Workshop Report to address these Terms of reference and fully document the input data and results.

1.3 List of Participants

Assessment Panel	
Adyan Rios (Lead Analyst)	NMFS/SEFSC
Richard Appeldoorn	SSC
J.J. Cruz-Motta	CFMC SSC, UPRM
Matt Damiano	NMFS/SEFSC
Sennai Habtes	USVI DPNR
Walter Keithly	SSC/LSU
Kevin McCarthy	NMFS/SEFSC
M. Refik Orhun	NMFS/SEFSC
Kyle Shertzer	NMFS/SEFSC
Virginia Shervette	Univ SC
Derek Soto	MER

Appointed Observers	
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Julian Magras	DAP STT/STJ

Observers	
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Jay Grove	NMFS/SEFSC
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Stephanie Martinez-Rivera	NMFS/SEFSC
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Observers	
Sarah Stephenson	NMFS/SEFSC
Joyah Watkins	Rice University

Staff	
Julie A. Neer	SEDAR
Liajay Rivera Garciá	CFMC Staff
Graciela Garcia-Moliner	CFMC Staff

1.4 List of Assessment Process Working Papers and Reference Documents

1.4.1 Documents Prepared for the Assessment Process

Document #	Title	Authors	Date Submitted
SEDAR84-AP-01	Report on the status of U.S. Caribbean stoplight parrotfish Sparisoma viride age, growth, and reproductive biology for the SEDAR84 Stock Assessment	Jesús M. Rivera Hernández and Virginia Shervette	6 July 2024

1.4.2 Reference Documents

Document #	Title	Authors
SEDAR84-RD11	The Commercial Yellowtail Snapper Fishery off Puerto Rico, 1983-2003	Nancie J. Cummings
SEDAR84-RD12	S8-DW-08: The commercial reef fish fishery in Puerto Rico with emphasis on yellowtail snapper, Ocyurus chrysurus: landings and catch per unit of effort from 1983 through 2003	Nancie J. Cummings and Daniel Matos-Caraballo
SEDAR84-RD13	The Net Buyback and Ban in St. Croix, U.S. Virgin Islands	Juan J. Agar, Flavia Tonioli, Chloe Fleming

2 Data-Informed Modeling Decisions

The data available for use in the current assessment are documented in the SEDAR 84 U.S. Caribbean Yellowtail Snapper St. Thomas and St. John Data Workshop Report (SEDAR, 2024). Provided here is a summary of those data with a focus on the associated model configurations explored using Stock Synthesis. Throughout this report, **bolded text** is used to highlight and summarize the model settings and configurations relevant to the various phases of model development.

Additional details for each data input are available in their respective references:

1. **Landings** from self-reported commercial fisher logbooks (Martínez Rivera et al., 2024)
2. **Length compositions** from shore-based port sampling (Godwin et al., 2024)
3. **Length compositions** from two fishery-independent surveys of reef fish (Grove et al., 2024)
4. **Indices of abundance** from two fishery-independent surveys of reef fish (Grove et al., 2024)
5. **Life history information** from otolith analysis and gonad histology (Shervette, Rivera Hernández, & Peña Alvarado, 2024; Shervette, Rivera Hernández, & Zajovits, 2024)

Based on the available data, the assessment was configured with one area, one season, one commercial fleet, and two fishery-independent surveys.

2.1 Commercial Fleet Data

2.1.1 Catch

The catch data for the commercial fleet came from the Caribbean Commercial Logbook program (Martínez Rivera et al., 2024). Beginning in 1996, part of the commercial landings was reported by species groups (e.g., snappers, groupers, parrotfishes, surgeonfishes, etc.), and by gear (hook and line, gill net, SCUBA, trap, etc.). All commercial fishery data reports included species groups beginning in 1998. In July of 2011, commercial landings were reported by species and gear.

The handline gear group made up 72% of the reported landings catch of Yellowtail Snapper in St. Thomas and St. John. All gears (handline, trap, rod and reel, and other) were included into a single commercial fleet (Table 7.1). Potential outliers discussed during the assessment webinars were investigated and retained as valid trips.

In the SEDAR 84 Stock Synthesis models, **the catch was input as biomass (in metric tons) and was treated as if it occurred over an entire fishing season; i.e., each fishing year.**

The years of the available species-specific self-reported commercial fisher logbook landings and effort data determined the start and end years of the Stock Synthesis models. **The start and end years of the model were 2012 and 2022, respectively.**

It is important to note that the stock was not unexploited at the start year of the available catch time series. The commercial landings of all snapper species reported in St. Thomas and St. John in 2012 was undergoing a meaningful decline. Combined snapper landings dropped by over 55% in just one year, from 121,187 pounds in 2010 to 76,193 pounds in 2011, followed by another 30% decrease in 2012 (SEDAR (2024), Table 3.1.3). Initial F was estimated for the commercial fleet and a corresponding initial equilibrium catch. A common option to define reference point for the initial equilibrium catch is to use the geometric mean of the first three years of available catches. However, because of the decline preceding the start year of the assessment, the assessment panel agreed on using a value higher than the geometric mean of the first three years. **The initial equilibrium catch was configured in initial runs as 25 metric tons**, a little under twice the geometric mean of the catches from 2012 - 2014, which was 26.4 metric tons).

The input standard error for the landings was set to 0.3. When implemented with few data inputs, Synthesis strongly prioritizes fitting the annual landings time series, often replicating the observed values almost exactly, particularly when small standard errors (e.g., 0.01) are used. The initial configurations with low input uncertainty resulted in the model tightly fitting both the observed landings and the input initial equilibrium catch. To allow the model greater flexibility in estimating the initial equilibrium catch, and avoid anchoring it too closely to the input value, a higher standard error of 0.3 was specified for the initial equilibrium catch. This increased uncertainty enables the model to balance trade-offs among other data sources and internal dynamics when estimating initial conditions. A description of the sequential model configurations and development process is provided later in this report.

A higher standard error of 2 was explored as part of the sensitivity analysis to evaluate the influence of extreme uncertainty in the initial equilibrium catch input. This value was intentionally selected to represent a scenario with minimal confidence, allowing the model to substantially down-weight this input and reveal how strongly model outputs depend on the assumed precision of the initial equilibrium catch.

Commercial discards reported by calendar year by Martínez Rivera et al. (2024) were minimal. Based on expert judgment and available information, discards of Yellowtail Snapper in the St. Thomas/St. John commercial fishery are considered negligible, with minimal associated mortality (SEDAR (2024)). Additionally, species-specific discard data were not collected in commercial logbooks prior to July 2015, leaving discards from earlier years unquantified. Given this limited data and the expectation of low discard rates, **discards were not explicitly included in the model inputs or parameterized through a retention function. The assessment assumed full retention of catch.**

Alternative model configurations associated with the commercial fleet data are described later in this report. They included:

- The initial equilibrium catch was explored via likelihood profiling.
- A higher standard error of 2 was explored via sensitivity analysis.

2.1.2 Length Composition

Gear-specific annual length frequencies for the commercial fleet came from the commercial shore-based port-sampling Trip Interview Program (Godwin et al., 2024). The Trip Interview Program (TIP) manages data from the U.S. Virgin Islands collected by Division of Fish and Wildlife personnel. Port sampling personnel collect length and weight data from fish landed by commercial fishing vessels, along with information about general area of capture and gear used. Data collection began in 1983 with frequent updates in best practices; the latest being in 2017. The Yellowtail Snapper length data from St. Thomas and St. John included 20,064 length observations across 1,078 unique port sampling interviews.

Although the catch data can be separated into handline and non-handline related gears, 85% of the length measurements for St. Thomas and St. John Yellowtail Snapper from 2012-2022 were associated with handlines. Those data were used to characterize the commercial fleet's length-based selectivity pattern. Since multiple fish length measurements can be obtained from a single sampled trip, each length does not represent an independent observation. **The relative model weighting of the commercial fleet length compositions was based on the number of trips sampled**.

From 2012 - 2022, the data included 7,351 shore-based length measurements obtained across 208 trips. Two trips were flagged and removed as potential outliers with unusually large lengths. **Due to low sample sizes of both fish and trips, the fishery-dependent commercial fleet length composition data were collapsed across all years 2012-2022** by implementing the super-period approach in Stock Synthesis.

The Trip Interview Program length compositions of the commercial fleet were assumed to be representative of the total catch. Although a federal minimum size limit exists, it does not apply in USVI territorial waters extending from land to 3 nautical miles offshore. Discussion at the data workshop emphasized that the federal regulations does affect retention, however there are insufficient data on the lengths of discarded fish to inform length-based retention.

A double normal function was used to model the relative vulnerability of capture by length for the commercial fleet. However, only two parameters were estimated, effectively describing a logistic selectivity for the commercial fleet. The double normal function allows for domed or logistic selectivity. It combines two normal distributions; the first describes the ascending limb, while the second describes the descending limb. Achieving the logistic shape with the double normal Stock Synthesis pattern facilitated model configurations for SEDAR 84. The two parameters used to achieve a logistic selectivity shape were the length associated with peak selectivity and the width of the ascending limb. Domed selectivity was explored for the fishery independent survey data described in the following section.

2.2 Survey Data

2.2.1 Index of Abundance

The National Coral Reef Monitoring Program (NCRMP) supports reef fish sampling on hard-bottom habitats from 0 to 30 meters depth (Grove et al., 2021). In St. Thomas and St. John, NCRMP sampling began in 2001 and was conducted every year from 2001 to 2011 and then every other year starting in 2013. The data used in SEDAR 84 were from nonconsecutive years during 2013 - 2022 when the survey was conducted island-wide. Data collected prior to 2017 were calibrated to account for a transition from belt transect to a cylinder survey method.

From 2020-2022, the Coral Reef Conservation Program (CRCP) funded a pilot survey to target the upper mesophotic habitats of St. Thomas and St. John. The Deep-NCRMP (DCRMP) has a sampling depth limit of 60 m (Grove et al., 2024).

Annual mean density and associated standard errors for NCMP and DCRMP for SEDAR 84 were provided by Grove et al. (2024). In Stock Synthesis, the time series of mean density across all observed lengths **were input as an index in numbers with a lognormal error distribution**. The associated length composition data, described in the following subsection, suggested that **the index reflected the abundance of juveniles but did not observe the larger adults concurrently observed in the commercial catch data**.

2.2.2 Length Composition

The NCRMP and DCRMP surveys in St. Thomas and St. John provided counts by individual lengths estimated to the nearest centimeter. **The length data inputs for both the commercial fleet and the surveys used 3-centimeter bins**, despite 1-centimeter data being available. This level of aggregation is common practice in stock assessments, as it helps reduce noise and overfitting associated with fine-scale variability that may not be informative for model estimation. Using 1-centimeter bins can introduce spurious detail due to measurement error or small-sample fluctuations. The 3-centimeter bins were used to strike a balance between preserving key patterns in the size composition while considering model stability.

A large proportion of small fish were observed in the NCRMP survey. **The smallest two bins, (2 - 5 centimeters) and (5 - 8 centimeters), were collapsed into a single bin (2 - 8 centimeters).**

Since multiple fish can be observed during a single dive, individual lengths are not independent observations. **The relative model weighting of the NCRMP survey and DCRMP survey length compositions across years was based on the number of paired dives.**

The length composition data provided reasonable support that younger fish were available to the NCRMP survey. Over half of the lengths from the NCRMP survey were smaller than 20 centimeters fork length, and 99% were below 32 centimeters fork length. Meanwhile, the length composition data also provided support that larger fish were available to the DCRMP. Over half of the lengths from the DCRMP survey were smaller than 26 centimeters fork length, and 98% were below 41 centimeters fork length. **Dome-shaped selectivity was explored for both the NCRMP and DCRMP surveys.**

Models were initially configured in Stock Synthesis with length composition data aggregated across the available years for each source of length data. Investigation of additional model configurations proceeded stepwise from the simplest configuration to those of moderate complexity. The steps included the inclusion of annual fishery-independent length compositions. The sequential model configurations are described later in this report.

2.3 Life History Data

The life history data used in the assessment included longevity-informed natural mortality, growth, length-weight, and maturity analyzed from 1,554 samples of Yellowtail Snapper collected across the U.S. Caribbean from 2013 to 2023 (Shervette, Rivera Hernández, & Peña Alvarado, 2024; Shervette, Rivera Hernández, & Zajovits, 2024). The largest fish was 57.2 centimeters fork length and the oldest was 26 years old.

Based on the available information, **the Yellowtail Snapper population was modeled from age 0 through age 26, and from 0 to 56-centimeters fork length, in 1-centimeter bins, with the largest values for each as plus groups.**

Note that SS3 allows the length bins of the data inputs to be larger than the bins used in the population model. **The bin size of all the length data inputs were 3 centimeters, the model's simulated population bin size was 1-centimeter bins.** When the population is modeled at a higher resolution concerning bin size, the likelihood function, which aims to match the observed data inputs and the simulated population estimates, operates at the resolution of the data inputs.

