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Stock assessment of American Samoa bottomfishes, 2023

Marc O. Nadon, Megumi C. Oshima, Erin C. Bohaboy, and Felipe Carvalho

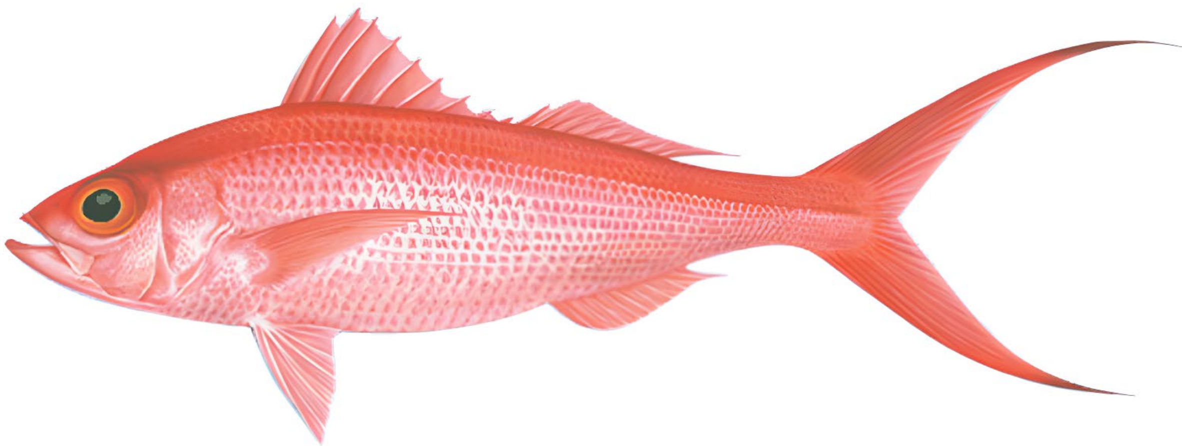

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Table of Contents

List of Tables

List of Figures

Executive Summary

The Western Pacific Regional Fishery Management Council's fishery ecosystem plan for American Samoa includes 11 bottomfish management unit species (BMUS) that have traditionally been assessed and managed as a group (i.e., a species complex). The 11 species in the BMUS complex are *Aphareus rutilans, Aprion virescens, Caranx lugubris, Etelis carbunculus, Etelis coruscans, Lethrinus rubrioperculatus, Lutjanus kasmira, Pristipomoides filamentosus, Pristipomoides flavipinnis, Pristipomoides zonatus,* and *Variola louti*. These species are targeted by a small yet valuable boat-based fishery in depths ranging around 100 m to 400 m. The previous 2019 assessment concluded this complex was both undergoing overfishing and was overfished. The current benchmark assessment for the American Samoa BMUS differs significantly from all previous efforts in terms of data inputs and model structure. A major improvement for this new benchmark was the move to single-species, age-structured models in the Stock Synthesis modeling framework for all BMUS except *E. carbunculus* and *P. filamentosus* (Methot and Wetzel 2013). Stock Synthesis 3.30 is an integrated statistical catch-at-age model that fits a population model to relative abundance and size composition data in a likelihood-based statistical framework to generate maximum likelihood estimates of population parameters, derived outputs, and their associated variability. These outputs are then used to determine stock status and to develop stock projections under different management scenarios.

The current assessments integrate catch, an abundance index, and length composition from four data sources: historical catches (pre-1986) from older reports; recent catches (post-1985) from boat- and shore-based creel surveys; length compositions from boat-based creel surveys and the biosampling program; and an abundance index from boat-based creel survey interviews. Historical catches were reconstructed for each species based on either direct reporting or total annual bottomfish catches broken down into respective species proportions using historical reports and early creel surveys from 1986 to 1995. Total annual catches for all species post-1985 in Tutuila and Manu'a Islands were obtained from the local government agency's boat- and shore-based creed surveys and was combined into one annual estimate. CPUE data were obtained from the boat-based creel survey to generate species-specific fishery-dependent indices from 2016 to 2021 for Tutuila and the Banks areas. Size frequency data from the biosampling program and the boat-based creel survey were combined for each species for the years 2010 to 2015.

A second major improvement to this benchmark was correcting several data issues that were present in previous assessments. These corrections include misidentification of species, catch records of species in areas outside of their known habitat, discrepancy in catch rate and effort units, and missing data for certain species or areas. Additionally, to account for uncertainty in catch estimates, thirty sets of bootstrapped catch data were generated. The thirty catch trajectories were iteratively put into the model to replace the original catch estimates and the model was re-fitted. Results from all thirty runs were integrated using the delta-multivariate lognormal estimator.

The general timeline of population abundance for BMUS in American Samoa has been of near pristine conditions in the late 1960s, followed by declining biomass in the 1970s during the "dory" program for nearshore species (*L. kasmira, L. rubrioperculatus,* and *C. lugubris* to a lesser extent) and in the 1980s during the "'alia" program, where deeper species started being targeted (i.e., the Etelinae snappers). The increased fishing effort associated with these programs led to several species being either overfished (*C. lugubris, L. rubrioperculatus,* and *P. zonatus*) or nearly so (*A. virescens, E. coruscans*, *P. flavipinnis*, and *V. louti*). Following these programs, the decreased fishing effort allowed the BMUS populations to bounce back to sustainable levels, between ~1.7 and 7 times their overfished reference point. In the terminal year of the model, 2021, all nine BMUS stock statuses were not overfished and overfishing was not occurring (see Figure S1 below). Overfishing is defined by fishing mortality (*F*) in 2021 being higher than F_{MSY} and overfished status is defined by spawning stock biomass (*SSB*) in 2021 being lower than *SSB* at the Minimum Stock Size Threshold (MSST; see Methods section).

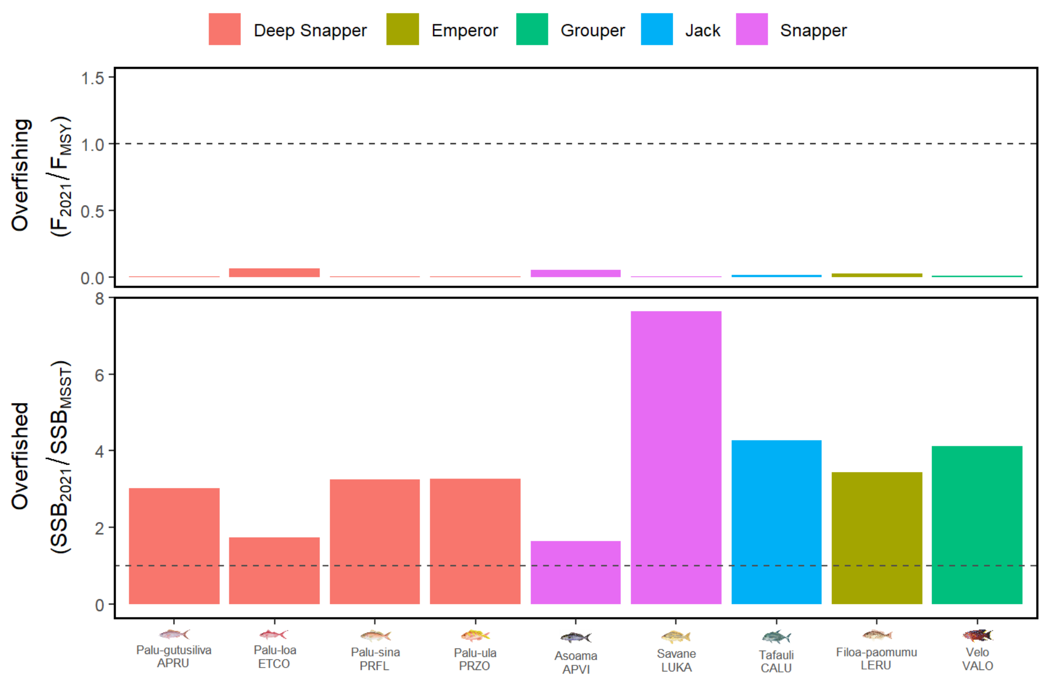

Figure S1 - Stock status in 2021 of the nine BMUS species with single-species assessment models in the terminal year of the model.

Catch projections for all nine BMUS were conducted for seven years from 2022 to 2028 using Stock Synthesis by extending the base case model with life-history and fishery dynamics assumed to remain constant through the projection period. A range of fixed catch quotas were run for all models (thirty bootstrapped models per species) to calculate the probability of overfishing or being overfished in each year. Distributions of the stock status quantities (SSB/SSB_{MSST} and F/F_{MSY}) at the fixed catch levels were generated using the delta-multivariate lognormal estimator. This approach was used for all species except *L. kasmira*, for which the median MSY estimate was determined to be the overfishing limit (OFL), due to only larger individuals being selected by the fishery and the stock remaining sustainable even at elevated *F* values.

1 Introduction

1.1 Background

In American Samoa, the bottomfishes occurring in federal waters (3 to 200 miles from shore) are currently managed by the Western Pacific Regional Fishery Management Council (WPRFMC) under the “Fishery Ecosystem Plan for the American Samoa Archipelago” (FEP; WPRFMC 2009). This FEP originally included 205 species or families of fish and invertebrates (17 bottomfish species) to be managed with catch limits or other regulations. However, most species within the FEP were reclassified as “ecosystem component species” in 2019, leaving only 11 “Bottomfish Management Unit Species” (BMUS) that required management by the WPRFMC in American Samoa (84 FR 2767). These 11 species were retained as they were considered by local fishermen and fisheries scientists to be the most important for management.

This report presents the benchmark stock assessment of BMUS deep-slope finfish species currently managed under the BMUS complex (Table 7-1). The BMUS are composed of six deep snappers (*Aphareus rutilans, Etelis carbunculus*, *E. coruscans*, *Pristipomoides filamentosus*, *P. flavipinnis*, and *P. zonatus*), two shallower snappers (*Aprion virescens* and *Lutjanus kasmira*), one emperor (*Lethrinus rubrioperculatus*), one jack (*Caranx lugubris*), and one grouper (*Variola louti*). All 11 species are wide-ranging Indo-Pacific tropical coastal species found generally between East Africa and Tahiti, including Hawaii (except for *L. rubrioperculatus*, *P. flavipinnis*, and *V. louti*). The black jack *C. lugubris* is the only circumtropical species. These species typically inhabit deep-slope areas from 100 m to 400 m, with *A. virescens*, *C. lugubris*, *L. kasmira*, *L. rubrioperculatus*, and *V. louti* habitat extending to shallow areas (< 10 m depth).

The American Samoa BMUS were initially combined and assessed as a complex using an informal index-based assessment method where annual nominal catch rates were compared to an indicator level representing 50% of average nominal catch rates between 1982 and 1984. Following this method, the American Samoa BMUS catch rates were deemed “not a cause for concern” from 2000 to 2005 (WPRFMC 2006). The first formal stock assessment of American Samoa bottomfishes was completed in 2007 (Moffitt et al. 2007). This assessment improved upon the index-based method by implementing a Bayesian surplus-production model which accounted for both process and observation errors and, among various improvements, captured uncertainty around stock status. The base case model for the 2007 stock assessment concluded that the BMUS complex was not overfished and not experiencing overfishing (Moffitt et al. 2007). The 2012 and 2016 assessment updates used a similar approach as the 2007 assessment, with additional data. These assessments reached similar conclusions regarding the stock status of the BMUS in American Samoa (Brodziak et al. 2012; Yau et al. 2016). The most recent assessment was completed in 2019 and used a similar Bayesian surplus-production model as the previous assessments. However, it incorporated improvements in data and modeling methodology as recommended by the Western Pacific Stock Assessment and Review process (WPSAR; Langseth et al. 2019). The 2019 assessment concluded the BMUS complex was both undergoing overfishing and in an overfished state.

