SEDAR

Southeast Data, Assessment, and Review

SEDAR 84

US Caribbean Yellowtail Snapper – Puerto Rico

SECTION III: Assessment Process Report

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Assessment Process Report Summary

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

- An annual species-specific catch time series from commercial logbooks
- Fishery-dependent length compositions from commercial port sampling
- Fishery-independent length compositions from a reef fish survey
- Fishery-independent indices 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, while length composition data from each source were aggregated across all available years. Model development proceeded stepwise from the simplest configuration to those of moderate complexity. Those sequential steps included the inclusion of dome-shaped selectivity, indices of abundance, and annual length compositions. Models were run with and without the estimation of recruitment deviations. Finally, sensitivities of assessment outcomes were investigated using alternative inputs for longevity-informed natural mortality, coefficient of variation on growth, and uncertainty on initial equilibrium catch.

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

Sensitivity analyses evaluated the effects of assumptions about natural mortality, growth variability, and initial equilibrium catch conditions. These scenarios showed that key uncertainties can influence estimated productivity and biological reference points, with, two of the six model configurations presented indicating that the stock could be overfished and that overfishing could be occurring. However, diagnostics and sensitivity analyses revealed important caveats, primarily due to the strong influence of fixed parameter assumptions including uncertainty initial conditions and the final value of the dome-shaped NCRMP index.

1 Introduction

1.1 Workshop Time and Place

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

1.2 Terms of Reference

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

1.3 List of Participants

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

Appointed Observers	
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Julian Magras	DAP STT/STJ

Observers	
Jerald S. Ault	Univ of Miami
Rachel Banton	NMFS/SEFSC
Sarah Beggerly	NMFS/SEFSC
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Carly Daiek	NMFS/SEFSC
Katherine Godwin	UM-CIMAS
Jennifer Granneman	NOAA
Jay Grove	NMFS/SEFSC
Walter Ingram	NMFS/SEFSC
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Observers	
Sarah Stephenson	NMFS/SEFSC
Joyah Watkins	Rice University

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

1.4 List of Assessment Process Working Papers and Reference Documents

1.4.1 Documents Prepared for the Assessment Process

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

1.4.2 Reference Documents

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

2 Data-Informed Modeling Decisions

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

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

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

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

2.1 Commercial Fleet Data

2.1.1 Catch

The catch data for the commercial fleet came from the Caribbean Commercial Logbook program (Martínez Rivera et al., 2024). Commercial fishery landings data for Yellowtail Snapper in Puerto Rico were available for the years 1983-2022.

The handline gear group made up 80% of the reported landings catch of Yellowtail Snapper in Puerto Rico. All gears (handline, trap, rod and reel, and other) were included into a single commercial fleet (Table 7.1). Potential outliers discussed during the assessment webinars were investigated and retained as valid trips.

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

The years of the available species-specific self-reported commercial fisher logbook landings and effort data determined the start and end years of the Stock Synthesis models. **The start and end years of the model were 1983 and 2022, respectively.**

It is important to note that the stock was not unexploited at the start year of the available catch time series. Appeldoorn et al. (1992) reported declines in landings across all reef fish combined, with landings in Puerto Rico peaking in 1979, reaching a low in 1988, and slightly increasing in 1989 and 1990. Initial F was estimated for the commercial fleet and a corresponding initial equilibrium catch. The reference point for the initial equilibrium catch was defined as the geometric mean of the first three years of available catches (168.3 metric tons).

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

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

Commercial discards are not reported in Puerto Rico fisher logbook data. Based on expert judgment and available information, discards of Yellowtail Snapper in the Puerto Rico commercial fishery are considered negligible, with minimal associated mortality (SEDAR (2024)). Given this limited data and the expectation of low discard rates, **discards were not explicitly included in the model inputs or parameterized through a retention function. The assessment assumed full retention of catch.**

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

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

2.1.2 Length Composition

Gear-specific annual length frequencies for the commercial fleet came from the commercial shore-based port-sampling Trip Interview Program (TIP) (Godwin et al., 2024). The Trip Interview Program manages data from Puerto Rico collected by Department of Natural & Environmental Resources personnel. Port sampling personnel collect length and weight data from fish landed by commercial fishing vessels, along with information about general area of capture and gear used. Data collection began in 1983 with frequent updates in best practices; the latest being in 2017. The Yellowtail Snapper length data from Puerto Rico included 103,730 length observations across 5,159 unique port sampling interviews.

Although the catch data can be separated into handline and non-handline related gears, 77% of the length measurements for Puerto Rico Yellowtail Snapper from 1983-2022 were associated with handlines. Those data were used to characterize the commercial fleet's length-based selectivity pattern. Since multiple fish length measurements can be obtained from a single sampled trip, each length does not represent an independent observation. **The relative model weighting of the commercial fleet length composition data was based on the number of trips sampled**.

From 1983 - 2022, the data included 83,341 shore-based length measurements obtained across 2,829 trips. Nineteen trips were flagged and removed as potential outliers with unusually large lengths. **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 was implemented in 1986, it did not apply in Puerto Rico territorial waters extending from land to 9 nautical miles offshore. In 2004, Puerto Rico established a compatible minimum size of Yellowtail Snapper.

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

2.2 Survey Data

2.2.1 Index of Abundance

The National Coral Reef Monitoring Program (NCRMP) supports reef fish sampling on hard-bottom habitats from 0 to 30 meters depth (Grove et al., 2021). In Puerto Rico, NCRMP sampling began in 2001 and was conducted every year from 2001 to 2012 and then 2014, 2016, 2019, and 2021. The data used in SEDAR 84 were from nonconsecutive years during 2014 - 2022 when the survey was conducted island-wide. Data collected prior to 2017 were calibrated to account for a transition from belt transect to a cylinder survey method.

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

2.2.2 Length Composition

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

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

The length composition data provided reasonable support that younger fish were available to the NCRMP survey. Over half of the lengths from the NCRMP survey were smaller than 20 centimeters fork length, and 99% were below 33 centimeters fork length. **Dome-shaped selectivity was explored for the NCRMP survey.**

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

2.3 Life History Data

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

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

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

2.3.1 Growth

The SS3 growth formulation requires five parameters:

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

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

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

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

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

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

2.3.2 Morphometric Conversion

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

2.3.3 Maturity and Fecundity

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

2.3.4 Stock Recruitment

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

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

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

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

2.3.5 Maximum Age and Natural Mortality

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

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

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

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

2.4 Summary of Data-Informed Modeling Configurations

- Based on the available data, the assessment was configured with one area, one season, one commercial fleet, and 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 1983 and 2022, respectively.
- Based on expert input and limited data, discards were not modeled. The assessment assumed full retention of catch.
- The input standard error for the landings was set to 0.3.
  - A higher standard error of 2 was explored via sensitivity analysis.
- The initial equilibrium catch was configured in initial runs as 168.3 metric tons.
  - The initial equilibrium catch was explored via likelihood profiling.
- The relative model weighting of the commercial fleet length composition data was based on the number of trips sampled.
- The length compositions of the commercial fleet were assumed to be representative of the total catch.
- A double normal function was used to model the relative vulnerability of capture by length for the commercial fleet.

2.4.2 Survey

- The NCRMP index reflected the abundance of juveniles.
- The survey was configured as an index in numbers with a lognormal error distribution.
- The relative model weighting of the surveys length composition data across years were based on the number of paired dives.
- The length data inputs used 3-centimeter bins.
- The model's simulated population bin size was 1-centimeter bins.
- The model development process explored dome-shaped selectivity for the fishery independent survey.

2.4.3 Life History

- The Yellowtail Snapper population was modeled from age 0 through age 26, and from 0 to 56-centimeters fork length, in 1-centimeter bins, with the largest values for each as plus groups.
- Parameter estimates for Von Bertalanffy growth parameter (K) and the length at maximum age (L_∞) were based on samples of Yellowtail Snapper collected across the U.S. Caribbean from 2013 to 2023.
- The estimated length at age zero from otolith analysis by Shervette, Rivera Hernández, & Peña Alvarado (2024) was modified in Stock Synthesis so that the length of the youngest age, age 0, was set to zero.
- Coefficients of variation for both younger and older ages were initially set to 0.15.
  - A higher growth coefficient of variation of 0.25 for younger ages was explored via sensitivity analysis.
- The length-weight relationship was W = 2.93 x 10^-5 L^ 2.8642, with weight in kilograms and length in centimeters.
- A natural mortality value of 0.208 was used in the initial model runs.
  - Alternative M values were explored through sensitivity analyses.
- Maturity was modeled as a logistic function.
- The fecundity of Yellowtail Snapper was estimated with a proxy (body weight * maturity at age).
- A Beverton-Holt stock-recruit function was used to parametrize the relationship between spawning output and resulting recruitment of age-0 fish.
- Sigma R and steepness were fixed at 0.7 and 0.99, respectively.
- In initial model configurations, annual deviations from the stock-recruit function were not estimated.
- Continuous recruitment was parameterized in SS3 using four settlement events.

3 Model Development

3.1 Framework

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

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

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

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

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

3.2 Overview

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

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

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

This report focuses on the results and sensitivities associated with the m3 models, evaluated under the various data configurations summarized in sec-data-summary. While a full discussion of sensitivity runs is provided later in the report, they are also summarized in Table 7.3 to help familiarize the reader with the terminology used throughout. For instance, model **v08_m3_s1** refers to the eighth scenario (**v08**, which includes an index, annual fishery-independent length compositions, and dome-shaped selectivity), the third level modification (**m3**, reflecting continuous recruitment and higher catch uncertainty), and the first sensitivity scenario (**s1**, higher uncertainty on growth). The numbering of model runs in Table 7.3 reflects a structured approach used to track configurations consistently across all three assessments. Not every model was used for every island because the data available varies, but the numbering stays the same so that the same model structure means the same thing across all islands and helps show how the models became more complex over time.

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

4 Model Diagnostics

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

4.1 Convergence

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

The models presented in this report all had a positive definite Hessian, indicating that each reached a local minimum and a locally optimal fit. None of the models had parameters that were bounded, suggesting the optimization was not constrained by parameter limits. Finally, the parameter gradients in all models were small and well below 0.001, which is commonly used in the R4SS R package to identify large gradients (Table 7.4).

4.2 Correlation Analysis

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

High correlations (correlation coefficients greater than 0.95 or less than -0.95) were observed between selectivity parameters for the v08_m2 and v31_m3 (Table 7.5).

In the initial default configurations of both the m1 and m2 model scenarios, the standard error on the initial equilibrium catch was fixed at a low value of 0.01. This tightly constrained the model to the input catch of 168.3 metric tons effectively limiting flexibility in estimating the corresponding initial fishing mortality. To address this issue, the standard error was increased to 0.3, allowing the estimated initial catch to diverge from the fixed input value (Table 7.6). The effects of increasing the standard error beyond 0.3 are discussed further in the sensitivity analyses section.

All model scenarios showed moderate or high correlations between some of the parameters used to define selectivity, except v19_m3. Correlations between these selectivity parameters is expected. While estimated values varied slightly among models, they produced similar length-based selectivity curves for the commercial fleet (Figure 8.1). Time blocks applied in model v31_m3 resulted with lower peaks in the first block (1983-2003), higher peak in the second block (2004-2010) for the commercial selectivity pattern (Figure 8.2). The selectivity for the NCRMP survey differed across the models, particularly with regard to the end selectivity. These differences, in addition to the correlations among NCRMP selectivity parameters, highlight that the estimated parameters informing the NCRMP selectivity relationship are not strongly informed by the available data.

4.3 Evaluating Variance

To check for parameters with high variance, parameter estimates are reported with their resulting standard deviations. Table 7.4 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 various parameters are being estimated with unusually high precision (less than 0.1). However, four parameters have large coefficients (greater than 0.3) including the initial fishing mortality, the NCRMP ascending selectivity, the NCRMP end selectivity and the NCRMP top selectivity.

Figure 8.3 illustrates how the estimates and uncertainty for the unfished recruitment (R0) and virgin spawning stock biomass change throughout the sequential steps of model

development. In general, increasing the complexity of the model results in wider distributions, particularly for the model with the annual fishery dependent data (v31_m3) and recruitment deviations estimated (v19_m3 and v31_m3). The uncertainty across the response surface for key parameters is further examined later in the report using likelihood profiles.

