SEDAR 84

Southeast Fisheries Science Center

Table of contents

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 a commercial logbook program
- Fishery-dependent length compositions from a commercial port sampling program
- 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, and parameterization of hermaphroditism.

Model diagnostics checked for convergence, goodness-of-fit, model consistency, and prediction skill by evaluating gradients, residual plots, likelihood profiles, hindcast cross-validation, correlation, and jitter analyses. All of the configurations resulted in inconclusive results, evidenced by low gradients, high variance, and likelihood profile diagnostics indicating discrepancies among the data and modeling structure. The SEDAR 84 assumptions require further assessment as the scenarios explored are not able to reliably estimate the stock status. Thus, the overfished status of the St. Croix stoplight parrotfish stock remains unknown. However, the available data do not indicate a decline in the abundance index concurrent with a decrease in landings and show constant trends in size composition quantiles. These findings suggest that the St. Croix stoplight parrotfish was not likely to be undergoing overfishing in 2022.

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 7.1). 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 redtail parrotfish (Sparisoma chrysopterum). 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 7.2).

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 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 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 6.1). 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 lower standard error of 0.3 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 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 x 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 (R0; estimated in log space) represents the asymptote or unfished recruitment levels.
- The variance term (sigma R) is the standard deviation of the log of recruitment and describes the amount of year-to-year variation in recruitment.

Only the virgin recruitment (R0) was estimated. **Sigma R and steepness were fixed at 0.7 and 0.99, respectively.** The primary assumption for steepness was that this stock is not a closed population, so recruitment may not be strongly tied to the local spawning stock biomass. **In initial model configurations, annual deviations from the stock-recruit function were not estimated.** Steepness and R0 were explored via likelihood profiling.

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

2.3.5 Maximum Age and Natural Mortality

Empirical estimates of natural mortality (M) can be derived using life history information such as longevity, growth, and maturity. For this assessment, the Natural Mortality Tool was used to estimate M (Cope & Hamel, 2022). Various methods were explored, incorporating factors such as maximum age, the Von Bertalanffy growth parameter (K), theoretical age at size zero (t0), 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 6.2 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), t0, 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 x 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 6.3 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 in SEDAR 84 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 St. Croix 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 6.3 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 6.4.

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. However, all models showed high final gradients for F_{MSY}, indicating poor convergence.

Despite achieving a solution and having unbounded parameters, the gradient warning for F_{MSY} raise concerns about model stability. The following sections further explore the convergence issues by examining parameter correlations, variances, and likelihood profiles to identify factors contributing to poor convergence and potential inconsistencies in the data.

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 configurations (Table 6.5). 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 models, 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 6.6). This adjustment reduced the overly strong correlation between Initial F and R0 by relaxing the constraint on initial fishing mortality.

Most models showed moderately high correlations (> 0.90) between the two parameters used to define 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 (*ADD SELECTIVITY FIGURE*).

4.3 Evaluating Variance

To check for parameters with high variance, parameter estimates are reported with their resulting standard deviations. Table 6.7 presents the model-estimated values and standard deviations for the main active parameters. While it's important to consider the scale of each parameter, the results suggest that key parameters are not being estimated with high precision. In particular, the coefficients of variation for initial fishing mortality are relatively high across all models, indicating considerable uncertainty in these estimates. Figure 7.3a illustrates how the estimate and uncertainty for the unfished recruitment (R0) changes throughout the sequential steps of model development. The uncertainty in 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 annual and unfished spawning biomass depletion (as a fraction of unfished spawning biomass). Table 6.8 shows this information and it is also plotted in **?@fig-ssb** and **?@fig-ssb-ratio**.

Compared to the other m3 models, Model v3_m2 had extremely highest uncertainty for fishing mortality and other derived quantities (Figure 7.3c). The configurations for models v3_m2 and v7_m2 include estimation of recruitment deviations, the high uncertainty resulting from these model scenarios is expected due to the data limited nature of the data inputs. (*ADD MORE HERE ABOUT THE PLOTS*)

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 7.4). Importantly, no jitter runs produced a lower likelihood than the best fit already identified for each model. (*RERUN AND INCREASE JITTER*)

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.

Figure 7.5 Figure 7.6 Figure 7.7 Figure 7.8

(*ADD MORE HERE ABOUT THE PLOTS*)

4.5.1 Catch

All models closely matched the observed 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 was to give the model more flexibility in estimating initial fishing mortality. This adjustment allowed the model to explore alternative fits while still remaining reasonable. This topic will also be revisited in the sensitivity analyses, where model runs with a lower catch standard error of 0.1 are compared. (*ADD PLOTS SHOWING EXACT ESTIMATE OF CATCH*)

4.5.2 Indices

For the models without recruitment deviation being estimated (models b_m2, and v1_m2), the predicted National Coral Reef Monitoring Program index is flat (Figure 7.5). In the models with estimated recruitment deviations, 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 7.5).

4.5.3 Length compositions

The model fits to the length composition across all years are provided in Figure 7.6. For the models without recruitment deviation being estimated (models b_m2, and v1_m2), the fits to the annual National Coral Reef Monitoring Program length composition data shown in Figure 7.7 were poor compared to those across all years and in Figure 7.6. In these scenarios, the predicted composition is similar across years, which leads to overestimating the proportion of the smallest size and underestimating intermediate or large sizes in 2012, 2017, and 2021.

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 7.9. 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 7.5). Particularly the severity of the retrospective pattern is most severe in the scenarios with recruitment deviations, models v3_m2 and v7_m2, with Mohn's rho statistics, 0.2 and 0.51, respectively.

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 initial equilibrium catch, steepness, and virgin recruitment (R0).

4.7.1 Steepness

Figure 7.12

4.7.2 Unfished Recruitment (R0)

Figure 7.10

4.7.3 Initial Equilibrium Catch

Figure 7.11

4.8 Sensitivity Runs

Sensitivity analyses were considered to evaluate the impact on key derived quantities. Sensitivities included considering alternatives for the CV on growth, the standard error associated with catch, the maximum age, the method used to model hermaphroditism and data weighting.

4.8.1 Growth CV

4.8.2 Natural Mortality

4.8.3 Single Sex Model

The second method for parameterizing hermaphroditism involved using a female-only model and accounting for sex transition to males as a reduction in fecundity.