1.2 Distribution

The American Samoa archipelago consists of the volcanic islands of Tutuila (and nearby Aunu'u), the Manu'a island group (Ta'u and Ofu-Olosega), and two coral atolls (Rose Atoll and Swains Island) more than 150 miles from Tutuila (Figure 8-1). The level of connectivity of the BMUS sub-populations around the archipelago and the significance of larval exchanges or adult movements between the different islands are still not entirely clear. In this report, the BMUS stocks were analyzed at the scale of the main island group and its associated banks (Figure 8-1) due to data limitations and current management stock definitions. Further population connectivity studies may suggest that future stock assessments be conducted at different spatial scales for this species.

1.3 Fisheries

The deep-slope fishes of American Samoa include snappers (Lutjanidae), emperors (Lethrinidae), jacks (Carangidae), and groupers (Serranidae). They support a valuable boat-based hook-and-line fishery in waters ranging primarily from 100 m to 400 m depths. Collectively referred to as "bottomfishing," this fishery is currently made up primarily of double-hulled aluminum "'alia" catamarans less than 30 feet in length that generally fish within 20 nautical miles around Tutuila (Levine and Allen 2009). There are also ʻalia boats in the Manuʻa Islands and several large vessels that fish the offshore banks east and south of Tutuila. Bottomfishing is a culturally significant activity in American Samoa and carries a high non-monetary value (Severance et al. 2013; Kleiber and Leong 2018). The American Samoa bottomfish fishery has undergone several cycles of development and attrition over the past several decades, mainly owing to government-sponsored boat-building programs, marketing initiatives, and natural disasters.

Prior to the 1970s, fishing for bottomfishes in American Samoa was non-commercial and performed close to shore using traditional techniques (Marr 1961; Itano 1996a, 1996b; Levine and Allen 2009). Historical accounts and archaeological evidence suggest harvests of bottomfishes were likely limited to the shallower species of Carangidae, Lethrinidae, and Lutjanidae (Nagaoka 1993; Herdrich and Armstrong 2008). From 1967 to 1970, the Government of American Samoa Office of Marine Resources, funded by the U.S. Bureau of Commercial Fisheries Federal Aid Program, conducted an exploratory fishing survey of the ledges around Tutuila aboard the 33-foot fiberglass vessel *Tautai A'e*. Species composition and catch rates of bottomfishes suggested a small-scale local commercial bottomfish fishery would be viable (Ralston 1979).

Following this survey, a succession of government-sponsored programs were conducted in American Samoa to develop the local bottomfish fishery by providing boats, training fishermen, improving technology, providing hydrographic charts, and supporting the marketing and transport of bottomfishes to commercial buyers (Itano 1996b, 1996a). In the early 1970s, the Dory Project provided boats to fishermen at low cost and led to a spike in bottomfishing, primarily in the relatively shallow waters around Tutuila. The fishery targeted mainly nearshore species such as *L. kasmira* and *Lethrinus* spp., with only a limited catch of deep snappers (<10%; Itano 1996b, 1996a). This initial spike in catch was followed by a drop as the fleet became dilapidated by the late 1970s (Itano 1996a, 1996b). The fishery grew again following the widespread adoption of aluminum ‘alia boats, the arrival of several larger diesel-powered vessels entering the fishery, government-sponsored training, and efforts to develop the export market for bottomfishes.

The American Samoa bottomfish fishery peaked during the early to mid-1980s with 45–50 vessels and more than 120,000 lb of reported bottomfish landings annually (Hamm and Quach 1988; Itano 1996a, 1996b). However, it is important to note this estimate likely includes landings of many non-BMUS. Several factors may have contributed to the reduction of bottomfish landings over the past several decades, including fleet damage due to hurricanes, market influences such as increased importing of bottomfish, higher operating costs for American Samoa fishermen, fishermen moving to the pelagic fisheries, and declining catch rates (Levine and Allen 2009; Langseth et al. 2019). The average annual estimated landings of BMUS in recent years was approximately 20,000 lb per year, but these numbers have declined to 8,000 lb in 2020 and less than 2,000 lb in 2021 due the COVID-19 pandemic (Langseth et al. 2019; Liddel and Yencho 2019).

1.4 Current 2023 benchmark assessment

The current benchmark assessment for the American Samoa BMUS differs significantly from all previous efforts. A major improvement for this new benchmark is to move to single-species age-structured models following the WPSAR panel recommendations associated with the 2016 assessment (Chaloupka et al. 2015). Specifically, the WPSAR panel recommended the exploration of models that can include length and life history data under a single-species modeling approach, given that complex-level assessments are limited to surplus-production models. An added benefit would be to reduce the weight of catch and catch-per-unit-effort data, which these models entirely rely on and which are hard to collect consistently in small, spatially diffused island fisheries. In contrast, the single-species assessments presented here are flexible and all appropriate data (catch, CPUE, life history, and sizes) were integrated into a single framework, namely the Stock Synthesis modeling framework (Methot and Wetzel 2013). Another major improvement was to incorporate historical catch from 1967 to 1985 using older government reports. This extended our models almost 20 years earlier than the 2019 report, to the start of the commercial bottomfish fishery. This report presents the first integrated stock assessment of domestic stocks in American Samoa and other U.S. territories.

In addition to significant changes in the modeling approach, the 2023 benchmark differs from the previous assessments on how it was developed. The present stock assessment is the culmination of a three-year effort that started in March 2020 with the release of the American Samoa Bottomfish Stock Assessment improvement plan (Figure 8-2). The improvement plan is a collaborative effort that involves Pacific Islands Fisheries Science Center (PIFSC) scientists, Department of Marine and Wildlife Resources (DMWR) staff, the Western Pacific Regional Fisheries Management Council (WPRFMC), and local fishermen to improve the quality and reliability of fishery stock assessments for American Samoa bottomfish. The improvement plan emphasizes constituent and stakeholder participation in the assessment development, transparency in the assessment process, and a rigorous review of the data available to develop the stock assessments.

A crucial part of the improvement plan, and its first component, was an in-depth exploration of all data available for the American Samoa bottomfish. The results of this exploration were published in a technical memorandum (see Nadon and Bohaboy 2022). This tech memo laid the foundation for a series of data workshops in American Samoa. The data workshops were attended by fishermen and community leaders and served to 1) deliver presentations about stock assessment, related life history, social science, and data science endeavors, and key data streams to American Samoa stakeholders; 2) provide critical opportunities for fishermen to offer local context and fishing knowledge to stock assessment scientists' interpretations of available data; and 3) present the input data as well as the potential approach chosen to develop the stock assessments before their production. Following these workshops, further investigations were conducted on certain discrepancies between the data and what fishermen reported which led to several important data corrections, which are presented in section 2.2.3 of this report.

2 Methods

2.1 Stock assessment model

Stock Synthesis (SS) is an integrated statistical catch-at-age model that is widely used for stock assessments in the United States and throughout the world (Methot and Wetzel 2013). SS takes relatively unprocessed input data in the form of observed catch, size/age composition, and relative abundance indices such as catch-per-unit-effort (CPUE), and incorporates the main population processes (e.g., mortality, selectivity, growth) to recreate population biomass trajectory and derived indicators of stock status. Because many of these inputs are correlated, the theory behind SS is that these should be modeled together, which helps to ensure that uncertainty in the input data is propagated through the assessment. SS comprises three subcomponents: (1) a population subcomponent that recreates the numbers- and biomass-at-age using estimates of natural mortality, growth, fecundity, etc.; (2) an observational sub-component that consists of observed (measured) quantities such as CPUE or proportion at length, weight, and/or age; and (3) a statistical subcomponent that uses likelihoods to quantify the fit of the observations to the re-created population. Basic equations and technical specifications underlying SS can be found in Methot (2000). We used SS version 3.30.19 with AD Model Builder (ADMB version 12.3, released 04/15/2022).

The current assessments integrate catch, an abundance index, and lengths from four data sources: historical (pre-1986) catches from older reports, catches from boat- and shore-based creel surveys (post-1985), length compositions from boat-based creel surveys and the biosampling program, and an abundance index from boat-based creel surveys. The sections below describe how each data source was processed to generate the inputs necessary for the SS model while also going into greater detail on the functioning of SS itself. Table 7-2 presents the main assumptions built into our SS model and includes links to the relevant sections in this report.

Following our in-depth analysis of the data available for bottomfish assessment in American Samoa (Nadon and Bohaboy 2022) and its associated stakeholder workshops, it was determined that there were insufficient data to generate a proper abundance index or size structures for *Pristipomoides filamentosus*. We did not attempt to run an assessment model for this species. Further, a new species of *Etelis* was recently described for the South Pacific (*Etelis boweni*; Andrews et al. 2021b) and this species is visually similar to *E. carbunculus* (a BMUS). This species reaches significantly larger sizes than *E. carbunculus* and its presence in the *E. carbunculus* length frequencies is clear (Nadon and Bohaboy 2022). Fishermen confirmed the presence of this larger “palu-malau” in American Samoa during data workshops. Since we cannot currently separate the two species, it is not possible to conduct an assessment on *E. carbunculus*.

2.2 Model inputs

This section describes the data processing steps used to generate catch, size, and CPUE model inputs. The full data and scripts workflows are presented in Figure 8-3 (catch), Figure 8-4 (length), and Figure 8-5 (CPUE). The final steps incorporating these processed data files into SS models and processing the model outputs are presented in Figure 8-6.

2.2.1 Data correction process

The current assessment work was preceded by an extensive exploration of the data available for bottomfish assessments in American Samoa (Nadon and Bohaboy 2022). This effort was followed by a series of workshops conducted with PIFSC scientists, DMWR staff, and local fishermen during which data patterns were discussed in the context of local fishing experience and knowledge. Following these workshops, further investigations were conducted on certain discrepancies between the data and what fishermen reported. We identified a series of issues that we corrected *a priori* to our assessment work. These issues were often linked to species misidentification, but other types of issues were also identified. Our general procedure was to be as parsimonious as possible with data corrections and filters and only apply these when species-specific data patterns were biologically improbable and after investigating the causes in coordination with the local science agency. We believe this approach strikes a good balance between removing clearly erroneous data while being careful to not introduce subjective data filters into our assessments. The following sections on catch, CPUE, and length data each have “data corrections” paragraphs which describe in details the specific data corrections that were implemented.

2.2.2 Historical catch reconstruction (1967–1985)

Prior to 1967, fishing for bottomfishes in American Samoa was non-commercial and performed close to shore using traditional techniques. As previously mentioned, there are no quantitative estimates of these early landings, but archaeological evidence suggest harvests of bottomfishes were limited to the shallower species of Carangidae, Lethrinidae, and Lutjanidae. From 1967 to 1985, a series of government projects took place to either explore or subsidize a bottomfish fishery: the *Tautai Aʻe* exploration project from 1967 to 1970, the Dory program from 1972 to 1980, and the ʻAlia program from 1980 to 1985. Those 3 efforts had associated catch reports that provided early estimates of bottomfish landings, sometimes at broad taxonomic scale (e.g., “bottomfish”, “Lethrinidae”, or “Pristipomoides”). Our 1967–1985 historical catch reconstruction consisted of 1) obtaining estimates of total bottomfish catch by year, 2) estimating the species proportions of this catch by year, and 3) applying the species proportion of each BMUS to the total bottomfish catch estimates, in order to obtain BMUS-specific catches.

