

SEDAR 84

Southeast Fisheries Science Center

Table of contents

Executive Summary	3
1 Background	4
1.1 Management	4
1.2 Assessment History	4
1.3 Modeling Framework	5
2 Data-Informed Modeling Decisions	6
2.1 Commercial Fleet	6
2.1.1 Catch Data	6
2.1.2 Size Composition Data	7
2.2 Survey Data	8
2.2.1 Index of Abundance	8
2.2.2 Size Composition Data	9
2.3 Life History Data	9
2.3.1 Growth	10
2.3.2 Morphometric Conversion	11
2.3.3 Maturity, Fecundity, and Hermaphroditism	11
2.3.4 Stock Recruitment	11
2.3.5 Maximum Age and Natural Mortality	12
2.4 Summary of Data-Informed Modeling Configurations	13
2.4.1 Commercial Fleet	13
2.4.2 National Coral Reef Monitoring Program Survey.	14
2.4.3 Biology	14
3 Model Development	16
3.1 Overview	16
4 Model Diagnostics	18
4.1 Convergence	18
4.2 Correlation Analysis	19
4.3 Evaluating Variance	19
4.4 Jitter Analysis	20
4.5 Residual Analysis	20
4.5.1 Catch	21
4.5.2 Indices	21

4.5.3	Length compositions	21
4.6	Retrospective Analysis	22
4.7	Likelihood Profiles	22
4.7.1	Unfished Recruitment (R_0)	23
4.7.2	Initial Equilibrium Catch	23
4.7.3	Steepness	23
4.8	Sensitivity Runs	23
4.8.1	Growth CV	24
4.8.2	Natural Mortality	24
4.8.3	Single Sex Model	24
4.8.4	Standard Error on Catch	25
4.8.5	Standard Error on Catch, and Natural Mortality	25
4.8.6	Single Sex Model, Standard Error on Catch, and Natural Mortality	26
5	Discussion	27
6	Research Recomendations	29
7	Tables	30
8	Figures	42
	References	65

Executive Summary

The SEDAR 84 St. Croix stoplight parrotfish (*Sparisoma viride*) 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 a reef fish survey
- A fishery-independent index of abundance from a reef fish survey
- 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 and length compositions 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. Those sequential steps included the inclusion of the index of abundance and annual fishery-independent length compositions. Models were run with and without the estimation of recruitment deviations. Finally, the sensitivity of the assessment outcomes was investigated using alternative inputs for longevity-informed natural mortality, coefficient of variation on growth, parameterization of hermaphroditism, and uncertainty on initial model equilibrium catch.

Model diagnostics assessed convergence, fit, and consistency using gradients, residuals, likelihood profiles, hindcast cross-validation, and jitter analyses. These 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, hermaphroditism, and initial 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 Background

The stoplight parrotfish (*Sparisoma viride*) is a sequential protogynous hermaphrodite that inhabits coral reefs in the Caribbean Sea, Florida, Gulf of Mexico, Bermuda, and Brazil. It is an herbivorous species that is targeted in reef fish fisheries throughout much of the Caribbean, including St. Croix, USVI.

1.1 Management

St. Croix stoplight parrotfish is managed under the St. Croix Fishery Management Plan (Crabtree, 2019). In 2023, the Caribbean Fisheries Management Council transitioned from species-based to island-based fisheries management (Figure 8.1). The management measures in the new island-based fishery management plans became effective on October 13, 2022.

The Parrotfish two stock complex includes two indicator stocks and five other species. The indicator species are stoplight parrotfish and redbtail parrotfish (*Sparisoma chrysopteron*). The allowable biological catch for the complex was established using tier 4a of the 4-tiered control rule. The allowable biological catch and the annual catch limit are 85,135 and 72,365 pounds whole weight, respectively.

A SEDAR 84 Data Workshop working paper summarizes federal management actions for stoplight parrotfish in St. Croix (Malone, 2024). On August 29, 2013, a 9-inch federal size limit was instituted by Final Regulatory Amendment 4. The size limit only applies in the U.S. EEZ surrounding St. Croix, defined as the federal waters ranging from 3 to 200 nautical miles (nm) (5.6 – 370 kilometers [km]) from the nearest coastline point of the U.S. Virgin Islands (Figure 8.2).

1.2 Assessment History

Before the current assessment, only one stock assessment had been attempted for St. Croix stoplight parrotfish (SEDAR, 2016). The SEDAR 46 evaluations were performed using the Data-Limited Methods Toolkit (Carruthers & Hordyk, 2018). The approach applied data-limited stock assessment models and management procedures. Ultimately, the results were not used for management advice.

1.3 Modeling 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 hermaphroditism and continuous recruitment, which are critical for accurately assessing St. Croix Stoplight Parrotfish.

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.

2 Data-Informed Modeling Decisions

The data available for use in the current assessment are documented in the SEDAR 84 US Caribbean Stoplight Parrotfish St. Croix 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.

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 a fishery-independent survey of reef fish (Grove et al., 2024)
4. **Index of abundance** from a fishery-independent survey of reef fish (Grove et al., 2024)
5. **Life history information** from otolith analysis and gonad histology (Rivera Hernández & Shervette, 2024)

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

2.1 Commercial Fleet

2.1.1 Catch Data

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. Various diving gears were combined to establish a dive gear group since the catch of stoplight parrotfish in St. Croix from this group made up 80% of the reported landings, all gears (dive 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 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 fishery had been ongoing for decades, and the total fishing effort in St. Croix in 2012 was undergoing a meaningful decline; thus, an initial F was estimated for the commercial fleet, and a corresponding initial equilibrium catch was input. A common option to define an initial equilibrium catch is to use the geometric mean of the first three years of available catches. However, because of the known decline in effort preceding the start year of the assessment, **the initial equilibrium catch was configured in initial runs as 30 metric tons**, a little over twice the geometric mean of the catches from 2012 - 2014.

The input standard error for the landings was set to a 0.3. When implemented with few data inputs, Stock synthesis will inherently nearly exactly fit the annual landings time series, regardless of the input standard error. Initial models were set up with a default standard error of 0.01. In addition to exactly fitting the annual landings time series, the models also exactly fit the input initial equilibrium catch. A higher standard error value of 0.3 was used to free up the estimation of the initial equilibrium catch. The sequential model configurations and model development are described later in this report.

Commercial discards reported by calendar year by Martínez Rivera et al. (2024) were not significant and based on the nature of spearfishing with the predominant dive gear, **the assessment assumed no discards.**

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 Size Composition Data

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 NOAA Fisheries, Southeast Fisheries Science Center Trip Interview Program collects length and weight data from fish landed by commercial fishing vessels, along with information about fishing areas and gears. Data collection began in 1983 with frequent updates in best practices; the latest being in 2017. The Stoplight Parrotfish length data from St. Croix included 29,582 length observations across 1,028 unique port sampling interviews.

Although the catch data can be separated into dive and non-dive related gears, 98% of the length measurements for St. Croix Stoplight parrotfish from 2012-2022 were associated with diving. These data were used to characterize the commercial fleet's size-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 size data included 1,033 shore-based length measurements obtained across 66 trips. Five 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 do not conclusively affect 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. Domed selectivity was not explored for St. Croix Stoplight Parrotfish. However, 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 size associated with peak selectivity and the width of the ascending limb.

2.2 Survey Data

2.2.1 Index of Abundance

The National Coral Reef Monitoring Program supports reef fish sampling on hard-bottom habitats from 0 to 30 meters depth (Grove et al., 2021). In St. Croix, sampling began in 2001 and was conducted every year from 2001 to 2012 and then every other year starting in 2015. The data used in SEDAR 84 were from 2012 - 2022 when the survey was conducted island-wide. Before 2017, the data are calibrated to account for the transition from belt transect to the cylinder survey method.

Annual mean density and associated standard errors for SEDAR 84 were provided by Grove et al. (2024). In Stock Synthesis, the time series of mean density across all observed sizes

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 and adults.

2.2.2 Size Composition Data

The three most recent years of the National Coral Reef Monitoring Program survey in St. Croix provided counts by individual lengths measured to the nearest centimeter. However, before 2017 the length observations were collected in 5-centimeter bins. **The length data inputs for both the commercial fleet and the three years of the survey with 1-centimeter length measurements were binned to match the survey's 2012 and 2015 5-centimeter bins.**

A large proportion of small fish were observed in the National Coral Reef Monitoring Program survey. **The smallest two bins, [1 - 6) and [6 - 11), were collapsed into a single bin [1 - 11).**

Since multiple fish can be observed from a single dive, individual lengths are not independent observations. **The relative model weighting of the National Coral Reef Monitoring Program survey length compositions across years was based on the number of paired dives.**

The length compositions provided reasonable support that younger and older fish were available to the National Coral Reef Monitoring Program survey. **Selectivity for the National Coral Reef Monitoring Program survey was fixed at 1 for all sizes.**

Models were initially configured in Stock Synthesis with length compositions aggregated across the available years for each source of length data and 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 1,801 samples of Stoplight Parrotfish collected across the U.S. Caribbean from 2013 to 2023 (Rivera Hernández & Shervette, 2024). The largest fish was 43.3 centimeters fork length and the oldest was 20 years old.

Based on the available information, **the Stoplight Parrotfish population was modeled from age 0 through age 20, and from 0 to 41-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. **Although the size bins of all the length data inputs were large (5 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 1,649 samples of Stoplight Parrotfish collected across the U.S. Caribbean from 2013 to 2023 (Rivera Hernández & Shervette, 2024). When t_0 was fixed to -0.06, K was 0.39 and L_{∞} 33.2 centimeters fork length. When t_0 was estimated, it was -0.52, K was 0.33, and L_{∞} was 33.8 centimeters fork length.

The SEDAR 84 assessment models were configured using the parameter estimates associated with the fixed t_0 . Furthermore, **the estimated size at age zero from otolith analysis by Rivera Hernández & Shervette (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) stoplight parrotfish observed in the survey size 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.

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 Rivera Hernández & Shervette (2024) was converted to weight in grams and length in centimeters and used as a fixed model input. **The length-weight relationship was $W = 3.18 \times 10^{-5} * L^{2.9}$, with weight (W) in kilograms and length (L) in centimeters.**

2.3.3 Maturity, Fecundity, and Hermaphroditism

Maturity was modeled as a logistic function. Parameter estimates for maturity were based on 1,801 samples of Stoplight Parrotfish collected across the U.S. Caribbean from 2013 to 2023 (Rivera Hernández & Shervette, 2024). **The fecundity of Stoplight Parrotfish was estimated with a proxy (body weight * maturity at age).**

Protogynous hermaphroditism was parameterized into the SS3 assessment framework in two ways. **The initial method to model hermaphroditism in Stock Synthesis used the average age of transition, an associated standard deviation, and a maximum transition rate input as fixed parameters in a two-sex model.** Additionally, the sex ratio between female and male fish at recruitment was 1, such that all individuals were recruited as females. Although this approach allows explicitly modeling numbers by sex and age over time, this approach could not capture the early age at transition and the overlap of both sexes directly observed across the range of ages studied by Rivera Hernández & Shervette (2024).

A second method for parameterizing hermaphroditism was explored as a sensitivity analysis. It involved using a female-only model and accounting for sex transition to males as a reduction in fecundity. A fecundity-at-age vector derived from a logistical fit to the Rivera Hernández & Shervette (2024) sex-at-age data was multiplied by maturity-at-age and fecundity-at-age. A caveat of using a single-sex model is that the exclusion of males does not allow for any potential sperm limitation. Although protogynous hermaphrodites tend to have sex ratios skewed towards males at larger sizes, the largest and oldest stoplight parrotfish observed by Rivera Hernández & Shervette (2024) were female.

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 (R_0 ; estimated in log space) represents the asymptote or unfished recruitment levels.
- The variance term (σ_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 (R_0) was estimated. **Sigma R and steepness were fixed at 0.7 and 0.99, respectively.** 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 R_0 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 size zero (t_0), asymptotic size (L_∞), and age at 50% maturity.

Inputs for the Natural Mortality Tool were sourced from Rivera Hernández & Shervette (2024), who observed a maximum age of 20 years for stoplight parrotfish in the U.S. Caribbean. However, the average age of 1,649 sampled fish was 5.4 years, with fewer than 1% of aged individuals reaching 13 years or older. More broadly across the Caribbean, a lower maximum age of 9 years was observed, with a suggested maximum lifespan of 12 years. In contrast, a tagging study in Bonaire indicated a potential maximum longevity of 30 years (Choat et al., 2003).

Table 7.2 summarizes these studies and 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). Lower values of maximum age obtained by Choat et al. (2003) corroborate with the higher estimate of mortality calculated using a meta-analysis available in the FishLife R package Thorson (2019). Although additional methods incorporating growth and maturity were explored using the Natural Mortality Tool, their applicability remains uncertain due to the species' sex-changing nature. Specifically, the methods `Hamel_K`, `Jensen_k 1`, `Jensen_k 2`, `Then_VBGF`, `Jensen_Amat`, and `Ri_Ef_Amat` do not account for protogynous hermaphroditism (Hamel, 2015; Jensen, 1996, 1997; Rikhter & Efanov, 1976; Then et al., 2015). Notably, the SEDAR 84 available inputs of age at 50% maturity reflect only the sexual maturity of females, while the Von

Bertalanffy growth parameters (K), t_0 , and asymptotic size were fit across males, females, and transitional individuals combined.

A natural mortality value of 0.27 was used in the initial model runs. This value corresponds with the maximum age of 20 years reported by Rivera Hernández & Shervette (2024). Model configurations incorporating an alternative M value associated with a 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 one fishery-independent survey.

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.
- The assessment assumed no discards.
- The input standard error for the landings was set to 0.3.
 - A lower standard error of 0.1 was explored via sensitivity analysis.
- The initial equilibrium catch was configured in initial runs as 30 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 National Coral Reef Monitoring Program Survey.

- The index reflected the abundance of juveniles and adults.
- The survey was configured as an index in numbers with a lognormal error distribution
- The relative model weighting of the survey length compositions across years was based on the number of paired dives.
- The length data inputs for both the commercial fleet and the three years of the survey with 1-centimeter length measurements were binned to match the survey's 2012 and 2015 5-centimeter bins.
- Although the size bins of all the length data inputs were large (5 centimeters), the model's simulated population bin size was 1-centimeter bins.
- The smallest two bins, [1-6) and [6-11), were collapsed into a single bin [1-11).
- Selectivity for the survey was fixed at 1 for all sizes.
- Models were initially configured in Stock Synthesis with length compositions aggregated across the available years for each source of length data and proceeded stepwise from the simplest configuration to those of moderate complexity.
 - The steps included the inclusion of annual fishery-independent length compositions.