4.8.4 Standard Error on Catch

5 Discussion

The diagnostics presented in the report highlight various caveats, largely associated with the relatively few data inputs available for the present assessment. Furthermore, the data lack contrast, resulting in which parameters high uncertainty and flat solution spaces.

These results indicate model structure discrepancies with models v3_m2 and v7_m2. These models lack information with which to base estimate of recruitment deviations (Figure 7.3d). Because the length data for model v3_m2 are aggregated across the available years, this model is most similar to an age structured production model. Although the recruitment deviations for model v3_m2 are small, the correlation between R0 and initial fishing mortality is still concerning particularly since the initial equilibrium fishing mortality profile showed very small changes in likelihood over a large range of equilibrium catch inputs.

6 Tables

Table 6.1: 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	Other
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 6.2: Empirical estimates of natural mortality (M) can be 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).

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	*Sparisoma viride*	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 6.3: 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.

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 6.4: 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	lower standard error on initial equilibrium catch

Table 6.5: St. Croix stoplight parrotfish correlations between estimated parameters by modeling scenario. 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 6.6: St. Croix stoplight parrotfish estimated initial equilibrium catch in metric tons by model scenario. 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 6.7: St. Croix stoplight parrotfish parameters, standard deviations (SD), and coefficient of variation (CV) by modeling scenario. CV is calculated as the SD divided by the parameter estimate.

Parameter	Scenario	Estimate	SD	CV
Commercial Selectivity Asend.	a_m3	2.25	0.98	0.44
	b_m3	2.27	0.98	0.43
	v1_m3	2.26	0.98	0.43
	v3_m3	2.48	0.83	0.33
	v7_m3	2.56	0.85	0.33
Commercial Selectivity Peak	a_m3	25.85	1.79	0.07
	b_m3	25.89	1.82	0.07
	v1_m3	25.87	1.81	0.07
	v3_m3	26.62	1.57	0.06
	v7_m3	26.98	1.74	0.06
Initial F	a_m3	0.19	0.08	0.42
	b_m3	0.12	0.03	0.28
	v1_m3	0.11	0.03	0.28
	v3_m3	1.20	1.20	1.00
	v7_m3	0.12	0.03	0.28
Unfished Recruitment (R0)	a_m3	5.51	0.27	0.05
	b_m3	5.29	0.33	0.06
	v1_m3	5.28	0.35	0.07
	v3_m3	5.09	0.23	0.04
	v7_m3	4.61	0.20	0.04

Table 6.8: 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 modeling scenario. 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 6.9: St. Croix stoplight parrotfish derived quantities for MSY SPR 40%. CV is calculated as the SD divided by the parameter estimate.

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
v1_m3_s6	10.28	0.75	0.07
v3_m2	26.31	1.60	0.06

Scenario	Estimate	SD	CV
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 6.10: St. Croix stoplight parrotfish estimated MSY SPR 40% in pounds.