Historical total bottomfish catch: Swerdloff (1972) reports the total bottomfish catch per month as well as some species composition for the *Tautai Aʻe* project. This project mainly fished on the broad Tutuila shallow shelf and caught mainly shallow and non-BMUS species such as *Lethrinus miniatus*, *Lutjanus gibbus*, Caranx sp., and “groupers”. The only BMUS specifically mentioned is *L. kasmira*, but the percentage of the catch is not reported. We therefore only used Swerdloff (1972) for the total bottomfish catch and not BMUS composition. The 1967–1970 annual values are reported in Table 7-3. We assumed no significant fishing took place in 1971, following the end of the *Tautai Aʻe* project.

Following this exploratory survey, the Dory program was implemented in 1972 and monthly or annual catches are reported in Ralston (1979) and a report by the American Samoa Office of Marine Resources (OMR 1976). Note those reports use fiscal years so we had to re-assign these annual catches into calendar years. The 1972–1974 total catches are used as is (Table 7-3) but we had to first calculate the ratio of reporting/active dories in 1975 and 1976 (Ralston 1979; Itano 1996a) in order to correct for unreported dory catches. For 1977 and 1978, we had to use the previous year CPUE (lb/dory/year; OMR 1976) multiplied by the number of active dories (Itano 1996a). For 1979 to 1981, we used the number of active boats (dories, alias, large diesel, etc.) reported in Itano (1996b) multiplied by the average CPUE by boat reported in 1982–1983 by Hamm and Quach (1988). Finally, Hamm and Quach (1988) provided total bottomfish catch between 1982 and 1985 (Table 7-3).

Historical species composition of the catch: We split the historical catch species composition into two distinct phases: the 1967-1979 *Tautai A'e* and Dory program phase which focused on the shallow shelves around Tutuila (Itano 1996a) and the 1980–1985 Alia program phase which started targeting the deep snappers further offshore (Hamm and Quach 1988). The species compositions for the first phase were obtained from Ralston (1979) which reported a rough species breakdown of the Dory catch in FY75 and FY76. In these tables, *L. kasmira* and *A. virescens* are the only BMUS specifically mentioned (Table 7-4). Other caught BMUS would have been reported as "Etelis and Pristipomoides spp.", "Lethrinus sp.", "Groupers", or "Jacks". To retrieve the species-specific BMUS catch from these groups, we use the proportion of each BMUS contained in these groups in the boat-based creel surveys (starting in 1986; Table 7-4). We first calculated these species proportions by region (Manu'a and Tutuila Islands) and averaged these proportions together weighted by regional proportions of bottomfish habitat (0.13 and 0.87, respectively). For the 1980–1985 phase, we used the proportion of BMUS in the total species-level identified catch as reported in Hamm and Quach (1988) between 1983 and 1985 (Table 7-5). We also used the 1986–1995 boat-based creel survey by region to obtain another estimate of species composition. The final BMUS proportion for this phase was the average of both estimates (Table 7-5).

The annual historical catch from 1967 to 1985 was calculated by multiplying the total annual bottomfish catch with the BMUS species proportions (Figure 8-7).

By 1986, the American Samoa Department of Marine and Wildlife Resources (DMWR) Boat-based Creel Survey Program (BBS) became fully operational and served as the primary source for fisheries data from 1986 to 2021 (see next section).

2.2.3 Boat-based and shore-based creel survey catch (1986–2021)

The DMWR boat- and shore-based creel surveys (BBS and SBS) are designed to monitor fisheries catch and participation. The BBS targets fishing vessels that are berthed at marinas and smaller trailered boats launched from boat ramps. The BBS began in the early 1980s with data management and sampling methodology mostly standardized by 1986. The BBS includes two data streams: (1) interviews of fishermen returning to port with observation of their catch, and (2) estimates of the number of boats leaving port and the number of trips taken. Together, these two data streams are used by NOAA Fisheries to estimate annual landings for management purposes. BBS creel interviews also provide catch per unit effort (CPUE) time series and fish length or weight composition observations for stock assessments (see sections below).

BBS creel interviews: On Tutuila, DMWR staff visit or monitor the four main ports of Pago Pago, Fagatogo, Utulei, and Faga‘alu to conduct interviews a minimum of 12 weekdays and 2 Saturday/holiday (weekend) days per month (Ma et al. 2022). In the Manu‘a Islands, the limited number of fishing boats and fishermen enabled a census of fishing trips until 2009, when staff on Ofu-Olosega and Ta‘u were no longer available. Since 2009, DMWR has not conducted regular BBS interviews in the Manu‘a Islands. In both areas, interviewers collected information on trip effort (hours fished, number and types of fishing gear, and number of fishermen), areas fished, economic information (trip cost, fish price per pound), and catch. Catch information included total catch per species in numbers and weight, sometimes including individual fish size observations in length or weight. Over the course of the survey, there have been some inconsistencies in species identification, selection of fish for size observations, and whether the number and weight of fish caught was directly measured or estimated based on a subset of the catch (see “Data correction” section below). Standardized staff training in fish species identification was implemented in 2016. Following this change, the surveyed catches have been identified to the species level almost entirely. However, in many years prior to 2016, only a subset of fish were identified to the species-level or measured, and there was no standard protocol for unbiased selection of individuals for size measurement subsampling.

BBS effort surveys: On Tutuila, DMWR staff visit or monitor the 4 main ports of Pago Pago, Fagatogo, Utulei, and Faga‘alu to estimate the number of fishing boats going out to sea a minimum of 12 weekdays and 2 Saturday/holiday (weekend) days per month, as staff and resources allow. In addition to conducting BBS interviews, staff perform participation counts by identifying boats that are away on fishing trips, either by noting empty berths at marinas or by observing boats departing or returning to port. Total fishing effort each year, in number of trips, is estimated by multiplying the average trips per day from the participation counts by the number of days per year within each expansion domain (gear, day type, and charter status). Additional adjustment factors are used to correct for trips where fishing gear was unknown, as well as to account for temporal under-coverage and un-sampled ports (Ma et al. 2022). DMWR does not conduct participation counts in the Manu‘a Islands.

Shore-based creel surveys: A small amount of BMUS catches are reported for a few shallower species by the shore-based creel survey (SBS). Similarly to the BBS, the SBS includes two data streams: 1) interviews of fishermen intercepted by survey technicians on the shore together with the observation of their catch, and 2) participation estimates (number of fishermen and types of fishing) made by observers from the shore. The SBS is conducted by technicians traveling along survey routes several times per month, stratified by time and type of day (weekend/holiday vs. weekday). Further details on the history and methodology of both the SBS and BBS are documented in Oram et al. (2011), Ma et al. (2022), and Nadon and Bohaboy (2022).

Annual catch estimation: Annual catch from Tutuila for each BMUS was estimated together with a measure of relative error following the expansion methodology described in Ma et al. (2022). Briefly, catch rates (catch per unit effort as lb landed per trip) are estimated for each of the expansion domains (gear type, day type, and charter status). The total number of fishing trips for each expansion domain is estimated from participation counts, then multiplied by catch rates within each expansion domain and summed across domains to give the annual estimate of total catch from Tutuila. All catches observed in SBS and BBS interviews from the Manuʻa Islands are included in the annual total catch estimates.

Data corrections: This section covers catch data issues that were found during data exploration and associated workshops. Many of these issues and associated fixes also applied to the CPUE abundance indices described in the next section.

First, the commonly caught grouper *Variola louti* almost disappeared from the boat-based creel survey after 2010, before reappearing in 2015 at a lower frequency. Fishermen disagreed with this pattern, stating that they did not notice a change in catch rates for this species throughout the years. It was also pointed out that a similarly looking species shared the same Samoan name (“velo”) and that these could be confounded in the data. After investigation, we concluded that these two *Variola* species were entered as *V. louti* from 1986–2009 and *V. albimarginata* from 2010–2014, before being separately identified after 2015, following the introduction of a standardized training protocol for creel interviews. To correct the pre-2015 data, we summed the catch for both species between 1986 and 2014 and allocated a portion of this catch to *V. louti*, based on the proportion of *V. louti* in the total *Variola* catch between 2016 and 2021 (0.236).

Another discrepancy between the observed catch time series and fisher experience was found for *Pristipomoides flavipinnis*. The original catch data showed little catch prior to 1997 and from 2005 to 2015. After some investigation, we found that an unofficial species named “*Pristipomoides rutilans*” was associated with the Samoan name “Palu-sina”, which is a name fishermen strongly associate with *P. flavipinnis*. Previous assessments had re-assigned the *P. rutilans* catch to *Aphareus rutilans* given the similar scientific name. However, assigning this catch to *P. flavipinnis* filled the missing data for this species from 1986–1996 and it appears likely that this is the correct re-assignment for the *P. rutilans* catch. Further, we noticed a strong peak in the *P. filamentosus* catch between 2010 and 2015 which corresponded neatly to an absence of *P. flavipinnis* catch in those years. It appears likely that an identification error occurred for *P. flavipinnis* in those years and that a portion of the *P. filamentosus* catch should be re-assigned to this species. To do so, we calculated the ratio of *P. flavipinnis* to *P. filamentosus* in the 2016–2021 period (0.934) and applied this ratio to the summed 2010–2015 catch of both species.

There was a marked absence of *Lethrinus rubrioperculatus* catch in the Manuʻa Islands throughout the catch time series. During our data workshop with Manuʻa fishermen, they stated that they catch this species on almost every trip. Much of the emperor family (Lethrinidae) catch around the Manuʻa Islands was identified simply as “Emperor”. We therefore used the proportion of the emperor catch around Tutuila identified as *L. rubrioperculatus* (0.32) to assign a portion of the emperor catch around the Manu’a Islands to this species.

Another correction applied following the data workshops was to remove *Pristipomoides zonatus* catches from the shore-based catch estimates (especially noticeable in the early years of this data set). This species is a well-known deep snapper that is never caught in shallow waters (this was confirmed by local fishermen during data workshops).

Prior to 2016, BBS and SBS interviews commonly recorded catch in taxonomic groups only. Overall, there were 9 groups potentially containing BMUS: *trevallies*, *jacks*, *bottomfish*, *groupers*, *deepwater snappers*, *pristipomoides/etelis*, *emperors*, *inshore groupers*, and *inshore snappers*. To re-assign this grouped catch to individual BMUS, we first calculated the species-level catch proportions within each of those groups before using these proportions to break-down annual catch estimates from these groups into their species components. These species proportions were calculated and applied in 10-year periods from 1986 to 2021 to control for potential temporal changes in the species composition of these groups. This approach was first introduced by Langseth et al. (2019) and they showed that the vast majority of BMUS catch in American Samoa was identified at the species level.

A discrepancy was found in the catch expansion script where catch rate was calculated in “kg/day” unit while the total annual effort used “number of trips” unit. The effort metric “number of days fished” was only recorded starting in 2000 and pre-2000 values were entered as “1” (effectively making the pre-2000 catch rate “kg/trip”). This discrepancy was fixed by calculating catch rate as “kg/trip” instead of “kg/day” to match the available total effort unit (“number of trips”). However, this change revealed another issue with the catch data. We found that some multiday bottomfish trips recorded by interviewers (at the end of their trip) were entered as multiple individual daily trips in the boat log (which is used to calculate total effort). This inflated the expanded catch as the mean “catch/trip” was elevated (given multiple days of fishing) and multiplied by an erroneously high number of trips.

For example, a three-day trip could be entered three times in the boat log, thus inflating the total number of trips in the year, and this inflated value would then be multiplied by an elevated “kg/trip” catch rate average given the multiday nature of this trip and other ones. This discrepancy was previously masked by the use of “kg/day” as the catch rate unit. This was especially true during the 2007–2009 period where many multiday trips occurred and caused a noticeable spike in the catch. To fix this issue, these duplicated trips were flagged and removed from the annual total number of trips estimates by matching interviews to specific trips in the boat log. For the non-interviewed trips, a correction factor was obtained from the interviewed portion of the boat log and applied to those trips. This reduced the noticeable (and erroneous) spike in catch between 2007 and 2009.