2.4.3 Biology

- The Stoplight Parrotfish population was modeled from age 0 through age 20, and from 0 to 41-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 Stoplight Parrotfish collected across the U.S. Caribbean from 2013 to 2023.
- The estimated size at age zero from otolith analysis by Rivera Hernández & Shervette (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 $W = 3.18 \times 10^{-5} L^{2.9}$, with weight in kilograms and length in centimeters.

- A natural mortality value of 0.27 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 Stoplight Parrotfish was estimated with a proxy (body weight * maturity at age).
- The initial method to model hermaphroditism used the average age of transition, an associated standard deviation, and a maximum transition rate input as fixed parameters in a two-sex model.
 - A second method for parameterizing hermaphroditism was explored as a sensitivity analysis.
- 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.
 - In configurations where recruitment deviations were estimated, sigma R was explored via likelihood profiling.
- Continuous recruitment was parameterized in SS3 using four settlement events.

3 Model Development

Stock Synthesis models were initially configured using an annual catch time series and compositions 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.

3.1 Overview

The SEDAR 84 model development process started with simple data-limited configurations, followed by exploring data-moderate configurations, individually and combined. Table 7.3 provides the shorthand naming conventions used for SEDAR 84 assessments of Caribbean stoplight parrotfish. 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 size 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 data-moderate considerations explored across the stoplight parrotfish and yellowtail snapper SEDAR 84 assessments included incorporating (a) indices, (b) annual fishery-independent size composition, (c) annual fishery-dependent size composition, (d) recruitment deviations, (e) dome-shaped selectivity, and (f) time blocks. Not all of these considerations were explored for Stoplight Parrotfish. However, the process sets up a reproducible and adaptable workflow across species and islands of model development with sequential model steps that consider methodological and intentional stepwise model explorations combined across individual complexity considerations.

The considerations detailed in Table 7.3 that were relevant for the stoplight parrotfish assessment were (a) indices, (b) annual fishery-independent size composition, and (d) recruitment deviations. Annual fishery-dependent size data (c) was not explored due to the low sample size. Dome-shaped selectivity (e) and selectivity-related time blocks (f) were also not considerations that factor into the dynamics and data reviewed for fishery in St. Croix. The initial setup steps and description of the modeling scenarios documented in this report are listed in Table 7.4.

The Stock Assessment Continuum Tool was used to develop the initial model setup by importing CSV input files and utilizing its user-friendly 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: hermaphroditism (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 described in the previous section. While a full discussion of sensitivity runs is provided later in the report, they are also summarized in Table 7.4 to help familiarize the reader with the terminology used throughout. For instance, model **v1_m3_s4** refers to the first scenario variation (**v1**, which includes an index and annual fishery-independent size data), the third level modification (**m3**, reflecting hermaphroditism, continuous recruitment and higher catch uncertainty), and the fourth sensitivity scenario (**s4**, assuming one sex).

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 to the extent possible.

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 7.8).

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 (e.g., > 0.95) suggest reconsidering modeling assumptions and parameterization.

High correlations (> 0.95) were observed across nearly all m2 model variation (Table 7.5). 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 v3_m2, where it was slightly lower but still substantial at -0.90.

In the initial default configurations of both the m1 and m2 model variations, 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 30 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 7.7). 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.

All m2 and m3 model variations showed moderately high correlations (> 0.90) between the two parameters used to define the commercial fleet logistic selectivity: the size at peak selectivity and the width of the ascending limb. Correlations between these selectivity parameters are expected. While estimated values varied slightly among models, they produced similar size-based selectivity curves for the commercial fleet (Figure 8.3).

4.3 Evaluating Variance

To check for parameters with high variance, parameter estimates are reported with their resulting standard deviations. Table 7.8 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 8.4 illustrates how the estimate and uncertainty for the unfished recruitment (R0) and virgin spawning stock biomass change throughout the sequential steps of model development. Generally increasing the complexity of the model across the model variations explored results in lower values for both of these parameters. The uncertainty across the response surface for key parameters are 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 as the initial biomass divided by the unfished biomass. Table 7.6 shows this information and it is also plotted in Figures 8.5a and 8.5b.

Compared to the other m3 model variations, Model v3_m2 had extremely highest uncertainty for fishing mortality and the lowest initial depletion reflected as the spawning biomass ratio (SSB Initial/SSB Unfished) (Table 7.6; Figure 8.5c). All of the m3 model variations resulted in relatively high uncertainty and limited contrast, with most years encompassing the 95% confidence intervals across the entire time series (Figure 8.5). The sensitivity runs described later build on the exploration of uncertainty in these model variations and help interpret conditions under which all of the model variations increasingly converge.

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 reasonable 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), the jitter analysis also performed well across all model scenarios (Figure 8.6). Importantly, no jitter runs produced a lower likelihood than the best fit already identified for each model.

4.5 Residual Analysis

The primary approach to address 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 extreme positive or

negative residual patterns indicate poor model performance and potential unaccounted-for process or observation error.

4.5.1 Catch

All models nearly exactly matched the observed 2012 - 2022 catch data, which was expected given the data-limited configurations used. These setups don't provide much additional information beyond the catch itself, so the model has little room to estimate catch values that differ from the input data. The effect of increasing the standard error on catch to 0.3 during the model development m3 variation 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 still remaining informed by the assumption of a larger level of historically sustained catch. Increasing the standard error from 0.01 to 0.3 resulted in lower estimates of the initial equilibrium catch (Table 7.7). 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 30 metric tons will also be noted with regard to the results of the likelihood profile for the equilibrium catch.

4.5.2 Indices

For the models without recruitment deviation being estimated (model variations b_m2, and v1_m2), the predicted National Coral Reef Monitoring Program index is flat (Figure 8.7). In the model variations with estimated recruitment deviations (v3_m3 and v7_m3), there is some improved fit to the index, whereby the slightly improved fits. Notably, the error rate was higher in 2014 and 2015, and none of models fit well to the highest value observed in 2015 (Figure 8.7).

4.5.3 Length compositions

Figure 8.8 shows the cumulative fit across all years between the observed and predicted length composition for the two model variations had aggregated size data (a_m3 and v3_m3). Figures 8.9, 8.10, and 8.11 provide the cumulative and the year specific length compositions for the model variations that included annual fishery-independent size data (b_m3, v1_m3, and v7_m3).

Among the models with the annual fishery-independent size data (b_m3, v1_m3, and v7_m3), the model with recruitment deviation being estimated (v7_m2), has improved fits to the annual National Coral Reef Monitoring Program length composition data (Figure 8.11b). In the scenarios without recruitment deviations (b_m3 and v_m3), the predicted composition is identical across years, which leads to overestimating the proportion

of the smallest size and underestimating intermediate or large sizes in 2012, 2017, and 2021 (Figures 8.9b and 8.10b). This is also evident in Figure 8.12 where the observed and predicted mean length by year are plotted.

4.6 Retrospective Analysis

A retrospective analysis is a helpful approach for addressing 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 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 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 size 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 the complete data sets.

The results of a five-year retrospective analysis are plotted in Figure 8.13. When more than 3 years are removed, the estimates of key quantities change. The sensitivity of the results to the removal of 2019 and 2018 data, is likely the result truncating the fishery-independent National Coral Reef Monitoring program index to end in 2017, corresponding with the highest observed value (Figure 8.7). Although all retrospectives show wide 95% confidence intervals, the severity of the retrospective pattern was most severe in the scenario with recruitment deviations and annual fishery dependent size data, variation v7_m2.

4.7 Likelihood Profiles

Profile likelihoods are used to examine the change in negative log-likelihood for each data source to address the stability of a given parameter estimate and to see how each data source influences 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 (R_0)

Figure 8.14 shows the profile likelihood for the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function for St. Croix stoplight parrotfish across model variations (a_m3, b_m3, v1_m3, v3_m3, and v7_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 8.15 shows the corresponding change in the MSY SPR 40% across the range of unfished recruitment values explored.

4.7.2 Initial Equilibrium Catch

Figure 8.16 shows the profile likelihood for the initial equilibrium catch for St. Croix stoplight parrotfish across model variations (a_m3, b_m3, v1_m3, v3_m3, and v7_m3). With the exception of model variation v3_m3, the models suggest improved fit associated with smaller values of fixed initial equilibrium catch. Meanwhile, v3_m3 shows a minimum around 24 metric tons, but is flat given the very small changes in the likelihoods across the range of values explored. Figure 8.17 shows the corresponding change in the MSY SPR 40% across the range of initial equilibrium catch values explored. This suggest that given further flexibility the initial equilibrium may be estimated lower and will be revisited in regard to the sensitivity runs.

4.7.3 Steepness

Figure 8.18 shows the profile likelihood for steepness parameter of the Beverton – Holt stock-recruit function for St. Croix stoplight parrotfish across model variations (a_m3, b_m3, v1_m3, v3_m3, and v7_m3). With the exception of a_m3, all models show lower likelihoods associated with higher values of steepness, driven by the fit to the length data. @Figure 8.19 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 7.4. The analyses explored alternative assumptions for the CV on growth, maximum age, the modeling approach for hermaphroditism, and the standard error applied to catch data.

For each model variation and sensitivity run:

- Table 7.7 provides the initial equilibrium catch
- Tables 7.9 and 7.10 provide the MSY proxy (based on SPR 40%)

- Table 7.11 summarizes the fishing mortality rate and spawning stock biomass ratios relative to the rate and biomass of the stock associated the MSY proxy (based on SPR 40%)

4.8.1 Growth CV

The first sensitivity scenario (s1) assumed coefficient of variation (CV) for young fish was increased from 0.15 to 0.25. Of all the sensitivities explored, the m3_s1 sensitivities resulted in the smallest change to the derived quantities relative to the corresponding m3 model configurations (Tables 7.7, 7.9, 7.10, and 7.11). 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 11 cm) observed in the 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 Rivera Hernández & Shervette (2024).

4.8.2 Natural Mortality

The second sensitivity scenario (s2) explored a lower natural mortality of 0.18, corresponding to a higher maximum age of 30 years. This higher maximum age, associated with tagging data by Choat et al. (2003), is significantly greater than the maximum age observed by Rivera Hernández & Shervette (2024). Although the 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 notable differences from the corresponding m3 configurations. These differences included lower initial equilibrium catch, reduced MSY estimates, lower spawning stock biomass ratios, and higher fishing mortality ratios (Tables 7.7, 7.9, 7.10, and 7.11).

4.8.3 Single Sex Model

The third sensitivity scenario (s3) explored an alternative method for parameterizing hermaphroditism. This approach used a female-only model, accounting for sex transition by reducing fecundity rather than explicitly modeling males. Interestingly, this configuration produced estimates of initial catch that were identical to the corresponding M3 models, slightly higher MSY estimates, similar spawning stock biomass ratios, and slightly lower fishing mortality ratios (Tables 7.7, 7.9, 7.10, and 7.11). This result demonstrates that the direct parameterization—despite its caveats, particularly for species where not all females

transition, can be restructured in a different way while yielding broadly consistent outcomes.

However, a key limitation of the m3_s3 single-sex models is the inability to capture potential sperm limitation due to the disproportionate removal of males, which may increase the risk of reduced reproductive output. As such, both model configurations provide useful perspectives and highlight the need for additional data and consideration to fully characterize uncertainty related to hermaphroditic biology in stoplight parrotfish. This uncertainty may represent a greater risk of overfishing compared to gonochoric species.

4.8.4 Standard Error on Catch

The fourth sensitivity scenario (s4) examined the effect of further relaxing the information that informs the initial model conditions. In the m3 model variations, a standard error of 0.3 was applied to the landings data (see Section 2.1.1). Compared to the m2 model variations, this resulted in lower estimates of initial equilibrium catch. However, likelihood profiles (see Section 4.7.2) showed improved fit at even lower 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_s4 sensitivities produced much lower estimates of initial catch and MSY, higher fishing mortality ratios, and similar biomass ratios compared to the M3 models (Tables 7.7, 7.9, 7.10, and 7.11).

These results highlight the significance of uncertainty in initial conditions. While the model fit improved with lower assumed historical catches, this also suggested a less productive stock. This sensitivity underscores the value of longer historical data series. Without them, there is considerable uncertainty in defining the initial conditions, and the M3_S4 results imply that if early landings were smaller than assumed in the M3 models, the stock may be inherently less productive.

Figure 8.20 shows that the estimates and associated uncertainty for unfished recruitment (R_0) and virgin spawning stock biomass in the m3_s4 sensitivity scenarios are shifted toward smaller values compared to the m3 model results. The time series of derived quantities for the m3_s4 scenarios are provided in Figure 8.21 and appear broadly similar to those from the m3 models shown in Figure 8.5.

4.8.5 Standard Error on Catch, and Natural Mortality

The fifth sensitivity scenario (s5) explored the combined implications of two key sensitivities that had notable effects on model outcomes: increased uncertainty around initial equilibrium catch and lower natural mortality associated with a higher maximum age. By evaluating

both assumptions simultaneously, this scenario helps communicate the compounding uncertainty associated with the baseline M3 model configurations.

The combined effect of these resulted in substantially higher estimates of relative fishing mortality and lower estimates of MSY and initial catch (Tables 7.7, 7.9, 7.10, and 7.11). As shown in Figure 8.22, the estimates and uncertainty for unfished recruitment (R_0) and virgin spawning stock biomass in the m3_s5 models are shifted to smaller values and show more consistency across configurations. The time series of derived quantities in Figure 8.23 indicate that the m3_s5 models converge on lower spawning output and higher fishing mortality relative to the M3 scenarios.

4.8.6 Single Sex Model, Standard Error on Catch, and Natural Mortality

Similar to the s3 sensitivity run, the sixth and final sensitivity scenario (s6) was conducted to evaluate whether the dynamics and implications observed in the s5 scenario persisted when the model was reconfigured as a single-sex model. The results from the m3_s6 sensitivity runs were closely aligned with those of the m3_s5 scenarios, indicating that the combined effects of lower natural mortality and increased uncertainty in initial catch are robust to the choice of sex structure in the model (Tables 7.7, 7.9, 7.10, and 7.11).

5 Discussion

This assessment presents a suite of model configurations developed to address key uncertainties in data and model structure, using an integrated framework to characterize the stock status of stoplight parrotfish in St. Croix. While the results broadly indicate that overfishing is not occurring and the stock is not overfished, the diagnostics and sensitivities explored in this report highlight critical caveats—primarily due to limited and low-contrast data inputs.