Stock Synthesis also provides estimates and standard deviations for derived quantities such as unfished spawning stock biomass, initial year spawning biomass, and the initial depletion. Initial depletion is defined as the initial biomass divided by the unfished biomass. Table 7.7 shows this information and it is also plotted in Figures 8.4a and 8.4b.

Compared to the other m3 model scenarios, Model v31_m3 had the highest initial depletion reflected in the highest spawning biomass ratio (SSB Initial/SSB Unfished) reported in Table 7.7. This ratio is also plotted as a time series of total biomass relative to virgin spawning biomass in Figure 8.4a. The sensitivity runs described later build on the exploration of uncertainty in these model scenarios.

4.4 Jitter Analysis

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

Consistent with earlier results indicating that the models reached local minima (positive definite Hessian), no jitter runs produced a lower likelihood than the best fit already identified for each model. However, with models frequently converging at higher likelihoods, the jitter analysis suggests some instability in the model scenarios (Figure 8.5).

Comparing the Spawning stock biomass over time and the selectivity patterns across the jitter runs reveals that the jittered runs resulted on different NCRMP selectivity patterns (Figure 8.6 and Figure 8.7).

4.5 Residual Analysis

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

4.5.1 Catch

All models closely matched the observed 1983 - 2022 catch data, which was expected given the data-limited configurations. In these configurations, Stock Synthesis relies heavily on the input catch data, with minimal additional information to support estimation of values that differ from the observations. The effect of increasing the standard error on the catch to 0.3 during the model development m3 scenario was to give the model more flexibility in estimating initial equilibrium catch and corresponding initial fishing mortality. This adjustment allowed the model to explore alternative fits while remaining informed by the assumption of a larger level of historically sustained catch. Increasing the standard error from 0.01 in the m2 model scenarios to 0.3 in the m3 model scenarios resulted in higher estimates of the initial equilibrium catch across all models, except v19 (Table 7.6). This topic will be revisited in the sensitivity analyses, where model runs with even higher catch standard error of 2 are compared. Allowing the estimated initial equilibrium catch to differ from the assumed initial equilibrium catch of 168.3 metric tons is further investigated via likelihood profiles (See Section 4.7.2).

4.5.2 Indices

For the models without recruitment deviation being estimated (a_m3, v01_m3, and v08_m3), the predicted NCRMP index is flat or shows a slight increase (Figure 8.8). In the model scenarios with estimated recruitment deviations (v19_m3 and v31_m3), there is only a slightly improved fit to the index capturing a slight increase over time. Notably, high uncertainty in the index was observed in 2021 of the NCRMP index (Figure 8.8).

4.5.3 Length Compositions

Figure 8.9 shows the cumulative fit across all years between the observed and predicted length composition by fleet for each model. Figure 8.10 shows the annual Pearson residuals by fleet for each model. Figure 8.11 provides the year-specific NRMP survey length

compositions for the model scenarios that included annual fishery-independent length data (v01_m3, v08_m3, v19_m3, and v31_m3). Figure 8.12 provides year-specific length compositions for the model scenario that included annual fishery-dependent length data (v31_m3).

To define the initial time blocks for model v31_m3, years corresponding to changes in Puerto Rico's territorial fishery regulations were used. While alternative breakpoints could be considered, 2004 and 2011 were initially selected. These years provide a reasonable fit to the commercial (TIP) length composition data (Figure 8.12). The resulting residuals show some trends but generally capture a shift in selectivity: from smaller fish being selected early in the time series, to larger fish, and eventually settling on a pattern similar to the selectivity estimated without a time block. Although a more detailed and comprehensive approach could be developed, it is important to consider the potential drivers behind the observed changes in selectivity patterns reflected in the data.

Among the models with the annual fishery-independent length data (v01_m3, v08_m3, v19_m3, and v31_m3), the models with recruitment deviation being estimated (v19_m3 and v31_m3), has improved fits to the annual NCRMP length composition data (Figure 8.9). In the scenarios without recruitment deviations, the predicted NCRMP composition is identical across years and similar to cumulative fit when the length data were aggregated in model a_m3. Figure 8.13 shows the observed and predicted mean length by year. In the model scenarios with estimated recruitment deviations (v19_m3 and v31_m3), there is an improved fit to the mean length capturing an increase over time.

Among the model with the annual fishery-dependent length data (v31_m3), the model with recruitment deviation being estimated (v31_m3), has improved fits to the overall commercial length composition data (Figure 8.9). Finally, Figure 8.14 shows the observed and predicted mean length by year. In the model scenarios without and with estimated recruitment deviations (v31_m3, respectively), there is decreased error and an improved fit to the mean length capturing an increase over time.

4.6 Retrospective Analysis

A retrospective analysis is a helpful approach for investigating the consistency of terminal year model estimates (e.g., SSB, Recruits, Fs) and is often considered a sensitivity exploration of impacts on key parameters from changes in data (Carvalho et al., 2021). The analysis sequentially removes a year of data and reruns the model. Suppose the resulting estimates of derived quantities such as SSB or recruitment differ significantly. In such a case, serial over- or underestimation of important quantities can indicate that the model has an unidentified process error and could require reassessing model assumptions. It is expected that removing data will lead to slight differences between the new terminal year estimates and the estimates for that year in the model with the complete time series of data. Estimates in years before the terminal year may have increasingly reliable information on cohort

strength. Therefore, slight differences are usually expected between model runs as more years of length composition data are sequentially removed. Ideally, the difference in estimates will be slight and randomly distributed above and below the estimates from the model with complete data set time series.

The results of a five-year retrospective analysis are plotted in Figure 8.15 and Figure 8.16. All retrospectives show wide 95% confidence intervals. The retrospective pattern was most divergent in the scenarios with recruitment deviations and annual fishery-independent length data, model v31_m3. The model v19_m3 retrospective is also unusual as the models ending in 2019 and 2020 reflect an entirely different pattern over the time series, with drastically different estimates for initial fishing mortality.

4.7 Likelihood Profiles

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

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

4.7.1 Unfished Recruitment (R0)

Figure 8.17 shows the profile likelihood for the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function for Puerto Rico Yellowtail Snapper across models. All models show relatively poorly defined minimums, with a range of equally plausible values reflected by only small changes in likelihood. However, with the current plots in the report, this is difficult to notice due to the large y-axis scale due to runs that converged at much higher likelihoods. A number of the profiles include peaks or spikes in the likelihood profile. These reflect some instability in the model scenarios also identified from the jitter analysis. Figure 8.18 shows the corresponding change in the Maximum Sustainable Yield Proxy based on SPR 40% across the range of unfished recruitment values explored. Across the range of R0 values explored (0.7 to 1.3 times the estimated R0 for each respective model), the estimates of the MSY proxy (based on SPR 40%) range between 100 and 300 metric tons and reflect a positive relationship with R0 (higher R0 values are associated with higher estimates of the MSY proxy).

4.7.2 Initial Equilibrium Catch

Figure 8.19 shows the profile likelihood for the initial equilibrium catch for Puerto Rico Yellowtail Snapper across model scenarios. A number of the profiles include peaks or spikes in the likelihood profile. These reflect some instability in the model scenarios also identified from the jitter analysis. The models, with the exception of v19_m3, suggest improved fit around 200 metric tons of fixed initial equilibrium catch. Model v19_m3 suggests that given further flexibility the initial equilibrium may be estimated lower. This was further examined through sensitivity runs further relaxing the information that informs the initial model conditions. Figure 8.20 shows the corresponding change in the MSY SPR 40% across the range of initial equilibrium catch values explored.

4.7.3 Steepness

Figure 8.21 shows the profile likelihood for the steepness parameter of the Beverton – Holt stock-recruit function for Puerto Rico Yellowtail Snapper across models. A number of the profiles include peaks or spikes in the likelihood profile. These reflect some instability in the model scenarios also identified from the jitter analysis. The lowest likelihoods are not associated with the highest values of steepness. Instead they are associated with intermediate steepness values between 0.7 and 0.9. Figure 8.22 shows the corresponding change in the MSY SPR 40% across the range of steepness values explored.

4.8 Sensitivity Runs

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

For each model scenario and sensitivity run:

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

4.8.1 Growth CV

The first sensitivity scenario (s1) assumed the coefficient of variation (CV) for young fish was increased from 0.15 to 0.25. The m3_s1 sensitivities resulted in a slight increase to estimated initial equilibrium catch relative to the corresponding m3 sensitivity model configurations Table 7.6. The MSY proxy (based on 40% SPR did not change relative to corresponding m3 configurations (Figures 7.8, 7.9). Lastly, all of the models except v19_s1, had higher spawning stock biomass ratios in 2022 and slightly lower relative 2022 fishing mortality rates copared to their corresponding s3 configurations (Table 7.10). Growth is a critical process in all stock assessment models, and in this assessment, the CV for young fish was a particularly relevant sensitivity to examine due to the large number of small individuals (less than 8 cm) observed in the NCRMP fishery-independent survey length compositions. While additional sensitivities related to growth were considered, they will be revisited in the discussion section as part of the research recommendations. The current models use the best available growth parameters from Shervette, Rivera Hernández, & Peña Alvarado (2024).

4.8.2 Natural Mortality

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

4.8.3 Standard Error on Catch

The third sensitivity scenario (s3) examined the effect of further relaxing the information that informs the initial model conditions. In the m3 model scenarios, a standard error of 0.3 was applied to the landings data (see Section 2.1.1). Compared to the m2 model scenarios, this resulted in higher estimates of initial equilibrium catch, except for model v19_m3. The likelihood profiles (see Section 4.7.2) for v19_m3 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. The s3 sensitivities produced similar estimates as the corresponding m3 models except for model

v19a_m3_s3 which had slightly lower initial catch, slightly higher yield (Tables 7.6, 7.8, 7.9, and 7.10).

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

4.8.4 Standard Error on Catch and Natural Mortality

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

The combined effect of these changes were similar to the third sensitivity scenario exploring only the standard error on catch, except for model v19_m2_s4 (Tables 7.6, 7.8, 7.9, and 7.10). Model v19_m2_s4 resulted in the highest fishing mortality ratio (2.02) and lowest biomass ratio (0.36) across all models documented in this report.

5 Discussion

This assessment presents a series of model configurations developed to address key uncertainties in both the data and model structure, using an integrated framework to evaluate the stock status of Yellowtail Snapper in Puerto Rico. Across the wide range of scenarios explored, two of the model configurations (v19a and v31a) indicate that the stock could be overfished and that overfishing could be occurring (Table 7.10). However, diagnostics and sensitivity analyses revealed important caveats, primarily due to the strong influence of fixed parameter assumptions including uncertainty initial conditions and the final value of the dome-shaped NCRMP index.

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

Among all sensitivity analyses, assumptions about historical catch levels had the greatest influence on model outcomes. Although not yet explored as a sensitivity in the current assessment, the models indicate that the interpretation of stock status is sensitive to the shape and extent of the NCRMP dome-shaped selectivity. These results highlight the importance of structured sensitivity testing to better understand how uncertainty affects model results. Future research should explore the use of model grids or ensemble approaches to formally incorporate uncertainty and improve the reliability of management advice.

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

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

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

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

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

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

6 Assessment Process Research Recommendations

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

- The differences in the NCRMP selectivity across models could benefit from additional exploration with informative priors within the Stock Synthesis framework.
- Expand fishery-independent survey time series and resolution (e.g., retain and use 1-cm length bin data where available).
- Further evaluate natural mortality and growth assumptions. Collect and analyze additional life history data to evaluate the accuracy around growth and natural mortality rates.
- Conduct focused research on historical catches and fishing history to inform and constrain early model conditions.
- Consider using simpler production models or age-structured models with fixed selectivity to isolate and evaluate different data inputs.
- Develop and evaluate model ensembles or uncertainty grids to guide catch advice under different plausible scenarios.
- Investigate stock connectivity to better understand local versus regional recruitment dynamics and their implications for informing steepness.
- Research methods, including simulations, to "right-size" model complexity to match data availability, avoiding overparameterization in data-limited contexts.
- Support Management Strategy Evaluations that are robust to key uncertainties to guide harvest advice.
- Ensure the continuation of fishery-independent survey programs (e.g., National Coral Reef Monitoring Program) with consistent spatial and temporal coverage.
- Maintain and expand commercial catch monitoring programs. Expand port sampling and other fishery-dependent data collection to fill gaps in length composition and effort data.