A small number of bottomfishing trips occurred in 2021 (the last year included in our models) which resulted in a small number of creel interviews and some BMUS not being recorded for that year. This resulted in a zero-catch estimate for *Pristipomoides flavipinnis* and *P. zonatus*, which is unlikely. To correct this, we updated the catch expansion script to select the previous year's domain-specific catch rate and combine it with the current year's expanded fishing effort per domain to generate a more accurate catch estimate for years with no creel interview observation for a given species. This generated a small, non-zero catch for *P. flavipinnis* (25 lb) and *P. zonatus* (109 lb).

Finally, as mentioned earlier, the Manu'a Islands had almost no BBS creel surveys after 2009, due to staffing issues (SBS interviews continued during this period). The few interviews reported after 2009 were insufficient to generate catch estimates between 2009 and 2021. To input this missing catch, we ran a simple linear model between the Tutuila and Manu'a Islands catch between 1986 and 2009 and used the 2010–2021 Tutuila catch to re-create the 2010–2021 Manu'a catch. We plotted and checked the full re-created Manu'a time series to ensure no spurious catch values were generated this way (note that the mean Manu'a catch from 1986 to 2009 represented only 14% of the total mean catch).

2.2.4 CPUE abundance indices

We used the boat-based creel survey dataset to produce a single standardized fishery-dependent index for each BMUS based on the "bottomfishing" fishing gear, as reported in that dataset. We first corrected some of the same data issues found with the creel survey catch data, as previously explained in section 2.2.3 and briefly listed below. We also applied filters related to fishing gear and availability of covariates (see *Data filter* section below). Importantly, we decided to limit the CPUE time series to the 2016-2021 period, after a more formal training protocol was implemented for creel interviewers (see details in section below).

Data corrections: As previously explained, several species identification issues were found while exploring the catch data and corrected (see section 2.2.3). Briefly, these are 1) *Variola louti* and *V. albimarginata* were confounded between 1986 and 2015; 2) some *Pristipomoides flavipinnis* were identified as *Pristipomoides rutilans* (a non-existent species); 3) *P. flavipinnis* appears to have been identified as *P. filamentosus* between 2010 and 2015; and 4) *Lethrinus rubrioperculatus* was not commonly identified in the Manu'a Islands, despite being commonly caught there (as explained by fishermen). Other odd patterns in the CPUE time series for various species had no clear explanation but were likely related to data collection issues. For example, the nominal and standardized CPUE for *Lutjanus kasmira* were constant between 1991 and 2015, dropped significantly in 2016, and stayed constant at this new level from 2016 to 2021.

Of note, 2016 is the year when a new species identification training protocol was implemented by DMWR and when species-level identification became consistent for all recorded catches. The fishing community also highlighted discrepancies between their observations of species abundance trends and some of the CPUE data trends. For these reasons—and given the potential impact inaccurate CPUE trends could have on our models—we decided to only use the CPUE data starting in 2016 for all species. There is very little CPUE data after 2009 from the Manu'a Islands due to the loss of creel surveyors (Nadon and Bohaboy, 2022). This means that the 2016–2021 CPUE indices only cover Tutuila and the Banks (roughly 87% of the total bottomfish habitat).

It is important to note that total annual catches from creel surveys are estimated as the product of catch rate and total fishing effort (Ma et al. 2022). Thus, the issues with the 1986–2015 CPUE, highlighted above, can also impact catch estimates. However, we did not want to simply remove the 1986-2015 catch from our models, given that a complete catch time series is the backbone of integrated models (and the reason why much effort was placed on re-creating the historical catch, for example). An investigation of the relationship between standardized CPUE and annual catch through a regression analysis showed that catch rates only explains 28% of the variability in catch, on average. This suggests that fishing effort had a much larger impact on our catch estimates than CPUE. Given this and the importance of keeping complete catch records, we decided to keep the 1986–2015 catch in our models (see Discussion section for further discussion on this matter).

Data filters: The data processing and filtering steps used to clean the data for CPUE standardization were built on the many improvements brought forward from Langseth et al. (2019). We first selected the principal fishing gear used to catch BMUS in American Samoa to generate CPUE indices (“bottomfishing”, DMWR gear code “4”). We did not include the “BTM/TRL mix” gear, as the fishing effort (i.e. hours fished) is confounded between trolling and bottomfishing. This removed 108 out of 411 available interviews. Another 8 interviews were removed as they were flagged as “incomplete” by creel surveyors or were missing the interview unique identifier (*catch_pk*). Another 26 interviews with either missing “number of gears” or outlier values (Num. of gear > 6) were removed. No interviews were removed due to missing covariates (see below), giving us a total of 269 interviews between 2016 and 2021.

Explanatory variables for CPUE standardization: We included the following variables, in addition to the *Year* variable which tracked annual changes in abundance and was automatically kept in all models: *Area*, *Year:Area* interaction, *Hours fished*, *Number of gears*, *Season*, *Wind speed*, *Type of day*, and two principal component variables related to catch composition (*PC1* and *PC2*; see further explanation below). Given the smaller number of CPUE data points, we simplified two explanatory variables compared to the 2019 assessment: we used *Seasons* instead of *Months,* and we reclassified the fishing grids into three broad *Areas* (Tutuila and Banks). This also allowed us to recuperate 32 interviews that did not have assigned fishing grids but had island-level information.

Of note, the absence of creel interviews in the Manu’a Islands after 2009 meant that this level was not present in our models. In another noteworthy change from the 2019 assessment, we decided to keep the CPUE unit in kg/trip and include the *Hours fished* and *Number of gears* variables in our models instead of dividing CPUE by these units and incorporating them in the response variable (i.e., kg/gear/hour). A preliminary data exploration showed that the relationship between *kg/trip* and the *number of gear* or *hours fished* was curvilinear and not directly proportional (1:1), which precluded us from including them directly in the CPUE units.

Type of day was reported as either weekend or weekday interviews and was explored in the standardization to capture potential differences between full-time fishermen, which we assumed would fish on the weekday, and part-time fishermen, which we assumed would fish on the weekends.

Wind speed data starting in July 1987 were available at a spatial scale similar to the reported DMWR fishing areas, with some gap in coverage. Average wind speed and direction values at a scale of 0.25 degree latitude x longitude were downloaded from https://oceanwatch.pifsc.noaa.gov/erddap/griddap/ccmp-daily-v2-1-NRT.html (accessed 06/05/2022). These data were spatially merged with the CPUE dataset based on fishing date and the GPS coordinates of the center points of each DMWR fishing area.

Depending on the species targeted, the "bottomfishing" gears selected for CPUE indices can be deployed in different configurations and different habitats. Therefore, targeting may have a non-negligible impact on CPUE. Unfortunately, the creel dataset does not include species targeting information. We controlled for species targeting by using a principal component analysis (PCA) on species composition in the catch to generate principal components that were then used in the CPUE standardization model (Winker et al. 2014). The Direct Principal Component approach consists of including principal components scores (PCs) derived from the species composition in the catch as predictors in the CPUE model (Winker et al. 2014). This procedure builds on the common assumption that the species composition of the catch is directly related to the extent of targeted effort (Pelletier and Ferraris 2000).

The first step in this procedure is to select the top species caught by the "bottomfishing" gear. Following Winker et al. (2014), we kept species representing a minimum of 1% of the total catch for this gear. The second step is to calculate the proportion of each of the species for each fishing record and doing a fourth-root transformation on these values to reduce the influence of the more abundant species on the PCA (Winker et al. 2014). The third step is to run the PCA analyses using the "prcomp" base R function and extracting the PC scores for each fishing record (labeled as "PC1", "PC2", etc.). A final step is to select the principal components to keep for the CPUE standardization model. Following Winker et al. (2014), we used the "nFactors" R package to obtain the Optimal Coordinate solution for Cattel's scree test (Raîche et al. 2013) while also selecting PCs which had eigenvalues higher than 1 (Kaiser-Guttman rule). Using the AIC and BIC values from the CPUE standardization model to select PCs was not recommended by Winker et al. (2014) as it tends to select for unnecessarily complex models with a high number of PCs. Following these rules, we selected PC1 and PC2 for our CPUE standardization analysis.

CPUE standardization models: Our CPUE indices were standardized using generalized additive models (GAM). A considerable proportion of trips in each CPUE dataset was represented by zero catches and we therefore used a delta-lognormal approach to standardize the CPUE indices. In this type of approach, the probability of catching a BMUS in a unit of fishing effort and the weight of the catch in a unit of effort (when a BMUS is caught) are modeled separately. A binomial distribution was used to model the probability of catching a BMUS in a given trip (1 = caught, 0 = not caught) with the explanatory variables described previously using a logit link function. Positive-only CPUE data were modeled using a lognormal response variable implemented by taking the natural logarithm of positive CPUE observations.

The *Year* categorical variable was included in all models, given that our goal is to produce annual estimates of a species' relative abundance. The following variables were also tested for inclusion in all models:

- Abundance variables: *Season* (categorical – 4 levels), *Area* (categorical – 2 levels), *Year:Area* interaction.
- Catchability or availability variables: *Type of day* (categorical – 2 levels), *Wind speed* (continuous), *Number of gears* (continuous), *Number of hours fished* (continuous), and catch-composition *PC1* and *PC2* (continuous).

The categorical variables were all fixed-effect and the continuous variables were fitted with smoother functions. These variables were selected using Akaike's Information Criterion: AIC = 2 × number of parameters − 2 × log(likelihood) (Burnham 2004). We used a backward-selection process using a 2 AIC improvement threshold for variable inclusion (i.e., the model with the extra variable needed to have an AIC value at least 2 units lower than the next, simpler model, to stop the backward selection process). Maximum likelihood parameter estimation was conducted using the "gam" function in R version 4.0, using the "mgcv" package.

Overall, only the *Year:Area* interaction was not selected in any model (Table 7-7), while *Number of gear* and *Number of hours fished* and the principal component variables were the most commonly selected variables (Table 7-7).

Model diagnostics and index calculation: All models were checked with the "gam.check" function of the "mgcv" package. We first verified that the models converged and that their Hessian matrix was positive definite. For the non-zero catch models, we checked the residuals and quantile-quantile plots to ensure they were normally distributed. We used the "DHARMa" R package to generate Q-Q plots for the binomial models. For all models, we generated partial effect plots on the continuous, smooth terms and visually checked their fit and shape. The diagnostic residual plots for all 18 CPUE standardization models (9 species x 2 model types) showed no major deviation from normality and heteroscedasticity assumptions (Figure 8-8 to Figure 8-16).

After selecting the best GAM models, we generated indices of relative abundance for all 9 BMUS following Campbell (2015). For each species, we first created a Walters' large table which contained all areas x time-period combinations (i.e., Areas by Years and Seasons). We then selected a standardizing level for all the other remaining variables (the ones related to catchability and availability, such as *windspeed*, *PC*s, or *type of day*). These standardizing levels were simply the most common level for categorical variables (ex. "weekday" for *Type of day*) and the median value for the continuous variables (e.g., 10 *hours fished* and 3 *number of gears*). Next, we generated expected values for both the non-zero catch and probability of catch models for the *i*-th year, *j*-th season, and *k*-th area using these standardized levels. Following this, we calculated the combined CPUE (non-zero catch x probability of catch) for each year-season-area combinations by exponentiating the expected log(non-zero catch), including bias correction, and using an inverse-logit transformation for the “probability of catch” expected values. Finally, we averaged those combined CPUE estimates across seasons and then calculated the weighted average of these annual CPUE estimates across areas using area weights of 0.89 for Tutuila and 0.11 for the banks, representing their proportion of the available bottomfish habitat (note: there was no Manu’a Islands data points, given the 2016–2021 data range). The standard deviation associated with these CPUE values were calculated using the approach described in Campbell (2015). Note that certain Year x Area combinations in our CPUE dataset had no observation for certain species, but this did not prevent us from filling all of the Walter’s large table cells given that the Year x Area interaction term was not selected in our models (i.e., there was thus no need for imputation; Campbell 2015).