A major source of uncertainty stems from the unknown initial conditions. The short time series, coarse resolution in length binning, and absence of early fishery information make it challenging for the models to resolve the historical state of the stock. Although the input standard error on landings was relaxed in some configurations to reduce assumptions, likelihood profiles revealed conflicts and flat solution spaces, signaling weak data contrast and limited signal for estimating key parameters like initial catch and recruitment.

Recruitment deviations, when estimated, are particularly uncertain, given the limited years of available data and large length bins. However, the availability of fishery-independent length data from the National Coral Reef Monitoring Program 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.

Natural mortality and assumptions about the historical catch levels were two of the most influential parameters across model sensitivities. The combined sensitivity scenario (s5) showed that increasing uncertainty in initial catch and assuming lower natural mortality led to lower MSY estimates and higher fishing mortality ratios. These patterns were robust across both sex-structured and single-sex model configurations.

Importantly, despite the broad range of explored scenarios, nearly all model configurations concluded that overfishing is not occurring and the stock is not overfished—except for a few sensitivities (e.g., m3_s6 for overfishing, and v3_m3_s2, v3_m3_s5, and v3_m3_s6 for overfished status) which reflected more pessimistic assumptions. This reinforces the value of exploring uncertainty via structured sensitivities and suggests a future direction toward developing model grids or ensembles to guide management advice.

While integrated models such as Stock Synthesis offer powerful tools for evaluating stock dynamics using multiple data sources, it may also be useful to explore simpler alternative models and to simulation test assumptions and risks of overparameterization. Further

research into model complexity and parsimony would help “right-size” assessment frameworks to match data richness.

Given that stoplight parrotfish is currently the only parrotfish species in the complex with a full SEDAR-based assessment, it may be worth reconsidering if catch limits for the entire parrotfish unit should be based on the combined historical average landings of two indicator species, as currently implemented, particularly if stoplight parrotfish catch continues to represent a significant portion of the total.

Additionally, 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, reproducible approach used in this assessment offers a framework that could be applied to other data-limited 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 Research Recommendations

To address 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 reduce uncertainty 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 vs. regional recruitment dynamics.
- Re-examine whether the current single-stock unit for parrotfish is appropriate, given available data only comprehensively evaluate *S. viride*.
- Research methods to “right-size” model complexity to match data availability, avoiding overparameterization in data-limited contexts.
- Expand simulation studies to understand trade-offs in model complexity vs. data requirements.
- Support MSEs that are robust to key uncertainties to guide harvest advice.
- Maintain and expand commercial catch monitoring programs
- Ensure the continuation of fishery-independent survey programs (e.g., NCRMP) with consistent spatial and temporal coverage.
- Expand port sampling and other fishery-dependent data collection to fill gaps in length composition and effort data.

7 Tables

Table 7.1: Commercial landings of Stoplight Parrotfish reported in St. Croix 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	Dive Gears	Other Gears
2012	18.99	41,869	97%	3%
2013	15.32	33,773	98%	2%
2014	9.88	21,774	87%	13%
2015	11.25	24,808	68%	32%
2016	11.10	24,481	58%	42%
2017	10.67	23,533	68%	32%
2018	3.29	7,262	90%	10%
2019	3.42	7,540	80%	20%
2020	9.93	21,883	71%	29%
2021	11.07	24,412	90%	10%
2022	7.44	16,398	74%	26%
Total	112.37	247,733	82%	18%

Table 7.2: Empirical estimates of natural mortality (M) derived using life history information and the Natural Mortality Tool (Cope & Hamel, 2022). The SEDAR assessment working paper SEDAR84-AP-01 is equivalent to Rivera Hernández & Shervette (2024). All models included in this report utilize the natural mortality estimate of 0.27 corresponding with the maximum age observed by Rivera Hernández & Shervette (2024), except three of the sensitivity scenarios (s2, s5, and s6) which utilize the 0.18 natural mortality corresponding with the estimated maximum age from tagging studies by Choat et al. (2003).

Input Source	Input Type	Input	M	Method
Choat et al. (2003)	Maximum age	30	0.180	Hamel_Amax
SEDAR84-AP-01	Maximum age	20	0.270	Hamel_Amax
Meta-analysis	Scientific name	<i>Sparisoma viride</i>	0.397	FishLife
Choat et al. (2003)	Maximum age	12	0.450	Hamel_Amax
Choat et al. (2003)	Maximum age	9	0.600	Hamel_Amax
SEDAR84-AP-01	Growth (k)	0.39	0.604	Hamel_k
SEDAR84-AP-01	Growth (k)	0.39	0.585	Jensen_k 1
SEDAR84-AP-01	Growth (k)	0.39	0.624	Jensen_k 2
SEDAR84-AP-01	Growth (L_{∞} , k)	33.2, 0.39	0.576	Then_VBGF
SEDAR84-AP-01	Growth (k)	0.33	0.512	Hamel_k
SEDAR84-AP-01	Growth (k)	0.33	0.495	Jensen_k 1
SEDAR84-AP-01	Growth (k)	0.33	0.528	Jensen_k 2
SEDAR84-AP-01	Growth (L_{∞} , k)	33.8, 0.33	0.573	Then_VBGF
SEDAR84-AP-01	Age at 50% maturity	1.6	1.030	Jensen_Amat
SEDAR84-AP-01	Age at 50% maturity	1.6	0.924	Ri_Ef_Amat

Table 7.3: Summary of process and naming conventions used for SEDAR 84 assessments describing model development noting the simplest data-limited configuration, exploring individual data-moderate considerations, individually and combined. The models focused on in the current report are associated with the codes in bold.

Model Development Process	Code	Sequential modeling steps
Data-limited	null	super-year size data
Data-moderate	a	index
Data-moderate	b	annual fishery-independent size data
Data-moderate	c	annual fishery-dependent size data
Data-moderate	d	recruitment deviations
Data-moderate	e	dome-shaped selectivity
Data-moderate	f	time blocks
Variation 1	v1	a + b
Variation 2	v2	a + c
Variation 3	v3	a + d
Variation 4	v4	a + e
Variation 5	v5	a + f
Variation 6	v6	a + b + c
Variation 7	v7	a + b + d
Variation 8	v8	a + b + e
Variation 9	v9	a + b + f
Variation 10	v10	a + c + d
Variation 11	v11	a + c + e
Variation 12	v12	a + c + f
Variation 13	v13	a + d + e
Variation 14	v14	a + d + f
Variation 15	v15	a + e + f
Variation 16	v16	a + b + c + d
Variation 17	v17	a + b + c + e
Variation 18	v18	a + b + c + f
Variation 19	v19	a + b + d + e
Variation 20	v20	a + b + d + f
Variation 21	v21	a + b + e + f
Variation 22	v22	a + b + c + d + e
Variation 23	v23	a + b + c + d + f
Variation 24	v24	a + b + c + e + f
Variation 25	v25	a + b + c + d + e + f

Table 7.4: Summary of process and naming conventions used across different model development stages of the SEDAR 84 St. Croix Stoplight Parrotfish stock assessment.

Stage	Code	Sequential modeling steps
Initial	ct	model initialized with continuum tool (ct)
Initial	m1	ct + hermaphroditism
Initial	m2	m1 + continuous recruitment
Initial	m3	m2 + catch uncertainty
Scenario	null	super-year size data
Scenario	a	index
Scenario	b	annual fishery-independent size data
Scenario	v1	index + annual fishery-independent size data
Scenario	v3	index + recruitment deviations
Scenario	v7	index + annual fishery-independent size data + recruitment deviations
Sensitivity	s1	higher CV on growth young
Sensitivity	s2	higher age and lower m
Sensitivity	s3	one sex (age-based fecundity = maturity * weight * sex ratio)
Sensitivity	s4	higher catch uncertainty
Sensitivity	s5	s2 + s4
Sensitivity	s6	s2 + s3 + s4

Table 7.5: St. Croix stoplight parrotfish correlations between estimated parameters across the m2 and m3 model variations. 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
a_m2	Initial F	Unfished Recruitment (R0)	-0.997
a_m2	Commercial Selectivity Asend.	Commercial Selectivity Peak	0.901
a_m3	Commercial Selectivity Asend.	Commercial Selectivity Peak	0.901
b_m2	Initial F	Unfished Recruitment (R0)	-0.995
b_m2	Commercial Selectivity Asend.	Commercial Selectivity Peak	0.911
b_m3	Commercial Selectivity Asend.	Commercial Selectivity Peak	0.903
v1_m2	Initial F	Unfished Recruitment (R0)	-0.995
v1_m2	Commercial Selectivity Asend.	Commercial Selectivity Peak	0.913
v1_m3	Commercial Selectivity Asend.	Commercial Selectivity Peak	0.902
v3_m2	Initial F	Unfished Recruitment (R0)	-0.904
v7_m2	Initial F	Unfished Recruitment (R0)	-0.997
v7_m2	Commercial Selectivity Asend.	Commercial Selectivity Peak	0.919
v7_m3	Commercial Selectivity Asend.	Commercial Selectivity Peak	0.919

Table 7.6: St. Croix stoplight parrotfish 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 variation (a_m3, b_m3, v1_m3, v3_m3, and v7_m3). CV is calculated as the SD divided by the parameter estimate.

Derived Quantity	Scenario	Estimate	SD	CV
SSB Unfished (mt)	a_m3	98.13	26.13	0.27
	b_m3	78.64	25.59	0.33
	v1_m3	73.54	25.45	0.35
	v3_m3	60.88	13.84	0.23
	v7_m3	37.67	7.56	0.20
SSB Initial (mt)	a_m3	65.21	19.86	0.30
	b_m3	59.32	19.98	0.34
	v1_m3	55.69	20.07	0.36
	v3_m3	16.55	7.60	0.46
	v7_m3	27.84	5.49	0.20
Ratio SSB Initial:Unfished	a_m3	0.66	0.09	0.13
	b_m3	0.75	0.05	0.06
	v1_m3	0.76	0.05	0.06
	v3_m3	0.27	0.14	0.53
	v7_m3	0.74	0.05	0.07

Table 7.7: St. Croix stoplight parrotfish estimated initial equilibrium catch in metric tons by model variation including across sensitivity runs. The input value was 30 metric tons with a standard error of 0.3.

Parameter	Scenario	a	b	v1	v3	v7
Commercial Equilibrium Catch	m2	29.99	29.98	29.98	30.00	29.98
	m3	25.39	15.66	14.24	28.39	8.00
	m3_s1	25.09	15.12	13.58	28.83	7.36
	m3_s2	12.28	9.89	8.90	18.23	6.92
	m3_s3	25.39	15.65	14.24	28.41	8.00
	m3_s4	5.74	3.78	2.24	24.30	0.00
	m3_s5	4.80	8.32	7.37	10.40	4.28
	m3_s6	4.80	8.32	7.37	10.40	4.28

Table 7.8: St. Croix stoplight parrotfish parameters, standard deviations (SD), and coefficient of variation (CV) by model variation (a_m3, b_m3, v1_m3, v3_m3, and v7_m3). CV is calculated as the SD divided by the parameter estimate.

Parameter	Scenario	Estimate	SD	CV	Gradient
Commercial Selectivity Asend.	a_m3	2.25	0.98	0.44	-4.0e-06
	b_m3	2.27	0.98	0.43	1.1e-05
	v1_m3	2.26	0.98	0.43	1.9e-05
	v3_m3	2.48	0.83	0.33	1.6e-05
	v7_m3	2.56	0.85	0.33	-1.1e-05
Commercial Selectivity Peak	a_m3	25.85	1.79	0.07	4.1e-06
	b_m3	25.89	1.82	0.07	-1.6e-05
	v1_m3	25.87	1.81	0.07	-5.9e-05
	v3_m3	26.62	1.57	0.06	-1.4e-05
	v7_m3	26.98	1.74	0.06	1.3e-05
Initial F	a_m3	0.19	0.08	0.42	2.5e-06
	b_m3	0.12	0.03	0.25	-9.4e-06
	v1_m3	0.11	0.03	0.27	-3.3e-05
	v3_m3	1.20	1.20	1.00	1.4e-05
	v7_m3	0.12	0.03	0.25	1.3e-05
Unfished Recruitment (R0)	a_m3	5.51	0.27	0.05	-5.9e-06
	b_m3	5.29	0.33	0.06	1.4e-06
	v1_m3	5.28	0.35	0.07	7.8e-06
	v3_m3	5.09	0.23	0.05	-2.0e-05
	v7_m3	4.61	0.20	0.04	7.2e-06

Table 7.9: St. Croix stoplight parrotfish derived quantities of the MSY proxy (based on SPR 40%) in metric tons by model variation (a_m3, b_m3, v1_m3, v3_m3, and v7_m3) and corresponding each model variation's six 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 7.10.

Scenario	Estimate	SD	CV
a_m2	38.12	6.36	0.17
a_m3	34.25	8.86	0.26
a_m3_s1	32.57	8.19	0.25
a_m3_s2	12.29	1.70	0.14
a_m3_s3	36.59	9.46	0.26
a_m3_s4	19.96	6.21	0.31
a_m3_s5	8.57	1.26	0.15
a_m3_s6	8.29	1.22	0.15
b_m2	50.10	9.01	0.18
b_m3	27.45	8.69	0.32
b_m3_s1	25.47	7.53	0.30
b_m3_s2	10.69	0.89	0.08
b_m3_s3	29.31	9.27	0.32
b_m3_s4	15.22	2.67	0.18
b_m3_s5	9.78	0.77	0.08
b_m3_s6	9.47	0.75	0.08
v1_m2	61.73	13.21	0.21
v1_m3	29.91	10.07	0.34
v1_m3_s1	27.63	8.52	0.31
v1_m3_s2	10.84	0.83	0.08
v1_m3_s3	32.67	10.98	0.34
v1_m3_s4	16.06	2.63	0.16
v1_m3_s5	9.96	0.72	0.07

Scenario	Estimate	SD	CV
v1_m3_s6	10.28	0.75	0.07
v3_m2	26.31	1.60	0.06
v3_m3	25.23	5.61	0.22
v3_m3_s1	24.06	5.46	0.23
v3_m3_s2	16.17	3.33	0.21
v3_m3_s3	27.61	6.13	0.22
v3_m3_s4	22.64	8.94	0.39
v3_m3_s5	10.91	3.05	0.28
v3_m3_s6	11.26	3.15	0.28
v7_m2	63.84	18.39	0.29
v7_m3	15.76	3.08	0.20
v7_m3_s1	14.05	2.33	0.17
v7_m3_s2	8.91	0.81	0.09
v7_m3_s3	17.26	3.37	0.20
v7_m3_s4	10.09	1.12	0.11
v7_m3_s5	7.41	0.77	0.10
v7_m3_s6	7.65	0.79	0.10

Table 7.10: St. Croix stoplight parrotfish derived quantities of the MSY proxy (based on SPR 40%) in pounds by model variation (a_m3, b_m3, v1_m3, v3_m3, and v7_m3) and corresponding each model variation's six sensitivity runs.