- The use of initial catch in this assessment was intended to inform an initial starting depletion for the population. However, model evaluations show it also strongly informs maximum sustainable yield estimates. This is an undesirable outcome and additional research into how to decouple these impacts would significantly improve model result reliability.
- Investigate data on the lengths of discarded fish to inform length-based retention. Explore parameterizing retention to improve selectivity of the commercial fleet and interpret the apparent high selectivity of larger individuals that are poorly estimated by the current models.

7 Tables

Table 7.1: Commercial landings of Yellowtail Snapper reported in Puerto Rico from 1983 - 2022 in metric tons and pounds by year, along with the percentage of the total commercial landings that came from each gear group.

Year	Metric Tons	Pounds	Handline	Other	Rod & Reel	Traps
1983	124.6	274,642	54%	5%	9%	32%
1984	103.2	227,434	58%	5%	11%	26%
1985	113.6	250,542	58%	9%	5%	28%
1986	56.7	124,992	50%	25%	4%	21%
1987	55.8	123,024	59%	19%	2%	20%
1988	62.5	137,865	66%	17%	2%	16%
1989	81	178,542	69%	10%	7%	13%
1990	95.2	209,973	75%	6%	7%	11%
1991	132.1	291,274	77%	6%	4%	13%
1992	112.7	248,505	76%	9%	4%	11%
1993	138.3	304,948	77%	7%	6%	10%
1994	132	290,964	74%	7%	7%	12%
1995	185.7	409,451	86%	5%	2%	7%
1996	173.6	382,775	78%	11%	1%	10%
1997	158.7	349,802	79%	9%	2%	10%
1998	146.3	322,521	85%	6%	1%	8%
1999	161.7	356,542	84%	6%	1%	8%
2000	286.9	632,458	85%	6%	2%	6%
2001	211	465,127	82%	7%	4%	7%
2002	153.3	338,019	79%	7%	3%	10%
2003	128	282,201	79%	5%	7%	9%
2004	156.3	344,518	80%	7%	4%	10%
2005	118.9	262,076	89%	4%	1%	6%
2006	124.6	274,593	91%	3%	0%	6%
2007	93.6	206,437	92%	4%	0%	4%
2008	169.5	373,610	95%	3%	0%	2%
2009	101	222,592	88%	3%	1%	8%
2010	97.4	214,799	90%	2%	1%	7%
2011	67.9	149,589	85%	7%	1%	7%

Year	Metric Tons	Pounds	Handline	Other	Rod & Reel	Traps
2012	94.4	208,152	83%	7%	1%	9%
2013	59.5	131,267	85%	4%	2%	9%
2014	87.5	192,808	88%	3%	1%	8%
2015	80.6	177,591	88%	2%	1%	8%
2016	85.3	188,121	89%	3%	1%	7%
2017	56.9	125,338	87%	4%	2%	7%
2018	67.7	149,199	85%	6%	1%	8%
2019	74.5	164,293	87%	6%	0%	7%
2020	56.3	124,185	78%	14%	0%	7%
2021	67.6	148,981	76%	16%	0%	9%
2022	79.3	174,936	78%	14%	1%	8%
Total	4,551.7	10,034,686	80%	7%	3%	10%

Table 7.2: Empirical estimates of natural mortality (M) derived using life history information and the Natural Mortality Tool (Cope & Hamel, 2022). All models included in this report utilize the natural mortality estimate of 0.208 corresponding with the maximum age observed by Shervette, Rivera Hernández, & Peña Alvarado (2024), except two of the sensitivity scenarios (s2 and s4) which utilize the 0.193 natural morality corresponding with the estimated maximum age from SEDAR (2020). Higher estimate of mortality result from the meta-analysis available in the FishLife R package (Thorson et al., 2017).

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

Table 7.3: Summary of process and naming conventions used across different model development stages of the SEDAR 84 Puerto Rico Yellowtail Snapper stock assessment. The numbering of model runs reflects a structured approach used to track configurations consistently across all three SEDAR 84 assessments.

Stage	Code	Sequential modeling steps
Initial	ct	model initialized with continuum tool (ct)
Initial	m1	ct + adjusted length at age zero
Initial	m2	m1 + continuous recruitment
Initial	m3	m2 + catch uncertainty
Scenario	null	catch and super-year length data
Scenario	a	index
Scenario	v01	index + annual fishery-independent length data
Scenario	v08	index + annual fishery-independent length data + dome-shaped fishery-independent selectivity
Scenario	v19	index + annual fishery-independent length data + dome-shaped fishery-independent selectivity + recruitment deviations
Scenario	v31	index + annual fishery-independent length data + annual fishery-dependent length data + dome-shaped fishery-independent selectivity + time block + recruitment deviations
Sensitivity	s1	higher CV on growth young
Sensitivity	s2	higher age and lower m
Sensitivity	s3	higher catch uncertainty
Sensitivity	s4	s2 + s3

Table 7.4: Puerto Rico Yellowtail Snapper parameters, standard deviations (SD), and coefficient of variation (CV) by model scenario (a_m3, v01_m3, v08_m3, v19_m3, v31_m3). CV is calculated as the SD divided by the parameter estimate.

Parameter	Scenario	Estimate	SD	CV	Gradient
Commercial Ascending Selectivity	a_m3	3.39	0.09	0.03	4.5e-08
	v01_m3	3.40	0.09	0.03	-1.1e-05
	v08_m3	3.45	0.09	0.03	3.6e-08
	v19_m3	3.61	0.09	0.02	-1.7e-04
	v31_m3	2.86	0.23	0.08	6.3e-06
Commercial Ascending Selectivity 1983 - 2003	v31_m3	3.08	0.15	0.05	-3.5e-05
Commercial Ascending Selectivity 2004 - 2010	v31_m3	3.81	0.20	0.05	4.8e-05
Commercial Selectivity Peak	a_m3	28.73	0.35	0.01	6.4e-08
	v01_m3	28.75	0.35	0.01	7.1e-06
	v08_m3	29.25	0.38	0.01	-2.7e-08
	v19_m3	30.53	0.57	0.02	1.1e-04
	v31_m3	29.70	0.70	0.02	-1.9e-05
Commercial Selectivity Peak 1983 - 2003	v31_m3	26.82	0.55	0.02	2.8e-05
Commercial Selectivity Peak 2004 - 2010	v31_m3	32.37	1.03	0.03	-8.1e-06
Initial F	a_m3	0.34	0.08	0.24	-6.7e-08
	v01_m3	0.36	0.08	0.22	-5.7e-07
	v08_m3	0.59	0.16	0.27	3.7e-09
	v19_m3	0.18	0.06	0.33	-2.3e-05
	v31_m3	0.82	0.18	0.22	-4.8e-07

Parameter	Scenario	Estimate	SD	CV	Gradient
NCRMP Ascending Selectivity	a_m3	6.61	4.55	0.69	-1.5e-10
	v01_m3	5.85	2.07	0.35	-3.5e-08
NCRMP Selectivity End	v08_m3	-0.18	0.20	-1.11	-4.5e-10
	v19_m3	0.13	0.28	2.15	1.7e-05
	v31_m3	-0.39	0.22	-0.56	-8.3e-05
NCRMP Selectivity Peak	a_m3	16.56	1.03	0.06	-1.1e-08
	v01_m3	16.95	1.17	0.07	6.6e-08
	v08_m3	7.34	0.56	0.08	-8.8e-10
	v19_m3	19.74	0.89	0.05	-5.5e-06
	v31_m3	18.97	0.90	0.05	-3.6e-05
NCRMP Selectivity Top	v08_m3	-0.47	0.04	-0.09	-4.0e-08
	v19_m3	-5.15	9.50	-1.84	-7.0e-07
	v31_m3	-3.16	0.62	-0.20	-4.0e-05
Unfished Recruitment (R0)	a_m3	7.16	0.01	0.00	9.7e-06
	v01_m3	7.16	0.01	0.00	-1.3e-07
	v08_m3	7.16	0.01	0.00	-3.7e-07
	v19_m3	6.96	0.05	0.01	1.4e-03
	v31_m3	7.03	0.06	0.01	-6.3e-05

Table 7.5: Puerto Rico Yellowtail Snapper correlations between estimated parameters across the m3 model scenarios. The table shows correlations greater than 0.9 or less than -0.9. Correlations that are greater than 0.95 or less than -0.95 are shown in red.

Scenario	Estimated Parameters		Correlation Coefficient
a_m2	Commercial Ascending Selectivity	Commercial Selectivity Peak	0.917
a_m3	Commercial Ascending Selectivity	Commercial Selectivity Peak	0.906
v01_m2	Commercial Ascending Selectivity	Commercial Selectivity Peak	0.919
v01_m3	Commercial Ascending Selectivity	Commercial Selectivity Peak	0.909
v08_m2	Commercial Ascending Selectivity	Commercial Selectivity Peak	0.917
v08_m2	NCRMP Selectivity Top	NCRMP Selectivity Peak	-0.982
v08_m3	Commercial Ascending Selectivity	Commercial Selectivity Peak	0.926
v19_m2	Initial F	Unfished Recruitment (R0)	-0.945
v31_m2	Commercial Ascending Selectivity	Commercial Selectivity Peak	0.922
v31_m2	Commercial Ascending Selectivity 1983	Commercial Selectivity Peak 1983	0.945
v31_m2	Commercial Ascending Selectivity 2004	Commercial Selectivity Peak 2004	0.909
v31_m3	Commercial Ascending Selectivity	Commercial Selectivity Peak	0.924
v31_m3	NCRMP Selectivity Top	NCRMP Selectivity Peak	-0.994
v31_m3	Commercial Ascending Selectivity 1983	Commercial Selectivity Peak 1983	0.935
v31_m3	Commercial Ascending Selectivity 2004	Commercial Selectivity Peak 2004	0.909

Table 7.6: Puerto Rico Yellowtail Snapper estimated initial equilibrium catch in metric tons by model scenario including across sensitivity runs. The input value was 168.3 metric tons with a standard error of 0.3.

Parameter	Scenario	a	v01	v08	v19	v31
Commercial Equilibrium Catch	m2	168.9	168.9	169.2	168.2	168.0
	m3	210.1	211.4	225.0	144.1	188.7
	m3_s1	225.5	225.8	232.3	156.5	193.8
	m3_s2	215.4	217.1	225.3	156.6	183.7
	m3_s3	210.9	212.2	225.2	135.5	197.4
	m3_s4	215.8	217.4	225.4	157.8	184.0

Table 7.7: Puerto Rico Yellowtail Snapper derived quantities for unfished and initial spawning stock biomass in metric tons (mt) along with standard deviations (SD) and coefficient of variation (CV) by model scenario (a_m3, v01_m3, v08_m3, v19_m3, v31_m3). CV is calculated as the SD divided by the parameter estimate.

Derived Quantity	Scenario	Estimate	SD	CV
SSB Unfished (mt)	a_m3	666.20	3.48	0.01
	v01_m3	666.52	3.48	0.01
	v08_m3	667.66	3.61	0.01
	v19_m3	547.68	29.37	0.05
	v31_m3	588.98	34.37	0.06
SSB Initial (mt)	a_m3	194.16	32.24	0.17
	v01_m3	189.51	31.52	0.17
	v08_m3	131.70	25.96	0.20
	v19_m3	261.56	41.57	0.16
	v31_m3	75.15	11.30	0.15
Ratio SSB Initial:Unfished	a_m3	0.09	0.00	0.04
	v01_m3	0.09	0.00	0.04
	v08_m3	0.10	0.01	0.06
	v19_m3	0.10	0.03	0.26
	v31_m3	0.15	0.02	0.11

Table 7.8: Puerto Rico Yellowtail Snapper derived quantities of the MSY proxy (based on SPR 40%) in metric tons by model scenario (a_m3, v01_m3, v08_m3, v19_m3, v31_m3) and corresponding each model scenario's four sensitivity runs. CV is calculated as the SD divided by the parameter estimate. Estimates of the MSY proxy are also presented in pounds in Table 7.9.