2.3.1 Growth

The SS3 growth formulation requires five parameters:

- Length at the youngest age
- Length at the maximum age
- Von Bertalanffy growth parameter (K)
- Coefficient of variation at the youngest age
- Coefficient of variation at the maximum age

Parameter estimates for Von Bertalanffy growth parameter (K) and the length at maximum age (L_∞) were based on 1,554 samples of Yellowtail Snapper collected across the U.S. Caribbean from 2013 to 2023 (Shervette, Rivera Hernández, & Peña Alvarado, 2024). When t_0 was fixed to -0.96, K was 0.23, and L_∞ was 42.4 centimeters fork length. When t_0 was estimated, it was -2.73, K was 0.12, and L_∞ was 50.8 centimeters fork length.

The SEDAR 84 assessment models were configured using the parameter estimates associated with the fixed t_0. Furthermore, **the estimated length at age zero from otolith analysis by Shervette, Rivera Hernández, & Peña Alvarado (2024) was modified in Stock Synthesis so that the length of the youngest age, age 0, was set to zero.** Without this modification, the model would be unable to fit the substantial amounts of small (<10cm) Yellowtail Snapper observed in the survey length composition data.

Coefficients of variation for both younger and older ages were initially set to 0.15. Ideally, growth coefficients of variation should be derived from observed length-at-age data, however, the assumed values are consistent with species of moderate growth variability (Ono et al., 2015; Schemmel et al., 2022).

Alternative model configurations associated with the growth data are described later in this report. They included:

- A higher growth coefficient of variation of 0.25 for younger ages was explored via sensitivity analysis.

2.3.2 Morphometric Conversion

The relationship between weight in grams and length in millimeters provided by Shervette, Rivera Hernández, & Peña Alvarado (2024) was converted to weight in grams and length in centimeters and used as a fixed model input. **The length-weight relationship was $W = 2.93 \times 10^{-5} * L^{2.8642}$, with weight (W) in kilograms and length (L) in centimeters.**

2.3.3 Maturity and Fecundity

Maturity was modeled as a logistic function. Parameter estimates for maturity were based on 1,876 samples of Yellowtail Snapper collected across the U.S. Caribbean from 2013 to 2023 (Shervette, Rivera Hernández, & Peña Alvarado, 2024). **The fecundity of Yellowtail Snapper was estimated with a proxy (body weight * maturity at age).**

2.3.4 Stock Recruitment

A Beverton-Holt stock-recruit function was used to parametrize the relationship between spawning output and resulting recruitment of age-0 fish. The stock-recruit function requires three parameters:

- Steepness (h) characterizes the initial slope of the ascending limb (i.e., the fraction of recruits produced at 20% of the unfished spawning biomass).
- The virgin recruitment (R0; estimated in log space) represents the asymptote or unfished recruitment levels.
- The variance term (sigma R) is the standard deviation of the log of recruitment and describes the amount of year-to-year variation in recruitment.

Only the virgin recruitment (R0) was estimated. **Sigma R and steepness were fixed at 0.7 and 0.99, respectively.** The 0.7 sigma R reflects slightly high variation in recruitment. A value of 0.6 is a moderate level of recruitment variability, with lower values indicating lower variability and more predictable year-to-year recruitment. The primary assumption for steepness was that this stock is not a closed population, so recruitment may not be strongly tied to the local spawning stock biomass. **In initial model configurations, annual deviations from the stock-recruit function were not estimated.** Steepness and R0 were explored via likelihood profiling.

Continuous recruitment was parameterized in SS3 using four settlement events. Equal proportions of recruits were assigned to each settlement event, and they were spaced such that recruitment would happen in months 1, 4, 7, and 10. This allowed growth to be staggered, reflecting a closer approximation of the observed stock dynamic of year-round spawning activity.

2.3.5 Maximum Age and Natural Mortality

Empirical estimates of natural mortality (M) can be derived using life history information such as longevity, growth, and maturity. For this assessment, the Natural Mortality Tool was used to estimate M (Cope & Hamel, 2022). Various methods were explored, incorporating factors such as maximum age, the Von Bertalanffy growth parameter (K), theoretical age at length zero (t_0), asymptotic length (L_∞), and age at 50% maturity.

Inputs for the Natural Mortality Tool were sourced from Shervette, Rivera Hernández, & Peña Alvarado (2024), which observed a maximum age of 26 years for Yellowtail Snapper in the U.S. Caribbean. However, the mean age of 1,554 sampled fish was 5 years.

Table 7.2 summarizes the empirical methods used to estimate M based on available life history data. The primary approach for determining natural mortality in this assessment was longevity-based (Hamel & Cope, 2022).

A natural mortality value of 0.208 was used in the initial model runs. This value corresponds with the maximum age of 26 years reported by Shervette, Rivera Hernández, & Zajovits (2024). Model configurations incorporating an alternative M value associated with a slightly higher maximum age were explored through sensitivity analyses, which are discussed later in this report.

2.4 Summary of Data-Informed Modeling Configurations

- Based on the available data, the assessment was configured with one area, one season, one commercial fleet, and two fishery-independent surveys.

2.4.1 Commercial Fleet

- The catch was input as biomass (in metric tons) and was treated as if it occurred over an entire fishing season; i.e., each fishing year.
- The start and end years of the model were 2012 and 2022, respectively.
- Based on expert input and limited data, discards were not modeled. The assessment assumed full retention of catch.
- The input standard error for the landings was set to 0.3.
  - A higher standard error of 2 was explored via sensitivity analysis.
- The initial equilibrium catch was configured in initial runs as 25 metric tons.
  - The initial equilibrium catch was explored via likelihood profiling.
- The relative model weighting of the commercial fleet length compositions was based on the number of trips sampled.
- Due to low sample sizes, the fishery-dependent commercial fleet length composition data were combined across all years.

- The length compositions of the commercial fleet were assumed to be representative of the total catch.
- A double normal function was used to model the relative vulnerability of capture by length for the commercial fleet.

2.4.2 Survey

- The NCRMP index reflected the abundance of juveniles.
- The DCRMP index reflected larger fish than the NCRMP index.
- The surveys were configured as an index in numbers with a lognormal error distribution
- The relative model weighting of the surveys length compositions across years were based on the number of paired dives.
- The length data inputs used 3-centimeter bins.
- The model's simulated population bin size was 1-centimeter bins.
- The smallest two bins, (2 - 5 centimeters) and (5 - 8 centimeters), were collapsed into a single bin (2 - 8 centimeters).
- The surveys were set up in the models with dome-shaped selectivity.

2.4.3 Life History

- The Yellowtail Snapper population was modeled from age 0 through age 26, and from 0 to 56-centimeters fork length, in 1-centimeter bins, with the largest values for each as plus groups.
- Parameter estimates for Von Bertalanffy growth parameter (K) and the length at maximum age (L_∞) were based on samples of Yellowtail Snapper collected across the U.S. Caribbean from 2013 to 2023.
- The estimated length at age zero from otolith analysis by Shervette, Rivera Hernández, & Peña Alvarado (2024) was modified in Stock Synthesis so that the length of the youngest age, age 0, was set to zero.
- Coefficients of variation for both younger and older ages were initially set to 0.15.
  - A higher growth coefficient of variation of 0.25 for younger ages was explored via sensitivity analysis.
- The length-weight relationship was W = 2.93 x 10^-5 L^ 2.8642, with weight in kilograms and length in centimeters.

- A natural mortality value of 0.208 was used in the initial model runs.
  - Alternative M values were explored through sensitivity analyses.
- Maturity was modeled as a logistic function.
- The fecundity of Yellowtail Snapper was estimated with a proxy (body weight * maturity at age).
- A Beverton-Holt stock-recruit function was used to parametrize the relationship between spawning output and resulting recruitment of age-0 fish.
- Sigma R and steepness were fixed at 0.7 and 0.99, respectively.
- In initial model configurations, annual deviations from the stock-recruit function were not estimated.
- Continuous recruitment was parameterized in SS3 using four settlement events.

3 Model Development

3.1 Framework

Stock Synthesis V3.30.22 was the modeling approach applied in the current SEDAR 84 assessment because of compatibility with the available data and consistency with standard practices.

Stock Synthesis is a statistical catch-at-age model that uses a population model, an observation model, and an estimation model and applies a likelihood function in the estimation process (Methot et al., 2020). Stock Synthesis, commonly referred to as SS3, has been applied extensively worldwide for stock assessment evaluations (Methot & Wetzel, 2013). It has also been used for previous data-limited and data-moderate SEDAR assessments, including the SEDAR 57 assessments and subsequent updates for Caribbean Spiny Lobster (*Panulirus argus*), and the SEDAR 80 assessments for Queen Triggerfish (*Balistes vetula*) (SEDAR, 2019, 2022).

The Stock Synthesis modeling framework is a compatible tool for SEDAR stock assessments in the U.S. Caribbean because it can accommodate a wide range of model complexities, from data-limited to highly detailed assessments (Cope, 2024). Stock Synthesis allows for the characterization of stock, fishing fleet, and survey dynamics through various parameters, which can be either fixed based on external data or estimated when sufficient assessment data are available. Additionally, it can incorporate complex biological dynamics, such as continuous recruitment, which is appropriate for accurately assessing St. Thomas and St. John Yellowtail Snapper.

Finally, R packages such as r4ss and ss3diags facilitate critical evaluations of model reliability and model comparisons (Carvalho et al., 2021; Taylor et al., 2021). For example, R4SS provides visualization and diagnostic tools to summarize and interpret fit, convergence, and key output metrics. SS3diags focuses on retrospective analyses, hind-casting, and residual pattern evaluations. The integration of these tools allows rigorous uncertainty analysis, streamlined sensitivity analyses, and enhanced transparency in decision-making.

Stock Synthesis models were initially configured using an annual commercial catch time series and length compositions data that were aggregated across the available years for each source of length data. Model development proceeded stepwise from the simplest configuration to those of moderate complexity.

3.2 Overview

The SEDAR 84 model development process started with simple data-limited configurations, followed by exploring data-moderate configurations, individually and combined. The simplest configurations aggregated length compositions across years by implementing the super-period approach in Stock Synthesis. When using super-periods, the estimation model generates annual values, but the likelihood function will compare the expected composite to the data composite across the super-period. When using this approach on the length composition data, Stock Synthesis models will still aim to identify parameter values for selectivity that achieve a fit between the predicted and observed data.

The initial setup steps and description of the modeling scenarios documented in this report are listed in Table 7.3. For the SEDAR 84 Yellowtail Snapper assessment, the data-moderate considerations explored included: (a) indices of abundance, (b) annual fishery-independent length compositions, (c) dome-shaped selectivity, and (d) recruitment deviations. Additional model configurations were not pursued. For example, annual fishery-dependent length composition data were not considered due to low sample sizes.

The Stock Assessment Continuum Tool was used to develop the initial model setup by importing CSV input files and utilizing its Shiny application interface (Cope, 2024). Starting from the Continuum Tool (ct) model, a series of sequential modifications were applied to represent three key biological and data-related complexities: adjusted length at age zero (m1), continuous recruitment (m2), and increased catch uncertainty (m3).

This report focuses on the results and sensitivities associated with the m3 models, evaluated under the various data configurations summarized in sec-data-summary. While a full discussion of sensitivity runs is provided later in the report, they are also summarized in Table 7.3 to help familiarize the reader with the terminology used throughout. For instance, model **v4__m3__s1** refers to the fourth scenario (**v4**, which includes an index and dome-shaped selectivity), the third level modification (**m3**, reflecting continuous recruitment and higher catch uncertainty), and the first sensitivity scenario (**s1**, higher uncertainty on growth).

Due to the lack of an estimable spawner-recruit relationship across the explored models, a commonly used 40% spawning potential ratio (SPR) was used as a proxy for Maximum Sustainable Yield (MSY) and as the basis for management reference points (Shertzer et al., 2024). The SPR proxy reflects the ratio of expected lifetime reproductive potential under fished conditions compared to virgin conditions.

4 Model Diagnostics

Model diagnostics aimed to follow the conceptual process described by Carvalho et al. (2021). Their approach includes evaluating goodness of fit, information sources and structure, prediction skill, convergence, and model plausibility. Although Carvalho et al. (2021) advise detours and additional model explorations when initial diagnostic tests fail, advanced diagnostics, such as likelihood profiles, retrospective, and jitter analyses, were conducted even when initial tests failed to comprehensively communicate the various model configurations explored.

4.1 Convergence

Three approaches were used to check for model convergence. They were investigating for the presence of (1) bounded parameters, (2) high final gradients, and (3) a positive definite hessian. As described by Carvalho et al. (2021), checking for bounded parameters can indicate discrepancies with data or model structure. Additionally, small final gradients and a positive definite hessian can indicate that the objective function achieved good convergence.

The models presented in this report all had a positive definite Hessian, indicating that each reached a local minimum and a locally optimal fit. None of the models had parameters that were bounded, suggesting the optimization was not constrained by parameter limits. Finally, the parameter gradients in all models were small and well below 0.001, which is commonly used in the R4SS R package to identify large gradients (Table 7.7).

4.2 Correlation Analysis

High correlation among parameters can lead to flat response surfaces and poor model stability. By performing a correlation analysis, modeling assumptions that lead to inadequate configurations can be identified. Because of the highly parameterized nature of stock assessment models, some parameters are expected to be correlated (e.g., stock recruit parameters). However, many strongly correlated parameters suggest reconsidering modeling assumptions and parameterization.