Scenario	a	b	v1	v3	v7
m2	84,039	110,450	136,093	57,997	140,739
m3	75,500	60,510	65,947	55,620	34,751
m3_s1	71,811	56,150	60,908	53,047	30,975
m3_s2	27,089	23,571	23,896	35,651	19,638
m3_s3	80,660	64,612	72,036	60,859	38,041
m3_s4	44,007	33,559	35,413	49,915	22,241
m3_s5	18,890	21,570	21,949	24,055	16,333
m3_s6	18,286	20,874	22,658	24,832	16,856

Table 7.11: St. Croix stoplight parrotfish 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 one are shown in red font.

Metric	Scenario	a	b	v1	v3	v7
F Current / F SPR 40%	m2	0.13	0.09	0.06	0.22	0.05
	m3	0.14	0.18	0.14	0.23	0.33
	m3_s1	0.15	0.20	0.16	0.24	0.41
	m3_s2	0.60	0.74	0.64	0.61	0.89
	m3_s3	0.12	0.15	0.10	0.16	0.23
	m3_s4	0.26	0.38	0.30	0.25	0.53
	m3_s5	0.98	0.85	0.73	0.78	1.00
	m3_s6	1.07	0.93	0.64	0.69	0.88
SSB 2022 / SSB SPR 40%	m2	1.79	1.85	2.31	1.38	2.52
	m3	1.77	1.73	2.12	1.38	1.56
	m3_s1	1.75	1.70	2.08	1.38	1.40
	m3_s2	1.25	1.16	1.30	0.81	1.04
	m3_s3	1.75	1.71	2.14	1.40	1.59
	m3_s4	1.64	1.52	1.83	1.39	1.48
	m3_s5	1.05	1.10	1.23	0.90	1.08
	m3_s6	1.00	1.03	1.26	0.91	1.13

8 Figures

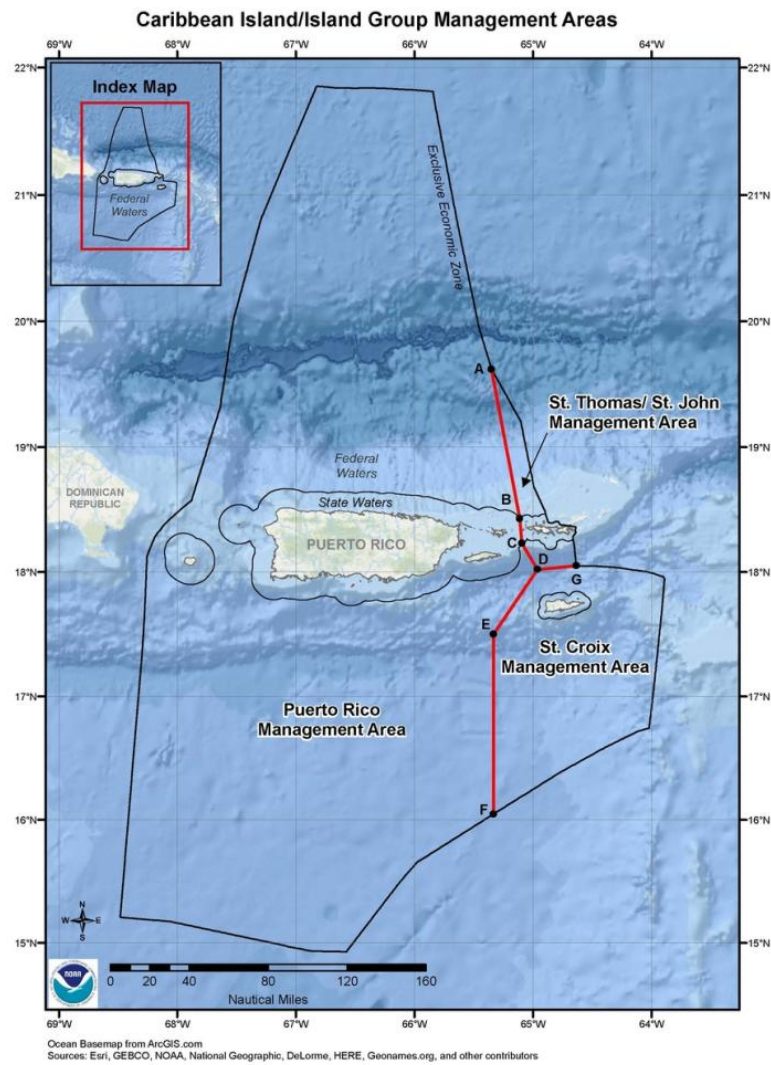


Figure 8.1: Jurisdictional boundaries of the Caribbean Fishery Management Council.

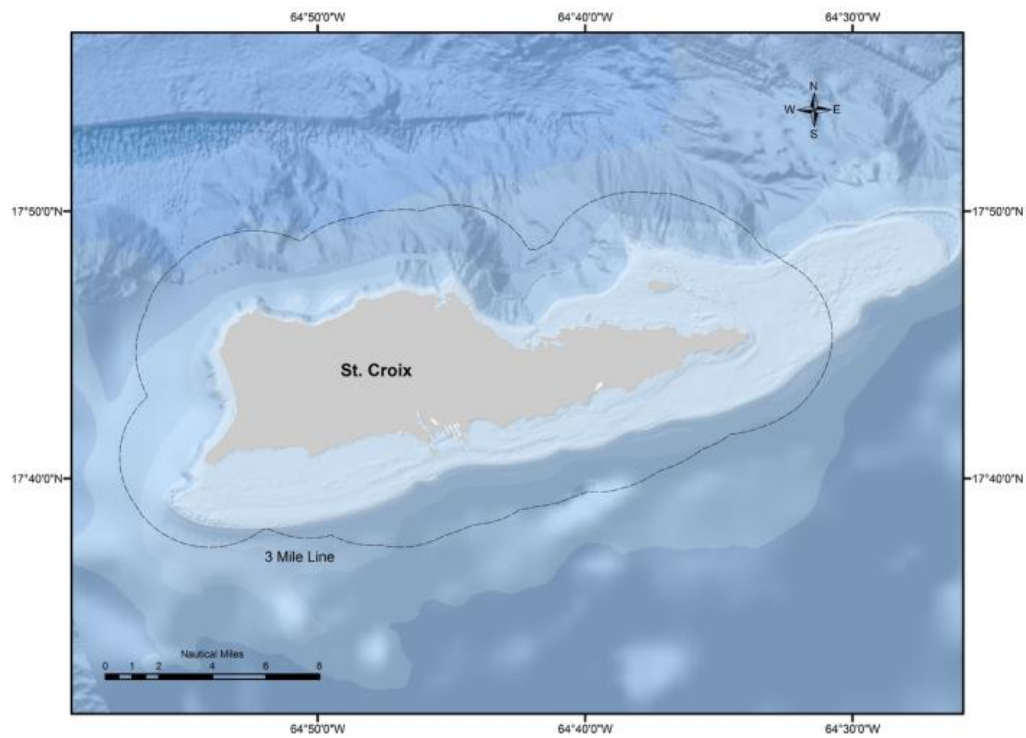


Figure 8.2: The U.S. EEZ is defined as the federal waters ranging from 3 to 200 nautical miles (5.6 – 370 kilometers) from the nearest coastline point of the US Virgin Islands.

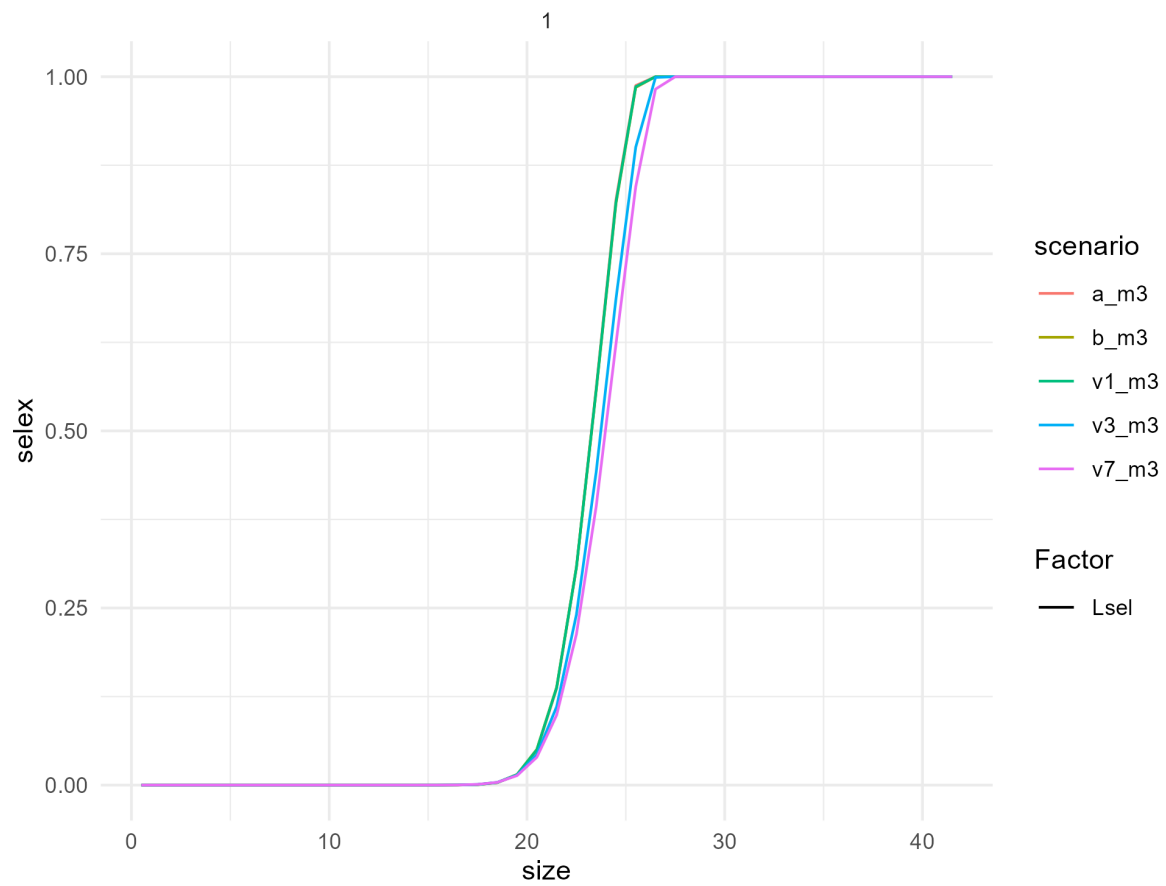
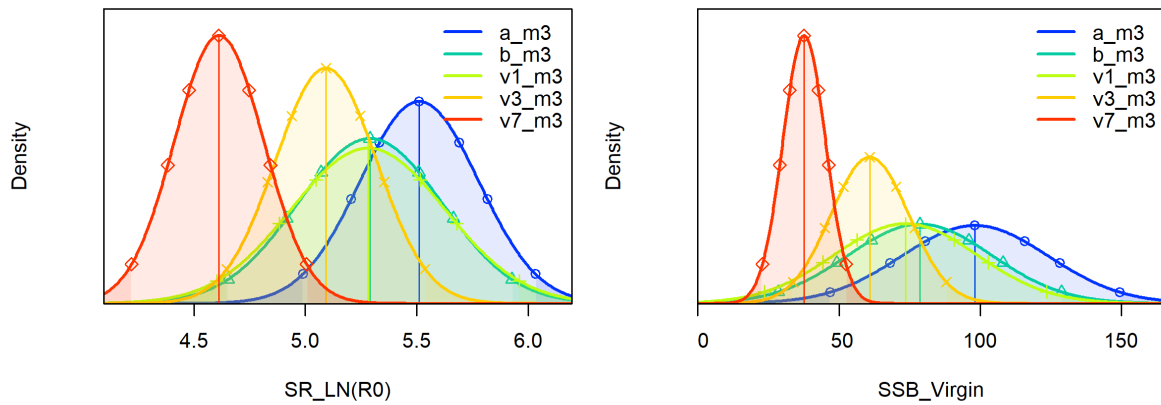


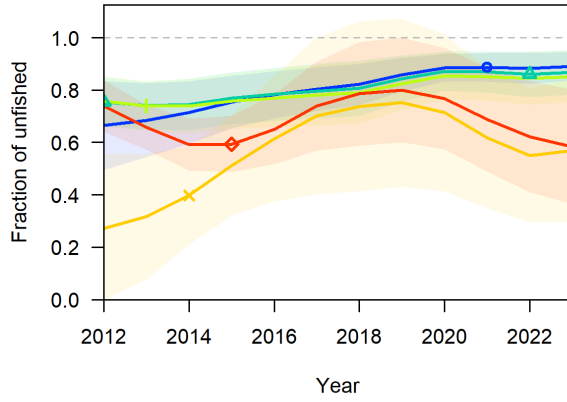
Figure 8.3: St. Croix stoplight parrotfish commercial fleet logistic selectivity across model variations (a_m3, b_m3, v1_m3, v3_m3, and v7_m3).



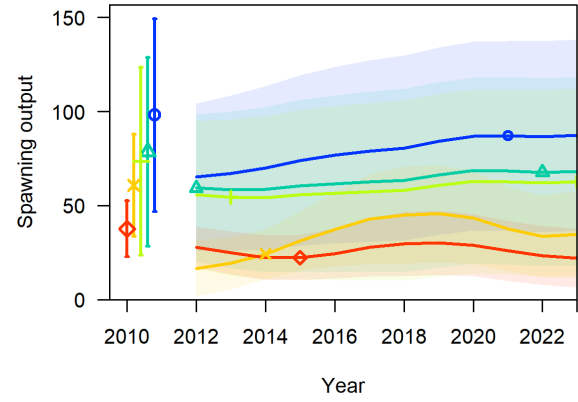
(a) Unfished recruitment

(b) Virgin Spawning Stock Biomass

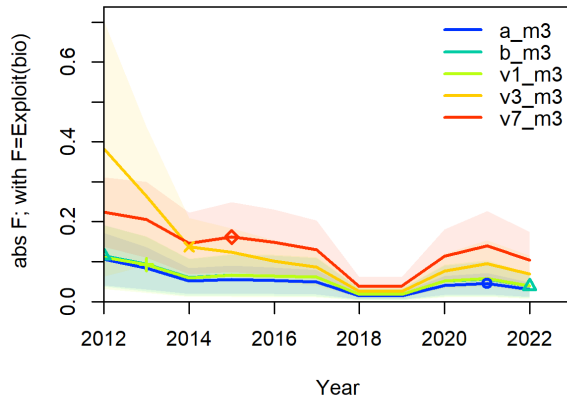
Figure 8.4: St. Croix stoplight parrotfish parameter distribution for (a) the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function and (b) virgin spawning stock biomass in metric tons across model variations (a_m3 , b_m3 , $v1_m3$, $v3_m3$, and $v7_m3$).