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

7 Figures
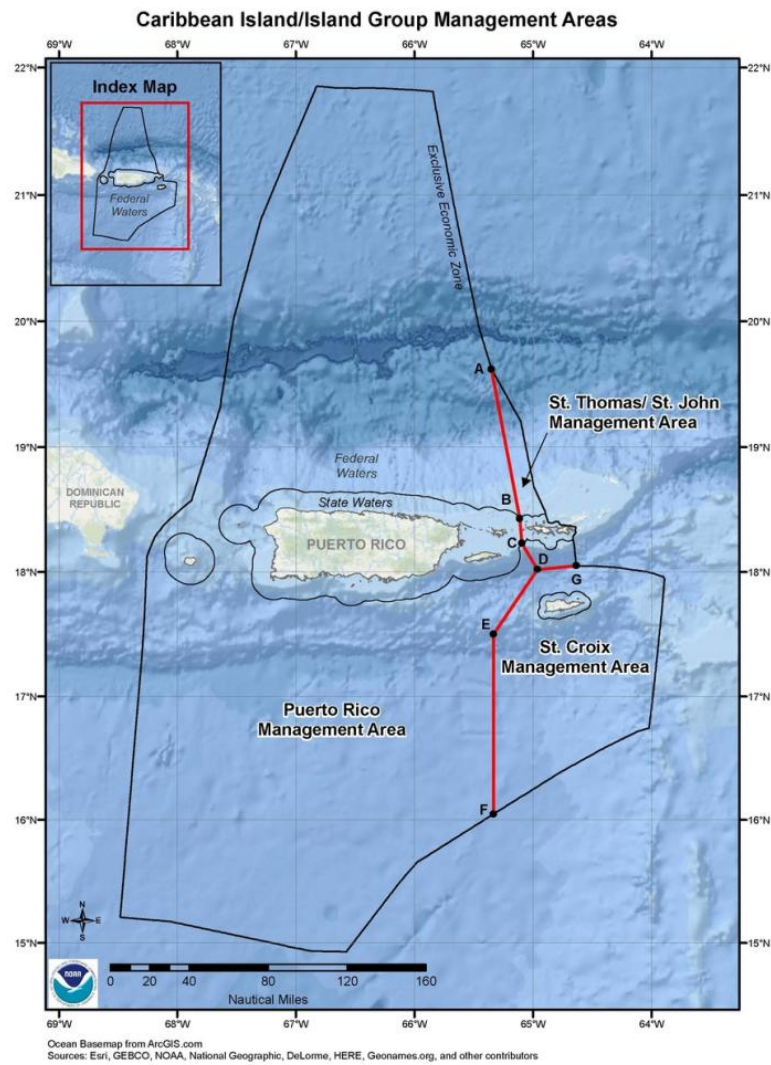
Figure 7.1: Jurisdictional boundaries of the Caribbean Fishery Management Council.
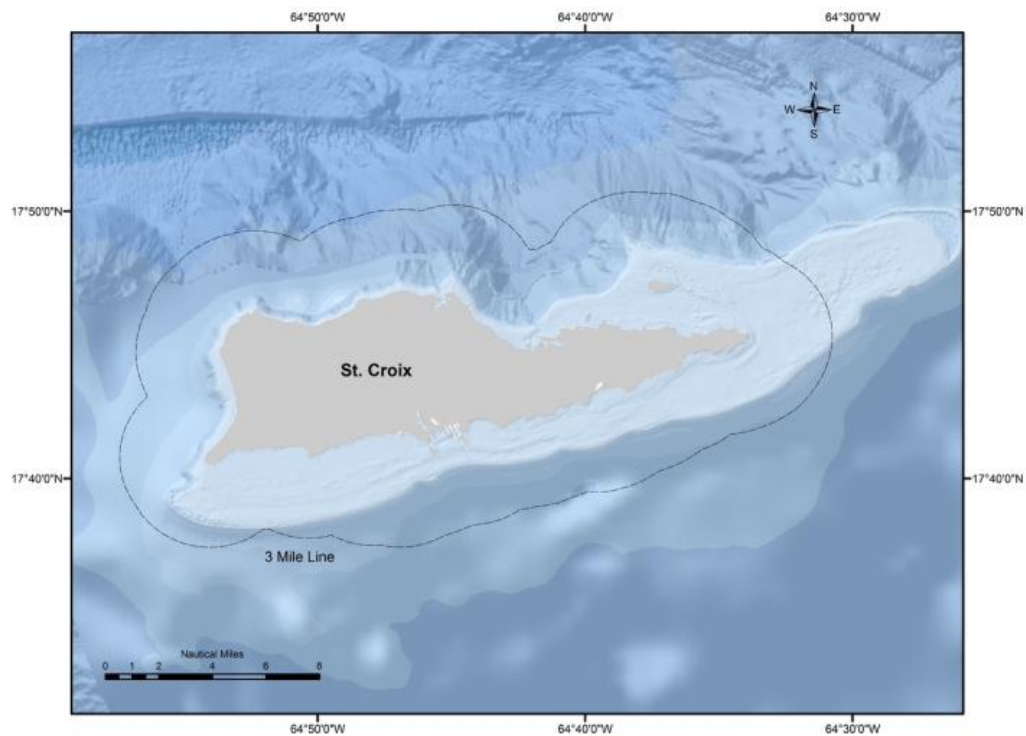
Figure 7.2: The U.S. EEZ is defined as the federal waters ranging from 3 to 200 nautical miles (5.6 – 370 kilometers) from the nearest coastline point of the US Virgin Islands.
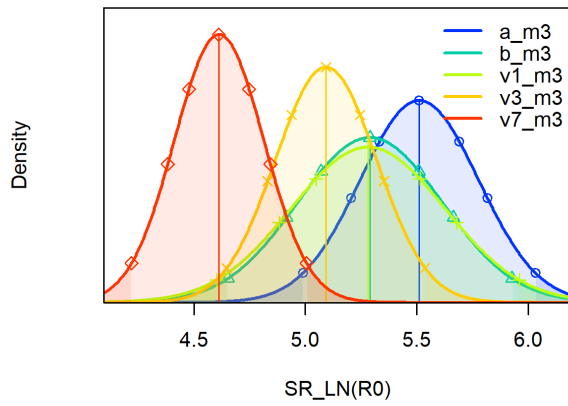
(a) Unfished recruitment (r0)
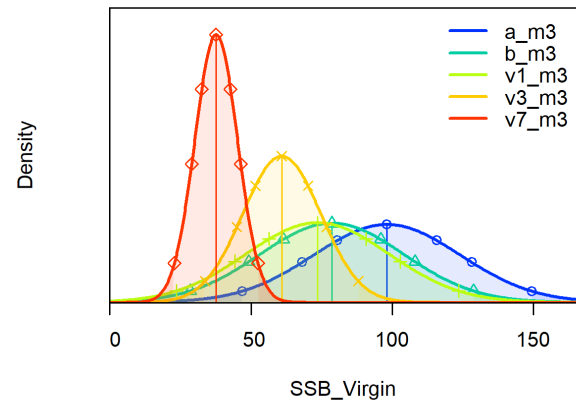
(b) Virgin Spawning Stock Biomass