High correlations (correlation coefficients greater than 0.95 or less than -0.95) were observed across nearly all m2 model scenarios (Table 7.4). One particularly noteworthy correlation was between the estimates of initial fishing mortality (Initial F) and unfished recruitment (R0), which exceeded -0.99 in all models except for version v19_m2, where it was slightly lower but still substantial at -0.94.

In the initial default configurations of both the m1 and m2 model scenarios, the standard error on the initial equilibrium catch was fixed at a low value of 0.01. This tightly constrained the model to the input catch of 25 metric tons effectively limiting flexibility in estimating the corresponding initial fishing mortality. To address this issue, the standard error was increased to 0.3, allowing the estimated initial catch to diverge from the fixed input value (Table 7.6). This adjustment reduced the overly strong correlation between Initial F and R0 by relaxing the constraint on initial fishing mortality. The effects of increasing the standard error beyond 0.3 are discussed further in the sensitivity analyses section.

The v4_m2 and v4_m3 model scenarios showed high correlations (> 0.95) between the two parameters used to define the commercial fleet logistic selectivity: the length at peak selectivity and the width of the ascending limb. Correlations between these selectivity parameters is expected. While estimated values varied slightly among models, they produced similar length-based selectivity curves for the commercial fleet (Figure 8.1).

4.3 Evaluating Variance

To check for parameters with high variance, parameter estimates are reported with their resulting standard deviations. Table 7.7 presents the model-estimated values and standard deviations for the main active parameters. While it's important to consider the scale of each parameter, the results suggest that key parameters are not being estimated with high precision. In particular, the coefficients of variation for initial fishing mortality are relatively high across all models, indicating considerable uncertainty in these estimates.

Figure 8.2 illustrates how the estimate and uncertainty for the unfished recruitment (R0) and virgin spawning stock biomass change throughout the sequential steps of model development. In general, increasing the complexity of the model with annual fishery-independent length composition data (models v8_m3 and v19_m3) results in slightly higher values for both of these parameters. The uncertainty across the response surface for key parameters is further examined later in the report using likelihood profiles.

Stock Synthesis also provides estimates and standard deviations for derived quantities such as unfished spawning stock biomass, initial year spawning biomass, and the initial depletion. Initial depletion is defined as the initial biomass divided by the unfished biomass. Table 7.5 shows this information and it is also plotted in Figures 8.3a and 8.3b.

Compared to the other m3 model scenarios, Model v19_m3 exhibited the highest initial depletion reflected in the lowest spawning biomass ratio (SSB Initial / SSB Unfished) reported in Table 7.5. This ratio is also plotted as a time series of total biomass relative to virgin spawning biomass in Figure 8.3a. The sensitivity runs described later further explore the uncertainty associated with these model scenarios.

4.4 Jitter Analysis

Jitter analysis is a relatively simple method that can be used to assess model stability and to determine whether the search algorithm has found a global, as opposed to local, solution. The premise is that all starting values are randomly altered (or 'jittered') by an input constant value, and the model is rerun from the new starting values. If the resulting population trajectories across many runs converge to the same solution, this provides support that a global minimum has been obtained. This process is not fault-proof; no guarantee can ever be made that the 'true' solution has been found or that the model does not contain misspecification. However, if the jitter analysis results are consistent, it provides additional support that the model is performing well and has come to a stable solution. For this assessment, a jitter value of 0.2 was applied to the starting values, and 30 runs were completed. The jitter value defines a uniform distribution in cumulative normal space to generate new initial parameter values (Methot et al., 2020).

Consistent with earlier results indicating that the models reached local minima (positive definite Hessian), no jitter runs produced a lower likelihood than the best fit already identified for each model. However, with models frequently converging at higher likelihoods, the jitter analysis suggests some instability in the model scenarios (Figure 8.4).

4.5 Residual Analysis

The primary approach to investigate model performance was a residual analysis of model fit to each data set (e.g., catch, length compositions, indices). Any temporal trend in model residuals or disproportionately high residual values can indicate model misspecification and poor performance. Ideally, residuals are randomly distributed, conform to the assumed error structure for that data source, and are not of extreme magnitude. Any extremely positive or negative residual patterns indicate poor model performance and potential unaccounted-for process or observation error.

4.5.1 Catch

All models closely matched the observed 2012–2022 catch data, as expected given the data-limited configurations. In these configurations, Stock Synthesis relies heavily on the input catch data, with minimal additional information to support estimation of values that differ from the observations. The effect of increasing the standard error on the catch to 0.3 during the model development m3 scenario was to give the model more flexibility in estimating initial equilibrium catch and corresponding initial fishing mortality. This adjustment allowed the model to explore alternative fits while remaining informed by the assumption of a larger level of historically sustained catch. Increasing the standard error from 0.01 in the m2 model scenarios to 0.3 in the m3 model scenarios resulted in higher estimates of the initial equilibrium catch (Table 7.6). This topic will be revisited in the sensitivity analyses, where model runs with even higher catch standard error of 2 are compared. Additional justifications for further allowing the estimated initial equilibrium catch to differ from the assumed initial equilibrium catch of 25 metric tons is further investigated via likelihood profiles (See Section 4.7.2).

4.5.2 Indices

For the models without recruitment deviation being estimated (model scenarios v4_m2, and v8_m2), the predicted NCRMP and DCRMP indices are flat (Figures 8.5 and 8.6). In the model scenarios with estimated recruitment deviations (v19_m3), there is some a slight overall decline in the estimated indices. Notably, high uncertainty in the index was observed in 2013 of the NCRMP index (Figure 8.5).

4.5.3 Length Compositions

Figure 8.7 shows the cumulative fit across all years between the observed and predicted length composition for the model scenario that had aggregated length data (v4_m3). Figures 8.8 and 8.9 provide the cumulative and the year-specific length compositions for the model scenarios that included annual fishery-independent length data (v8_m3, and v19_m3).

Among the models with the annual fishery-independent length data (v8_m3, and v19_m3), the model with recruitment deviation being estimated (v19_m3), has improved fits to the annual NCRMP and DCRMP length composition data (Figure 8.9b). In the scenarios without recruitment deviations (v8_m3), the predicted NCRMP composition is identical across years and similar to cumulative fit when the length data were aggregated in model v4_m3. Finally, Figure 8.10 shows the observed and predicted mean length by year.

4.6 Retrospective Analysis

A retrospective analysis is a helpful approach for investigating the consistency of terminal year model estimates (e.g., SSB, Recruits, Fs) and is often considered a sensitivity exploration of impacts on key parameters from changes in data. The analysis sequentially removes a year of data and reruns the model. Suppose the resulting estimates of derived quantities such as SSB or recruitment differ significantly. In such a case, serial over- or underestimation of important quantities can indicate that the model has an unidentified process error and could require reassessing model assumptions. It is expected that removing data will lead to slight differences between the new terminal year estimates and the estimates for that year in the model with the complete time series of data. Estimates in years before the terminal year may have increasingly reliable information on cohort strength. Therefore, slight differences are usually expected between model runs as more years of length composition data are sequentially removed. Ideally, the difference in estimates will be slight and randomly distributed above and below the estimates from the model with complete data set time series.

The results of a five-year retrospective analysis are plotted in Figure 8.11. All retrospectives show wide 95% confidence intervals. The retrospective pattern was most divergent in the scenario with recruitment deviations and annual fishery-independent length data, model v19_m2. In this scenario, the spawning biomass shows sensitivity to the removal of 2019 and 2018 data.

4.7 Likelihood Profiles

Profile likelihoods are used to assess the stability of parameter estimates by examining changes in the negative log-likelihood for each data source and evaluating the influence of each source on the estimate. The analysis is performed by holding a given parameter at a constant value and rerunning the model. The model is run repeatedly over a range of reasonable parameter values. Ideally, the graph of change in likelihood values against parameter values will yield a well-defined minimum. When the profile plot shows conflicting signals or is flat across its range, the given parameter may be poorly estimated.

Typically, profiling is carried out for key parameters, particularly those defining the stock-recruit relationship (steepness, virgin recruitment, and sigma R). Profiles were explored across virgin recruitment (R0), initial equilibrium catch, and steepness.

4.7.1 Unfished Recruitment (R0)

Figure 8.12 shows the profile likelihood for the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function for St. Thomas and St. John

Yellowtail Snapper across model scenarios (v4,_m3, v8_m3 and v19_m3). All models show conflicting signals and relatively poorly defined minimums, with a range of equally plausible values reflected by only small changes in likelihood. Figure 8.13 shows the corresponding change in the Maximum Sustainable Yield Proxy based on SPR 40% across the range of unfished recruitment values explored.

4.7.2 Initial Equilibrium Catch

Figure 8.14 shows the profile likelihood for the initial equilibrium catch for St. Thomas and St. John Yellowtail Snapper across model scenarios (v4_m3, v8_m3, and v19_m3). The models suggest improved fit associated with larger values of fixed initial equilibrium catch. Figure 8.14 shows the profile likelihood for the initial equilibrium catch for St. Thomas and St. John Yellowtail Snapper across model scenarios (v4_m3, v8_m3, and v19_m3). The profiles indicate improved model fit with larger fixed values of initial equilibrium catch. A few of the sensitivity runs, specifically two from the v4_m3 scenario and three from the v19_m3 scenario, appear as peaks or spikes in the likelihood profile. These reflect local minima where the model settled on alternative estimates of the DCRMP selectivity end parameter. Although they affect the smoothness of the profile, these peaks are not considered a concern for the overall analysis. Figure 8.15 shows the corresponding change in the MSY SPR 40% across the range of initial equilibrium catch values explored. This suggests that given further flexibility the initial equilibrium may be estimated higher. This was further examined through sensitivity runs further relaxing the information that informs the initial model conditions.

4.7.3 Steepness

Figure 8.16 shows the profile likelihood for the steepness parameter of the Beverton – Holt stock-recruit function for St. Thomas and St. John Yellowtail Snapper across model scenarios (v4_m3, v7_m3, and v19_m3). The lowest likelihoods are predominantly associated with the lowest values of steepness, driven by the fit to the length data. Figure 8.17 shows the corresponding change in the MSY SPR 40% across the range of steepness values explored.

4.8 Sensitivity Runs

Sensitivity analyses were conducted to evaluate the impact of key model assumptions on derived quantities. Details of the process and naming conventions are provided in Table 7.3. The analyses explored alternative assumptions for the CV on growth, fixed input for maximum age-informed mortality, and the standard error applied to catch data.

For each model scenario and sensitivity run:

- Table 7.6 provides the initial equilibrium catch
- Tables 7.8 and 7.9 provide the MSY proxy (based on SPR 40%)
- Table 7.10 summarizes the fishing mortality rate and spawning stock biomass ratios relative to the rate and biomass of the stock associated with the MSY proxy (based on SPR 40%)

4.8.1 Growth CV

The first sensitivity scenario (s1) assumed the coefficient of variation (CV) for young fish was increased from 0.15 to 0.25. The m3_s1 sensitivities resulted in a slight change to the derived quantities relative to the corresponding m3 sensitivity model configurations (Tables 7.6, 7.8, 7.9, and 7.10). Growth is a critical process in all stock assessment models, and in this assessment, the CV for young fish was a particularly relevant sensitivity to examine due to the large number of small individuals (less than 8 cm) observed in the NCRMP fishery-independent survey length compositions. While additional sensitivities related to growth were considered, they will be revisited in the discussion section as part of the research recommendations. The current models use the best available growth parameters from Shervette, Rivera Hernández, & Peña Alvarado (2024).

4.8.2 Natural Mortality

The second sensitivity scenario (s2) explored a slightly lower natural mortality of 0.193, corresponding to a higher maximum age of 28 years (SEDAR, 2020). This higher maximum age, observed along the northern range of the species (off North Carolina and South Carolina), is only slightly older than the maximum age of 26 years observed by Shervette, Rivera Hernández, & Zajovits (2024). Although the true maximum age is often larger than the maximum age observed, particularly for species that have sustained historical fishing pressure, the Hamel (2015) method estimates natural mortality based on the maximum observed age. In this assessment, age is the only factor used to inform the estimate of natural mortality, making it important to consider the implications of assuming a lower M, which reflects a less productive stock. The m3_s2 sensitivity models showed the only slight differences from the corresponding m3 configurations. These differences included lower spawning stock biomass ratios, and higher fishing mortality ratios and similar equilibrium catch and estimates of maximum sustainable yield proxy (Tables 7.6, 7.8, 7.9, and 7.10).

4.8.3 Standard Error on Catch

The third sensitivity scenario (s3) examined the effect of further relaxing the information that informs the initial model conditions. In the m3 model scenarios, a standard error of 0.3 was applied to the landings data (see Section 2.1.1). Compared to the m2 model scenarios, this resulted in higher estimates of initial equilibrium catch. However, likelihood profiles (see

Section 4.7.2) showed improved fit at even higher fixed estimates of equilibrium catch. This led to the exploration of increased input uncertainty using a standard error of 2.0 associated with the input equilibrium catch.

Effectively, this provides greater flexibility in estimating initial conditions, which are known to be difficult to resolve without longer time series. The m3_s3 sensitivities produced extremely higher estimates of initial catch and Maximum Sustainable Yield, lower fishing mortality ratios, and moderately high biomass ratios compared to the m3 models (Tables 7.6, 7.8, 7.9, and 7.10).