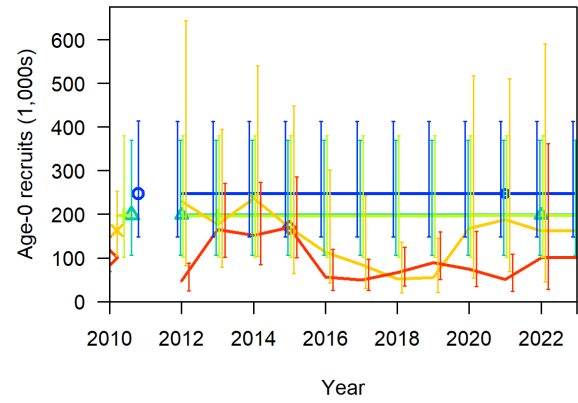
(a) Spawning Biomass Ratio



(b) Spawning Biomass

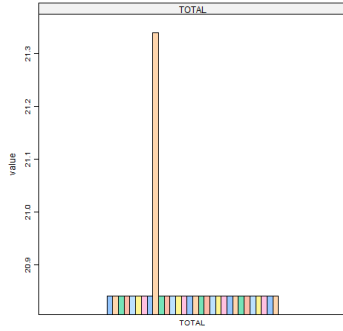


(c) Fishing Mortality

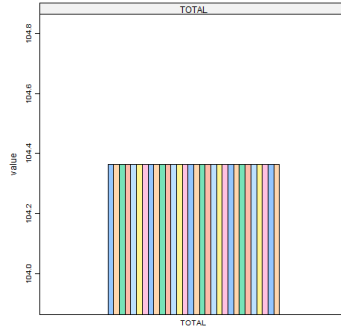


(d) Recruitment

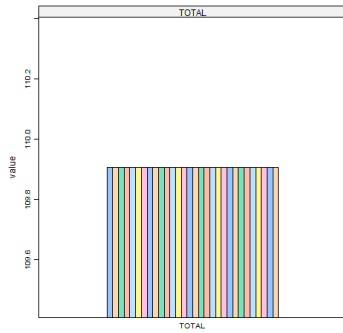
Figure 8.5: St. Croix stoplight parrotfish derived quantity time series across model variations (a_m3, b_m3, v1_m3, v3_m3, and v7_m3). Derived quantities plotted over time for (a) the relative spawning stock biomass (total biomass / virgin spawning stock biomass), (b) spawning stock biomass in metric tons, (c) fishing mortality (total biomass killed / total biomass), (d) and recruitment in thousands of fish. The shaded areas and vertical bars in the derived quantities time series represent 95% confidence intervals.



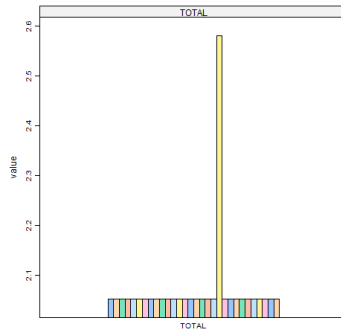
(a) Model a_m3



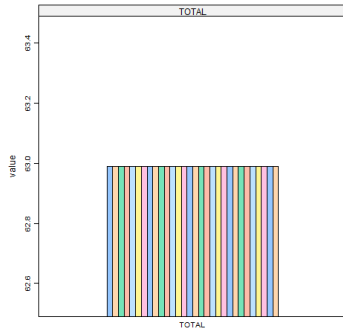
(b) Model b_m3



(c) Model v1_m3

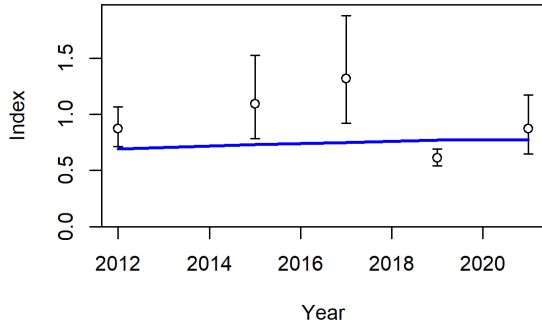


(d) Model v3_m3

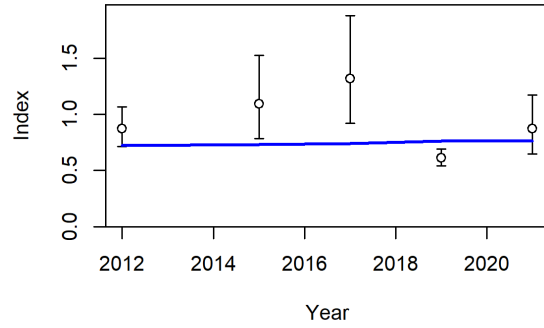


(e) Model v7_m3

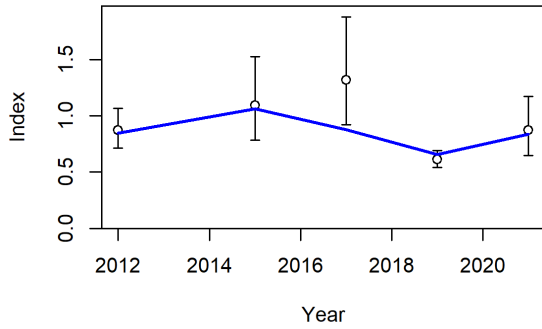
Figure 8.6: St. Croix stoplight parrotfish jitter analysis total likelihood across model variations (a_m3, b_m3, v1_m3, v3_m3, and v7_m3). Each panel gives the results of 30 runs of the corresponding model variation where the starting parameter values for each run were randomly changed by 20% from each model's predicted values using a uniform distribution in cumulative normal space.



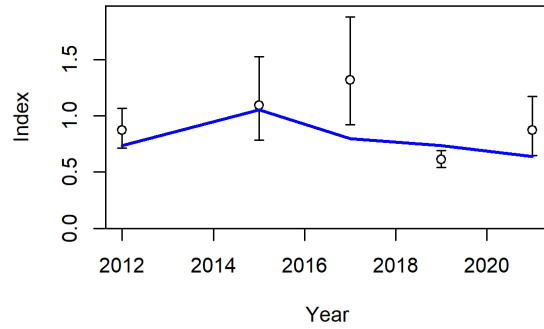
(a) a_m3



(b) v1_m3

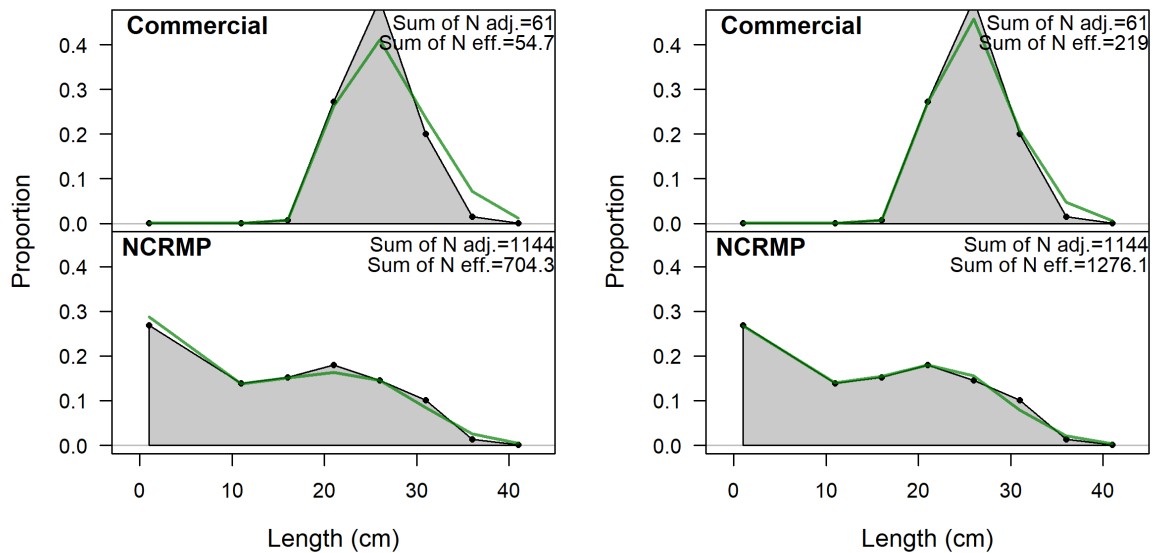


(c) v3_m3



(d) v7_m3

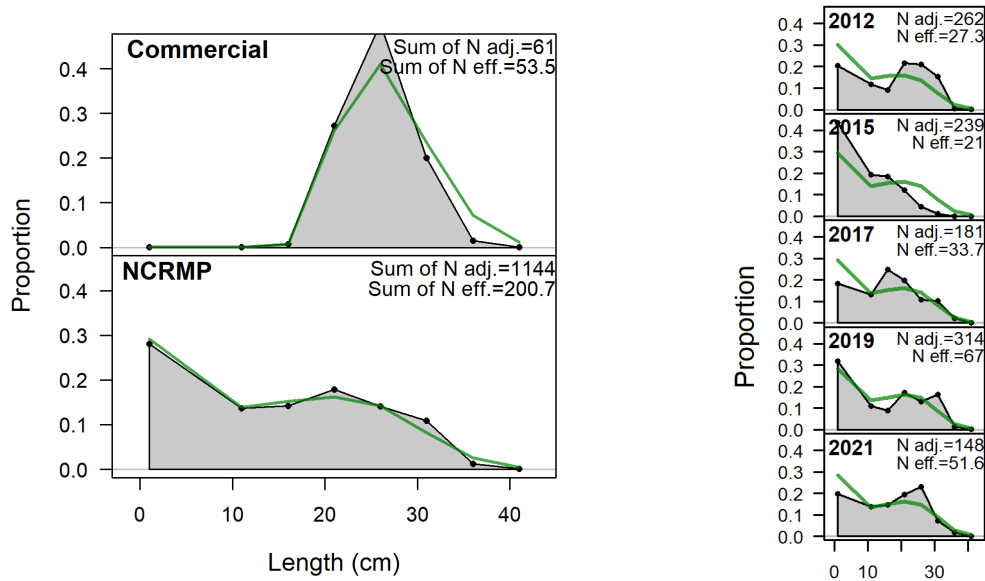
Figure 8.7: St. Croix stoplight parrotfish National Coral Reef Monitoring Program observed (open circles) and predicted (blue line) indices of relative abundance and associated standard errors across model variations (a_m3, v1_m3, v3_m3, and v7_m3). Model variation b_m3 is not provided as its configuration does not include an index. Lines indicate 95% uncertainty interval around observed index values based on the model assumption of lognormal error. Model variation a_m3 and v1_m3 do not estimate recruitment deviations, while model variations v3_m3 and v7_m3 do.



(a) a_m3 across all years

(b) v3_m3 across all years

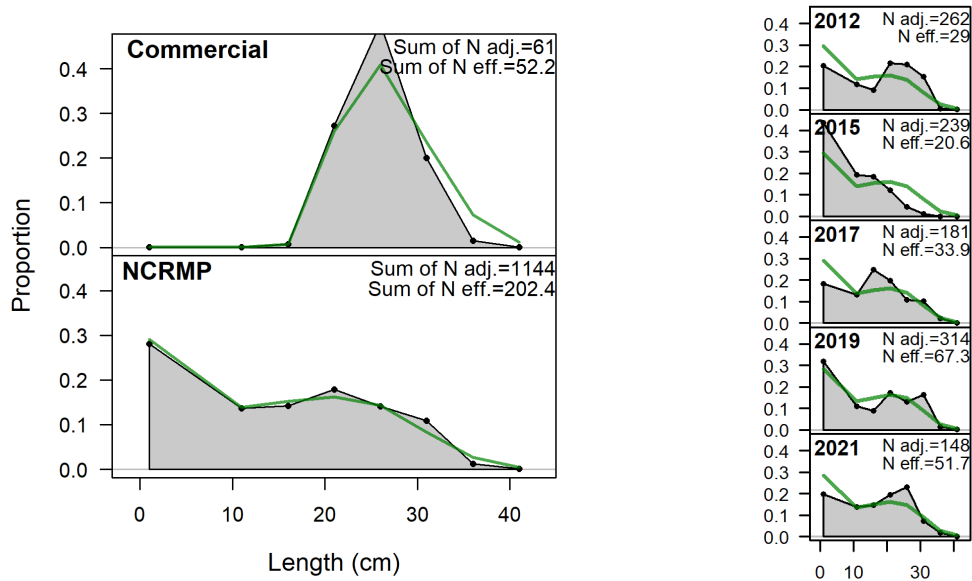
Figure 8.8: St. Croix stoplight parrotfish observed and predicted length distributions in centimeters aggregated across years for the Commercial and NCRMP length compositions for the (a) a_m3 model variation. Green lines represent predicted length compositions, while gray regions represent observed length compositions. The effective sample size used to weight the length composition data is provided by N adj (the input sample size), and N eff (the calculated effective sample size), are shown in the upper right corners. Since super years are utilized for the commercial fleet and the national coral reef monitoring survey in these model variations, the fits to annual data are not shown.