(c) Fishing Mortality

38

(d) Recruitment

Figure 7.3: StoC: investigating most-fished parameter distributions for the network shape of the
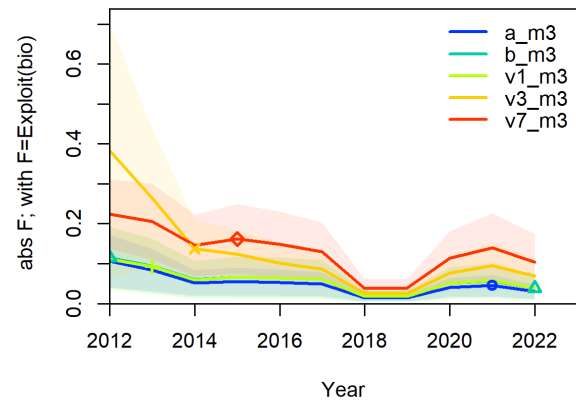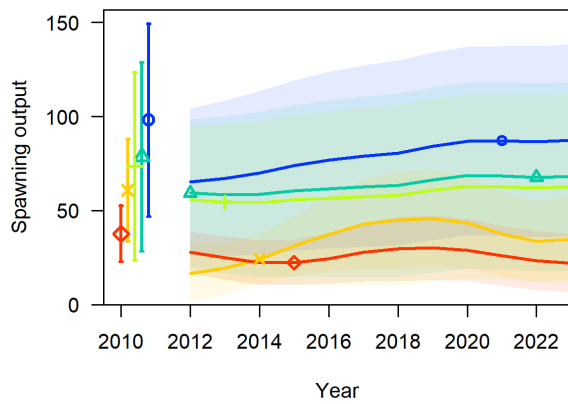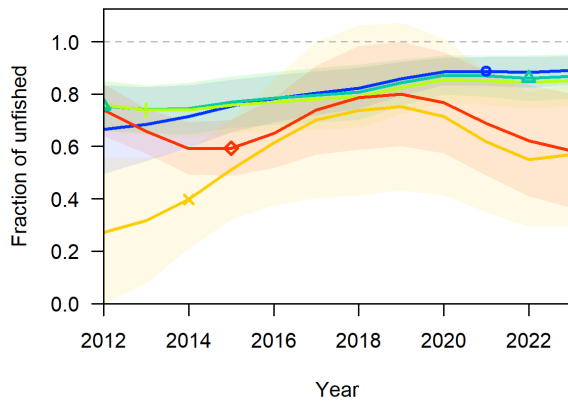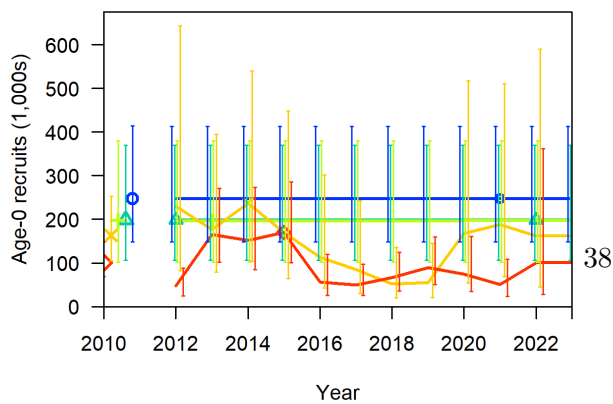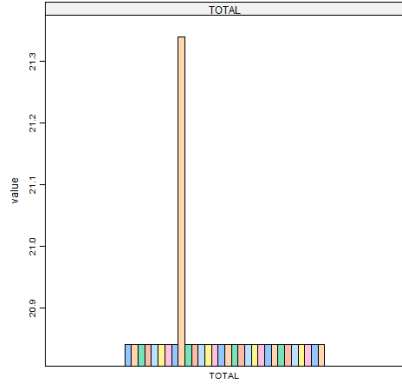
(a) Model a_m3
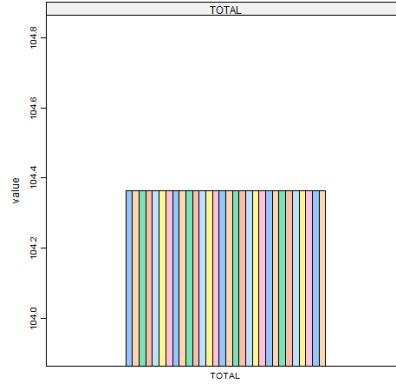
(b) Model b_m3
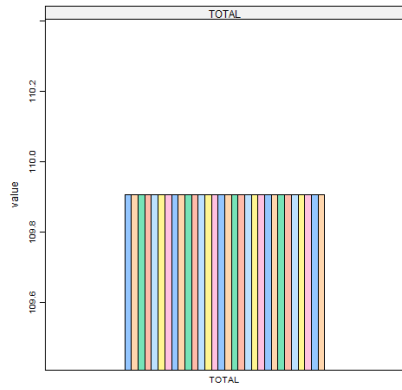
(c) Model v1_m3
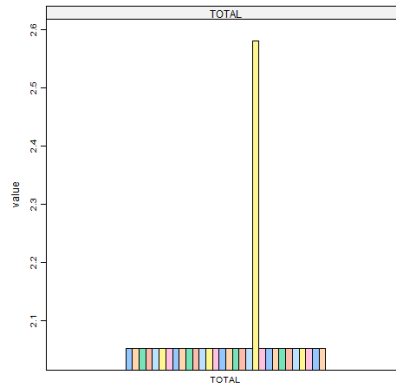
(d) Model v3_m3
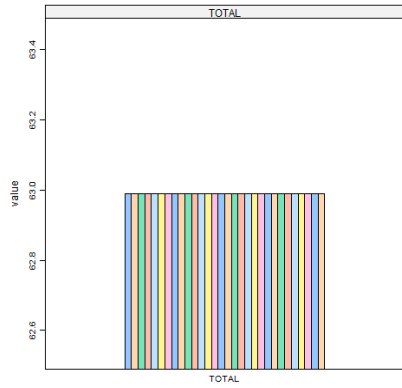
(e) Model v7_m3

Figure 7.4: St. Croix stoplight parrotfish jitter analysis total likelihood. Each panel gives the results of 30 model runs where the starting parameter values for each run were randomly changed by 20% from the base model's values using a uniform distribution in cumulative normal space.
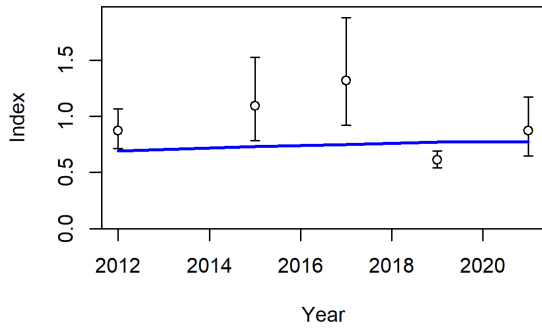
(a) a_m3
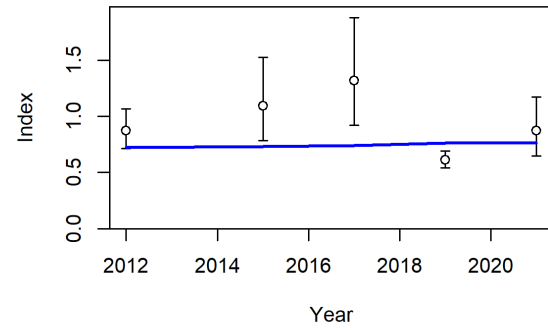
(b) v1_m3
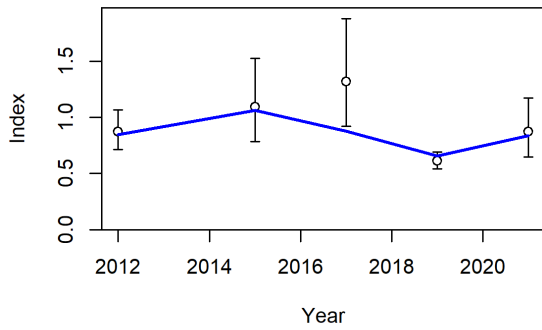
(c) v3_m3
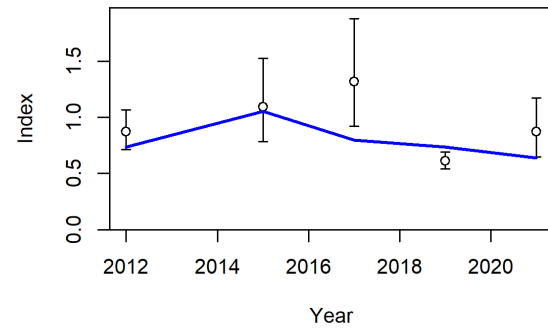
(d) v7_m3