These results highlight the significance of uncertainty in initial conditions and underscores the value of longer historical data series. Without them, there is considerable uncertainty in defining the initial conditions, and the m3_s3 results imply that if early landings were larger than assumed in the m3 models, the stock may be more productive.

Figure 8.18 shows that the estimates and associated uncertainty for unfished recruitment (R0) and virgin spawning stock biomass in the m3_s3 sensitivity scenarios are shifted towards higher values compared to the m3 model results (See Figure 8.2). The time series of derived quantities for the m3_s3 scenarios are provided in Figure 8.19 and appear broadly similar to those from the m3 models shown in Figure 8.3, with the exception of the scale and notably higher uncertainty.

4.8.4 Standard Error on Catch and Natural Mortality

The fourth sensitivity scenario (s4) explored the combined implications of two sensitivities: increased uncertainty around initial equilibrium catch and lower natural mortality associated with higher maximum age. By evaluating both assumptions simultaneously, this scenario investigates the compounding uncertainty associated with the baseline m3 model configurations.

The combined effect of these changes were similar to the third sensitivity scenario exploring only the standard error on catch (Tables 7.6, 7.8, 7.9, and 7.10). As shown in Figure 8.20, the estimates and uncertainty for unfished recruitment (R0) and virgin spawning stock biomass in the m3_s4 models are also similar to those of the prior sensitivity plotted in Figure 8.18. The time series of derived quantities in Figure 8.21 indicate that the m3_s4 models converge on drastically higher spawning output and lower fishing mortality relative to the m3 scenarios.

5 Discussion

This assessment presents a series of model configurations developed to address key uncertainties in both the data and model structure, using an integrated framework to evaluate the stock status of Yellowtail Snapper in St. Thomas and St. John. Across the wide range of scenarios explored, all model configurations consistently indicated that the stock is not overfished and that overfishing is not occurring (Table 7.10). However, diagnostics and sensitivity analyses revealed important caveats, primarily due to the strong influence of fixed parameter assumptions including initial conditions and growth.

A major source of uncertainty stems from unknown initial catch levels, which are strongly tied to the resulting levels of sustainable yield. Because these dynamics remain confounded we strongly recommend either extending the catch history if a reliable catch time series extending back to the unexploited state is available or exploring methods that decouple the estimation of initial fishing mortality and starting year depletion level.

Among all sensitivity analyses, assumptions about historical catch levels had the greatest influence on model outcomes. These results highlight the importance of structured sensitivity testing to better understand how uncertainty affects model results. Future research should explore the use of model grids or ensemble approaches to formally incorporate uncertainty and improve the reliability of management advice.

Growth is a key biological input that influences estimates of stock productivity and selectivity. Alternative growth curves should be considered, potentially by incorporating broader regional data sets and accounting for the length and age distribution of samples. The variability of size at age for Yellowtail Snapper noted in Shervette, Rivera Hernández, & Zajovits (2024) is an important consideration, thus revisiting the growth inputs via additional sensitivities could strengthen the biological realism and performance of future assessments.

Recruitment deviations, when estimated, were particularly uncertain, given the limited years of available data. However, the availability of fishery-independent length data from the NCRMP and DCRMP surveys provides a valuable information source. The observed abundance of small fish may allow better inference of recruitment in future assessments. Finer resolution data (e.g., using 1 cm bins for specific years) could improve model performance and reduce uncertainty.

Integrated models such as Stock Synthesis are powerful not only for synthesizing multiple data sources but also for making key assumptions explicit and testable. Without this flexibility, assessments risk producing outputs that must be taken at face value, with little opportunity to evaluate the effects of underlying assumptions.

While not every species will have sufficient data for an integrated assessment, wherever possible, structured scenario testing should be pursued to explore alternative hypotheses and better understand the drivers of population dynamics. Such efforts strengthen the scientific foundation for management advice and help balance the need for both rigorous and practical assessment frameworks.

This assessment assumes an open population with recruitment not tightly linked to local spawning stock. This assumption could benefit from future exploration of regional connectivity, as it has implications for both model structure and management scale. If connectivity across islands is strong, larger-scale stock definitions or spatially explicit metapopulation modeling approaches may be warranted.

Finally, the stepwise modeling approach used in this assessment offers a framework that could be applied to other Caribbean species. Expanding the approach through targeted data collection and method development could improve the timeliness and robustness of stock assessments across the region. This will require continued support for long-term monitoring programs, higher-resolution data collection, and investment in model development and bridging exercises to deliver science-based, real-time management advice.

6 Assessment Process Research Recommendations

To mitigate some of the data uncertainties it is recommended to:

- Expand fishery-independent survey time series and resolution (e.g., retain and use 1-cm length bin data where available).
- Further evaluate natural mortality and growth assumptions. Collect and analyze additional life history data to evaluate the accuracy around growth and natural mortality rates.
- Conduct focused research on historical catches and fishing history to inform and constrain early model conditions.
- Consider using simpler production models or age-structured models with fixed selectivity to isolate and evaluate different data inputs.
- Develop and evaluate model ensembles or uncertainty grids to guide catch advice under different plausible scenarios.
- Investigate stock connectivity to better understand local versus regional recruitment dynamics and their implications for informing steepness.
- Research methods, including simulations, to "right-size" model complexity to match data availability, avoiding overparameterization in data-limited contexts.
- Support Management Strategy Evaluations that are robust to key uncertainties to guide harvest advice.
- Ensure the continuation of fishery-independent survey programs (e.g., National Coral Reef Monitoring Program) with consistent spatial and temporal coverage.
- Maintain and expand commercial catch monitoring programs. Expand port sampling and other fishery-dependent data collection to fill gaps in length composition and effort data.
- The use of initial catch in this assessment was intended to inform an initial starting depletion for the population. However, model evaluations show it also strongly informs maximum sustainable yield estimates. This is an undesirable outcome and additional

research into how to decouple these impacts would significantly improve model result reliability.

- At the data workshop, workshop participants emphasized that federal regulations do affect retention, however there were insufficient data on the lengths of discarded fish to inform length-based retention. Explore parameterizing retention to improve selectivity of the commercial fleet and interpret the apparent high selectivity of larger individuals that are poorly estimated by the current models.

7 Tables

Table 7.1: Commercial landings of Yellowtail Snapper reported in St. Thomas St. John from 2012-2022 in metric tons and pounds by year, along with the percentage of the total commercial landings that came from each gear group.

Year	Metric Tons	Pounds	Handline	Other	Rod and Reel	Traps
2012	15.08	33,251	69%	22%	1%	9%
2013	10.74	23,685	67%	21%	1%	11%
2014	14.18	31,261	67%	19%	2%	12%
2015	11.01	24,273	80%	8%	2%	11%
2016	12.72	28,034	74%	9%	3%	13%
2017	10.33	22,772	71%	9%	4%	16%
2018	9.70	21,377	73%	5%	2%	20%
2019	11.29	24,881	76%	4%	3%	18%
2020	12.00	26,456	80%	1%	3%	15%
2021	7.47	16,477	71%	0%	9%	20%
2022	8.16	17,984	70%	0%	11%	19%
Total	122.67	270,451	72%	10%	3%	14%

Table 7.2: Empirical estimates of natural mortality (M) derived using life history information and the Natural Mortality Tool (Cope & Hamel, 2022). All models included in this report utilize the natural mortality estimate of 0.208 corresponding with the maximum age observed by Shervette, Rivera Hernández, & Peña Alvarado (2024), except two of the sensitivity scenarios (s2 and s4) which utilize the 0.193 natural morality corresponding with the estimated maximum age from SEDAR (2020).

Input Source	Input Type	Input	M	Method
SEDAR (2020)	Maximum age	28	**0.193**	Hamel_Amax
Shervette, Rivera Hernández, & Peña Alvarado (2024)	Maximum age	26	**0.208**	Hamel_Amax
Meta-analysis	Scientific name	*Ocyurus chrysurus*	0.348	FishLife

Table 7.3: Summary of process and naming conventions used across different model development stages of the SEDAR 84 St. Thomas and St. John Yellowtail Snapper stock assessment.

Stage	Code	Sequential modeling steps
Initial	ct	model initialized with continuum tool (ct)
Initial	m1	ct + adjusted length at age zero
Initial	m2	m1 + continuous recruitment
Initial	m3	m2 + catch uncertainty
Scenario	null	catch and super-year length data
Scenario	a	index
Scenario	v1	index + annual fishery-independent length data
Scenario	v4	index + dome-shaped selectivity
Scenario	v8	index + annual fishery-independent length data + dome-shaped selectivity
Scenario	v19	index + annual fishery-independent length data + dome-shaped selectivity + recruitment deviations
Sensitivity	s1	higher CV on growth young
Sensitivity	s2	higher age and lower m
Sensitivity	s3	higher catch uncertainty
Sensitivity	s4	s2 + s3

Table 7.4: St. Thomas and St. John Yellowtail Snapper correlations between estimated parameters across the m2 and m3 model scenarios. The table shows correlations greater than 0.9 or less than -0.9. Correlations that are greater than 0.95 or less than -0.95 are shown in red.

Scenario	Estimated Parameters		Correlation Coefficient
v4_m2	Initial F	Unfished Recruitment (R0)	-0.992
v4_m2	Commercial Selectivity Asend.	Commercial Selectivity Peak	0.963
v4_m3	Commercial Selectivity Asend.	Commercial Selectivity Peak	0.959
v8_m2	Initial F	Unfished Recruitment (R0)	-0.990
v19_m2	Initial F	Unfished Recruitment (R0)	-0.943

Table 7.5: St. Thomas and St. John Yellowtail Snapper derived quantities for unfished and initial spawning stock biomass in metric tons (mt) along with standard deviations (SD) and coefficient of variation (CV) by model scenario (v4_m3, v8_m3, and v19_m3). CV is calculated as the SD divided by the parameter estimate.

Derived Quantity	Scenario	Estimate	SD	CV
SSB Unfished (mt)	v4_m3	163.01	43.16	0.26
	v8_m3	186.18	45.96	0.25
	v19_m3	180.57	43.06	0.24
SSB Initial (mt)	v4_m3	42.85	20.47	0.48
	v8_m3	45.10	17.23	0.38
	v19_m3	25.66	9.91	0.39
Ratio SSB Initial:Unfished	v4_m3	0.26	0.13	0.48
	v8_m3	0.24	0.09	0.39
	v19_m3	0.14	0.07	0.46

Table 7.6: St. Thomas and St. John Yellowtail Snapper estimated initial equilibrium catch in metric tons by model scenario including across sensitivity runs. The input value was 25 metric tons with a standard error of 0.3.

Parameter	Scenario	v4	v8	v19
Commercial Equilibrium Catch	m2	25.01	25.01	25.02
	m3	30.95	35.44	35.84
	m3_s1	34.10	36.88	38.68
	m3_s2	31.14	35.09	34.93
	m3_s3	146.98	201.85	135.83
	m3_s4	130.99	186.93	116.44

Table 7.7: St. Thomas and St. John Yellowtail Snapper parameters, standard deviations (SD), and coefficient of variation (CV) by model scenario (v4_m3, v8_m3, and v19_m3). CV is calculated as the SD divided by the parameter estimate.

Parameter	Scenario	Estimate	SD	CV	Gradient
Commercial Selectivity Asend.	v4_m3	2.34	0.70	0.30	2.4e-05
	v8_m3	-5.69	5.93	-1.04	-3.7e-07
	v19_m3	-5.12	7.24	-1.41	-9.6e-07
Commercial Selectivity Peak	v4_m3	28.49	1.51	0.05	-2.6e-05
	v8_m3	25.43	2.25	0.09	-4.4e-06
	v19_m3	25.42	3.13	0.12	-7.5e-06
DCRMP Selectivity End	v4_m3	-0.34	0.33	-0.97	-1.6e-06
	v8_m3	-0.74	0.30	-0.41	-1.4e-06
	v19_m3	-0.93	0.32	-0.34	3.4e-06
DCRMP Selectivity Peak	v4_m3	18.42	0.49	0.03	1.1e-06
	v8_m3	18.76	0.55	0.03	-5.3e-06
	v19_m3	17.89	0.65	0.04	1.4e-05
DCRMP Selectivity Top	v4_m3	-1.21	0.17	-0.14	-4.9e-07
	v8_m3	-1.25	0.16	-0.13	-1.6e-05
	v19_m3	-1.17	0.15	-0.13	7.9e-06
Initial F	v4_m3	0.47	0.34	0.72	-6.2e-08
	v8_m3	0.50	0.28	0.56	-2.0e-07
	v19_m3	1.06	0.72	0.68	-9.7e-07
NCRMP Selectivity End	v4_m3	-1.91	0.25	-0.13	1.7e-07
	v8_m3	-1.78	0.24	-0.13	5.4e-06
	v19_m3	-1.93	0.24	-0.12	5.6e-06
NCRMP Selectivity Peak	v4_m3	8.21	0.31	0.04	-1.6e-05
	v8_m3	8.17	0.31	0.04	1.2e-06
	v19_m3	7.17	0.50	0.07	1.6e-05
	v4_m3	-0.70	0.04	-0.06	-1.2e-05

Parameter	Scenario	Estimate	SD	CV	Gradient
NCRMP Selectivity Top	v8_m3	-0.70	0.04	-0.06	1.2e-05
	v19_m3	-0.67	0.04	-0.06	4.5e-05
Unfished Recruitment (R0)	v4_m3	5.75	0.26	0.05	-1.1e-05
	v8_m3	5.88	0.25	0.04	3.2e-06
	v19_m3	5.85	0.24	0.04	9.5e-06

Table 7.8: St. Thomas and St. John Yellowtail Snapper derived quantities of the MSY proxy (based on SPR 40%) in metric tons by model scenario (v4_m3, v8_m3, and v19_m3) and corresponding each model scenario's four sensitivity runs. CV is calculated as the SD divided by the parameter estimate. Estimates of the MSY proxy are also presented in pounds in Table 7.9.