(a) b_m3 across all years

(b) b_m3 by year

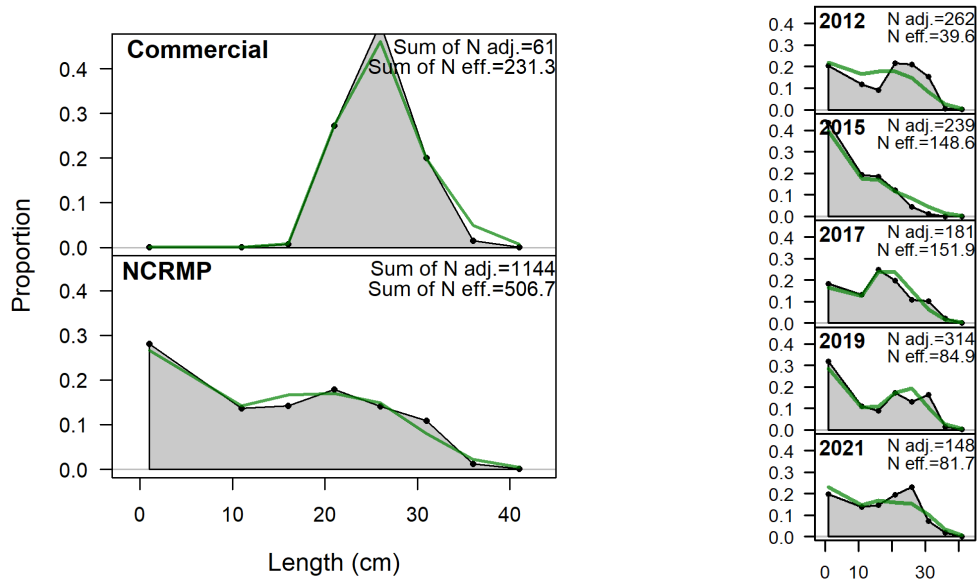
Figure 8.9: St. Croix stoplight parrotfish observed and predicted length distributions in centimeters (a) aggregated across years and (b) by year for the Commercial and NCRMP length compositions for the b_m3 model variation. Green lines represent predicted length compositions, while gray regions represent observed length compositions. The effective sample size used to weight the length composition data is provided by N adj (the input sample size), and N eff (the calculated effective sample size), are shown in the upper right corners.



(a) v1_m3 across all years

(b) v1_m3 by year

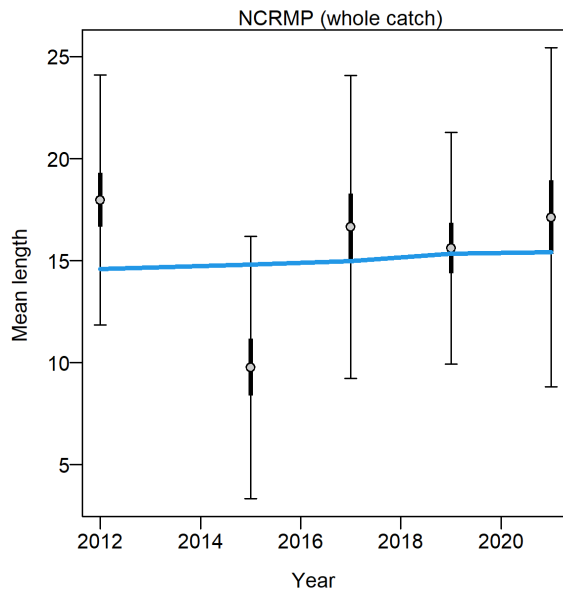
Figure 8.10: St. Croix stoplight parrotfish observed and predicted length distributions in centimeters (a) aggregated across years and (b) by year for the Commercial and NCRMP length compositions for the v1_m3 model variation. Green lines represent predicted length compositions, while gray regions represent observed length compositions. The effective sample size used to weight the length composition data is provided by N adj (the input sample size), and N eff (the calculated effective sample size), are shown in the upper right corners.



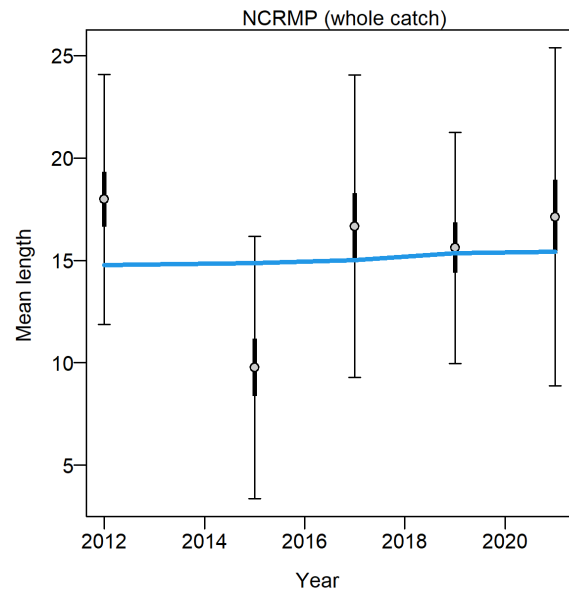
(a) v7_m3 across all years

(b) v7_m3 by year

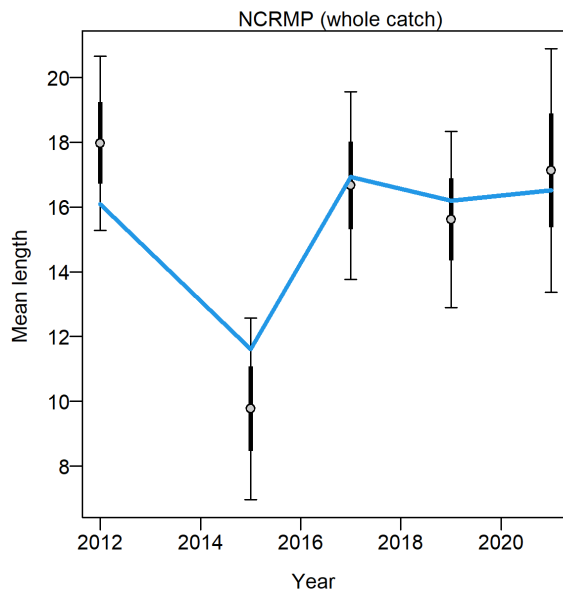
Figure 8.11: St. Croix stoplight parrotfish observed and predicted length distributions in centimeters (a) aggregated across years and (b) by year for the Commercial and NCRMP length compositions for the v7_m3 model variation. Green lines represent predicted length compositions, while gray regions represent observed length compositions. The effective sample size used to weight the length composition data is provided by N adj (the input sample size), and N eff (the calculated effective sample size), are shown in the upper right corners.



(a) b_m3

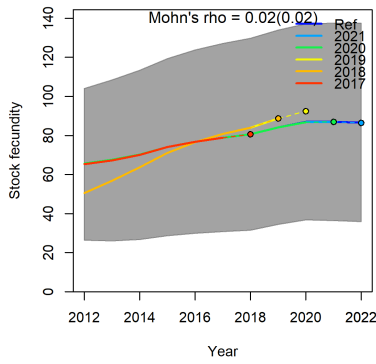


(b) v1_m3

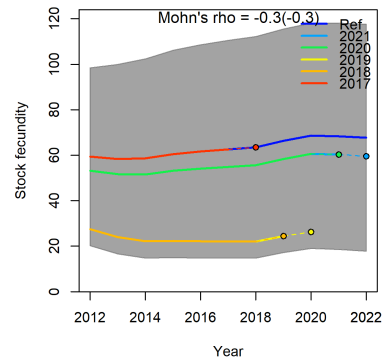


(c) v7_m3

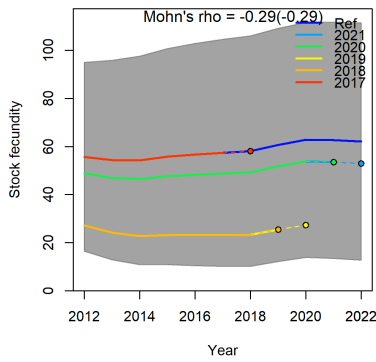
Figure 8.12: St. Croix stoplight parrotfish observed (open circles) and predicted (blue line) mean length in centimeters by year across model variations that include annual fishery-independent data without recruitment deviations (b_m3, v1_m3) and with recruitment deviations (v7_m3).



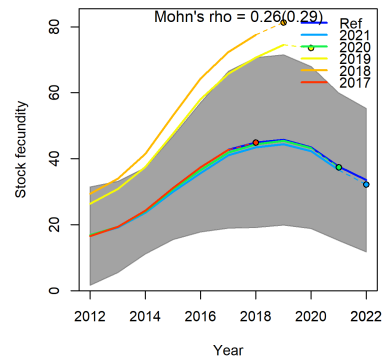
(a) a_m3



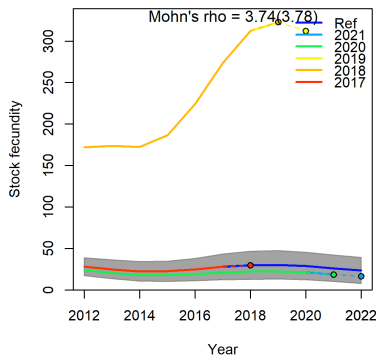
(b) b_m3



(c) v1_m3

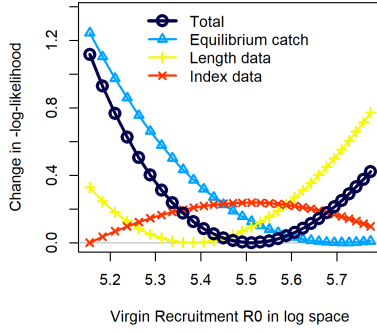


(d) v3_m3

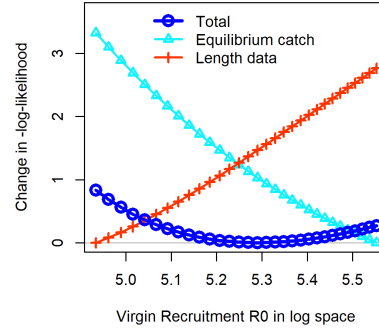


(e) v7_m3

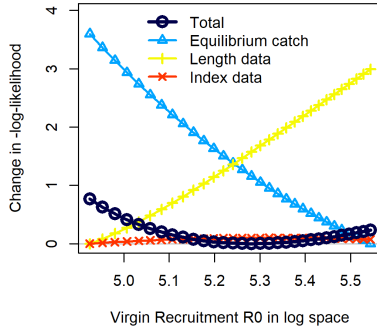
Figure 8.13: St. Croix stoplight parrotfish retrospective analysis of spawning stock biomass (SSB) conducted by refitting models after removing five years of observation, one year at a time sequentially. Mohn's rho statistics and the corresponding "hindcast rho" measure the severity of retrospective patterns. One-year-ahead projections denoted by color-coded dashed lines with terminal points. Grey shaded areas are the 95% confidence intervals.



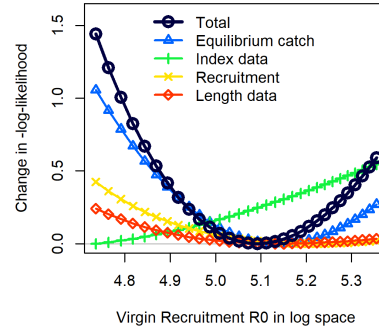
(a) a_m3



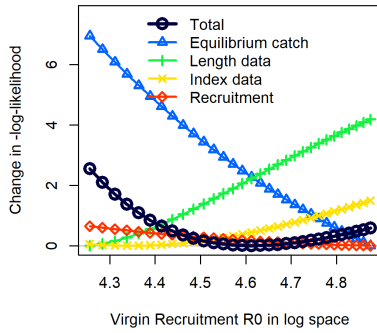
(b) b_m3



(c) v1_m3

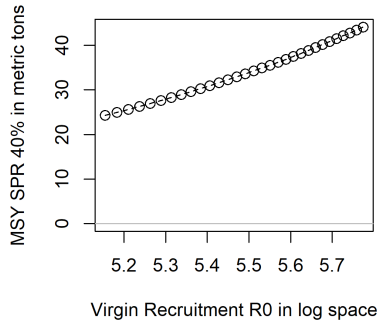


(d) v3_m3

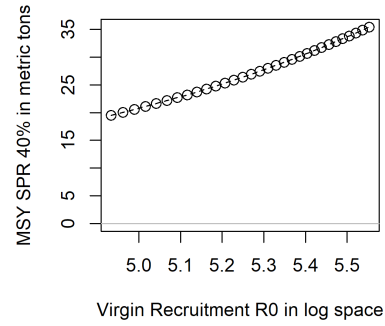


(e) v7_m3

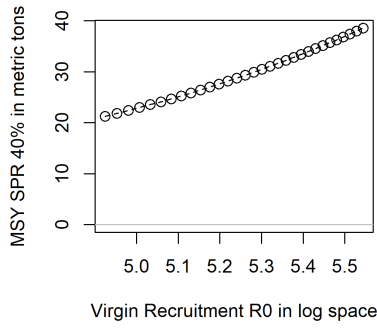
Figure 8.14: The profile likelihood for the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function for St. Croix stoplight parrotfish across model variations (a_m3, b_m3, v1_m3, v3_m3, and v7_m3). Each line represents the change in negative log-likelihood value for each of the data sources fit in the model across the range of fixed steepness values tested in the profile diagnostic run.



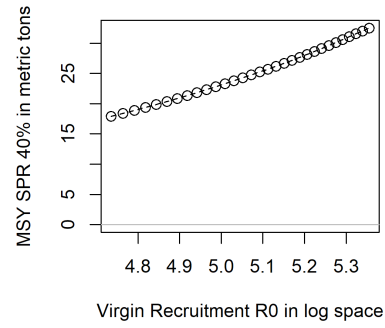
(a) a_m3



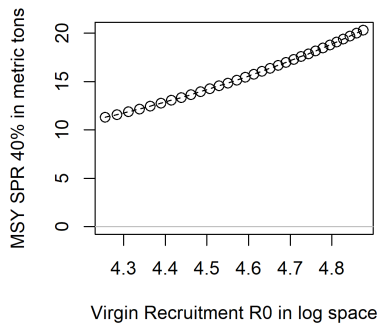
(b) b_m3



(c) v1_m3

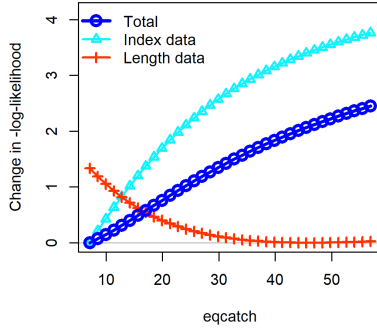


(d) v3_m3

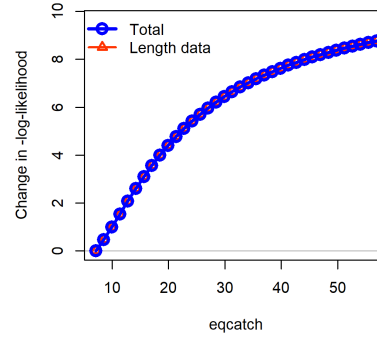


(e) v7_m3

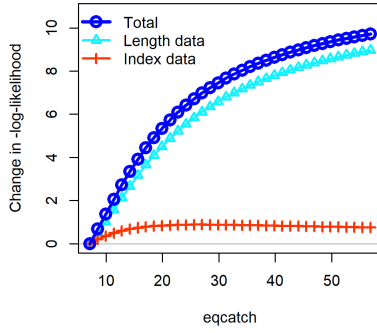
Figure 8.15: Estimates of the MSY proxy (based on SPR 40%) across the range of unfished recruitment values explored in the St. Croix stoplight parrotfish likelihood profile. These estimates, expressed in metric tons, are shown for model variations a_m3, b_m3, v1_m3, v3_m3, and v7_m3.