The resulting CPUE indices are presented in Table 7-8. To evaluate the impact of different variables on the CPUE time series, we also calculated these indices for progressively simpler models, starting with the best model, and plotted these together along with the nominal CPUE time series (Figure 8-8 to Figure 8-16).

2.2.5 Size frequency data

Size data for BMUS in American Samoa are available, in order of abundance, from the biosampling program, the boat-based creel surveys (BBS), diver surveys, commercial receipts, and the shore-based creel survey. The size observations from the diver surveys, commercial receipts, and shore-based creel surveys were either insufficient in numbers (all three sources), limited to a small fraction of the depth habitat (diver surveys), or with limited species-level observations (commercial receipts; Nadon and Bohaboy, 2022). We therefore only included size data from the better-quality BBS and biosampling program in our assessment models. Length data from these two sources, described further below, were filtered for the “bottomfishing” gear and combined.

We used the following approach to down-weigh the input length sample size in years where length measurements came disproportionately from smaller sub-regions. The input sample size in each year was calculated by comparing the number of length measurements (N) in each of the 3 areas (Tutuila, Manu’a Islands, and the Banks) with the expected number of length measurements in each area, given the proportion of bottomfish habitat in each area and total number of measurements in a given year (Input N = area proportion x total N). If N was larger than the expected N, the Input N was set to the expected N (thus reducing their weight). If N was lower than the expected N, it was not adjusted. Regional habitat proportions were calculated as the proportion of total BMUS habitat (depth <400 m) available in each region (Tutuila: 0.79, Manu’a: 0.13, and the Banks: 0.08). As an example, if length observations in a year were distributed as 33 for Tutuila, 33 for Manu’a, and 33 for the Banks, the input sample size for Tutuila would be kept at 33, but the same value for the Manu’a Islands would be reduce to 12.9 (i.e., 0.13 x 99) and 7.9 for the Banks (i.e., 0.08 x 99). The total input sample size for that year would be 54 instead of the original 99.

Sizes from BBS surveys (2004–2021): Individual fish size data were collected in terms of weight during the early years of the BBS, then switched to predominantly length in 2006 (Nadon and Bohaboy, 2022). The number of individual size observations collected per year for each species was generally small before 2006 and highly variable for all species thereafter, with typically greater than 150 measurements per year for the most consistently encountered BMUS (*L. rubrioperculatus* and *L. kasmira*) and less than 15 measurements per year for the rarely encountered BMUS (*P. filamentosus*, *P. flavipinnis*, and *V. louti*).

Starting in 2016, BBS interviewers placed a high priority on measuring the length of every fish and subsampling was only occasionally applied in instances when interviewers had limited access to the catch, usually due to time constraints (personal communication, T. Lavata'i, DMWR). For 2016–2019: greater than 90% of interviews containing the more numerous species (*A. virescens*, *L. rubrioperculatus*, and *L. kasmira*) included measurements for every fish; greater than 98% of interviews containing *A. rutilans*, *C. lugubris*, and *E. coruscans* included measurements for every fish; and 100% of all *E. carbunculus*, *P. filamentosus*, *P. flavipinnis*, *P. zonatus*, and *V. louti* have been measured.

Sizes from the biosampling program (2010–2015): Biosampling surveyors in American Samoa began regular sampling of reef and bottomfishes in October 2010 at the Fagatogo marketplace in Pago Pago. All biosampling supplies, training, technical support, contracts for local fishermen, and external support for processing collected specimens (otoliths, gonads, and fin clips) were provided by PIFSC. All fish lengths and weights were obtained using a 75-cm fish measuring board, 1-m calipers or 150-cm tape measure (when needed for larger fish), and a digital bench scale. Most of the biosampling effort was geared towards documenting species composition and collecting length and weight measurements of the entire catch brought to market by individual fishermen (Sundberg 2015). The biosampling data for American Samoa starts in October 2010 and ends in September 2015. During that time, a large number of fish were recorded in the data set, almost entirely from Tutuila and mainly for nearshore reef fishes. However, a fair number of size measurements (13,255) were made on BMUS species as well.

Data corrections: For both data sets, we filtered length observations below 15 cm since the few individuals in this size range were unlikely to have been caught using normal bottomfishing gear or were likely data entry mistakes (this removed 45 out of 25,000 length observations). Further, we also filtered outlier length observations above a given maximum length for each species, using length data from reliable sources to define a given maximum length (e.g., life history study, diver data, and biosampling program). This removed another 267 observations out of the 25,000 total observations.

For the biosampling dataset, the *Aprion virescens* the biosampling size distribution was oddly shaped, with a strong skew towards smaller individuals (we only kept the BBS size data for this species). This would suggest a different selectivity for the biosampling “bottomfishing” gear, which is odd as this strong pattern was not observed for other species, where both data sources had similar length frequencies (i.e., similar size structures with biosampling mean length about 1 to 4 cm smaller).

For the boat-based survey dataset, we did not use pre-2016 *V. louti* length data, given that they were confounded with *V. albimarginata* in creel interviews (see section 2.2.3 – Data corrections). Further, the size structures for *L. rubrioperculatus* in the early years (2004-2009) of the creel length data showed strange bimodal patterns that were not apparent later and are not realistic given their life history. An investigation of the data for this species during that specific period showed that secondary creel interviewers (outside the main two) did not capture the full range of lengths. After selecting data only from the main interviewers (interviewer ID "13" and "27"), the bimodal pattern disappeared. No irregular pattern was seen for size data in other species and we therefore did not apply this filter to them.

2.2.6 Population dynamics

This section describes the source of the various biological parameters used in our Stock Synthesis models, as well as some key assumptions related to population demographic structure. For biological parameters, we reviewed the scientific literature for published life history parameters related to growth, longevity, and maturity. This search was not restricted to local studies given the paucity of peer-reviewed literature for some of the BMUS. This paucity of information also led us to use time-invariant life history parameters. If multiple growth or maturity studies were available for a species, we prioritized using local studies followed by the most recent, in-depth studies (even if from a different geographical area). If no life history studies were available or if the published parameters were contradictory (e.g., a local maximum length is much greater than the L_{inf} estimated in a non-local life history study), we used the StepwiseLH meta-analytical approach described in Nadon and Ault (2016) and Nadon and Erickson (2021). This approach relies on a local estimate of maximum length to provide family-specific probability distributions for all main life history parameters. The maximum length suggested for this approach is the 99th percentile observation of a length data set (L_{99}) which we used to filter out potentially erroneous extreme length observations. All population dynamics input parameter values, assumptions, and sources used in our models are detailed for each species in the Species report section of this report.

Spatial and temporal span: As discussed in the introduction, the BMUS stocks were analyzed at the scale of the main American Samoa area (Tutuila, Manu'a Islands, and the nearby banks) as individual, well-mixed, populations (Figure 8-1). These assessments cover the 1967 to 2021 period with the first year matching the start of the *Tautai A'e* project, which represents the oldest data available and is near the start of the modern fishery for most BMUS, especially the deeper species. The end year of 2021 was selected since the 2022 data were incomplete at the time of our analyses.

Sex structure: For five out of nine assessed BMUS, there is no evidence of sex-specific patterns related to growth or a sex ratio different from 1:1 (*A. rutilans*, *A. virescens*, *C. lugubris*, *L. kasmira*, and *P. flavipinnis*). For these species, growth was assumed to identical for males and females. Growth for *E. coruscans* and *P. zonatus* was modeled separately given the clear sex-specific differences in growth established by life history studies. These species were not hermaphroditic. For these two species, growth was modeled separately between males and females. For the 7 species listed above, recruitment was split evenly between both sexes.

Finally, two species were protogynous hermaphroditic but showed no sex-specific growth patterns (*L. rubrioperculatus* and *V. louti*). For these two species, all annual recruits were assigned as females and transitioned to males within our models following an age-at-transition parameter obtained from the literature. Spawning biomass was calculated in terms of female-only mature biomass, but alternative model runs were included with the hermaphroditic option turned off.

Reproduction and recruitment: Maturity was defined solely for females, given the spawning stock biomass and its relationship to recruitment was strictly related to mature female biomass (Methot and Wetzel 2013). Maturity was defined as a logistic function of length. Fecundity (number of eggs per female) was set to be proportional to female body weight. Total reproductive output for each BMUS population was therefore set to be directly proportional to total mature female biomass.

Due to catch and CPUE data were available annually, a single season per year was used in the models. Therefore, the BMUS populations were assumed to have one spawning and recruitment period at the beginning of each time step, which corresponds to the first month of each year. A standard Beverton-Holt stock-recruitment relationship was used in this assessment. The expected annual recruitment in year "y" (R_y) was a function of spawning biomass in the same year (SSB_y), steepness (h), and virgin recruitment (R_0). Steepness is the fraction of R_0 when the spawning stock biomass is at 20% of its unfished level (SSB_0). To keep our models parsimonious, given the data-limited nature of our BMUS assessments, we did not include recruitment deviations in our base SS models. We did include them in alternate model runs, where deviations around expected recruitment values were assumed to follow a lognormal distribution with standard deviation (σ_R) (Methot 2000; Methot and Wetzel 2013).

In the alternate runs, these annual recruitment deviations were estimated based on the information available in the data and the central tendency that penalizes the log (recruitment) deviations in excess of σ_R. The σ_R parameter was fixed to approximate the expected variability based on independent estimates of σ_R from the FishLife 2.0 R package (Thorson 2019). The natural log of R_0 was estimated in the base-case models. Lee et al. (2012) concluded that steepness is estimable for relatively low productivity stocks with good contrast in spawning stock biomass, given a correctly specified model. However, estimating steepness (h) within the BMUS assessment models is likely to be imprecise and biased because the contrast in the spawning biomass over the assessment period is relatively poor. Given this, we followed the same approach as for σ_R and used an independent estimate of steepness from the FishLife 2.0 R package (Thorson 2019) derived from a meta-analysis. Nevertheless, we note here that this steepness estimate is subject to considerable uncertainty and further work is needed to evaluate steepness for BMUS. Sensitivity runs on steepness were used to evaluate the model's sensitivity to this parameter.

Age and growth: Maximum age (A_{max}) in each BMUS models was based on the maximum reported age of each species in the literature or, if unavailable, from the StepwiseLH tool. We modeled the relationship between fork length (FL) and age with a von Bertalanffy growth function using the Schnute (1981) parameterization:

$$L_2 = L_{Amax} + (L_1 - L_{Amax})e^{-K(A_2 - A_1)}$$

Eq. 1

where L_1 and L_2 are the sizes associated with ages, A_1 and A_2, respectively, L_{Amax} is the length at the maximum age A, and K is the growth coefficient. These parameters were obtained directly from life history publications except for *A. virescens*, for which we had raw age-length data. The coefficients of variation (CV) parameters that describe the variability of individual fish length at specific ages were derived from the variability of individual aged fish around L_{inf} in growth studies. Stock Synthesis assumes linear growth between ages 0 and A_1.

Individual variability in growth was implemented using the growth types or "platoons" option in Stock Synthesis. We set the number of platoons to three with the ratio of "between" to "within" platoon variability set to 0.7 (the default value). The distribution of recruits in each platoon followed a normal distribution, with the central platoon getting 0.7 of recruits and the two other ones getting 0.15 of recruits each. Using platoons is necessary to remove the bias introduced by differential survivorship-at-age between growth types, which results in incorrectly higher *F* estimates (Hordyk et al. 2016).