Scenario	MSY Proxy	SD	CV
v4_m2	22.81	2.19	0.10
v4_m3	26.96	7.02	0.26
v4_m3_s1	28.59	7.30	0.26
v4_m3_s2	26.37	7.16	0.27
v4_m3_s3	121.44	143.28	1.18
v4_m3_s4	110.79	130.70	1.18
v8_m2	22.89	1.83	0.08
v8_m3	30.42	7.48	0.25
v8_m3_s1	31.27	7.64	0.24
v8_m3_s2	29.61	7.46	0.25
v8_m3_s3	165.21	189.76	1.15
v8_m3_s4	155.39	182.57	1.17
v19_m2	21.24	0.76	0.04
v19_m3	29.46	6.99	0.24
v19_m3_s1	30.85	7.23	0.23
v19_m3_s2	28.97	7.03	0.24
v19_m3_s3	110.19	128.86	1.17
v19_m3_s4	97.06	115.65	1.19

Table 7.9: St. Thomas and St. John Yellowtail Snapper derived quantities of the MSY proxy (based on SPR 40%) in pounds by model scenario (v4_m3, v8_m3, and v19_m3) and corresponding each model scenario's four sensitivity runs.

Scenario	**v4**	**v8**	**v19**
m2	50,291	50,470	46,826
m3	59,429	67,060	64,952
m3_s1	63,041	68,930	68,008
m3_s2	58,135	65,287	63,874
m3_s3	267,723	364,234	242,934
m3_s4	244,259	342,578	213,970

Table 7.10: St. Thomas and St. John Yellowtail Snapper fishing mortality rate and spawning stock biomass ratios relative to the rate and biomass of the stock associated with the MSY proxy (based on SPR 40%). The relative fishing mortality ratio is expressed as a three-year geometric mean of the annual fishing mortality rates for 2020-2022 divided by the fishing mortality rate associated with MSY SPR 40%. Relative fishing mortality rates that are above one are shown in red font. The relative stock biomass ratio is expressed as the 2022 spawning biomass divided by the spawning stock biomass at MSY SPR 40%. Relative fishing mortality ratios that are below 0.75 are shown in red font.

Metric	Scenario	v4	v8	v19
F Current / F SPR 40%	m2	0.27	0.26	0.53
	m3	0.22	0.19	0.35
	m3_s1	0.21	0.18	0.32
	m3_s2	0.24	0.21	0.37
	m3_s3	0.04	0.03	0.07
	m3_s4	0.05	0.03	0.09
SSB 2022 / SSB SPR 40%	m2	1.60	1.61	0.82
	m3	1.65	1.70	0.92
	m3_s1	1.65	1.71	0.95
	m3_s2	1.56	1.61	0.88
	m3_s3	1.90	1.96	1.19
	m3_s4	1.80	1.87	1.15

8 Figures

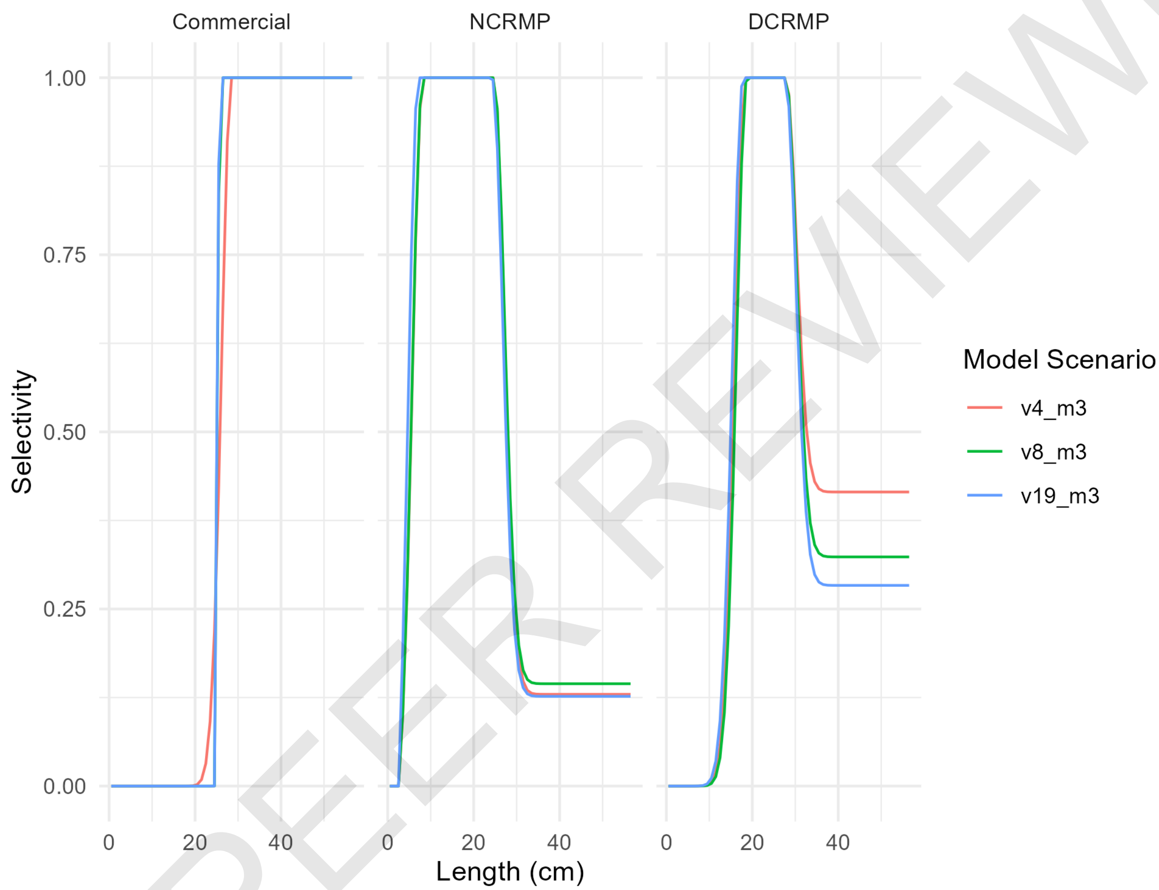
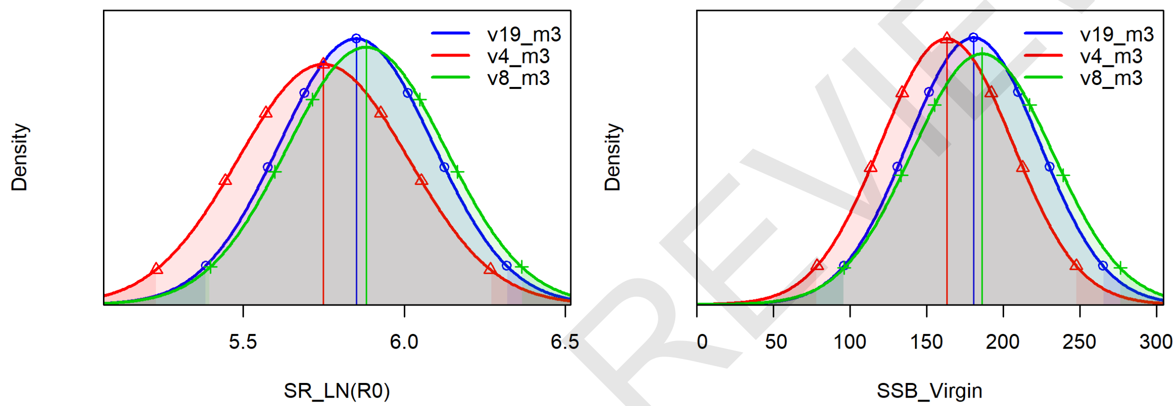


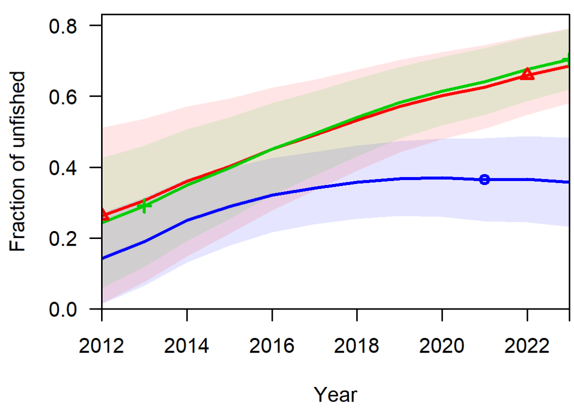
Figure 8.1: St. Thomas and St. John Yellowtail Snapper commercial fleet logistic selectivity and National Coral Reef Monitoring Survey (NCRMP) and Deep Coral Reef Monitoring Survey (DCRMP) domed selectivity across model scenarios (v4_m3, v8_m3, and v7_m3). Selectivity patterns reflect the probability that a fish of a given length will be caught by a particular fishing fleet or observed in a given survey.



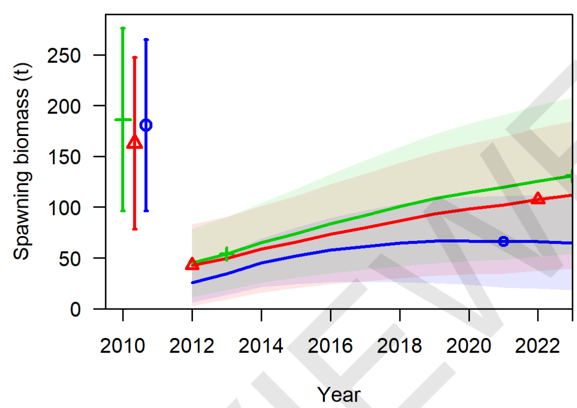
(a) Unfished recruitment

(b) Virgin Spawning Stock Biomass

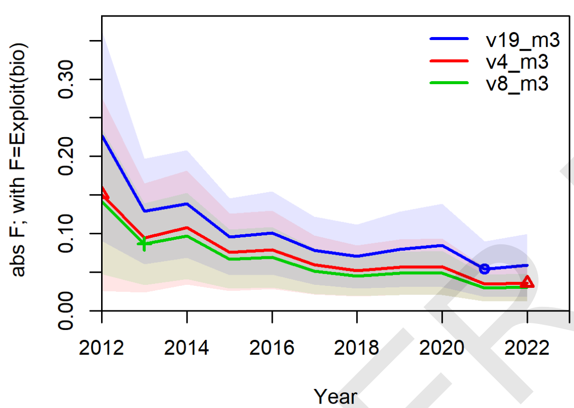
Figure 8.2: St. Thomas and St. John Yellowtail Snapper parameter distribution for (a) the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function and (b) virgin spawning stock biomass in metric tons across model scenarios (v4_m3, v8_m3, and v19_m3).



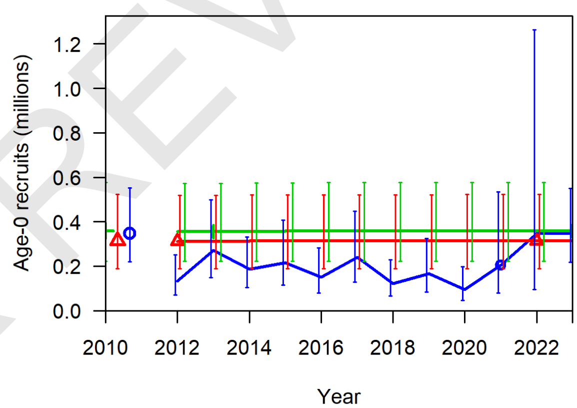
(a) Spawning Biomass Ratio



(b) Spawning Biomass

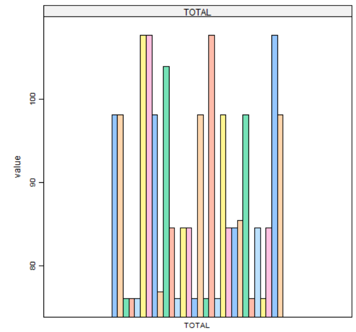


(c) Fishing Mortality

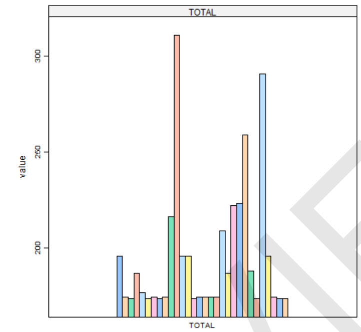


(d) Recruitment

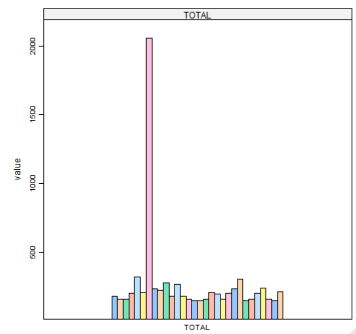
Figure 8.3: St. Thomas and St. John Yellowtail Snapper derived quantity time series across model scenarios (v4_m3, v8_m3, and v19_m3). Derived quantities plotted over time for (a) the relative spawning stock biomass (total biomass / virgin spawning stock biomass), (b) spawning stock biomass in metric tons, (c) fishing mortality (total biomass killed / total biomass), (d) and recruitment in millions of fish. The shaded areas and vertical bars in the derived quantities time series represent 95% confidence intervals. The values plotted prior to the model start year of 2012 reflect the unfished conditions and associated 95% confidence intervals.