Figure 7.5: St. Croix stoplight parrotfish National Coral Reef Monitoring Program observed (open circles) and predicted (blue line) indices of relative abundance and associated standard errors by modeling scenario. Lines indicate 95% uncertainty interval around observed index values based on the model assumption of lognormal error.
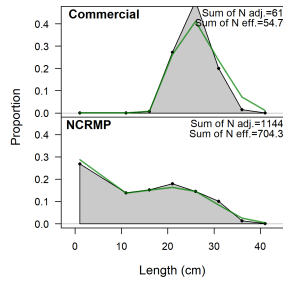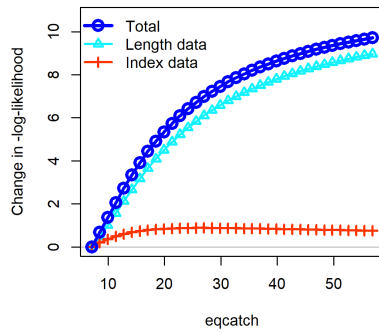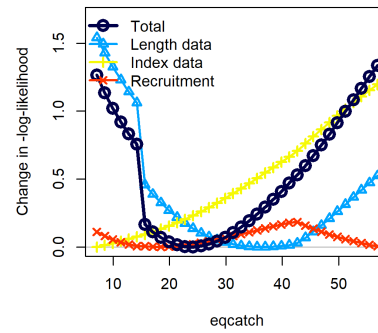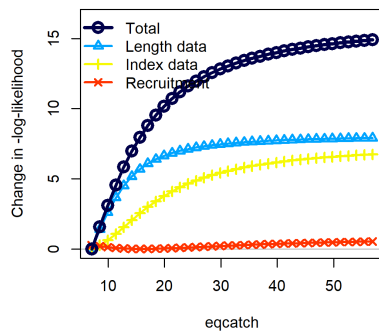
(a) a_m3
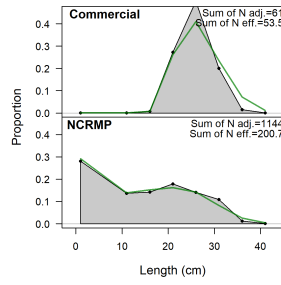
(b) b_m3
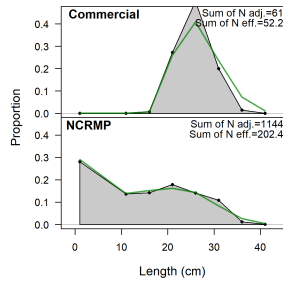
(c) v1_m3
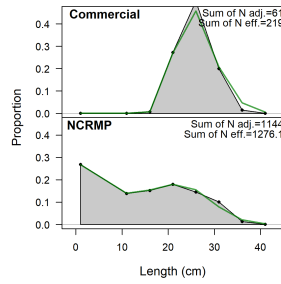
(d) v3_m3
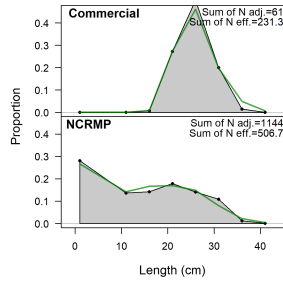
(e) v7_m3

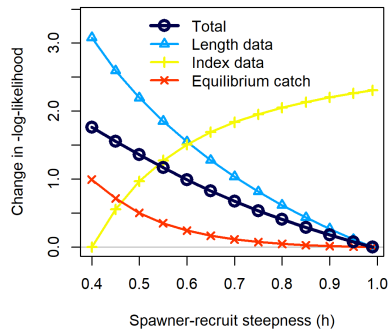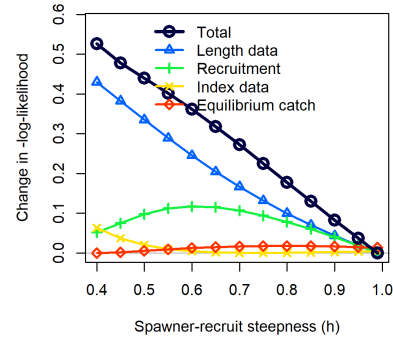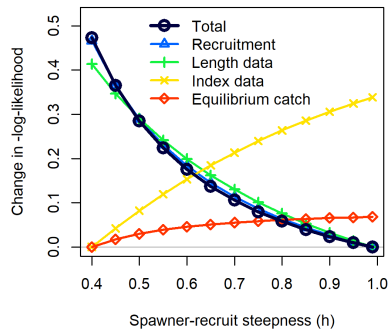Figure 7.6: St. Croix stoplight parrotfish observed and predicted length distributions aggregated across years for the Commercial and NCRMP length compositions by modeling scenario. Green lines represent predicted length compositions, while gray regions represent observed length compositions. The effective 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 used in the McAllister-Ianelli tuning method), are shown in the upper right corners.