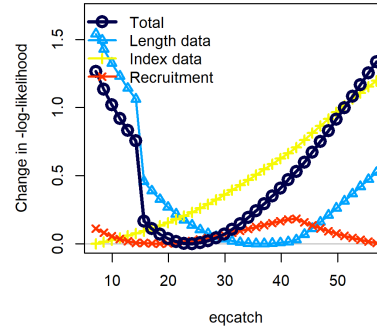
(a) a_m3



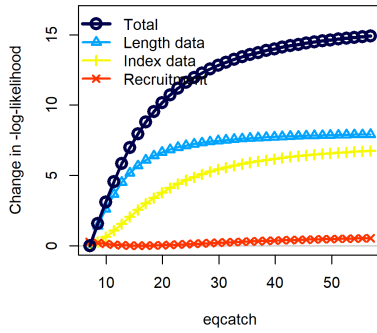
(b) b_m3



(c) v1_m3

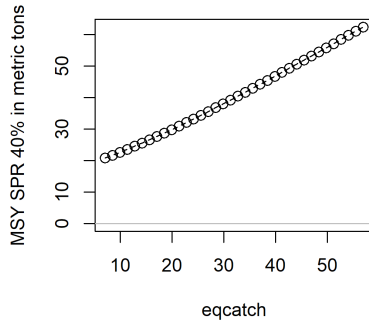


(d) v3_m3

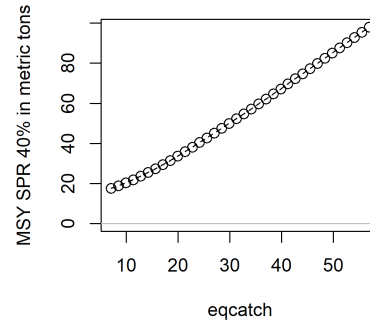


(e) v7_m3

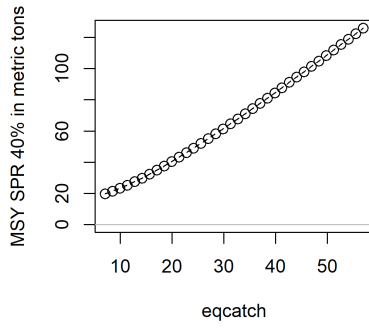
Figure 8.16: The profile likelihood for the fixed initial equilibrium catch for for St. Croix stoplight parrotfish across model variations (a_m3, b_m3, v1_m3, v3_m3, and v7_m3). Each line represents the change in negative log-likelihood value for each of the data sources fit in the model across the range of fixed steepness values tested in the profile diagnostic run.



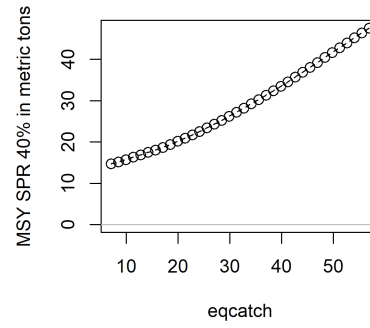
(a) a_m3



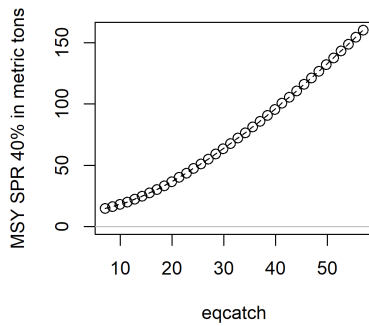
(b) b_m3



(c) v1_m3

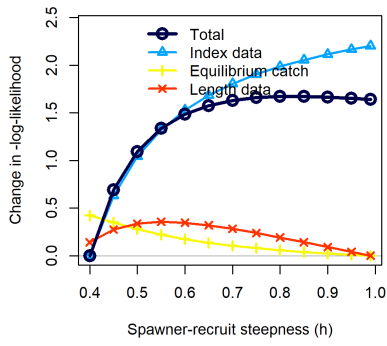


(d) v3_m3

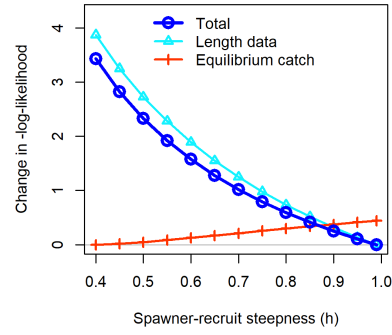


(e) v7_m3

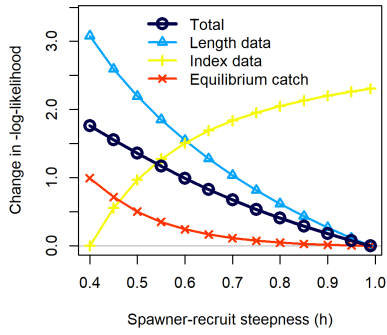
Figure 8.17: Estimates of the MSY proxy (based on SPR 40%) across the range of initial equilibrium catch values explored in the St. Croix stoplight parrotfish likelihood profile. These estimates, expressed in metric tons, are shown for model variations a_m3, b_m3, v1_m3, v3_m3, and v7_m3.



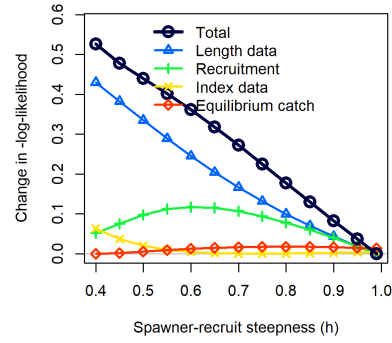
(a) a_m3



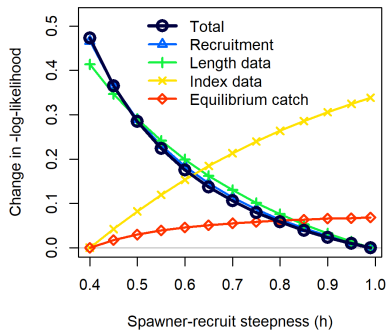
(b) b_m3



(c) v1_m3

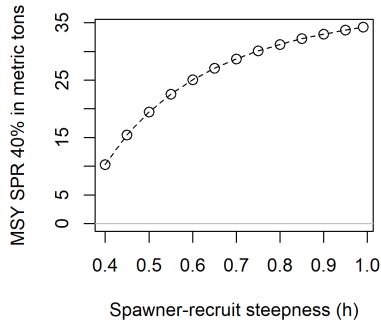


(d) v3_m3

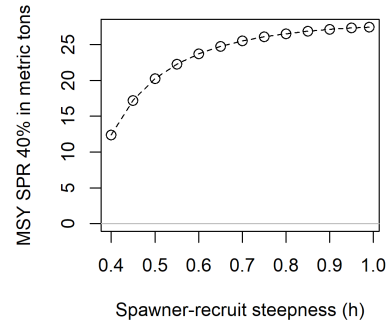


(e) v7_m3

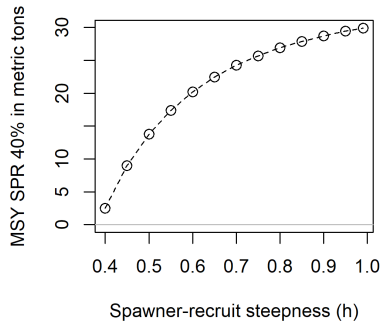
Figure 8.18: The profile likelihood for the steepness parameter of the Beverton – Holt stock-recruit function for St. Croix stoplight parrotfish across model variations (a_m3, b_m3, v1_m3, v3_m3, and v7_m3). Each line represents the change in negative log-likelihood value for each of the data sources fit in the model across the range of fixed steepness values tested in the profile diagnostic run.



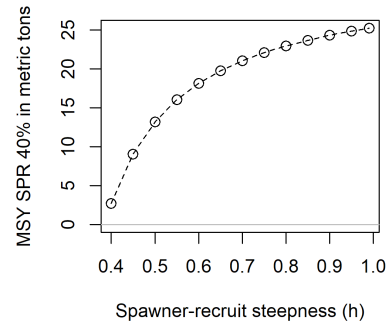
(a) a_m3



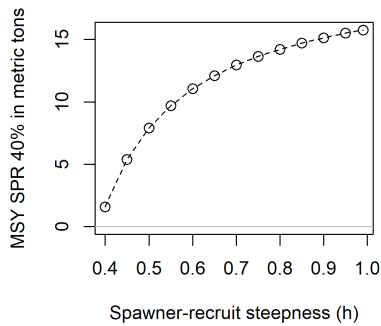
(b) b_m3



(c) v1_m3



(d) v3_m3



(e) v7_m3

Figure 8.19: Estimates of the MSY proxy (based on SPR 40%) across the range of steepness values explored in the St. Croix stoplight parrotfish likelihood profile. These estimates, expressed in metric tons, are shown for model variations a_m3, b_m3, v1_m3, v3_m3, and v7_m3.

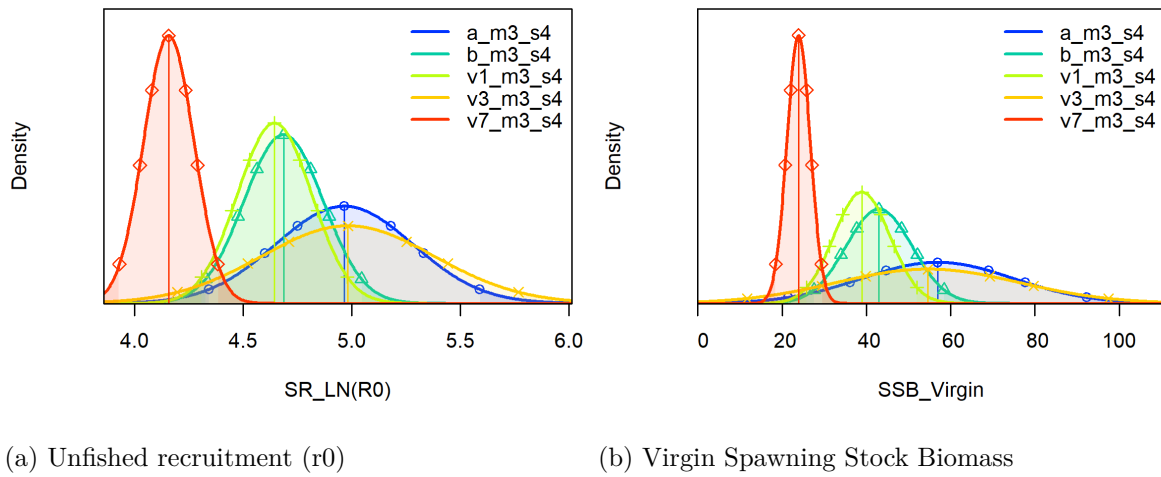


Figure 8.20: St. Croix stoplight parrotfish parameter distribution for (a) the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function and (b) virgin spawning stock biomass in metric tons across model variations (a_m3_s4 , b_m3_s4 , $v1_m3_s4$, $v3_m3_s4$, and $v7_m3_s4$).

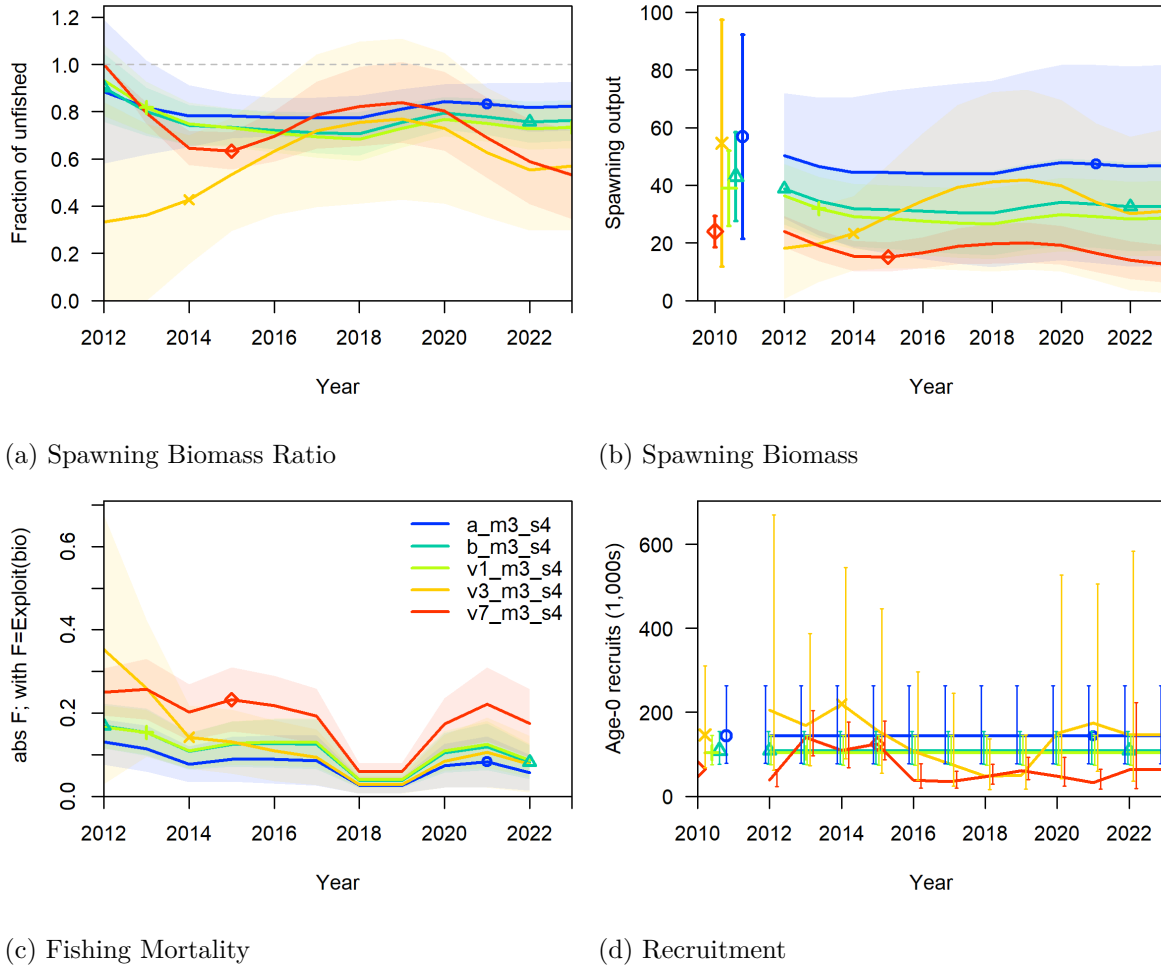


Figure 8.21: St. Croix stoplight parrotfish derived quantity time series across model variations (a_m3_s5, b_m3_s5, v1_m3_s5, v3_m3_s5, and v7_m3_s5). Derived quantities plotted over time for (a) the relative spawning stock biomass (total biomass / virgin spawning stock biomass), (b) spawning stock biomass in metric tons, (c) fishing mortality (total biomass killed / total biomass), (d) and recruitment in thousands of fish. The shaded areas and vertical bars in the derived quantities time series represent 95% confidence intervals.