(a) Model v4_m3

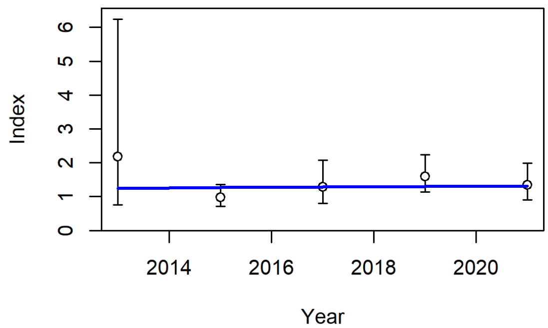


(b) Model v8_m3

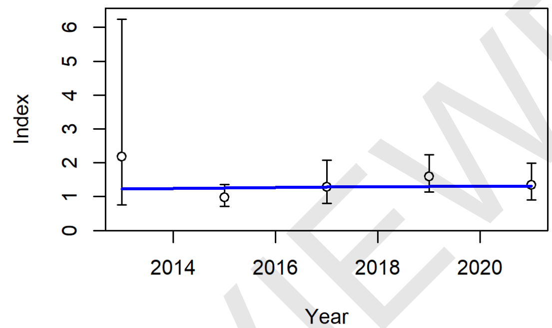


(c) Model v19_m3

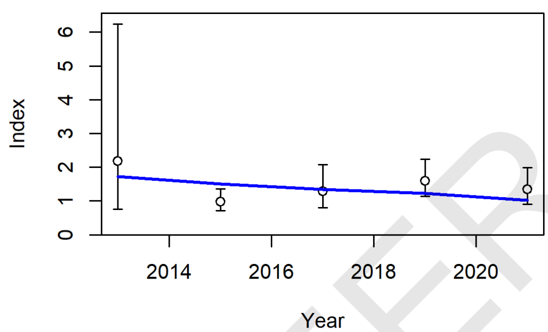
Figure 8.4: St. Thomas and St. John Yellowtail Snapper jitter analysis total likelihood across model scenarios (v4_m3, v8_m3, and v19_m3). Each panel gives the results of 30 runs of the corresponding model scenario where the starting parameter values for each run were randomly changed by 20% from each model's predicted values using a uniform distribution in cumulative normal space.



(a) v4_m3

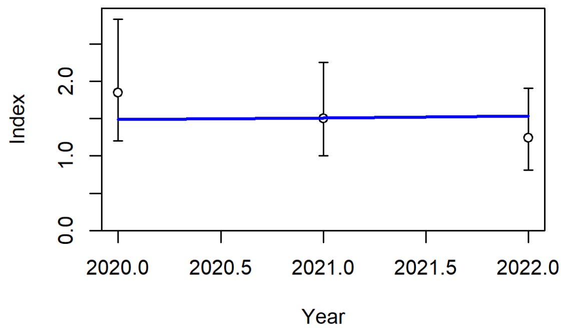


(b) v8_m3

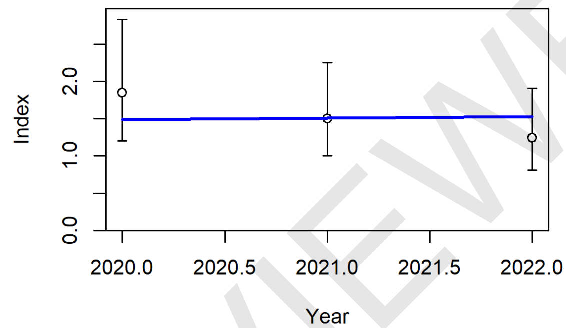


(c) v19_m3

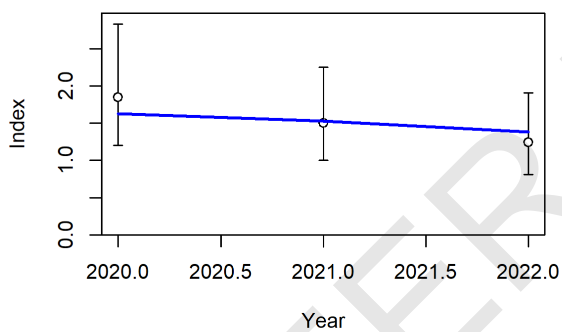
Figure 8.5: St. Thomas and St. John Yellowtail Snapper National Coral Reef Monitoring Program (NCRMP) observed (open circles) and predicted (blue line) indices of relative abundance and associated standard errors across model scenarios (v4_m3, v8_m3, and v19_m3). Error bars indicate a 95% uncertainty interval around observed index values based on the model assumption of lognormal error. Model scenarios v4_m3 and v8_m3 do not estimate recruitment deviations, while model scenarios v19_m3 does.



(a) v4_m3

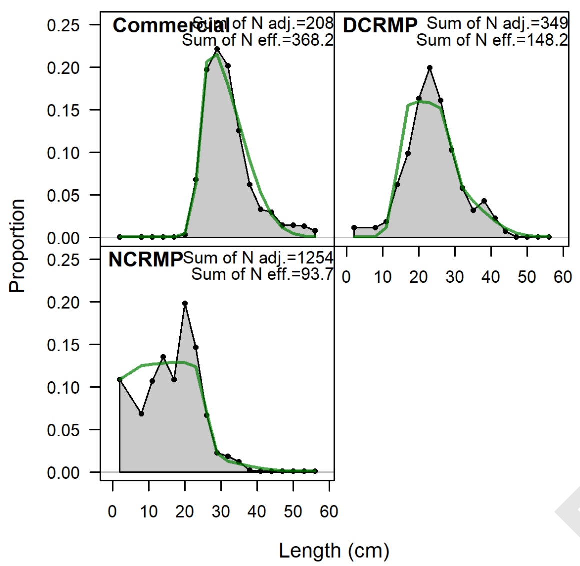


(b) v8_m3



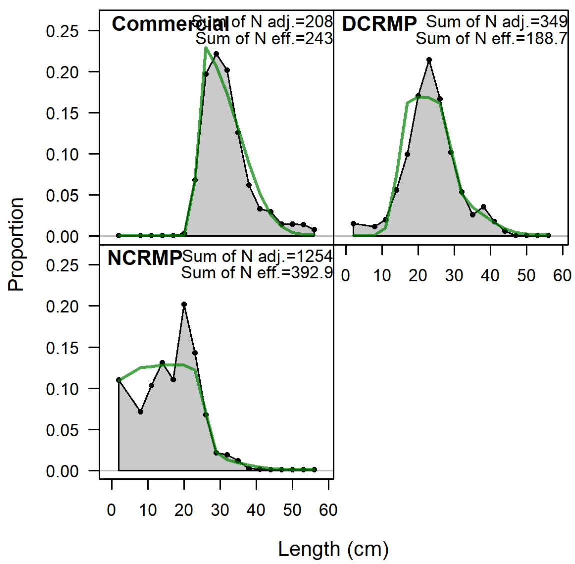
(c) v19_m3

Figure 8.6: St. Thomas and St. John Yellowtail Snapper Deep National Coral Reef Monitoring Program (DCRMP) observed (open circles) and predicted (blue line) indices of relative abundance and associated standard errors across model scenarios (v4_m3, v8_m3, and v19_m3). Error bars indicate a 95% uncertainty interval around observed index values based on the model assumption of lognormal error. Model scenarios v4_m3 and v8_m3 do not estimate recruitment deviations, while model scenarios v19_m3 does.

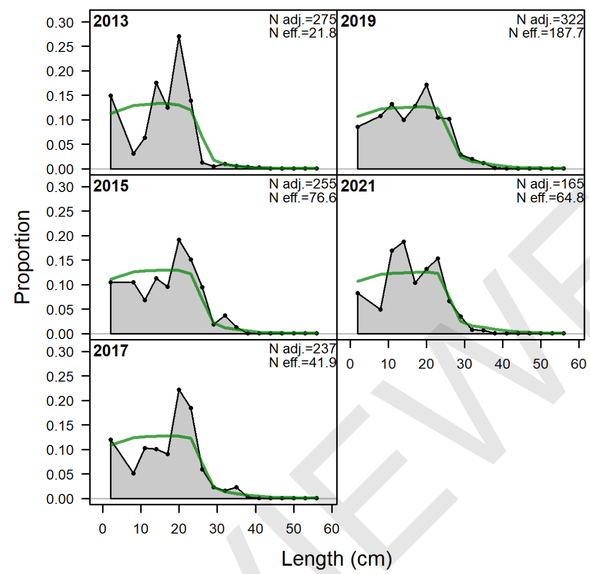


(a) v4_m3 across all years

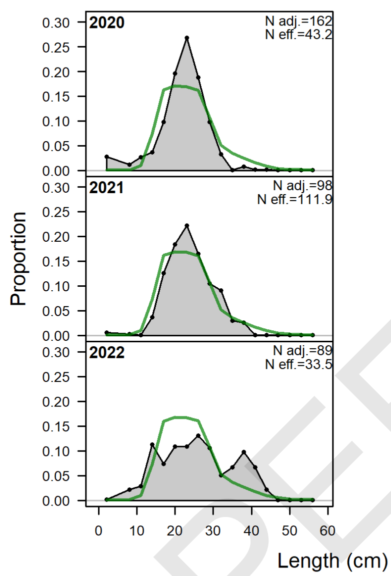
Figure 8.7: St. Thomas and St. John Yellowtail Snapper observed and predicted length distributions in centimeters aggregated across years for the Commercial (TIP), National Coral Reef Monitoring Survey (NCRMP) and Deep Coral Reef Monitoring Survey (DCRMP) length compositions for the (a) v4_m3 model scenario. Green lines represent predicted length compositions, while gray regions represent observed length compositions. The effective sample sizes used to weight the length composition data are provided by N adj (the input sample size) and N eff (the calculated effective sample size) and are shown in the upper right corners. Since super years are utilized for the commercial fleet, NCRMP, and DCRMP survey in these model scenarios, the fits to annual data are not shown.



(a) v8_m3 across all years

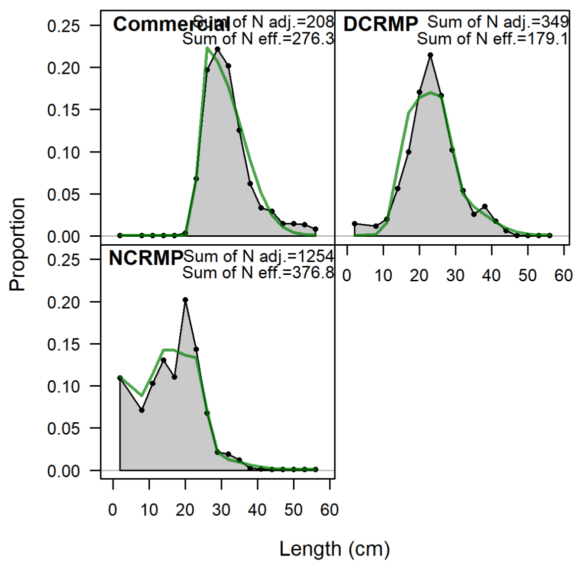


(b) v8_m3 NCRMP by year

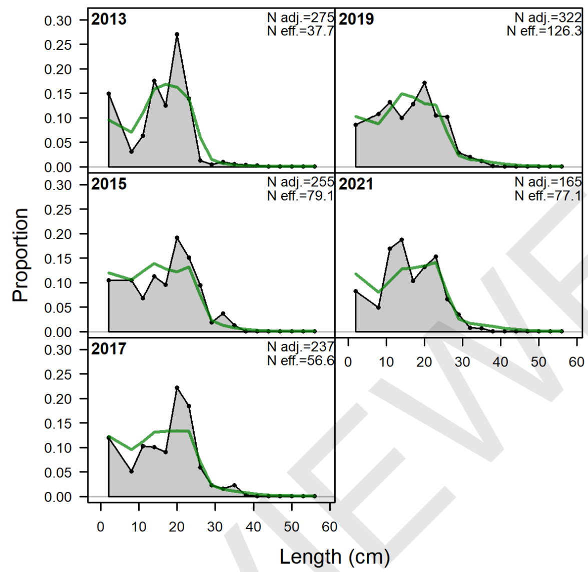


(c) v8_m3 DCRMP by year

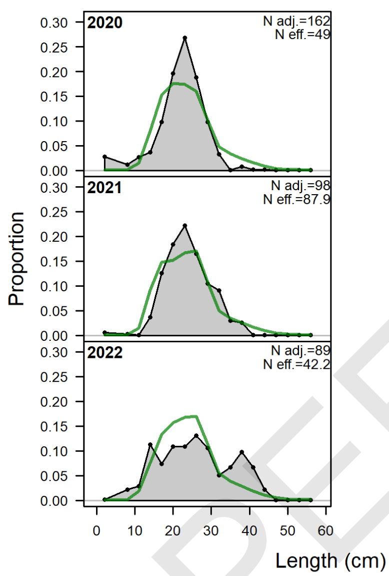
Figure 8.8: St. Thomas and St. John Yellowtail Snapper observed and predicted length distributions in centimeters (a) aggregated across years, (b) by year for the National Coral Reef Monitoring Survey (NCRMP), and (c) by year for the Deep Coral Reef Monitoring Survey (DCRMP) length compositions for the v8_m3 model scenarios. Green lines represent predicted length compositions, while gray regions represent observed length compositions. The effective sample sizes used to weight the length composition data are provided by N adj (the input sample size) and N eff (the calculated effective sample size) and are shown in the upper right corners.