Scenario	MSY Proxy	SD	CV
a_m3	187.77	1.09	0.01
a_m3_s1	187.61	1.04	0.01
a_m3_s2	187.35	1.19	0.01
a_m3_s3	187.86	1.09	0.01
a_m3_s4	187.43	1.18	0.01
v01_m3	187.93	1.09	0.01
v01_m3_s1	187.70	1.04	0.01
v01_m3_s2	187.68	1.19	0.01
v01_m3_s3	188.02	1.08	0.01
v01_m3_s4	187.75	1.18	0.01
v08_m3	190.35	1.24	0.01
v08_m3_s1	190.06	1.16	0.01
v08_m3_s2	190.40	1.35	0.01
v08_m3_s3	190.41	1.23	0.01
v08_m3_s4	190.54	1.35	0.01
v19_m3	159.97	7.82	0.05
v19_m3_s1	156.01	7.05	0.05
v19_m3_s2	158.86	8.15	0.05
v19_m3_s3	157.95	8.62	0.05
v19_m3_s4	159.63	8.43	0.05
v31_m3	177.98	10.34	0.06
v31_m3_s1	179.31	11.00	0.06
v31_m3_s2	174.86	9.98	0.06

Scenario	MSY Proxy	SD	CV
v31_m3_s3	185.85	11.34	0.06
v31_m3_s4	175.25	10.10	0.06

Table 7.9: Puerto Rico Yellowtail Snapper derived quantities of the MSY proxy (based on SPR 40%) in pounds by model scenario (a_m3, v01_m3, v08_m3, v19_m3, v31_m3) and corresponding each model scenario's four sensitivity runs.

Scenario	a	v01	v08	v19	v31
m3	413,958	414,315	419,650	352,671	392,374
m3_s1	413,600	413,797	419,022	343,937	395,306
m3_s2	413,047	413,770	419,753	350,233	385,505
m3_s3	414,169	414,522	419,789	348,229	409,733
m3_s4	413,212	413,922	420,071	351,928	386,364

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

Metric	Scenario	a	v01	v08	v19	v31
F Current / F SPR 40%	m3	0.63	0.63	0.60	1.58	1.05
	m3_s1	0.59	0.59	0.57	1.77	0.91
	m3_s2	0.70	0.69	0.65	1.79	1.16
	m3_s3	0.63	0.63	0.59	1.64	0.82
	m3_s4	0.69	0.69	0.64	2.02	1.15
SSB 2022 / SSB SPR 40%	m3	1.06	1.06	1.11	0.46	0.66
	m3_s1	1.13	1.13	1.16	0.43	0.79
	m3_s2	0.97	0.97	1.02	0.41	0.60
	m3_s3	1.06	1.07	1.11	0.45	0.82
	m3_s4	0.97	0.97	1.03	0.36	0.60

8 Figures

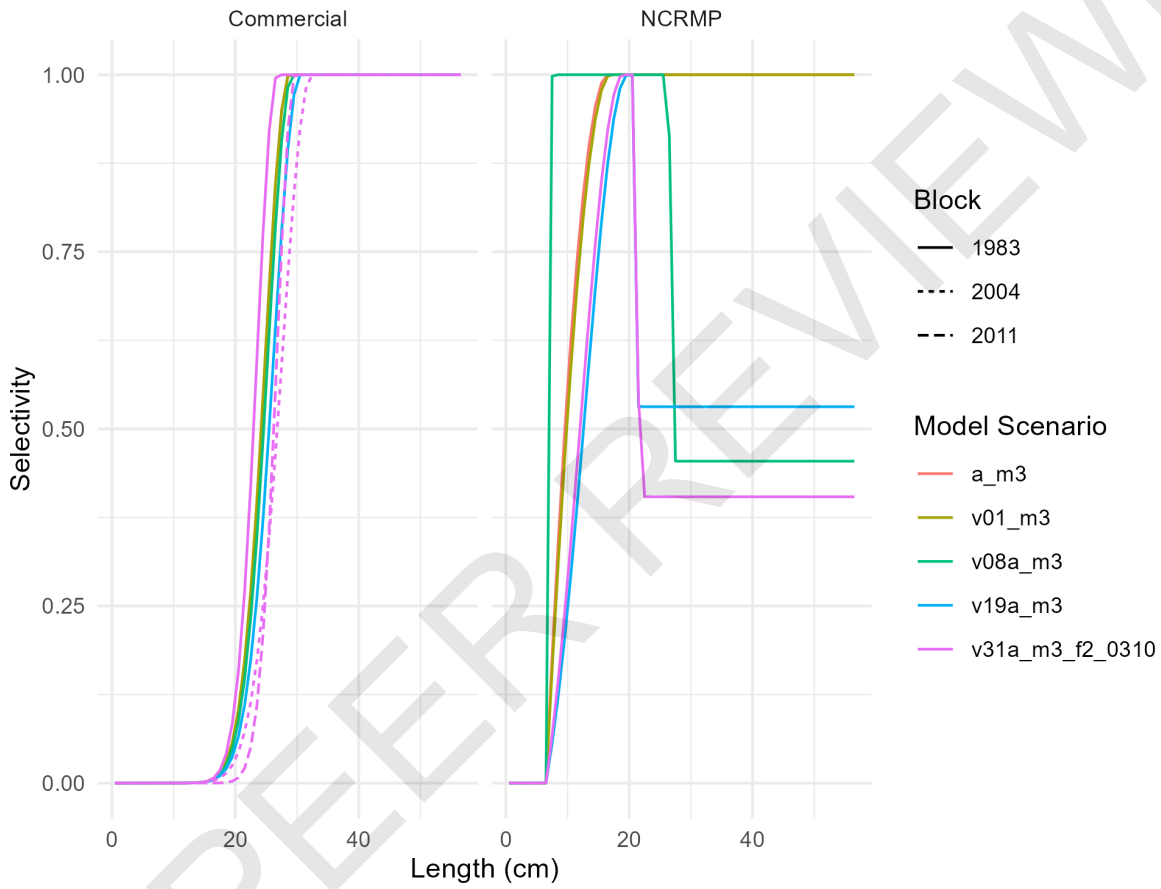
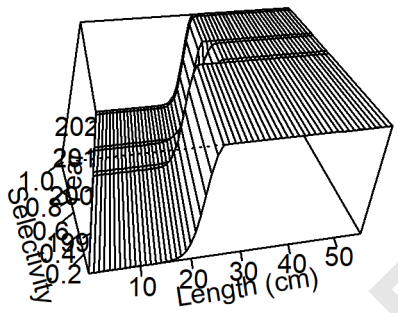
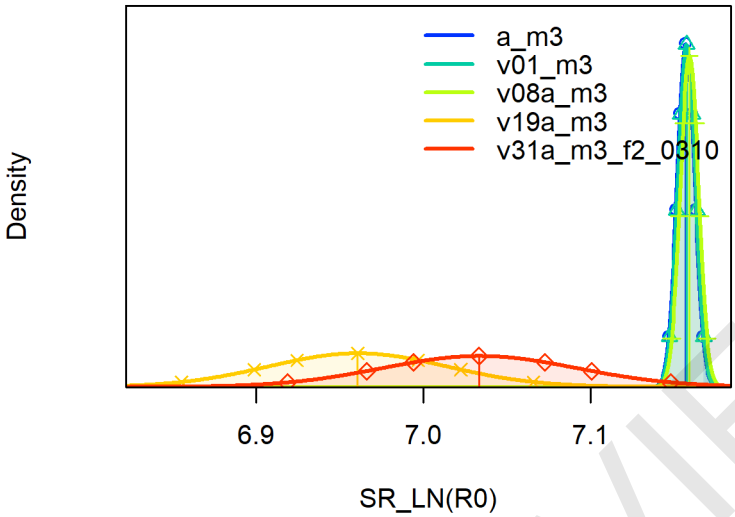


Figure 8.1: Puerto Rico Yellowtail Snapper commercial fleet and NCRMP survey selectivity across model scenarios (a_m3, v01_m3, v08_m3, v19_m3, v31_m3). Selectivity patterns reflect the probability that a fish of a given length will be caught by a particular fishing fleet or observed in a given survey. To define the initial time blocks for model v31_m3, years corresponding to changes in Puerto Rico's territorial fishery regulations were used. While alternative breakpoints could be considered, 2004 and 2011 were initially selected.

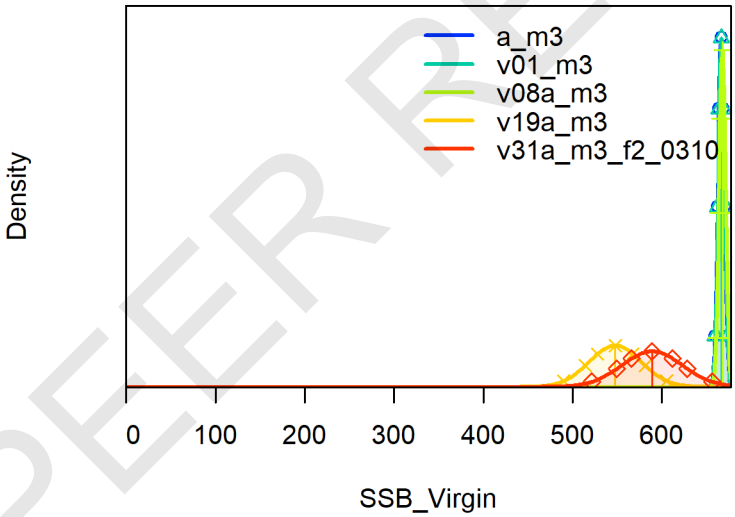


(a) Model v31_m3

Figure 8.2: Puerto Rico Yellowtail Snapper commercial fleet logistic selectivity across model scenarios with time blocks (v31_m3). To define the initial time blocks for model v31_m3, years corresponding to changes in Puerto Rico's territorial fishery regulations were used. While alternative breakpoints could be considered, 2004 and 2011 were initially selected.

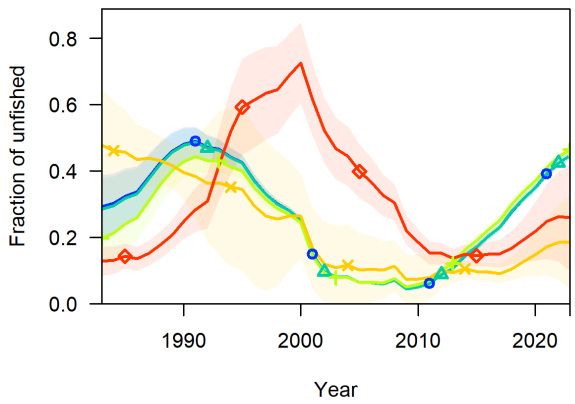


(a) Unfished recruitment

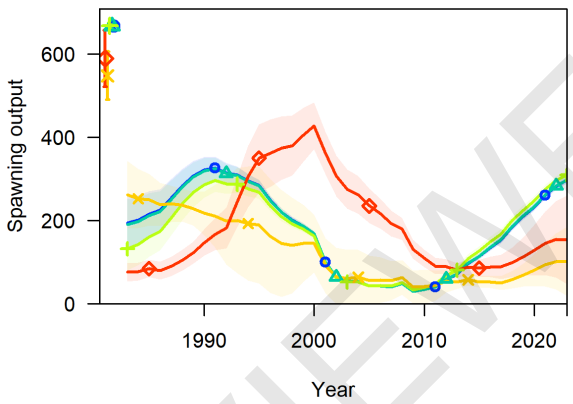


(b) Virgin Spawning Stock Biomass

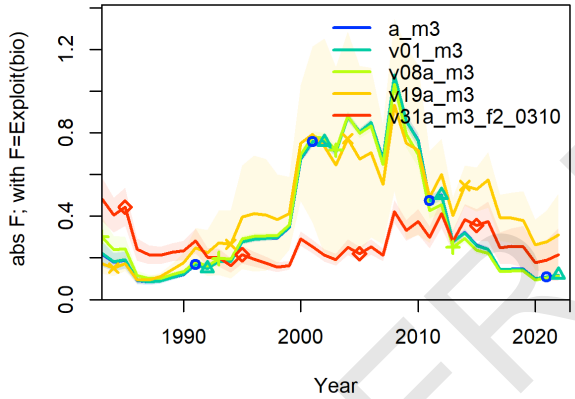
Figure 8.3: Puerto Rico Yellowtail Snapper parameter distribution for (a) the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function and (b) virgin spawning stock biomass in metric tons across model scenarios (a_m3, v01_m3, v08_m3, v19_m3, v31_m3).