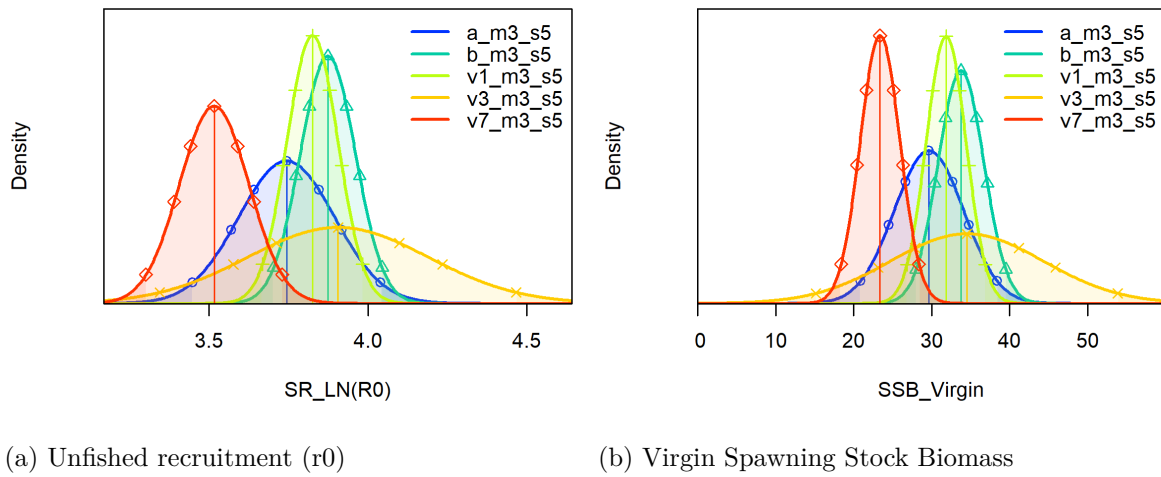


Figure 8.22: St. Croix stoplight parrotfish parameter distribution for (a) the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function and (b) virgin spawning stock biomass in metric tons across model variations (a_m3_s5 , b_m3_s5 , $v1_m3_s5$, $v3_m3_s5$, and $v7_m3_s5$).

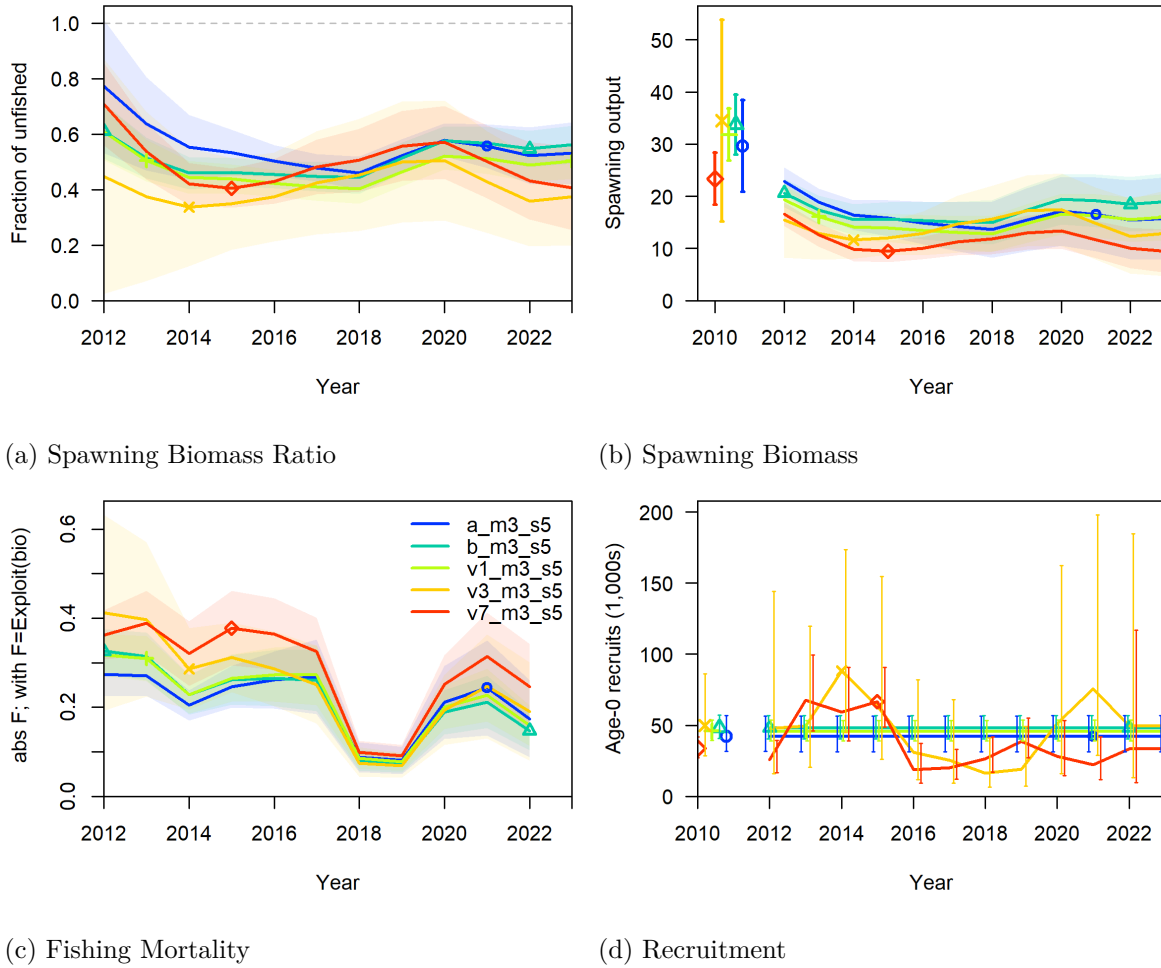


Figure 8.23: St. Croix stoplight parrotfish derived quantity time series across model variations (a_m3_s5, b_m3_s5, v1_m3_s5, v3_m3_s5, and v7_m3_s5). Derived quantities plotted over time for (a) the relative spawning stock biomass (total biomass / virgin spawning stock biomass), (b) spawning stock biomass in metric tons, (c) fishing mortality (total biomass killed / total biomass), (d) and recruitment in thousands of fish. The shaded areas and vertical bars in the derived quantities time series represent 95% confidence intervals.

References

- Carruthers, T. R., & Hordyk, A. R. (2018). The Data-Limited Methods Toolkit (DLMtool): An R package for informing management of data-limited populations. *Methods in Ecology and Evolution*, 9(12), 2388–2395. <https://doi.org/10.1111/2041-210x.13081>
- Carvalho, F., Winker, H., Courtney, D., Kapur, M., Kell, L., Cardinale, M., Schirripa, M., Kitakado, T., Yemane, D., Piner, K. R., Maunder, M. N., Taylor, I., Wetzel, C. R., Doering, K., Johnson, K. F., & Methot, R. D. (2021). A cookbook for using model diagnostics in integrated stock assessments. *Fisheries Research*, 240, 105959. <https://doi.org/10.1016/j.fishres.2021.105959>
- Choat, J. H., Robertson, D. R., Ackerman, J. L., & Posada, J. M. (2003). An age-based demographic analysis of the Caribbean stoplight parrotfish *Sparisoma viride*. *Marine Ecology Progress Series*, 246, 265–277. <https://doi.org/10.3354/meps246265>
- Cope, J. (2024). *Stock assessment continuum tool*. <https://github.com/shcaba/SS-DL-tool>
- Cope, J., & Hamel, O. S. (2022). Upgrading from M version 0.2: An application-based method for practical estimation, evaluation and uncertainty characterization of natural mortality. *Fisheries Research*, 256, 106493. <https://doi.org/10.1016/j.fishres.2022.106493>
- Crabtree, R. E. (2019). *Comprehensive Fishery Management Plan for the St. Croix Exclusive Economic Zone Including Environmental Assessment, Regulatory Impact Review, and Fishery Impact Statement*. <https://repository.library.noaa.gov/view/noaa/45275>
- Godwin, K., Rios, A., & Dettloff, K. (2024). *SEDAR 84 trip interview program (TIP) size composition analysis of stoplight parrotfish (sparisoma viride) in st. Croix, u.s. Caribbean, 1983-2022* (p. 10). <https://sedarweb.org/documents/sedar-84-dw-11-sedar-84-trip-interview-program-tip-size-composition-analysis-of-stoplight-parrotfish-sparisoma-viride-in-st-croix-u-s-caribbean-1983-2022/>
- Grove, L. J. W., Blondeau, J., & Ault, J. (2024). *Fishery-independent reef fish visual survey population density and length composition for stoplight parrotfish in the st. croix* (p. 11). <https://sedarweb.org/documents/sedar-84-dw-14-fishery-independent-reef-fish-visual-survey-population-density-and-length-composition-for-stoplight-parrotfish-in-the-st-croix/>
- Grove, L. J. W., Blondeau, J., & Ault, J. S. (2021). *National coral reef monitoring program's reef fish visual census metadata for the u.s. caribbean*. (p. 55). <https://sedarweb.org/documents/sedar-80-wp-02-national-coral-reef-monitoring-programs-reef-fish-visual-census-metadata-for-the-u-s-caribbean/>
- Hamel, O. S. (2015). A method for calculating a meta-analytical prior for the natural mortality rate using multiple life history correlates. *ICES Journal of Marine Science*, 72(1), 62–69. <https://doi.org/10.1093/icesjms/fsu131>

- Hamel, O. S., & Cope, J. M. (2022). Development and considerations for application of a longevity-based prior for the natural mortality rate. *Fisheries Research*, 256, 106477. <https://doi.org/10.1016/j.fishres.2022.106477>
- Jensen, A. L. (1996). Beverton and holt life history invariants result from optimal trade-off of reproduction and survival. *Canadian Journal of Fisheries and Aquatic Sciences*, 53(4), 820–822. <https://doi.org/10.1139/f95-233>
- Jensen, A. L. (1997). Origin of relation between k and linf and synthesis of relations among life history parameters. *Canadian Journal of Fisheries and Aquatic Sciences*, 54(5), 987–989. <https://doi.org/10.1139/f97-007>
- Malone, G. (2024). *Summary of management actions for stoplight parrotfish (sparisoma viride) from st. Croix (1985 - 2021) as documented within the management history database* (p. 16). <https://sedarweb.org/documents/sedar-84-dw-05-summary-of-management-actions-for-stoplight-parrotfish-sparisoma-viride-from-st-croix-1985-2021-as-documented-within-the-management-history-database/>
- Martínez Rivera, S., Johnson, K., & Orhun, M. R. (2024). *SEDAR 84 commercial fishery landings of stoplight parrotfish (sparisoma viride) in st. Croix, US caribbean, 2012-2022* (p. 20). <https://sedarweb.org/documents/sedar-84-dw-03-sedar-84-commercial-fishery-landings-of-stoplight-parrotfish-sparisoma-viride-in-st-croix-us-caribbean-2012-2022/>
- Methot, R. D., & Wetzel, C. R. (2013). Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research*, 142, 86–99. <https://doi.org/10.1016/j.fishres.2012.10.012>
- Methot, R. D., Wetzel, C. R., Taylor, I. G., & Doering, K. (2020). Stock synthesis user manual: Version 3.30.15. *Northwest Fisheries Science Center (U.S.)*. <https://doi.org/10.25923/5WPN-QT71>
- Rikhter, V. A., & Efanov, V. N. (1976). 12. <https://www.nafo.int/icnaf/library/docs/1976/res-08.pdf>
- Rivera Hernández, J. M., & Shervette, V. (2024). *Report on the status of U.S. Caribbean stoplight parrotfish Sparisoma viride age, growth, and reproductive biology for the SEDAR84 Stock Assessment* (p. 22). <https://sedarweb.org/documents/sedar-84-ap-01-report-on-the-status-of-u-s-caribbean-stoplight-parrotfish-sparisoma-viride-age-growth-and-reproductive-biology-for-the-sedar84-stock-assessment>
- SEDAR. (2016). *SEDAR 46 caribbean data-limited species stock assessment report*. <https://sedarweb.org/documents/sedar-46-final-stock-assessment-report-caribbean-data-limited-species/>
- SEDAR. (2019). *SEDAR 57 stock assessment report u.s. Caribbean spiny lobster* (p. 232). <http://sedarweb.org/sedar-57>
- SEDAR. (2022). *SEDAR 80 US caribbean queen triggerfish puerto rico final stock assessment report*. <https://sedarweb.org/documents/sedar-80-us-caribbean-queen-triggerfish-puerto-rico-final-stock-assessment-report/>
- SEDAR. (2024). *SEDAR 84 US caribbean stoplight parrotfish st. Croix data workshop report*. <https://sedarweb.org/documents/sedar-84-us-caribbean-stoplight-parrotfish-st-croix-data-workshop-report/>
- Taylor, I. G., Doering, K. L., Johnson, K. F., Wetzel, C. R., & Stewart, I. J. (2021). Beyond

visualizing catch-at-age models: Lessons learned from the r4ss package about software to support stock assessments. *Fisheries Research*, 239, 105924.

<https://doi.org/10.1016/j.fishres.2021.105924>

Then, A. Y., Hoenig, J. M., Hall, N. G., Hewitt, D. A., & Handling editor: Ernesto Jardim. (2015). Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of Marine Science*, 72(1), 82–92. <https://doi.org/10.1093/icesjms/fsu136>

Thorson, J. T. (2019). Predicting recruitment density dependence and intrinsic growth rate for all fishes worldwide using a data-integrated life-history model. *Fish and Fisheries*, 21(2), 237–251. <https://doi.org/10.1111/faf.12427>

Thorson, J. T., Munch, S. B., Cope, J. M., & Gao, J. (2017). Predicting life history parameters for all fishes worldwide. *Ecological Applications*, 27(8), 2262–2276. <https://doi.org/10.1002/eap.1606>