(a) v19_m3 across all years

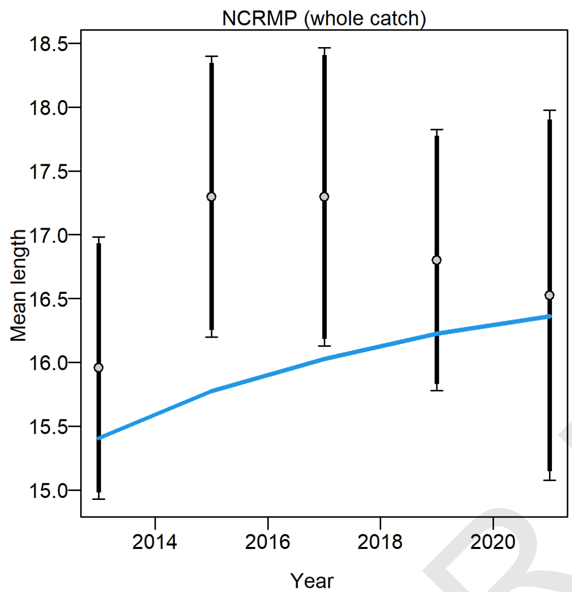


(b) v19_m3 NCRMP by year

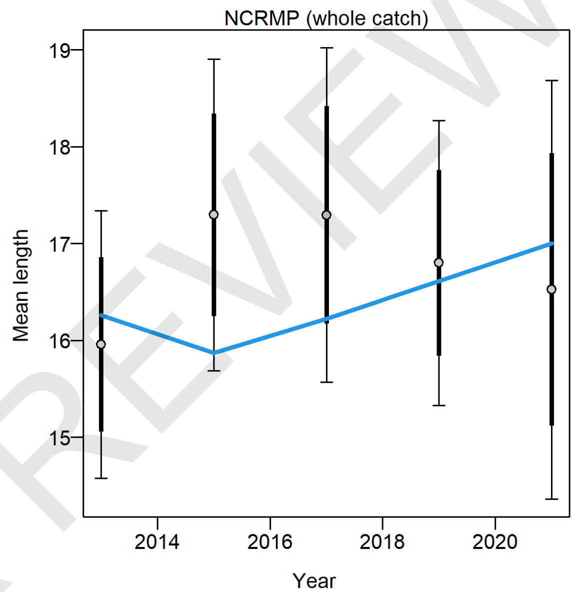


(c) v19_m3 DCRMP by year

Figure 8.9: St. Thomas and St. John Yellowtail Snapper observed and predicted length distributions in centimeters (a) aggregated across years, (b) by year for the National Coral Reef Monitoring Survey (NCRMP), and (c) by year for the Deep Coral Reef Monitoring Survey (DCRMP) length compositions for the v19_m3 model scenarios. Green lines represent predicted length compositions, while gray regions represent observed length compositions. The effective sample sizes used to weight the length composition data are provided by N adj (the input sample size) and N eff (the calculated effective sample size) and are shown in the upper right corners.

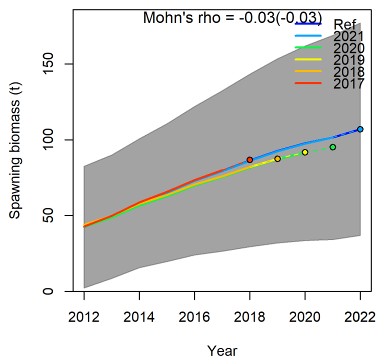


(a) v8_m3

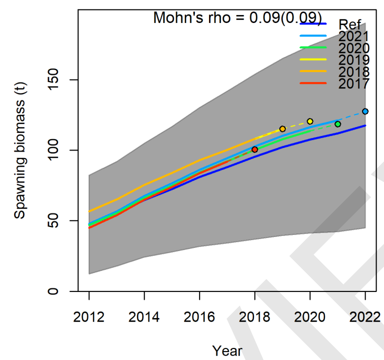


(b) v19_m3

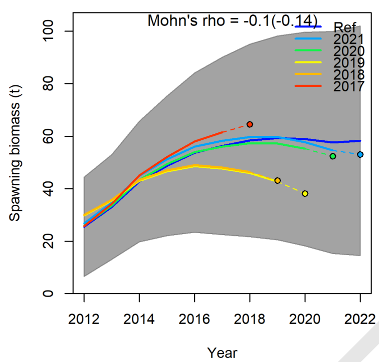
Figure 8.10: St. Thomas and St. John Yellowtail Snapper observed (open circles) and predicted (blue line) mean length in centimeters by year across model scenarios that include annual fishery-independent National Coral Reef Monitoring Survey (NCRMP) data without recruitment deviations (v8_m3) and with recruitment deviations (v19_m3).



(a) v4_m3

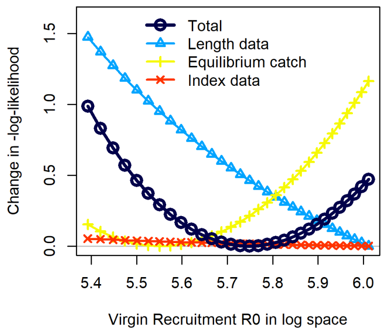


(b) v8_m3

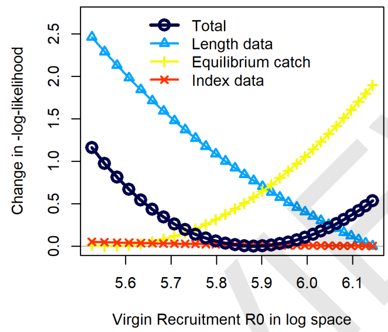


(c) v19_m3

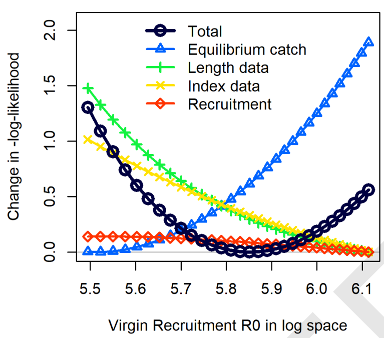
Figure 8.11: St. Thomas and St. John Yellowtail Snapper retrospective analysis of spawning stock biomass (SSB) conducted by refitting models after removing five years of observation, one year at a time sequentially. Mohn's rho statistics and the corresponding "hindcast rho" measure the severity of retrospective patterns. The reference models (Ref) include the full time series ending in 2022.One-year-ahead projections are denoted by color-coded dashed lines with terminal points. Grey shaded areas are the 95% confidence intervals.



(a) v4_m3

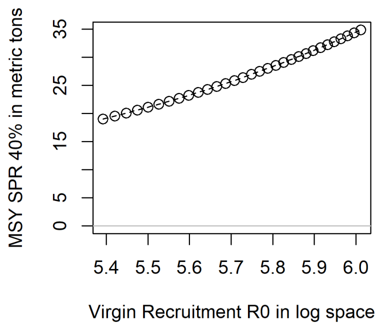


(b) v8_m3

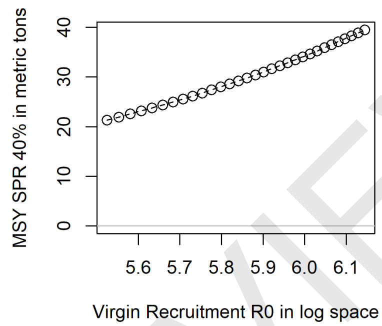


(c) v19_m3

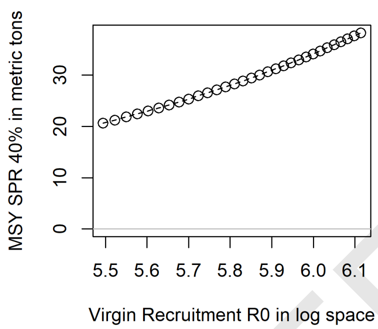
Figure 8.12: The profile likelihood for the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function for St. Thomas and St. John Yellowtail Snapper across model scenarios (v4_m3, v8_m3, and v19_m3). Each line represents the change in negative log-likelihood value for each of the data sources fit in the model across the range of fixed unfished recruitment values tested in the profile diagnostic run.



(a) v4_m3

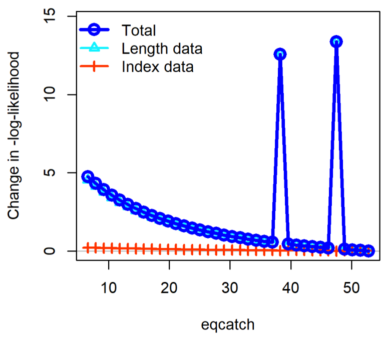


(b) v8_m3

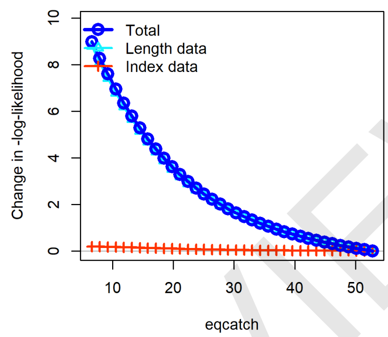


(c) v19_m3

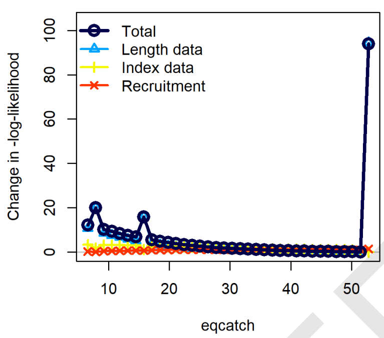
Figure 8.13: Estimates of the MSY proxy (based on SPR 40%) across the range of unfished recruitment values explored in the St. Thomas and St. John Yellowtail Snapper likelihood profile. These estimates, expressed in metric tons, are shown for model scenarios v4_m3, v8_m3, and v19_m3.



(a) v4_m3

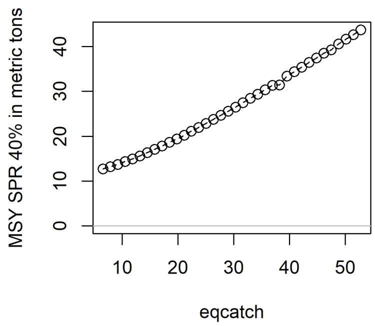


(b) v8_m3

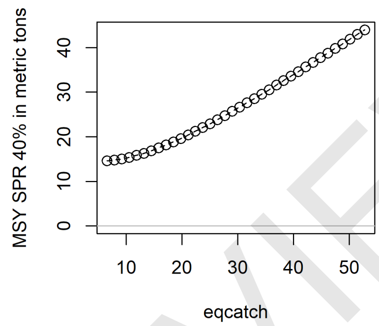


(c) v19_m3

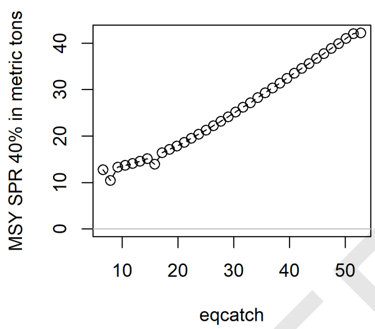
Figure 8.14: The profile likelihood for the fixed initial equilibrium catch for St. Thomas and St. John Yellowtail Snapper across model scenarios (v4_m3, v8_m3, and v19_m3). Each line represents the change in negative log-likelihood value for each of the data sources fit in the model across the range of fixed equilibrium catch values tested in the profile diagnostic run.



(a) v4_m3

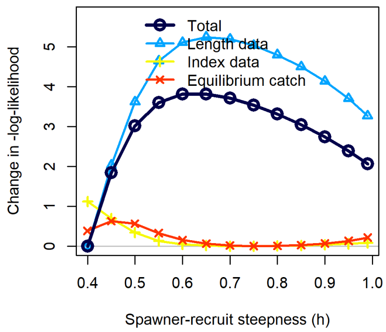


(b) v8_m3

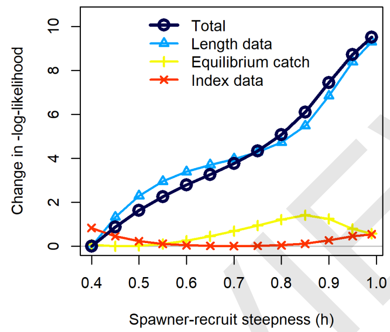


(c) v19_m3

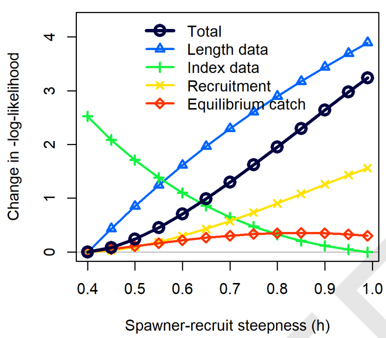
Figure 8.15: Estimates of the MSY proxy (based on SPR 40%) across the range of initial equilibrium catch values explored in the St. Thomas and St. John Yellowtail Snapper likelihood profile. These estimates, expressed in metric tons, are shown for model scenarios v4_m3, v8_m3, and v19_m3.