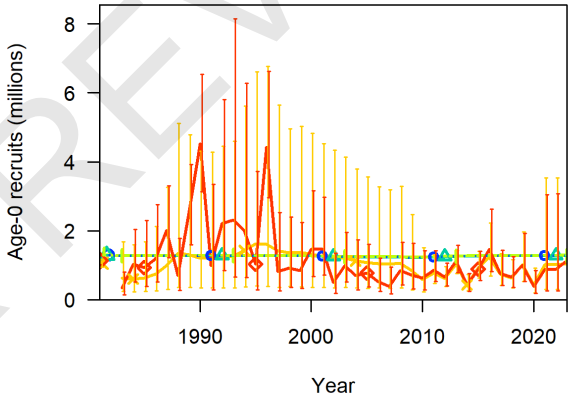
(a) Spawning Biomass Ratio



(b) Spawning Biomass

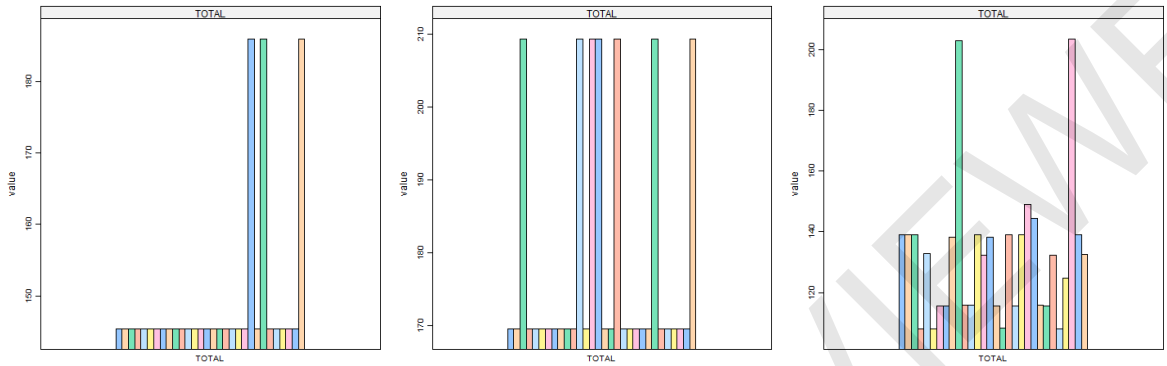


(c) Fishing Mortality

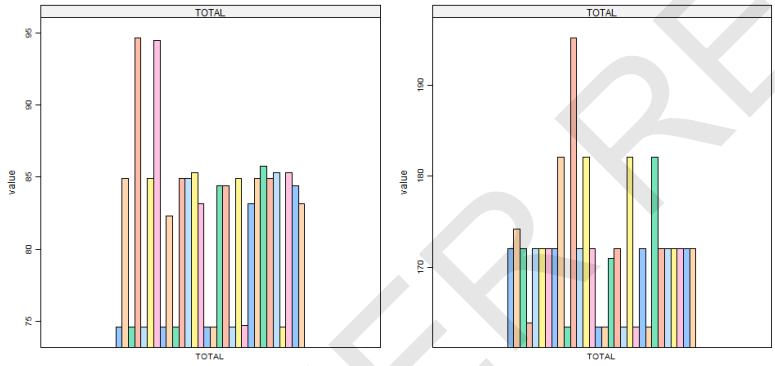


(d) Recruitment

Figure 8.4: Puerto Rico Yellowtail Snapper derived quantity time series across model scenarios (a_m3, v01_m3, v08_m3, v19_m3, v31_m3). Derived quantities plotted over time for (a) the relative spawning stock biomass (total biomass / virgin spawning stock biomass), (b) spawning stock biomass in thousands of metric tons, (c) fishing mortality (total biomass killed / total biomass), (d) and recruitment in millions of fish. The shaded areas and vertical bars in the derived quantities time series represent 95% confidence intervals. The values plotted prior to the model start year of 2012 reflect the unfished conditions and associated 95% confidence intervals.

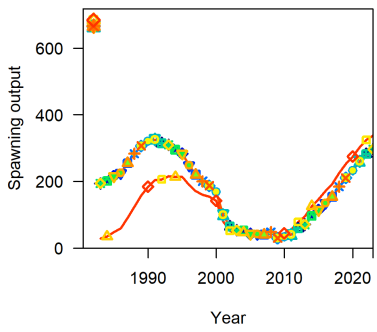


(a) Model a_m3 (b) Model v01_m3 (c) Model v08_m3

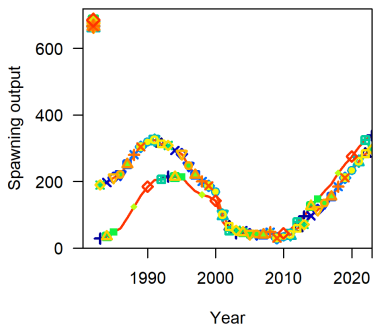


(d) Model v19_m3 (e) Model v31_m3

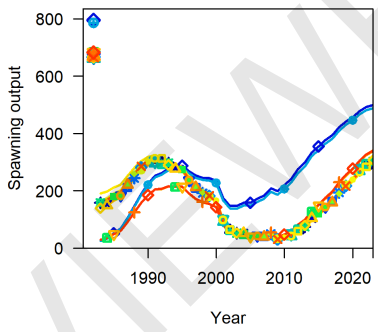
Figure 8.5: Puerto Rico Yellowtail Snapper jitter analysis total likelihood across model scenarios (a_m3, v01_m3, v08_m3, v19_m3, v31_m3). Each panel gives the results of 30 runs of the corresponding model scenario where the starting parameter values for each run were randomly changed by 20% from each model's predicted values using a uniform distribution in cumulative normal space.



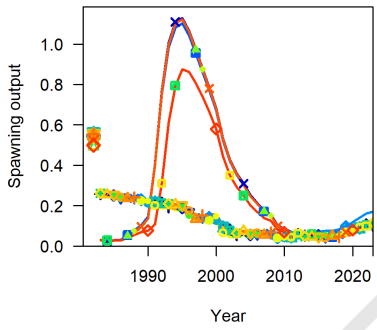
(a) Model a_m3



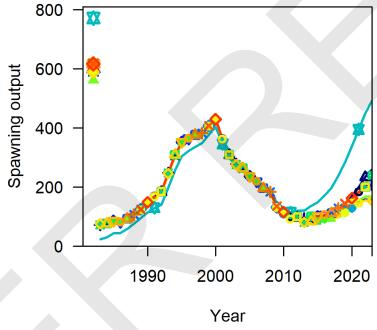
(b) Model v01_m3



(c) Model v08_m3

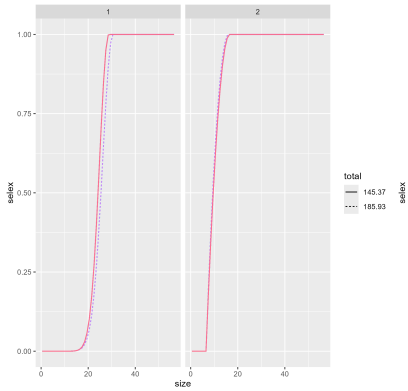


(d) Model v19_m3

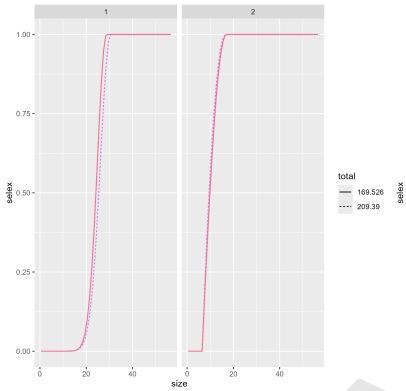


(e) Model v31_m3

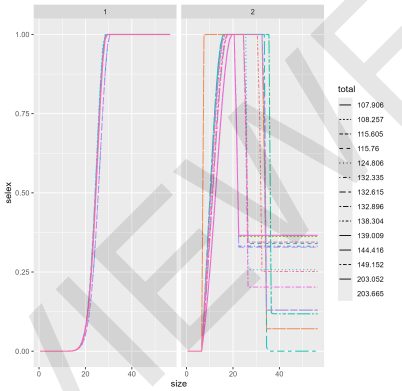
Figure 8.6: Puerto Rico Yellowtail Snapper jitter analysis relative spawning stock biomass in metric tons (a_m3, v01_m3, v08_m3, v31_m3) and in thousands of metric tons (v19_m3) across jitters. Each panel gives the results of 30 runs of the corresponding model scenario where the starting parameter values for each run were randomly changed by 20% from each model's predicted values using a uniform distribution in cumulative normal space.



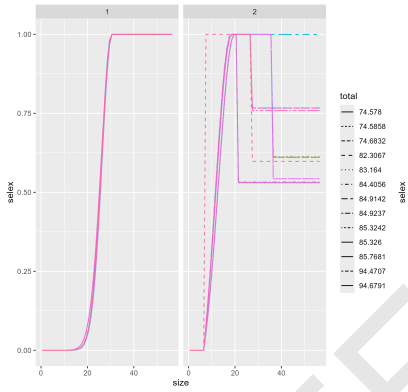
(a) Model a_m3



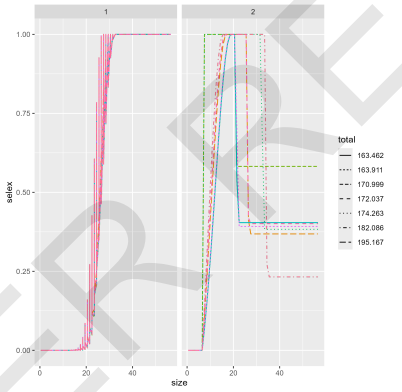
(b) Model v01_m3



(c) Model v08_m3

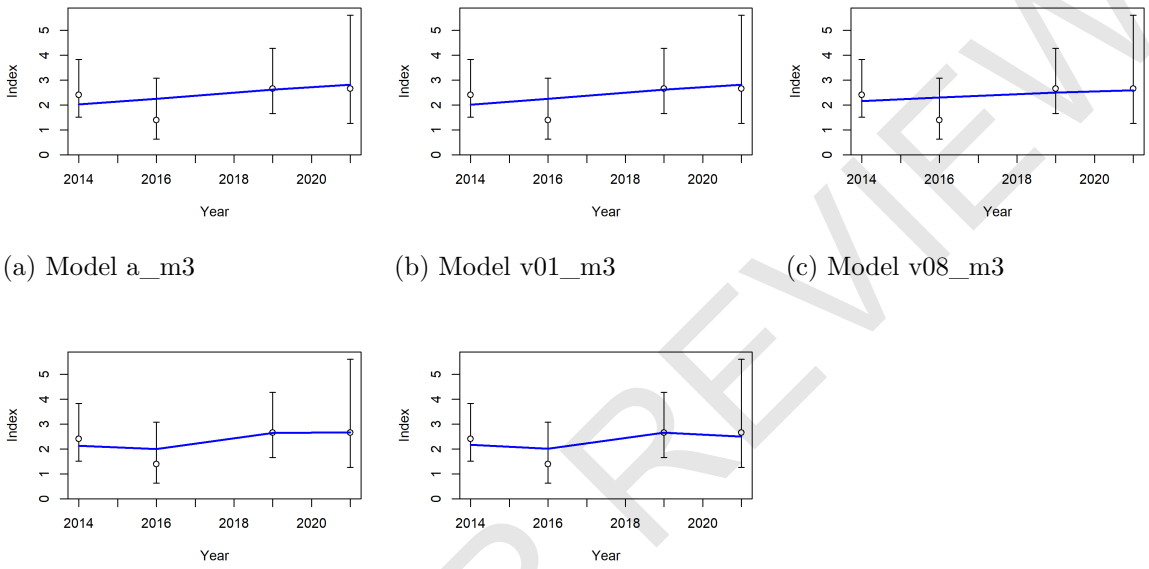


(d) Model v19_m3



(e) Model v31_m3

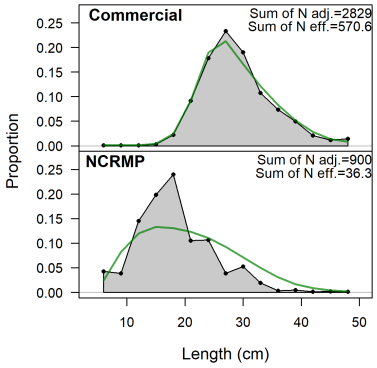
Figure 8.7: Puerto Rico Yellowtail Snapper jitter analysis length-based selectivity by fleet across model scenarios (a_m3, v01_m3, v08_m3, v19_m3, v31_m3). Each panel gives the results of 30 runs of the corresponding model scenario where the starting parameter values for each run were randomly changed by 20% from each model's predicted values using a uniform distribution in cumulative normal space.