41

(a) b_m3   (b) v1_m3   (c) v7_m3
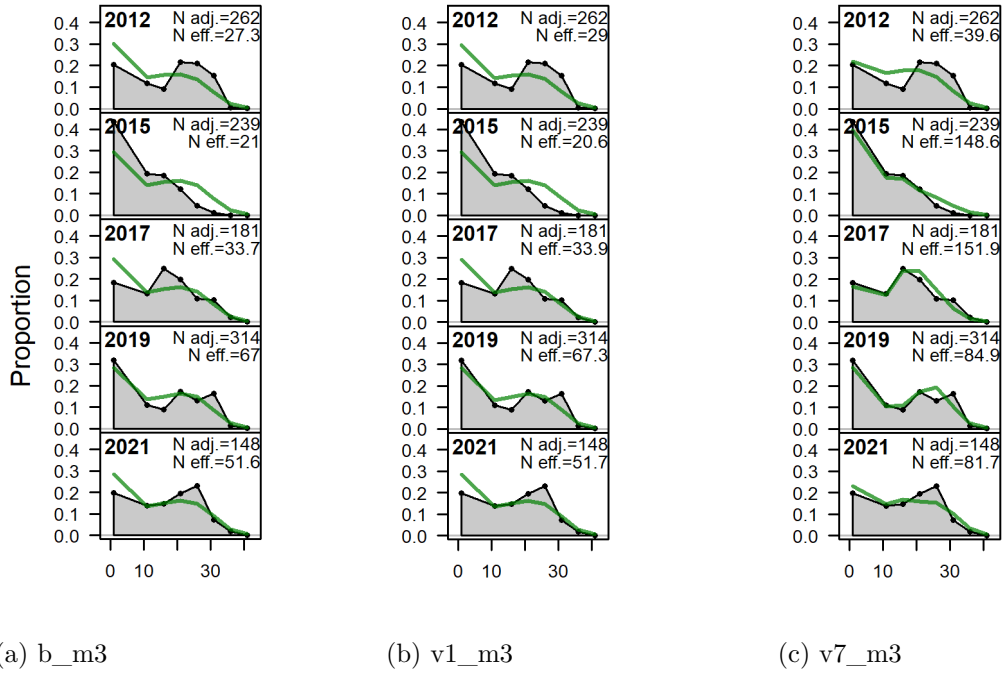
Figure 7.7: St. Croix stoplight parrotfish observed and predicted length distributions for the NCRMP length composition data by year and modeling scenario. Green lines represent predicted length compositions, while gray regions represent observed length compositions. The effective sample size used to weight the length composition data is provided by N adj (the input sample size), and N eff (the calculated effective sample size used in the McAllister-Ianelli tuning method), are shown in the upper right corners.
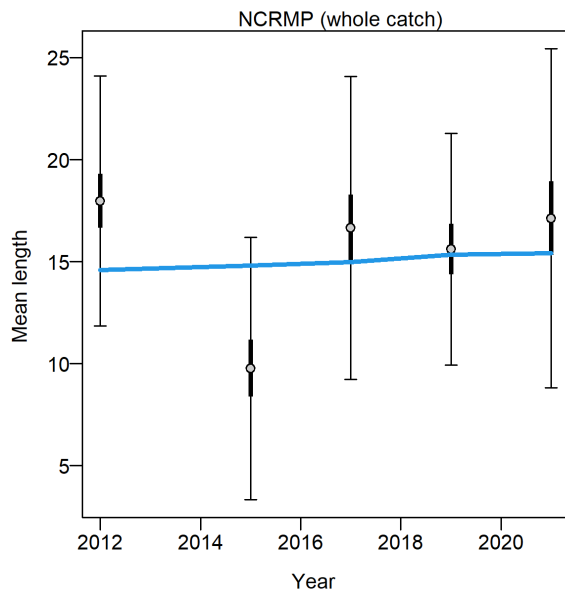
(a) b_m3
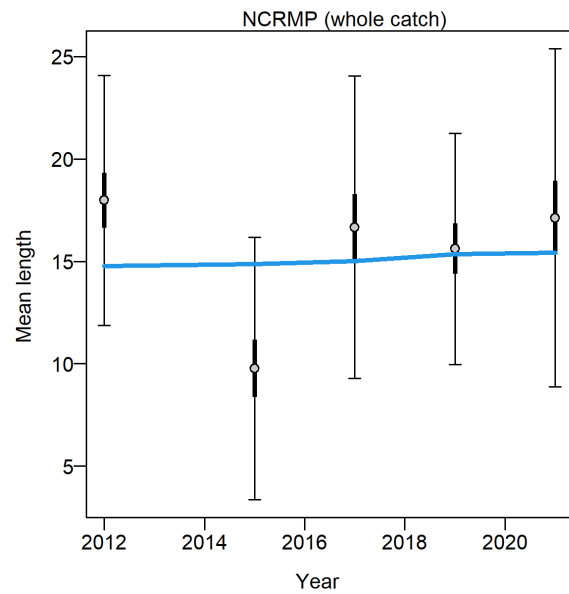
(b) v1_m3
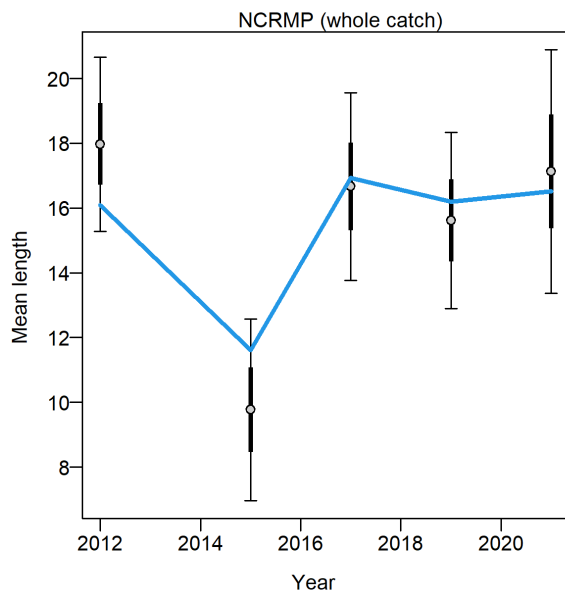
(c) v7_m3