(a) v4_m3



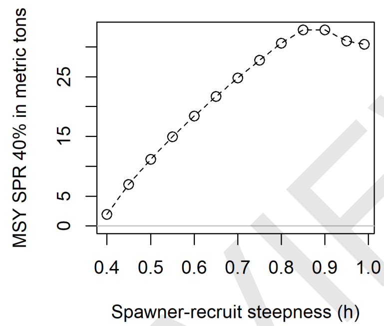
(b) v8_m3



(c) v19_m3

Figure 8.16: The profile likelihood for the steepness parameter of the Beverton – Holt stock-recruit function for St. Thomas and St. John Yellowtail Snapper across model scenarios (v4_m3, v8_m3, and v19_m3). Each line represents the change in negative log-likelihood value for each of the data sources fit in the model across the range of fixed steepness values tested in the profile diagnostic run.

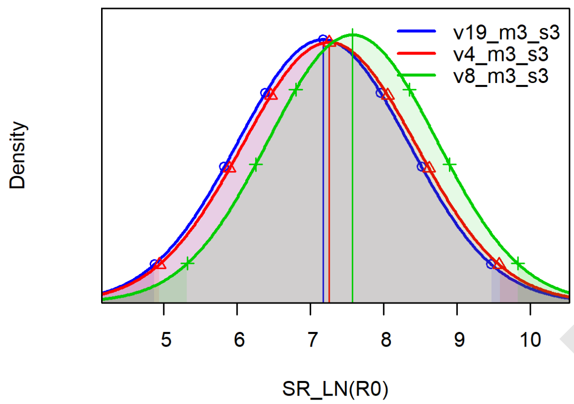
(a) v4_m3



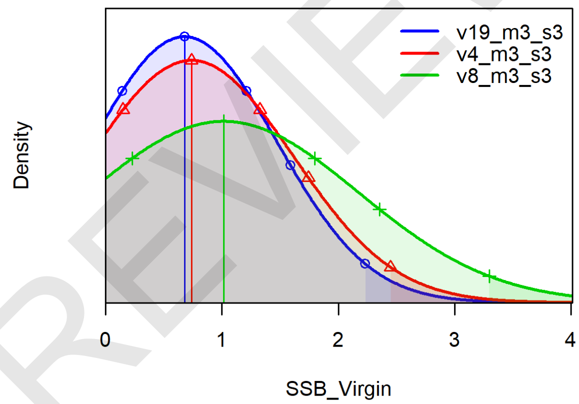
(b) v8_m3

(c) v19_m3

Figure 8.17: Estimates of the MSY proxy (based on SPR 40%) across the range of steepness values explored in the St. Thomas and St. John Yellowtail Snapper likelihood profile. These estimates, expressed in metric tons, are shown for model scenarios v4_m3, v8_m3, and v19_m3.

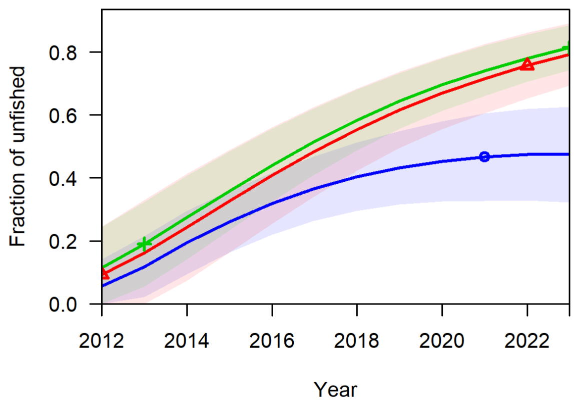


(a) Unfished recruitment (R0)

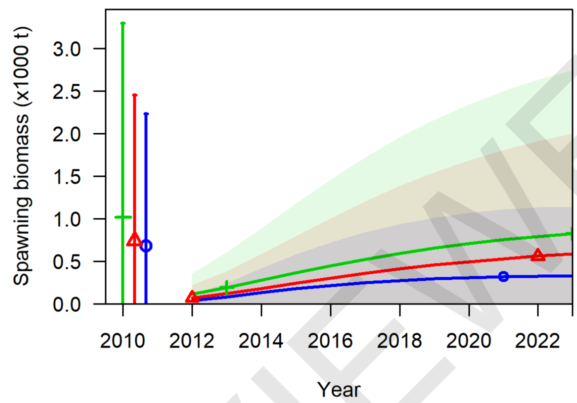


(b) Virgin Spawning Stock Biomass

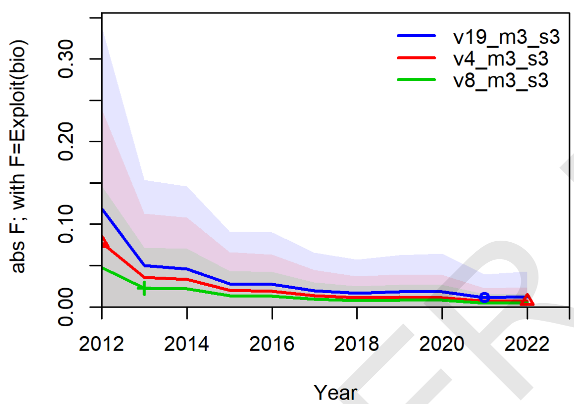
Figure 8.18: St. Thomas and St. John Yellowtail Snapper parameter distribution for (a) the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function and (b) virgin spawning stock biomass in metric tons across model scenarios (v4_m3_s3, v8_m3_s3, and v19_m3_s3).



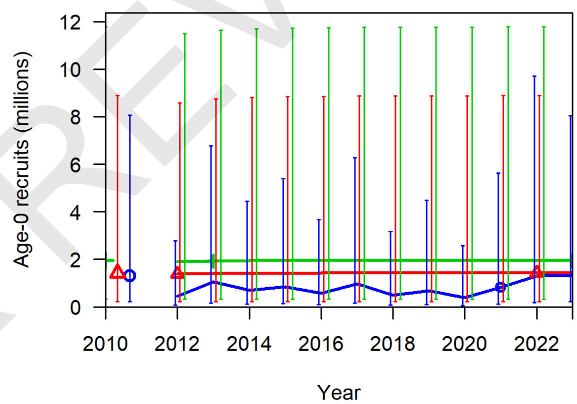
(a) Spawning Biomass Ratio



(b) Spawning Biomass

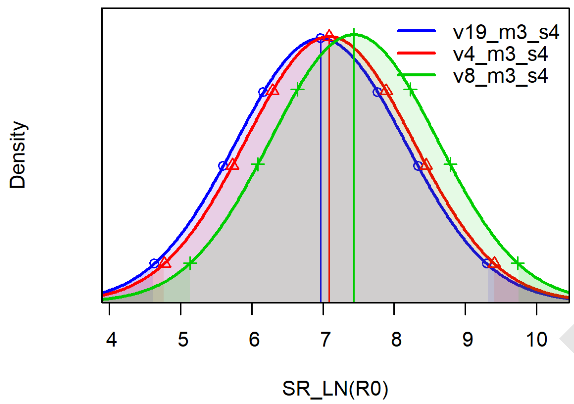


(c) Fishing Mortality

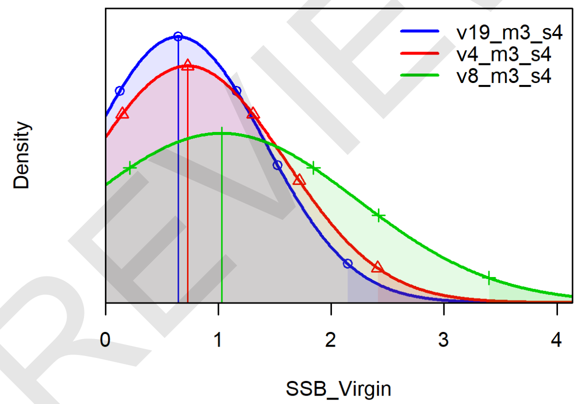


(d) Recruitment

Figure 8.19: St. Thomas and St. John Yellowtail Snapper derived quantity time series across model scenarios (v4_m3_s3, v8_m3_s3, and v19_m3_s3). Derived quantities plotted over time for (a) the relative spawning stock biomass (total biomass / virgin spawning stock biomass), (b) spawning stock biomass in metric tons, (c) fishing mortality (total biomass killed / total biomass), (d) and recruitment in millions of fish. The shaded areas and vertical bars in the derived quantities time series represent 95% confidence intervals. The values plotted prior to the model start year of 2012 reflect the unfished conditions and associated 95% confidence intervals.

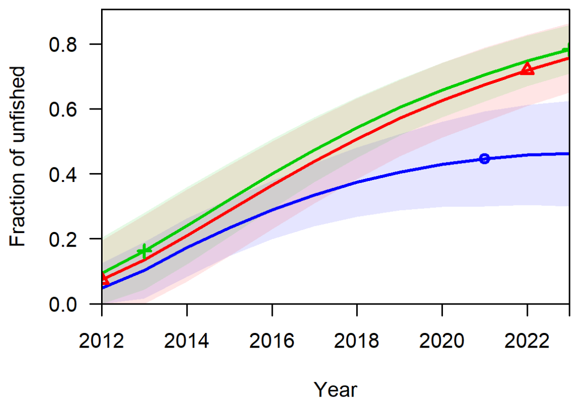


(a) Unfished recruitment (R0)

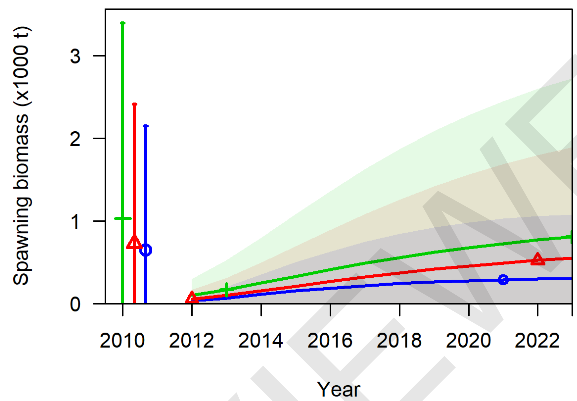


(b) Virgin Spawning Stock Biomass

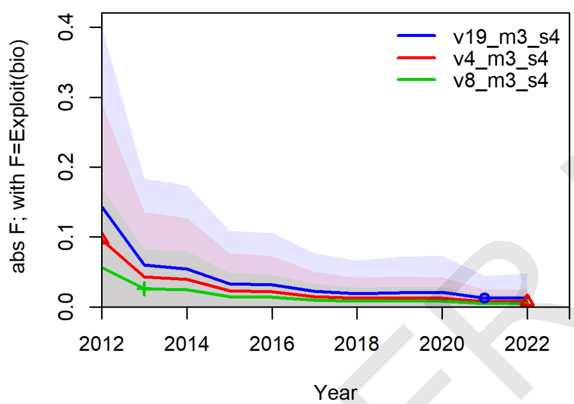
Figure 8.20: St. Thomas and St. John Yellowtail Snapper parameter distribution for (a) the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function and (b) virgin spawning stock biomass in metric tons across model scenarios (v4_m3_s4, v8_m3_s4, and v19_m3_s4).



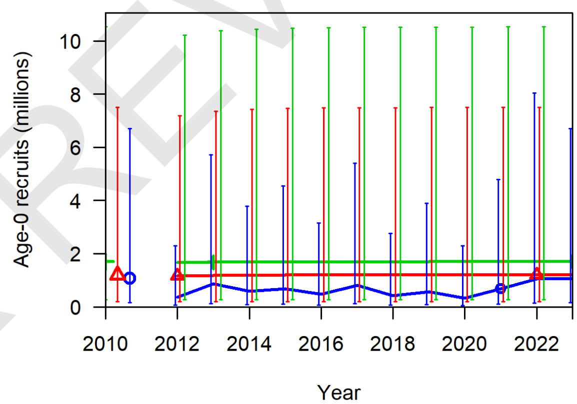
(a) Spawning Biomass Ratio



(b) Spawning Biomass



(c) Fishing Mortality



(d) Recruitment

Figure 8.21: St. Thomas and St. John Yellowtail Snapper derived quantity time series across model scenarios (v4_m3_s4, v8_m3_s4, and v19_m3_s4). Derived quantities plotted over time for (a) the relative spawning stock biomass (total biomass / virgin spawning stock biomass), (b) spawning stock biomass in metric tons, (c) fishing mortality (total biomass killed / total biomass), (d) and recruitment in millions of fish. The shaded areas and vertical bars in the derived quantities time series represent 95% confidence intervals. The values plotted prior to the model start year of 2012 reflect the unfished conditions and associated 95% confidence intervals.

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