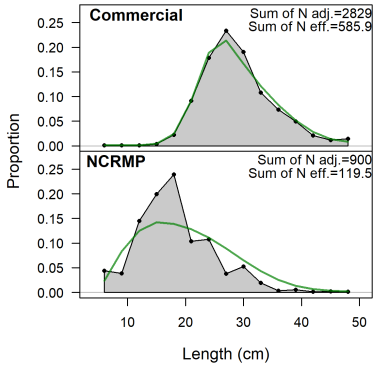
(a) Model a_m3 (b) Model v01_m3 (c) Model v08_m3

(d) Model v19_m3 (e) Model v31_m3

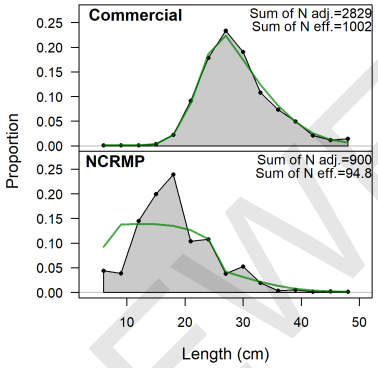
Figure 8.8: Puerto Rico Yellowtail Snapper National Coral Reef Monitoring Program (NCRMP) observed (open circles) and predicted (blue line) indices of relative abundance and associated standard errors across model scenarios (a_m3, v01_m3, v08_m3, v19_m3, v31_m3). Error bars indicate a 95% uncertainty interval around observed index values based on the model assumption of lognormal error. Model scenarios a_m3, v01_m3, and v08_m3 do not estimate recruitment deviations, while model scenarios v19_m3 and v31_m3 do.



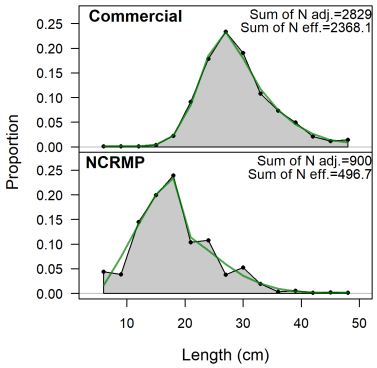
(a) Model a_m3



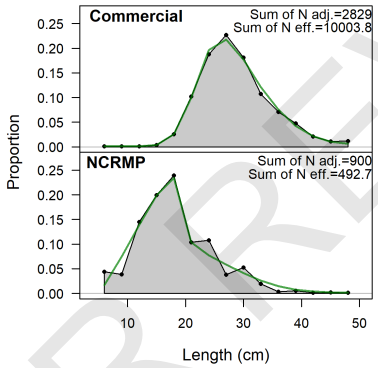
(b) Model v01_m3



(c) Model v08_m3

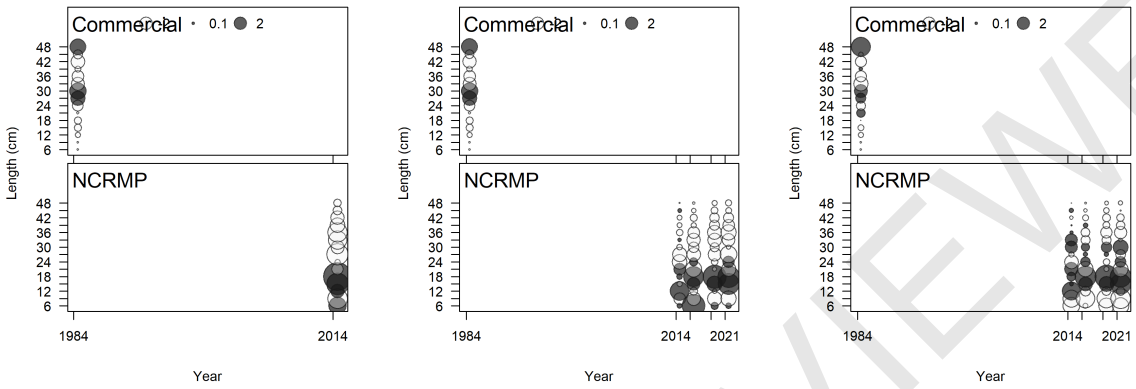


(d) Model v19_m3

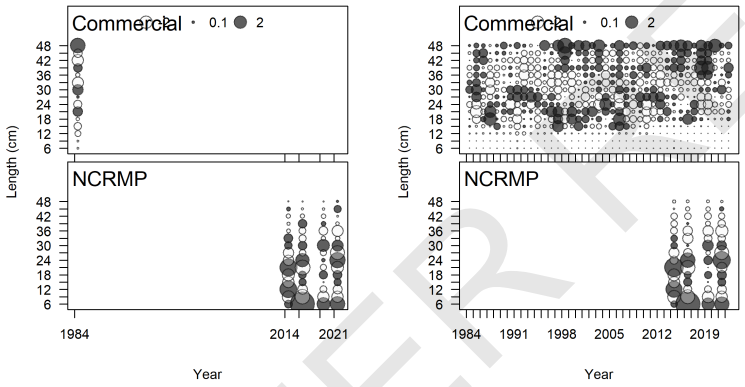


(e) Model v31_m3

Figure 8.9: Puerto Rico Yellowtail Snapper observed and predicted length distributions in centimeters aggregated across years for the Commercial (TIP) and National Coral Reef Monitoring Survey (NCRMP) length composition across model scenarios (a_m3, v01_m3, v08_m3, v19_m3, v31_m3). Green lines represent predicted length compositions, while gray regions represent observed length compositions. The effective sample sizes used to weight the length composition data are provided by N adj (the input sample size) and N eff (the calculated effective sample size) and are shown in the upper right corners. Model scenarios a_m3, v01_m3, and 08_m3 do not estimate recruitment deviations, while model scenarios v19_m3 and v31_m3 do. Super years are utilized for the commercial fleet in scenarios a_m3, v01_m3, v08_m3, and v19_m3 and for the national coral reef monitoring survey in scenario a_m3.

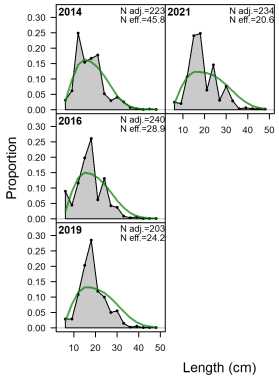


(a) Model a_m3 (b) Model v01_m3 (c) Model v08_m3

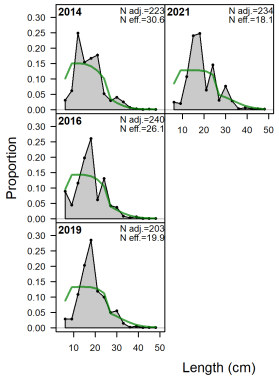


(d) Model v19_m3 (e) Model v31_m3

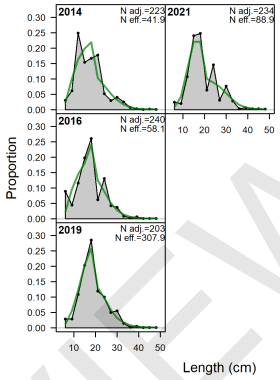
Figure 8.10: Puerto Rico Yellowtail Snapper length composition Pearson residuals, by fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). Model scenarios a_m3, v01_m3, and v08_m3 do not estimate recruitment deviations, while model scenarios v19_m3 and v31_m3 do. Super years are utilized for the commercial fleet in scenarios a_m3, v01_m3, v08_m3, and v19_m3 and for the national coral reef monitoring survey in scenario a_m3.



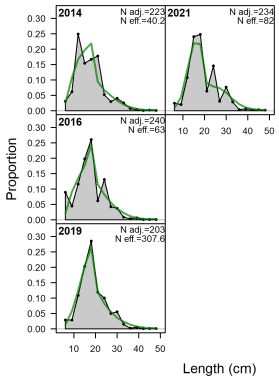
(a) Model v01_m3 NCRMP by year



(b) Model v08_m3 NCRMP by year



(c) Model v19_m3 NCRMP by year



(d) Model v31_m3 NCRMP by year

Figure 8.11: Puerto Rico Yellowtail Snapper observed and predicted length distributions in centimeters by year for the National Coral Reef Monitoring Survey (NCRMP) length compositions for across model scenarios. Green lines represent predicted length compositions, while gray regions represent observed length compositions. The effective sample sizes used to weight the length composition data are provided by N adj (the input sample size) and N eff (the calculated effective sample size) and are shown in the upper right corners.

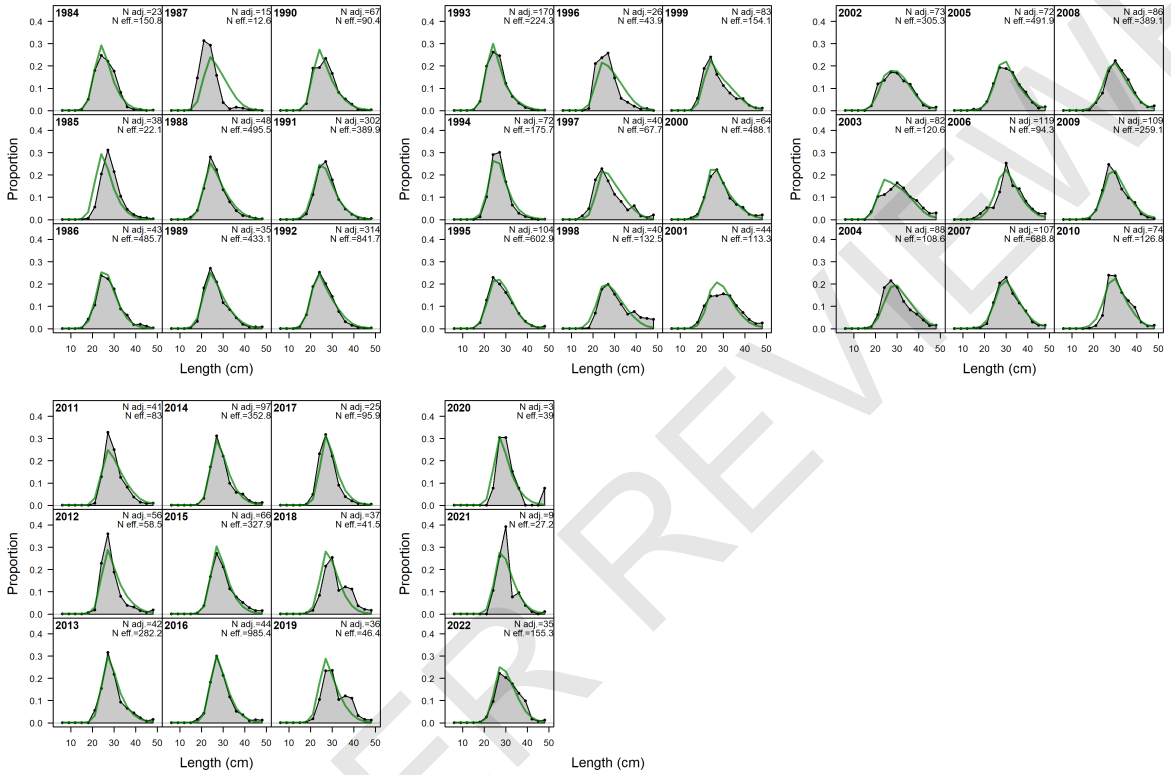
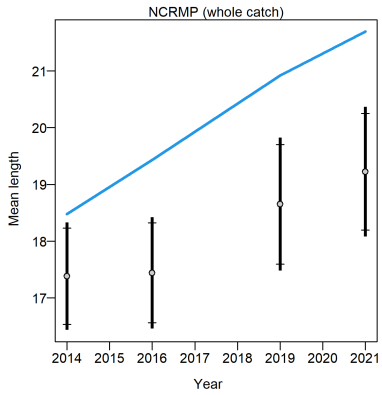
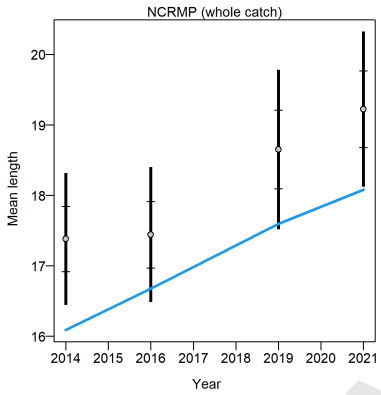