Figure 7.8: St. Croix stoplight parrotfish observed (open circles) and predicted (blue line) mean length by year and modeling scenario.
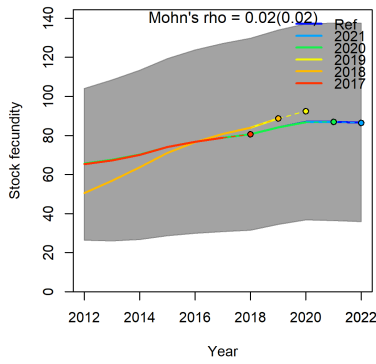
(a) a_m3
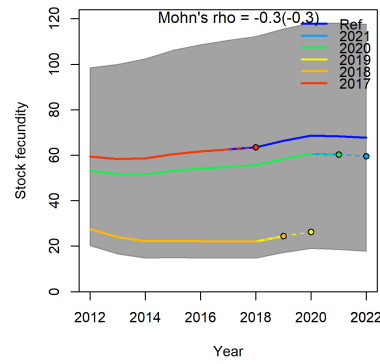
(b) b_m3
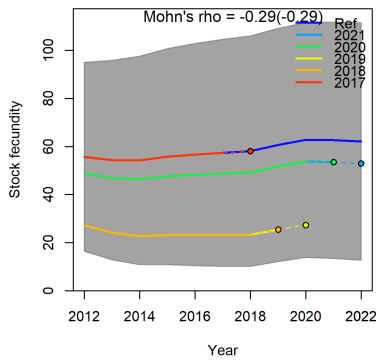
(c) v1_m3
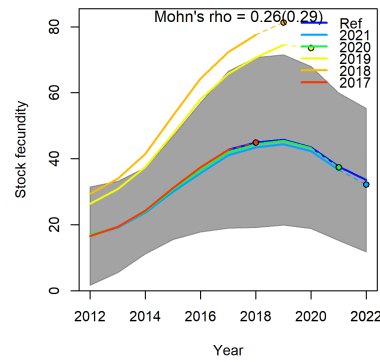
(d) v3_m3
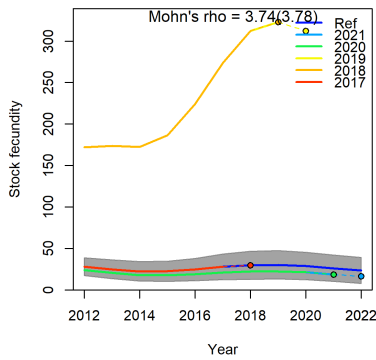
(e) v7_m3
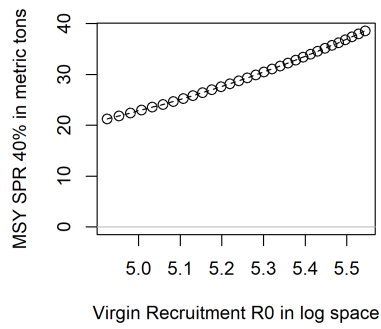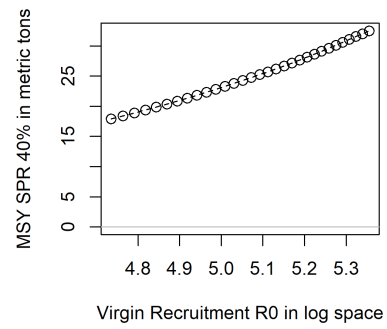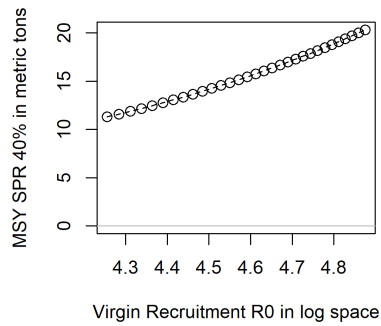
Figure 7.9: St. Croix stoplight parrotfish retrospective analysis of spawning stock biomass (SSB) conducted by refitting models after removing five years of observation, one year at a time sequentially. Mohn's rho statistics and the corresponding "hindcast rho" measure the severity of retrospective patterns. One-year-ahead projections denoted by color-coded dashed lines with terminal points. Grey shaded areas are the 95% confidence intervals.
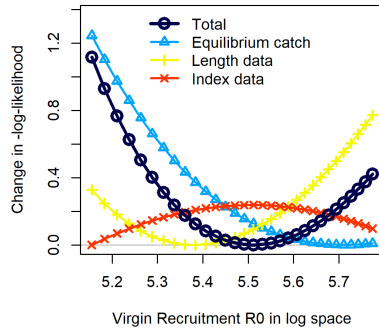
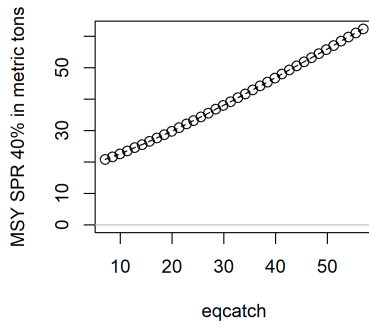(a) a_m3
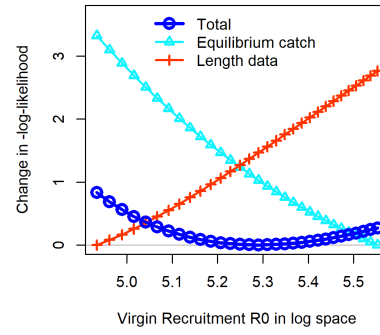
(b) b_m3
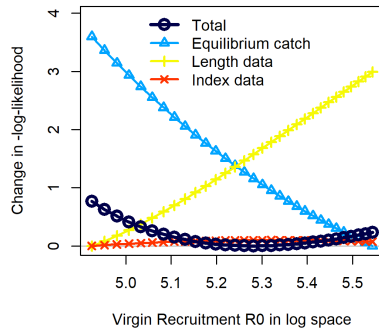
(c) v1_m3
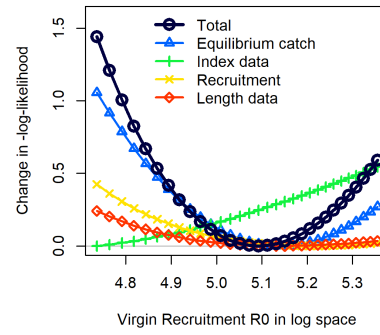
(d) v3_m3
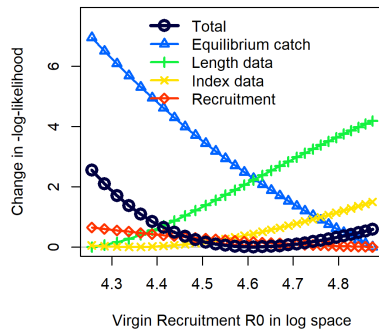
(e) v7_m3

Figure 7.10: St. Croix stoplight parrotfish unfished recruitment profile.
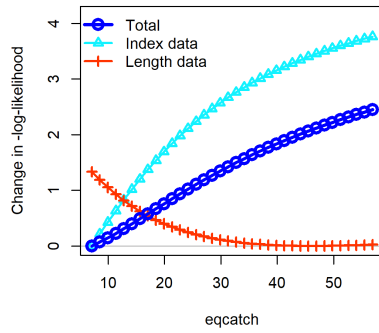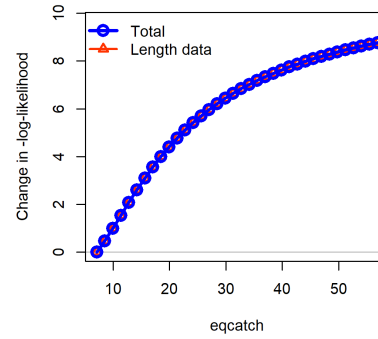
(a) a_m3