Natural mortality: We obtained estimates of natural mortality (*M*) using the well-established relationship between longevity and *M* (Hoenig 1983), as modified by Then et al. (2014). This approach typically uses a relationship of the form:

$$M = \frac{-\log(S_{Amax})}{a_\lambda} \quad \text{Eq. 2}$$

where S_{Amax} is the fraction of a cohort remaining at the observed maximum age (A_{max}), by which we defined longevity. While Then et al. (2014) slightly modified this equation, Hamel and Cope (2022) re-fitted their data set with a more appropriate linear model and came up with a numerator value of 5.4 (or $S \sim 0.005$). We used the Hamel and Cope (2022) equation with this numerator for all BMUS *M* estimates.

We did not have independent estimates of *M per se* and had to rely on this longevity-based approach. Although there are other data-poor methods for estimating natural mortality, involving other parameters (e.g., K, L_{inf}, L_{mat}, water temperature), Then et al. (2014) and Kenchington (2014) clearly suggest that longevity-only methods are better performing. It is important to consider the potential difficulty in obtaining a representative longevity value in heavily exploited stocks or when only a small number of age observations are available. For this reason, we also compared our observed maximum age with values from the StepwiseLH meta-analytical tool, where warranted.

Weight-at-length: For all BMUS, we used a non-sex-specific weight-length relationship to convert between catch-at-weight and weight-at-length data ($W = \alpha L^{\beta}$) within the SS framework. The α scaling and the β volumetric parameters were obtained from an extensive study done in Guam (Kamikawa et al. 2015).

Initial conditions: For our BMUS assessment, it was necessary to make some assumptions about the structure of the stock before the start of the main population dynamics period (pre-1967). Typically, two approaches are used to implement starting structure. The first approach starts the model as far back as necessary to satisfy the notion that the period before the estimation of population dynamics was in an unfished or nearly unfished state. The second approach estimates initial conditions assuming equilibrium catch (the equilibrium catch is the catch taken from a fish stock when it is in equilibrium with fishery removals and natural mortality, balanced by stable recruitment and growth). The initial fishing mortality rates in the assessment model that remove these equilibrium catches were estimated which allowed the model to start at an appropriate depletion level. For each BMUS, we first implemented a Stock Synthesis model with an estimated initial *F* for a given equilibrium catch. If this initial *F* estimate was near zero, we simply re-ran the models with initial conditions set to an unfished state. This is a reasonable assumption given the low fishing effort in American Samoa pre-1970s on deep-slope fishes (Itano 1996b, 1996a; Nadon and Bohaboy 2022).

2.2.7 Fishery dynamics

Catch uncertainty: To capture uncertainty of the BMUS catch estimates, we used the parametric bootstrap function in Stock Synthesis to generate 30 sets of bootstrapped catch data. The samples were generated from a lognormal distribution with a mean of the expected catch and a standard deviation of the input observation error. The models were then re-run using each of the thirty bootstrapped catch trajectories while all of the other input data (length composition and CPUE index) remained the same. To integrate these bootstrap model runs and determine stock status quantities (e.g., SSB_{2021}/SSB_{MSST}, F_{2021}/F_{MSY}), we used the delta-multivariate lognormal estimator (delta-MVLN; Winker et al. 2019) implemented with the *SSdeltaMVLN* function from the *ss3diags* R package (Winker et al. 2022). The delta-MVLN method is a faster alternative to other computationally- and time-intensive methods needed to derive joint posterior distributions for management quantities from multiple integrated age-structured models such as Stock Synthesis (Walter and Winker 2020). The delta-MVLN method uses the maximum likelihood estimates (MLE), standard errors, and correlation matrix of stock status quantities as described in Winker et al. (2019). From the correlation matrix and standard errors extracted from Stock Synthesis, a variance-covariance matrix (*VCM*) can be derived as:

$$VCM_{x,y} = \begin{Bmatrix} \sigma_x^2 & cov_{x,y} \\ cov_{x,y} & \sigma_y^2 \end{Bmatrix} \qquad \text{Eq. 3}$$

where the variance of x, σ_x^2 and variance of y, σ_y^2 can be approximated as:

$$\sigma_x^2 = \log\left(1 + \left(\frac{SE_u}{u}\right)^2\right) \text{ and } \sigma_y^2 = \log\left(1 + \left(\frac{SE_v}{v}\right)^2\right) \qquad \text{Eq. 4}$$

using the asymptotic standard error (SE_u and SE_u) estimates for $u = SSB/SSB_{MSY}$ and $v = F/F_{MSY}$ respectively. The covariance of x and y can be approximated on a natural log-scale by:

$$cov_{x,y} = log\left(1 + \rho_{u,v}\sqrt{\sigma_x^2\sigma_y^2}\right) \qquad \text{Eq. 5}$$

where $\rho_{u,v}$ is the correlation of u and v. The posterior distribution for SSB/SSB_{MSY} and F/F_{MSY} are generated with a multivariate-normal distribution and the vector of MLE of x and y ($\mu_{x,y}$) by:

$$Kobe_{x,y} = MVN(\mu_{x,y}, VCM_{x,y}) \qquad \text{Eq. 6}$$

and the joint distribution of SSB/SSB_{MSY} and F/F_{MSY} is calculated as the exponential of the posterior distribution ($Kobe_{x,y}$). The posterior distribution was generated from 1,000 Monte-Carlo iterations.

The Delta-MVLN method was used on each of the thirty bootstrap catch models and all outputs were combined to calculate the median and 95% confidence intervals of *SSB*, *F*, SSB/SSB_{MSST}, and F/F_{MSY}.

Selectivity: Stock synthesis requires gear-specific selectivity parameters to relate catch, size frequency, and CPUE observations to population dynamics. Size structure patterns in the BMUS datasets suggested that selectivity was related to body length and followed a simple logistic pattern that was time-invariant in the relatively short time window when size data are available (2004–2021). The following logistic equation relating selectivity (*S*) to length was used in the SS model:

$$S_L = \frac{1}{1 + e^{\left[-\ln(19)\frac{L - L_{S50}}{L_{S95} - L_{S50}}\right]}} \qquad \text{Eq. 7}$$

where L_{S50} and L_{S95} are the sizes at 50% and 95% selectivity, respectively.

By providing Stock Synthesis with size frequencies from the “bottomfishing” gear type, the model was able to estimate size selectivity parameters in our single-fleet SS models.

Catchability: Catchability (*q*), the proportion of the stock captured per unit of effort, was estimated (solved analytically) for each CPUE index. Therefore, these indices were assumed to be proportional to vulnerable biomass (the biomass selected by the bottomfishing gear) with a scaling factor of *q*. It was assumed that *q* was constant over time for each index.

Fishing mortality: Fishing mortality was estimated using the hybrid *F* method in Stock Synthesis. This method implements the Pope’s approximation to provide initial *F* values before further iterative adjustments to the Baranov continuous *F* values (Methot and Wetzel 2013).

Data observation models: The current assessment model fitted three data components: (1) total catch, (2) CPUE relative abundance indices, and (3) length composition data. Stock Synthesis estimates population (e.g., R_0) and fishing parameters (e.g., *selectivity*, *F*) by minimizing the negative log-likelihood of an objective function given the input data and assumptions.

The reported DMWR total catches were assumed to be unbiased. As discussed below, the variability in total catch was high in this dataset and we fitted our SS models to bootstrapped catch data before generating our final model outputs.

The relative abundance indices were assumed to have lognormally distributed errors with SE in log $\sqrt{\log_e(1 + CV^2)}$ space, which is approximately equivalent to CV (SE/estimate) in normal space where the log(SE) = CV. The estimated CVs of each index in this assessment are shown in Table 7-8. However, the reported CVs for the abundance indices only capture observation errors within the standardization model and are related to the number of data points in the analysis, with larger datasets having smaller CVs. They do not reflect process errors that are inherent in the link between the unobserved vulnerable population and observed abundance indices. Total observation errors for abundance indices could be adjusted within the model using the “extra log SD” parameter, if required (for most models, this parameter was estimated at “zero” and simply turned off in subsequent model iterations).

We assumed that the size composition data had a Dirichlet-multinomial error distribution with the error variance determined by the effective sample size (shown as “N adj.” on the size structure plots in the Species report section). This added an extra parameter to our SS models (theta). Using the Dirichlet-multinomial error distribution is advantageous because it integrates compositional data weighting directly in the model estimation (Thorson et al. 2017). In this stock assessment, size measurements of fish were assumed to be random samples of fish from the entire population (within the size selection range of the “bottomfish” gear). Further, we set a minimum of 45 length observations per year to avoid spurious length compositions in our models. Length data from years with less than 45 observations were combined with adjacent years in order to obtain at least 45 observations and analyzed in Stock Synthesis as a super-period (Methot and Wetzel 2013).

2.3 Model diagnostics

Running diagnostic tests is an important step in determining the robustness of our parameter estimates in integrated stock assessment models. One of the advantages of the integrated SS framework is that it allows for a broad range of model diagnostics. For the current assessments, we followed the practical guidelines for implementing selected diagnostic tools as provided in by Carvalho et al. (2021). Based on this paper, we used model diagnostics to assess issues associated with: (1) model convergence, (2) fit to the data, and (3) model consistency. The diagnostics results were not used as a definitive metric to accept or reject a model, but instead to support model development and transparently lay out potential issues with our models (Maunder et al. 2022).

2.3.1 Model convergence

Model convergence was assessed using several criteria as suggested by Carvalho et al. (2021). The first diagnostic was whether the Hessian (i.e., the matrix of second derivatives of the likelihood with respect to the parameters) inverted. The second measure is the maximum gradient component, which, ideally, should be low (<0.0001 is a standard value). The third diagnostic involved altering or “jittering” the starting values of the estimated parameters to evaluate whether the model converges to a global solution rather than a local minimum. These diagnostics are not fault-proof and no guarantee can ever be made that the 'true' solution has been found or that the model is not mis-specified. However, if the jitter analysis results are consistent (i.e., the jittered models converge on the same solution), it provides additional support that the model is performing well and has come to a stable solution. For the assessments presented here, a jitter value of 0.1 (10%) was applied to the starting values and 100 runs were completed.

2.3.2 Fit to the data

The main approach used to assess model fit and performance was residual analysis of model fit to the CPUE indices and length composition data. Any temporal trends in model residuals can be indicative of model misspecification and poor performance. It is not expected that any model will perfectly fit to the observed data, but ideally, residuals will be randomly distributed and conform to the assumed error structure for that data source. Any extreme patterns of positive or negative residuals are indicative of poor model performance and potential unaccounted for process or observation error.

2.3.3 Model consistency

To evaluate model consistency, we used two diagnostics: likelihood profiling of $\log(R_0)$ and retrospective analysis.

Likelihood profiling was used to examine the change in log-likelihood for each data source in order to address the stability of a given parameter estimate, and to see how each individual data source influences the estimate. The analysis is performed by holding the given parameter at a constant value and re-running the model. This is repeated for a range of reasonable parameter values. Ideally, the graph of likelihood values against parameter values will give a well-defined minimum, indicating that data sources are in agreement. When a given parameter is not well estimated, the profile plot may show conflicting signals across the data sources. The equilibrium recruitment parameter (R_0) is commonly profiled because it represents an ideal global scaling parameter given that unfished (virgin) recruitment is proportional to unfished biomass.

A retrospective analysis is a useful approach for addressing the consistency of terminal year model estimates. The analysis sequentially removes the last year of data set and re-runs the model. If the resulting estimates of derived quantities such as *SSB* or recruitment differ significantly, particularly if there is serial over- or under-estimation of any important quantities, it can indicate that the model has some unidentified misspecification. It is expected that removing data will lead to slight differences between the new terminal year estimates and the updated estimates for that year in the model with the full data. Oftentimes additional data, especially compositional data, will improve estimates in years prior to the new terminal year due to the information on cohort strength becomes more reliable.