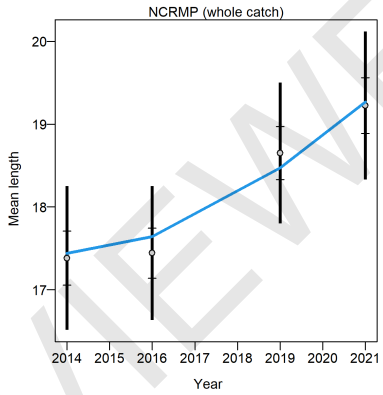
Figure 8.12: Puerto Rico Yellowtail Snapper observed and predicted length distributions in centimeters by year for the commercial fleet length compositions for the v31_m3 model scenarios. Green lines represent predicted length compositions, while gray regions represent observed length compositions. The effective sample sizes used to weight the length composition data are provided by N adj (the input sample size) and N eff (the calculated effective sample size) and are shown in the upper right corners.



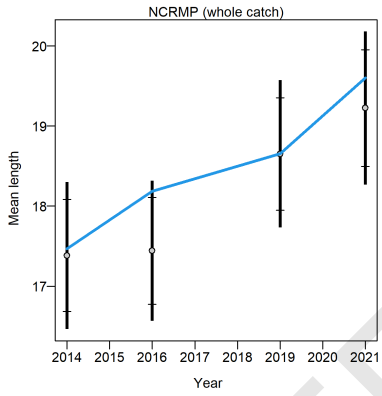
(a) Model v01_m3



(b) Model v08_m3

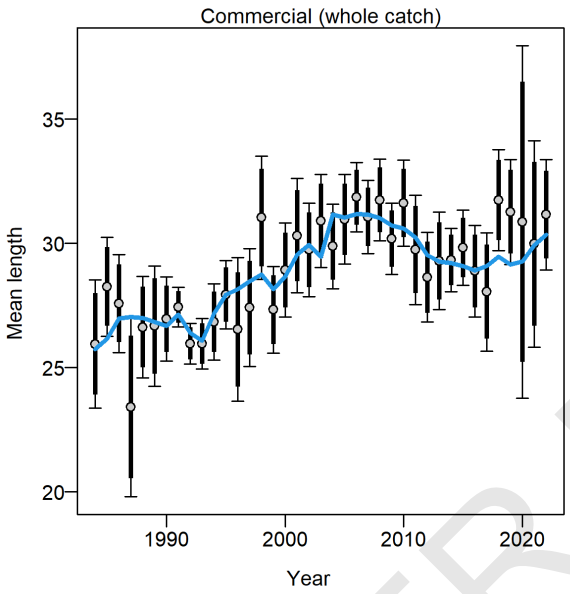


(c) Model v19_m3



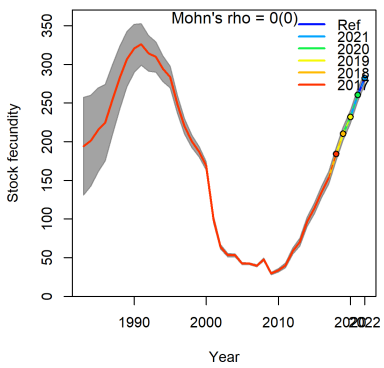
(d) Model v31_m3

Figure 8.13: Puerto Rico Yellowtail Snapper observed (open circles) and predicted (blue line) mean length in centimeters by year across model scenarios that include annual fishery-independent National Coral Reef Monitoring Survey (NCRMP) data without recruitment deviations (v01_m3 and v08_m3) and with recruitment deviations (v19_m3 and v31_m3).

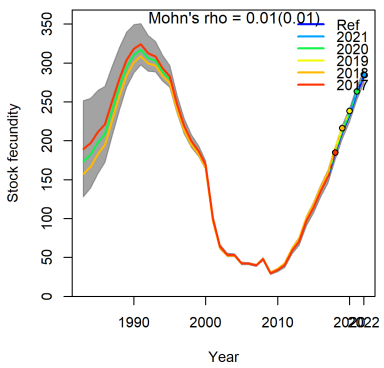


(a) Model v31_m3

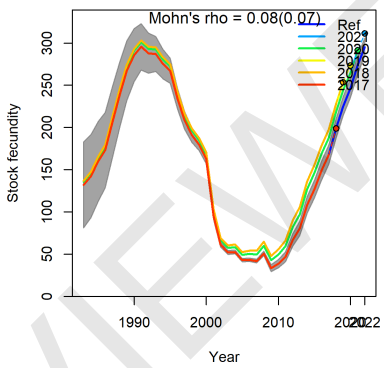
Figure 8.14: Puerto Rico Yellowtail Snapper observed (open circles) and predicted (blue line) mean length in centimeters by year across model scenarios that include annual fishery-dependent commercial data and recruitment deviations (v31_m3).



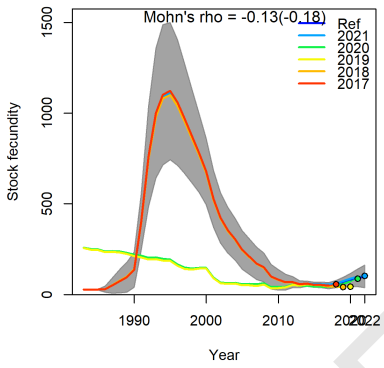
(a) Model a_m3



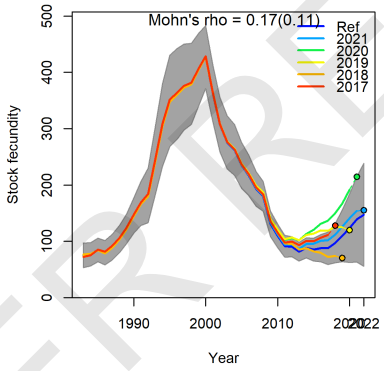
(b) Model v1_m3



(c) Model v08_m3

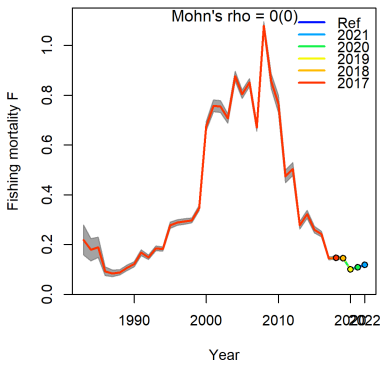


(d) Model v19_m3

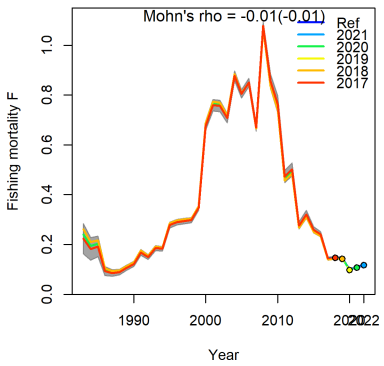


(e) Model v31_m3

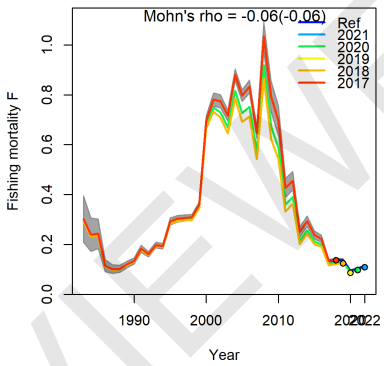
Figure 8.15: Puerto Rico Yellowtail Snapper retrospective analysis of fecundity conducted by refitting models after removing five years of observation, one year at a time sequentially. Mohn's rho statistics and the corresponding "hindcast rho" measure the severity of retrospective patterns. The reference models (Ref) include the full time series ending in 2022. One-year-ahead projections are denoted by color-coded dashed lines with terminal points. Grey shaded areas are the 95% confidence intervals.



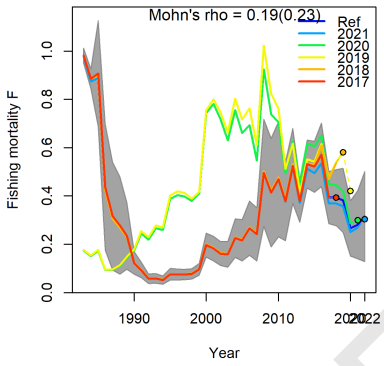
(a) Model a_m3



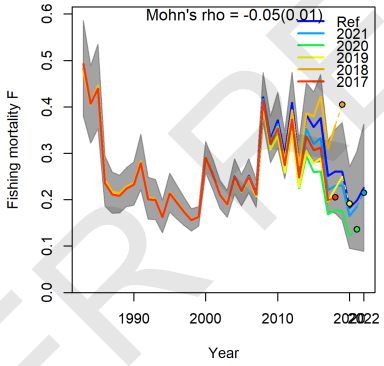
(b) Model v1_m3



(c) Model v08_m3

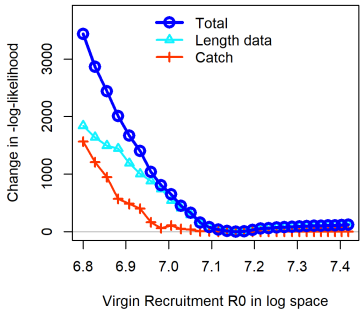


(d) Model v19_m3

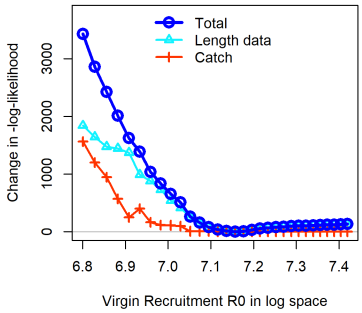


(e) Model v31_m3

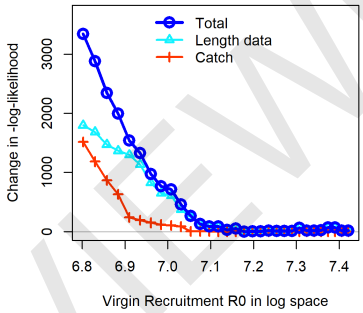
Figure 8.16: Puerto Rico Yellowtail Snapper retrospective analysis of fishing mortality conducted by refitting models after removing five years of observation, one year at a time sequentially. Mohn's rho statistics and the corresponding "hindcast rho" measure the severity of retrospective patterns. The reference models (Ref) include the full time series ending in 2022. One-year-ahead projections are denoted by color-coded dashed lines with terminal points. Grey shaded areas are the 95% confidence intervals.