(b) b_m3

(c) v1_m3

(d) v3_m3

(e) v7_m3

Figure 7.11: St. Croix stoplight parrotfish initial equilibrium catch profile (*ADD MORE HERE ABOUT THE PLOTS*).
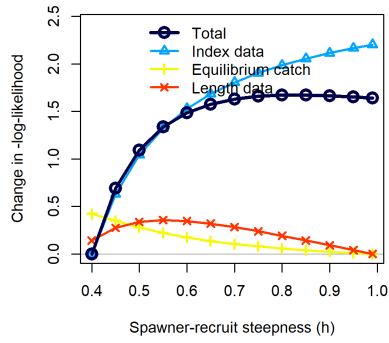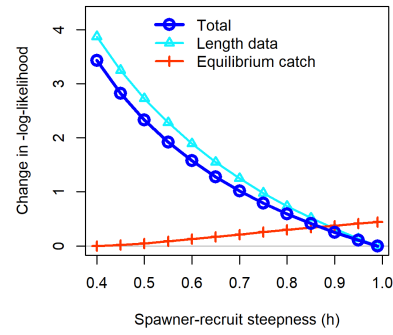
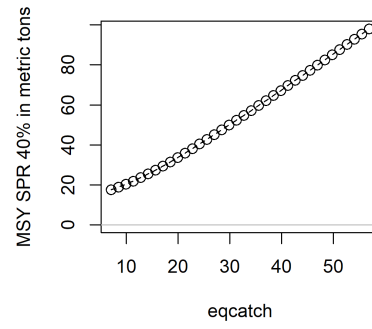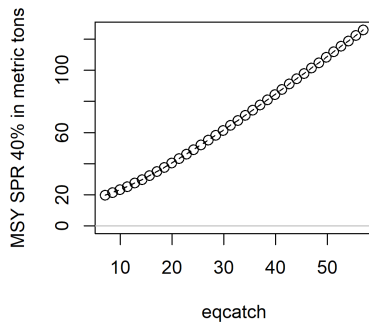(a) a_m3

(b) b_m3

(c) v1_m3

(d) v3_m3

(e) v7_m3

Figure 7.12: St. Croix stoplight parrotfish steepness profile (*ADD MORE HERE ABOUT THE PLOTS*).
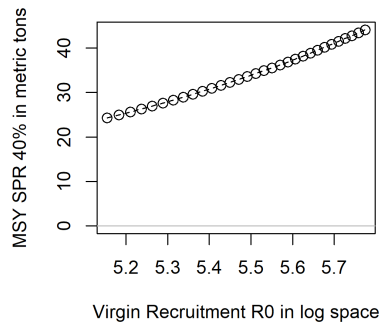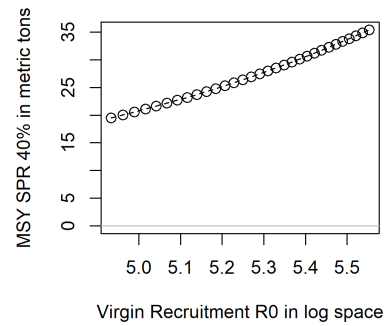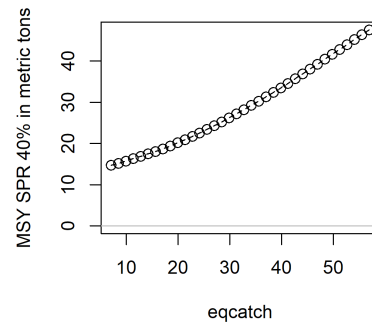
(a) a_m3

(b) b_m3

(c) v1_m3

(d) v3_m3

(e) v7_m3

Figure 7.13: St. Croix stoplight parrotfish unfished recruitment profile.
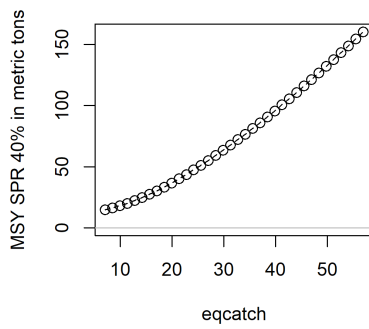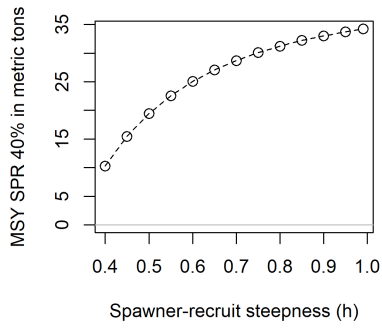
(a) a_m3

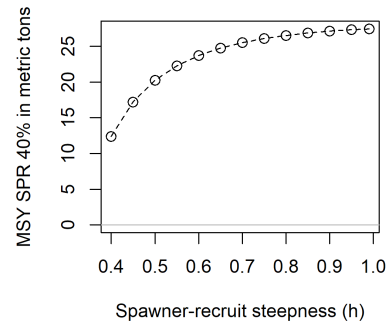(b) b_m3

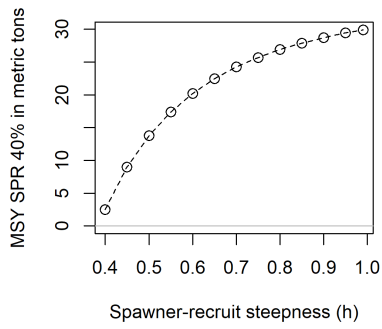(c) v1_m3

(d) v3_m3

(e) v7_m3

Figure 7.14: St. Croix stoplight parrotfish initial equilibrium catch profile (*ADD MORE HERE ABOUT THE PLOTS*).
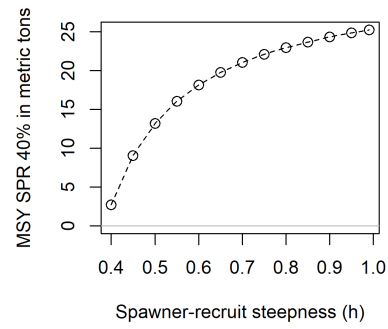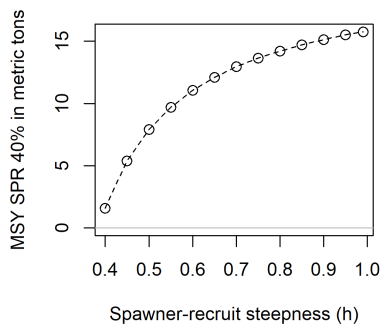
(a) a_m3

(b) b_m3

(c) v1_m3

(d) v3_m3

(e) v7_m3

Figure 7.15: St. Croix stoplight parrotfish steepness profile (*ADD MORE HERE ABOUT THE PLOTS*).

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