Therefore, slight differences are expected between model runs as more years of data are peeled away. Ideally, the difference in estimates will be slight and more or less randomly distributed above and below the estimates from the model with the complete data sets. Although measuring retrospective patterns has proved challenging, the most commonly used metric is the rho ("ρ") statistic proposed by Mohn (1999), which measures the relative difference between an estimated quantity from an assessment with a shorter time series and the same quantity estimated from the full time-series. Interpreting the Mohn's rho statistic is subjective. However, a rule of thumb was proposed by Hurtado-Ferro et al. (2015), which states that values of Mohn's rho falling outside the range of −0.15 to 0.20 indicate the presence of a noticeable retrospective pattern for long-lived species. A five-year retrospective analysis was carried out for the assessments presented here.

2.3.4 Assessment strategy

The assessments presented here rely on catch, CPUE, and length composition data within an integrated model framework. As noted in section 2.2.4, the CPUE time series (2016–2021) was truncated due to an accumulation of concerns with the 1987–2015 creel survey data (i.e., concerns raised by fishermen and DMWR staff during workshops, discovery of numerous species misidentification and other data errors, unexplainable patterns, etc.). As indicated by component likelihood analyses and profiling, our models relied primarily on length and catch time series, with a moderate support from the CPUE data. The performance of data-moderate SS assessments based on catch and length data only has been the topic of a recent publication by Rudd et al. (2021). Their study concluded that such an approach is a viable application for fisheries with life history information, time series of removals, and as little as a snapshot or short time series of representative length compositions. In addition, a recent application of SS assessments based on catch and length data only was adopted by the Pacific Fishery Management Council (Langseth et al. 2021).

During the model development phase, we first focused on improving the fits to the observed data (CPUE and length frequency) and obtaining a stable likelihood profile with an informative minimum. A key part of the early exploration involved assessing which parameters could be estimated from the input data and which needed to be fixed. The base-case was chosen as the version of the model with the best fit to the data while also making reasonable assumptions about model parameterization. From this base-case, a set of one-off sensitivities was chosen to test the impact on model results of choices made regarding key fishery and biological parameter assumptions. These sensitives are as follows:

Life history parameters: We tested alternative specifications of our life-history parameters when local studies were not available. We either selected parameters from alternative growth and maturity studies or implemented the StepwiseLH approach to generate a set of alternative parameters. Natural mortality is a parameter that is hard to estimate and is influential in most assessments. We tested values representing plus and minus 10% adjustments of this parameter. Further, for our two protogynous hermaphroditic species (*L. rubrioperculatus* and *V. louti*), we tested models with this option turned off (i.e., females do not transition and continue contributing to the SSB throughout their lifespan).

Recruitment: Steepness is a challenging parameter to estimate from observations or within a stock assessment model, but it tends to be influential on assessment predictions, given that it mediates the relationship between spawners and recruits. We examined the impact of 10% adjustments to this parameter in alternate runs. We also examined the impact of using recruitment deviations in our models, using σ_R values from the FishLife 2.0 package.

Historical catch and alternate model start year: Catches during the early years of exploitation of a fish stock can be influential on the estimation of unfished population size (e.g., R_0). However, standardized methods to monitor fishing are unlikely to be in place during the first years of a newly developing fishery and catch estimates are likely more uncertain than later in the time series. In our analyses, we used data reported from preliminary fisheries investigations from 1967 to 1985 that predated the standardized implementation of the boat-based creel survey program in 1986. To investigate the influence of early catch estimates on assessment model dynamics and results, we included alternate model runs with start year 1986 for all species.

2.4 Reference points

Amendment 6 of the Fishery Ecosystem Plan (FEP) for American Samoa established methods for determining fishing mortality and stock biomass reference values. The determination of a stock being overfished and/or experiencing overfishing is achieved by comparing current conditions to these reference values. Overfished is defined as the stock biomass B falling below the Minimum Stock Size Threshold (MSST) of $(1 – M) \times B_{MSY}$ where M is the natural mortality rate of the complex and B_{MSY} is the biomass that produces the maximum sustainable yield (Figure 8-17). Overfishing is defined as a fishing rate F that exceeds the Maximum Fishing Mortality Threshold (MFMT) of F_{MSY}. F_{MSY} is the fishing rate that produces maximum equilibrium catch (i.e., MSY), which is found through an iterative search algorithm in SS (Methot and Wetzel 2013). According to the FEP, the MFMT varies depending on whether biomass is above or below the MSST. If the stock biomass is above the MSST, the MFMT equals F_{MSY}, if the stock biomass falls below the MSST, the MFMT declines from F_{MSY} in proportion to the ratio of biomass to the biomass reference point.

The Fishery Ecosystem Plan (FEP) for American Samoa (WPRFMC 2009) specifies criteria for determining stock status based on fishing mortality rate and stock biomass relative to established reference points F_{MSY} and B_{MSY}. Under the FEP, a stock is overfished if the stock biomass (*SSB*) falls below the Minimum Stock Size Threshold (MSST) of $(1 – M) \times B_{MSY}$ where M is the natural mortality rate of the stock and B_{MSY} is the spawning biomass that produces the maximum sustainable yield (Figure 8-17). A stock is experiencing overfishing when the fishing mortality rate F exceeds the Maximum Fishing Mortality Threshold (MFMT). For American Samoa BMUS, if a stock is not overfished ($B > MSST$), then $MFMT = F_{MSY}$, which is the fishing mortality rate that produces the maximum catch that can be harvested on a continuing basis (MSY). If the stock is overfished (B <= MSST) then the MFMT is reduced from F_{MSY} in proportion to B/B_{MSY}.

2.5 Catch projections for 2022–2028

We estimated the risk of overfishing from 2022 to 2028 by generating large numbers of population simulations under different fixed catch scenarios. Stock projections were conducted for seven years from 2022 to 2028 using Stock Synthesis by extending the base-case model beyond 2021 using the forecast capabilities of SS. Projections were based on the results from the base-case model when life-history and fishery dynamics were assumed to remain constant through the projection period.

Fishery selectivity was assumed to remain constant in the projection period. The selectivity estimated in the terminal year of the base-case model was used for the projections (note: selectivity was time-invariant in all our models). Recruitment during the projection period was a function of projected SSB according to the stock-recruitment curve from the base-case model, with no deviations.

For the projections, a range of fixed annual catches were simulated in all thirty bootstrap models to provide the probability of the stock experiencing overfishing or being overfished in each year from 2024–2028. For the first two projection years (2022 and 2023), the mean catch of the last three years of data (2019–2021) was used since estimated catches in 2022 and 2023 were unknown at the time of the analysis (these years also do not fall under new management advice from this assessment, which would start in 2024 at the earliest). For example, *A. rutilans* annual catches between 2024 and 2028 were fixed at a constant value ranging from 2.5 to 5.5 mt in 0.2 mt increments while fixed catches of 0.5 mt were used for 2022–2023. Therefore, for this species, 450 Stock Synthesis models were fitted to the data and projected to 2028 (30 bootstraps x 15 fixed catch values).

We used the delta-multivariate log-normal (delta-MVLN) approach to generate distributions of projected stock status at various fixed catch levels (Walter and Winker 2020). This method infers within-model uncertainty from maximum likelihood estimates, standard errors, and the variance-covariance matrix of the stock status quantities (see section 2.2.7 for a detailed explanation). For each fixed catch scenario, the posterior distributions were generated by drawing 1,000 Monte Carlo samples (for *A. rutilans*, this would result in 450,000 total samples from 450 models and 1,000 MC draws). The probability of the stock being overfished in a given year was determined for each fixed catch scenario by dividing the number of samples where SSB_y was less than SSB_{MSST} by the total number of samples in that fixed catch scenario. The probability of the stock undergoing overfishing in a given year was determined for each fixed catch scenario by dividing the number of samples where F_y was less than F_{MSY} by the total number of samples in that fixed catch scenario. Finally, a risk table of overfishing probabilities by year and fixed catch level was completed by fitting a simple polynomial model to the probability of overfishing using fixed catch level as a predictor variable, for each individual year (Prob. Overfishing ~ Catch+Catch^2). Models were only fitted using “probability of overfishing” data points between 0.1 and 0.5. These relationships were typically linear, but we used a polynomial model to account for small curvatures in the relationship (see Figures 9.x-19 for examples).

The approach described above was used for all BMUS except one, *L. kasmira*. The fitted selectivity curve from the base case model resulted in only large individuals being vulnerable to the fishery, effectively shielding a large proportion of the stock from exploitation. The SS base model for this species showed that, effectively, all the vulnerable *L. kasmira* biomass could be harvested while keeping the stock above B_{MSY} (i.e., there is no F_{MSY} value *per se*). In this situation, SS will estimate *MSY* as the vulnerable biomass when *F*=2.9 or *H*=0.94 (the maximum limit set in our SS models) and B_{MSY} as the *SSB* at this harvest rate (R. Methot, pers. comm.). Given that this *MSY* value is the maximum catch possible given the selectivity curve, we used the median *MSY* estimate as the OFL for this species and the distribution of MSY around this central value to build the overfishing risk table.

3 Results

This section provides a brief overview of our BMUS assessments. Detailed results, including model diagnostics, comments, and specific concerns can be found in the Species Reports section at the end of this manuscript. In this report, we implemented 9 Stock Synthesis models out of the 11 BMUS. The remaining two species had either insufficient data (*P. filamentosus*) or data confounded by the presence of another recently described species (*E. carbunculus*). The status of these two stocks is currently unknown.

3.1 Model diagnostics

All nine base-case models reached convergence, as indicated by final likelihood gradient value below 0.0001 and positive definite Hessian matrices. The estimated parameters appeared to be at their global minima, as suggested by the successful jitter analyses, where 100 models were run with random initial starting values. The model fits to the standardized CPUE indices all passed the Runs test, but with root mean squared error (RMSE) typically higher than 30%. The models fit well to the overall length structure data, as shown in the species report figures. However, a single species failed the mean-length Runs test (*A. virescens*), likely due to a few years with low sample size or anomalously shaped size structure (and thus mean length value).

All nine models passed their retrospective analysis, with low Mohn's Rho values, typically between -0.1 and 0.1, or lower. A few species (*A. rutilans*, *E. coruscans*, and *P. flavipinnis*) had noticeable retrospective SSB scaling patterns, which were all related to removing anomalous size structure data, which affected F and therefore the population scale (i.e., increasing F scales the SSB lower and vice-versa). Further, likelihood profiles for the unfished recruitment parameter log(R_0) showed that this population-scaling parameter was mainly informed by length data, followed by catch, and, to a lesser extent, the CPUE index. Only two species, *C. lugubris* and *L. kasmira*, had R_0 estimates informed mainly by catch data, followed by length data. These profiles typically showed steep likelihood gradients towards a minima for low R_0 values, followed by a shallow gradient past the R_0 minima, indicating stronger certainty on the lower vs upper limits of the BMUS population sizes.

3.2 Alternate models

A primary source of uncertainty for our models were life history parameters, with only one assessed BMUS having parameters from a local source (*P. flavipinnis*). We used external life history parameters from studies conducted elsewhere in the Indo-Pacific for five other BMUS and used the StepwiseLH meta-analytical tool for the other 3 species (Nadon and Ault 2016). For most species, we tested the sensitivity of our models to alternate life history parameter sources. As expected, the models were sensitive primarily to the growth curve used, specifically the L_{inf} parameter and natural mortality associated with different sources. The population scale was more sensitive than final stock status. Surprisingly, removing the historical catches and starting our models in 1986—the start of the creel surveys—did not have significant impacts on either stock status in the final year or population scale. The only exception was *E. coruscans*, where the population scale (MSY, SSB_{MSST}, etc.) was approximately two times larger.