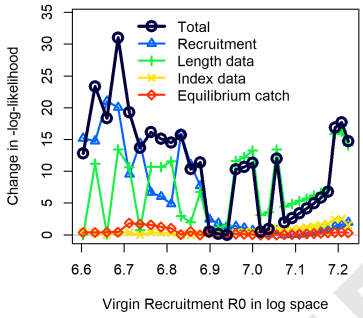
(a) Model a_m3



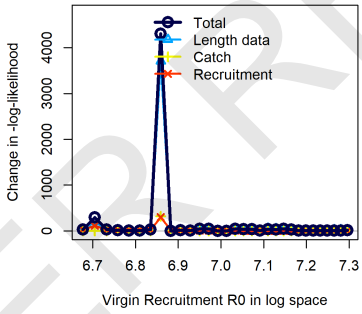
(b) Model v01_m3



(c) Model v08_m3

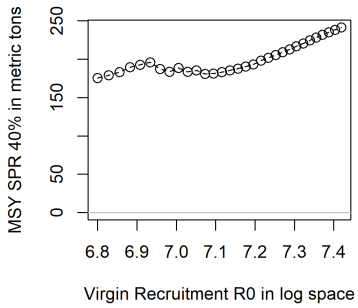


(d) Model v19_m3

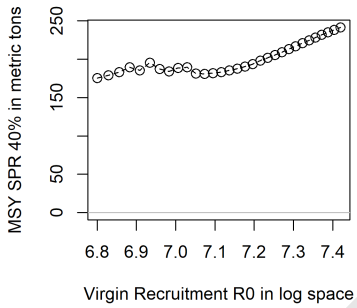


(e) Model v31_m3

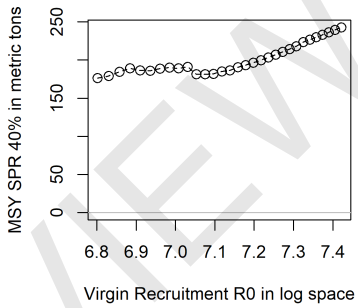
Figure 8.17: The profile likelihood for the natural log of the unfished recruitment parameter of the Beverton – Holt stock-recruit function for Puerto Rico Yellowtail Snapper across model scenarios (a_m3, v01_m3, v08_m3, v19_m3, v31_m3). Each line represents the change in negative log-likelihood value for each of the data sources fit in the model across the range of fixed unfished recruitment values tested in the profile diagnostic run.



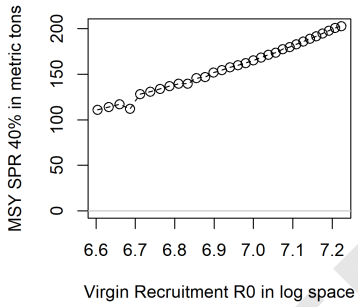
(a) Model a_m3



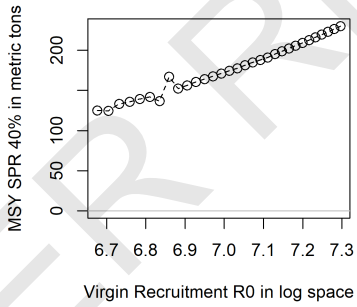
(b) Model v01_m3



(c) Model v08_m3

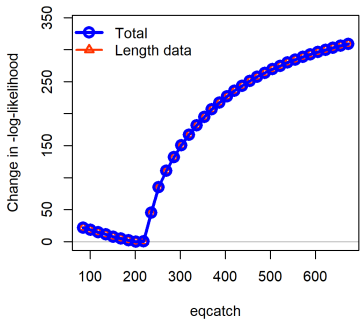


(d) Model v19_m3

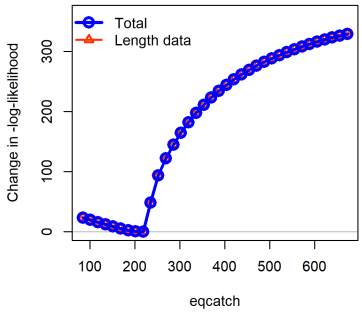


(e) Model v31_m3

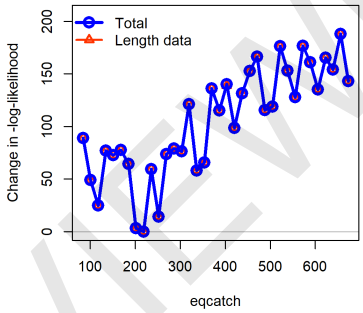
Figure 8.18: Estimates of the MSY proxy (based on SPR 40%) across the range of unfished recruitment values explored in the Puerto Rico Yellowtail Snapper likelihood profile. These estimates, expressed in metric tons, are shown for model scenarios a_m3, v01_m3, v08_m3, v19_m3, v31_m3.



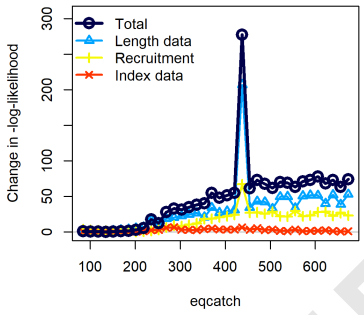
(a) Model a_m3



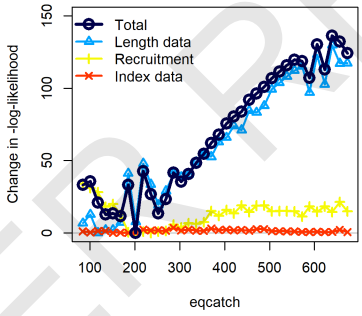
(b) Model v01_m3



(c) Model v08_m3

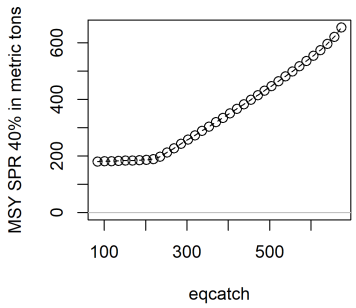


(d) Model v19_m3

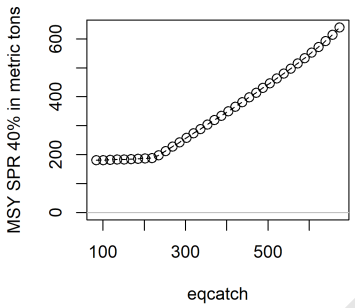


(e) Model v31_m3

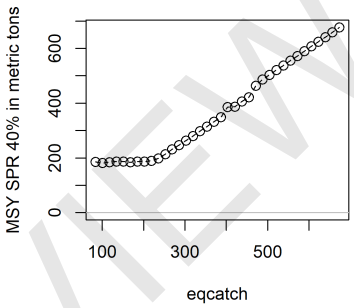
Figure 8.19: The profile likelihood for the fixed initial equilibrium catch for Puerto Rico Yellowtail Snapper across model scenarios (a_m3, v01_m3, v08_m3, v19_m3, v31_m3). Each line represents the change in negative log-likelihood value for each of the data sources fit in the model across the range of fixed equilibrium catch values tested in the profile diagnostic run.



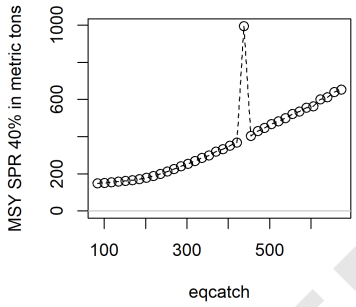
(a) Model a_m3



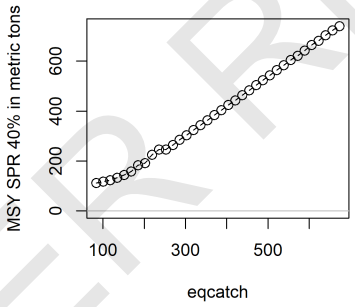
(b) Model v01_m3



(c) Model v08_m3

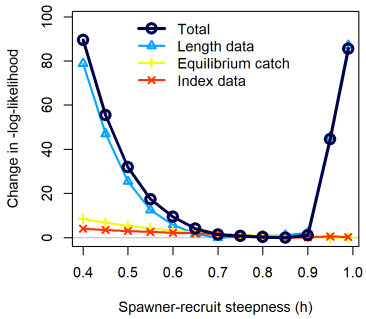


(d) Model v19_m3

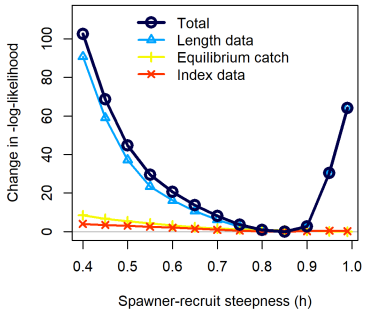


(e) Model v31_m3

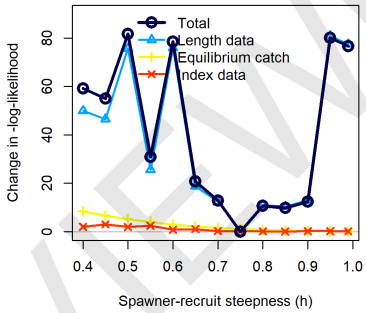
Figure 8.20: Estimates of the MSY proxy (based on SPR 40%) across the range of initial equilibrium catch values explored in the Puerto Rico Yellowtail Snapper likelihood profile. These estimates, expressed in metric tons, are shown for model scenarios a_m3, v01_m3, v08_m3, v19_m3, v31_m3.



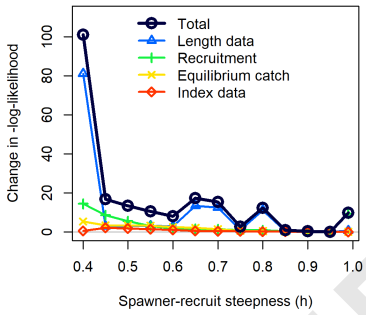
(a) Model a_m3



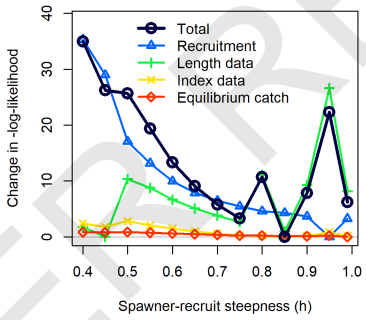
(b) Model v01_m3



(c) Model v08_m3

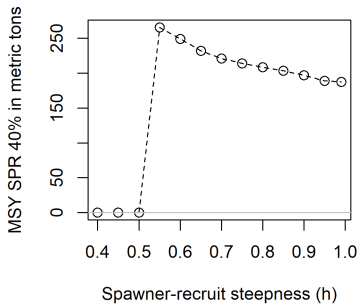


(d) Model v19_m3

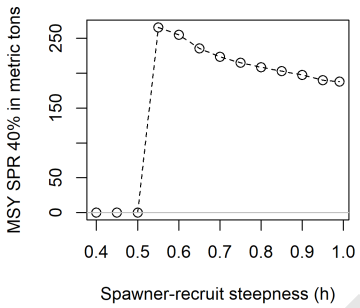


(e) Model v31_m3

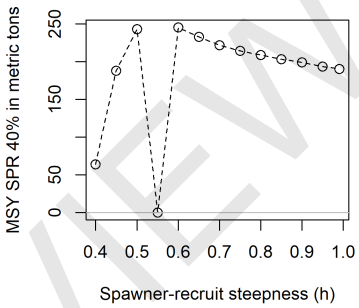
Figure 8.21: The profile likelihood for the steepness parameter of the Beverton – Holt stock-recruit function for Puerto Rico Yellowtail Snapper across model scenarios (a_m3, v01_m3, v08_m3, v19_m3, v31_m3). Each line represents the change in negative log-likelihood value for each of the data sources fit in the model across the range of fixed steepness values tested in the profile diagnostic run.



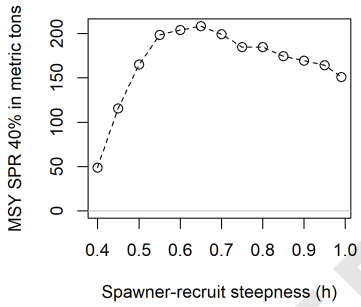
(a) Model a_m3



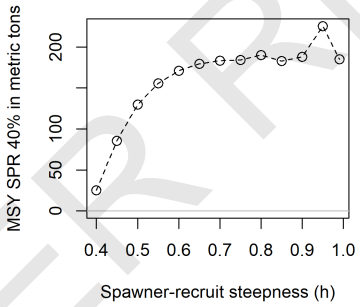
(b) Model v01_m3



(c) Model v08_m3



(d) Model v19_m3



(e) Model v31_m3

Figure 8.22: Estimates of the MSY proxy (based on SPR 40%) across the range of steepness values explored in the Puerto Rico Yellowtail Snapper likelihood profile. These estimates, expressed in metric tons, are shown for model scenarios a_m3, v01_m3, v08_m3, v19_m3, v31_m3.

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