Importantly, none of the 65 alternate scenarios resulted in overfishing or an overfished status in the final year of our models (2021).

3.3 Stock status

Table 7-9 presents a summary of selected stock status metrics, current catch, and overfishing limits for each species. In short, all nine BMUS had F/F_{MSY} values in 2021, the last year of our model, well below 1, the overfishing limit. Further, all nine BMUS had SSB/SSB_{MSST} values in 2021 above 1, the overfished limit. The two species closest to an overfished status were *Aprion virescens* (1.7) and *Etelis coruscans* (1.7). All other species had median *SSB* values at least 2.8 times higher than their SSB_{MSST}. Thus, none of the nine BMUS were either overfished or experiencing overfishing in 2021. However, seven out of the nine BMUS were either overfished (*C. lugubris*, *L. rubrioperculatus*, and *P. zonatus*) or came close to being overfished (*A. virescens, P. flavipinnis, E. coruscans,* and *V. louti*) in the 1980s and early 1990s, following the increased fishing effort associated with the dory and alia programs.

4 Discussion

The current report presents the first single-species integrated assessment of coastal stocks in American Samoa. Integrated models are considered the most optimal approach when conducting stock assessments because they assimilate all available data types and sources of uncertainty into a single model, allowing the different data components to work together inside a single statistical framework. Using the Stock Synthesis 3.30 software, we incorporated all appropriate data sources into individual models for nine bottomfish species. These data sources included historical catch reconstructed from reports of landings at a broad taxonomic level prior to 1986, catch reported from boat-based and shore-based creel surveys post 1985, catch-per-unit-effort indices from the main fishing gear, size-frequency data, and life-history parameters from various sources. The base models for all nine species performed well, with model diagnostics indicating that statistical optimizations were successful, the models fitted the data well, and parameter estimates were consistent when the models were updated with new data (e.g., no major retrospective pattern).

The main conclusions from these nine integrated assessments are as follows. As of 2021,

- No BMUS stock was overfished (SSB/SSB_{MSST} between 1.7 and 7.6)
- No BMUS stock was experiencing overfishing (F/F_{MSY} between <0.01 and 0.05)

The general population abundance trend for BMUS in American Samoa has been of near pristine conditions in the 1960s followed by declining biomass in the 1970s for nearshore species during the dory program (*L. kasmira*, *L. rubrioperculatus*, and *C. lugubris*) and declining biomass in the 1980s for deeper species (i.e., the Etelinae snappers) during the ‘alia program. The increased fishing effort associated with these programs led to several species becoming overfished (*C. lugubris*, *L. rubrioperculatus*, and *P. zonatus*) or nearly so (*A. virescens*, *E. coruscans, P. flavipinnis*, and *V. louti*). Following these programs, reduced fishing effort allowed the BMUS populations to bounce back to sustainable levels, between ~1.5 and 7 times their overfished reference point.

Our new models significantly relaxed the previous assessments’ reliance on the less reliable catch and CPUE data by incorporating length and life-history information. However, model parameters informed by size data can be sensitive to life history parameter values, and it is important to properly test our models’ sensitivity to these. For the BMUS, stock status determination appeared robust to uncertainty in the data and input parameters, with none of our alternate model scenarios resulting in overfishing or an overfished status in 2021. However, population scaling was sensitive to certain life history parameters, especially M and L_{inf}. This was not entirely surprising, as it is well known that fishing mortality rates are very sensitive to L_{inf} or M (Hordyk et al. 2015). The impact of changing these parameter values was especially noticeable for species with very low fishing mortality rates, nearing zero. In these cases, lowering L_{inf} or increasing M pushes F estimates even closer against 0, resulting in unrealistically large population biomass (i.e., as F asymptotes towards zero, population biomass, which is derived from catch and *F*, will tend towards infinity). Figure 8-18 shows two examples of the impact of lowering L_{inf} on population scale. We focused heavily on this issue during the WPSAR review. However, extensive explorations of L_{inf} and *M* values showed markedly similar values across many sources (studies, the StepwiseLH tool, and Stock Synthesis estimates) and no major changes in stock status and population scale (Table 7-10 and Table 7-11).

Beyond changes to key lie history parameters, other model scenarios tested were 1) removing historical catch, 2) including recruitment deviations, and 3) removing hermaphroditism for the two protogynous hermaphroditic species (*L. rubrioperculatus* and *V. louti*). *Etelis coruscans* was the only species with a population scale sensitive to historical catch estimates (i.e. starting our model in 1986 doubled the population size). However, we do not have any reason to doubt the general accuracy of our historical catch reconstruction for this species and others. Adding recruitment deviations to our models allowed them to fit to recent length and CPUE observations more tightly but did not significantly change population scaling or stock status. Finally, removing hermaphroditism from *L. rubrioperculatus* and *V. louti* did not change stock status but tended to slightly lower their population scale.

Of note, we did not systematically test the Lorenzen natural mortality estimator (Lorenzen 1996), which significantly increases natural mortality for juvenile fish. A recent uku assessment in Hawai'i (Nadon et al. 2020) showed that models using this *M* parametrization will simply double the number of recruits without changing other outcomes (the elevated early year *M* is simply balanced by increasing the number of recruits).

4.1 Previous assessments

The current assessments present a major improvement from previous ones by moving to single-species integrated models. This leap, and other improvements, directly addressed the following WPSAR panel recommendations from the 2015 panel that had not been addressed in the 2019 assessment:

1. Include a detailed explanation of the expansion algorithm used to generate catch data

We conducted a WPSAR review and published a report detailing this (Ma et al. 2021).

2. Explore splitting the BMUS into shallow and deep species components for future assessments and account for the varying BMUS species composition over time by either incorporating multilevel priors or in the CPUE data standardization process

We went further and separated the BMUS complex into individual species.

3. Explore length-based data and life history-based approaches for the assessment process if sufficient data is available.

We included length and life-history data in our integrated assessments.

The assessment also addressed the following recommendations from the 2019 WPSAR panel:

1. Investigations of relative productivity of species forming the BMUS complex. Consideration of grouping the species by productivity in standardization

We split the BMUS complex into individual species.

2. Data workshop, with the objectives of improving and validating (to the extent possible) the catch and effort data.

We conducted several data workshops with local fishermen and government agency workers and published an extensive data report (Nadon and Bohaboy, 2022).

4.2 Bridging analysis with 2019 assessment

The 2019 assessment used a Bayesian surplus-production model on a complex of eleven BMUS using solely catch and CPUE time series. It reached a conclusion that the BMUS complex was overfished which is different from our conclusion. It is difficult to pinpoint why our models reached different conclusions given how different the modeling approaches are, but this is likely due to a combination of the many improvements included in our models and other factors: 1) we used age-structured population modeling; 2) we split the BMUS complex into individual species; 3) we shifted the focus to length and life-history data; 4) we expanded the assessed period to 1967 by including almost twenty extra years of historical catches; 5) we fixed many data issues (species identification issues, catch expansion effort units, etc.); 6) we added recent years to the model which had low fishing efforts; and 7) we reduced the CPUE time series to the more reliable 2016-2021 period. We did not systematically investigate the impact of each of these differences, however, we did want to verify that removing the pre-2016 CPUE was not a principal cause of the stock status change. We ran the 9 base case models with the full CPUE time series and did not find changes in 2021 stock status (Figure 8-19) or major differences in population scale (Figure 8-20).

A declining CPUE trend from 2000 to 2017 was the primary driver of the 2019 BMUS assessment that found the complex to be overfished. A deeper investigation of that CPUE trend showed that *L. kasmira* mainly drove that decline (17% of the 1986-2017 BMUS catch), with *L. rubrioperculatus* (19%) and *C. lugubris* (6%) to a lesser degree (Figure 8-21 and Figure 8-22). The full *V. louti* CPUE index was not investigated, given the confounding species identification with *V. albimarginata* pre-2016. The deep snappers (Etelis and Pristipomoides spp.) did not show an overall decline in CPUE over that time period (*A. virescens* showed a slight decline).

There were some concerns raised about the *L. kasmira* CPUE decline during the WPSAR review. However, no changes in key life history parameters (L_{inf} and M; Table 7-10 and Table 7-11) or inclusion of the full CPUE time series in our model resulted in an overfished stock status in 2021, as mentioned previously. The abundant length data for this species clearly indicate that only a fraction of the stock is vulnerable to fishing (L_{S50} of 22.1 cm and L_{S95} of 25 cm), which is above the L_{mat50} of 18 cm and close to the L_{inf} of 24.6 cm. The reason for the CPUE decline is not clear, but we note that this pattern is primarily seen with the nearshore species (*L. kasmira*, *C. lugubris*, and *L. rubrioperculatus*), which could reflect a change in targeting towards the more highly prized deep snappers (which have mainly stable CPUE trends). These trends should be further investigated and a local growth curve for *L. kasmira* should be a research priority.

The sum of the nine BMUS overfishing limits (under the 2028 constant catch option) in the current assessment is about 50,000 lb, which is higher than the 2023 5,000 lb limit that was set following a rebuilding plan. It is however lower than the 2016 assessment update which estimate the OFL at 115,000 lb. From 2010 to 2015, average BMUS catches varied around 10 mt per year (22,000 lb). From 2015 to 2021, BMUS catch averaged about 5 mt (11,000 lb). MSY in the 2016 assessment was estimated at 76,000 lb (2015) and updated to 29,000 lb in 2019. The sum of the 9 MSY value in our 2023 benchmark is 18.5 mt or 41,000 lb (this excludes the portion of the MSY from *P. filamentosus* and *E. carbunculus*, which were not included in our assessment).

4.3 Indicator species

Two of the eleven bottomfish species could not be assessed due to either the presence of a confounded species in the data (*E. carbunculus*) or insufficient data (*P. filamentosus*). For these two species, we proposed the use of indicator species from the 9 assessed BMUS. The species that are likely most useful are *E. coruscans* and *P. flavipinnis*. Both species are Etelinae deep snappers that have similar longevity (28-55 years) and size (L_{inf} ranging between 40 and 85 cm; Table 7-12). These species occur at depths ranging from 100 to 400 m and are targeted together as part of the deep snapper fishery (Ahrens et al. 2022). This issue was discussed during the WPSAR review and based on this information, it was determined that *E. coruscans* would be an appropriate indicator species for *E. carbunculus* and that *P. flavipinnis* would be appropriate for *P. filamentosus*.

4.4 Future directions

The Stock Assessment Program at the Pacific Islands Fisheries Science Center (PIFSC) will continue exploring and improving the use of Stock Synthesis for domestic stocks, including integrating potential new sources of data. Local DMWR staff have been trained to distinguish *Etelis carbunculus* from the newly described species *Etelis boweni*, which may allow for these species to be assessed. However, it is unlikely that *Pristipomoides filamentosus* will be assessed in the future given its rarity in the catch and the associated lack of data. It may be possible to collect fishery-independent data on this species and others. For example, PIFSC has been conducting an annual Bottomfish Fishery-Independent Survey in Hawaii (BFISH program) since 2016.

These surveys consist of a combination of research fishing and underwater stereo video cameras and cover the entirety of the main Hawaiian Islands. These surveys have been used to generate estimates of total biomass for the 2018 Deep 7 assessment and will be used to create an abundance index in future assessments. The expansion of these surveys to the territories could provide independent estimates of biomass, a new fishery-independent abundance index, as well as an extra source of size composition data. Finally, our assessments only had one local growth curve, from an extensive study conducted by the PIFSC Life History Program on *P. flavipinnis*. The lack of local life history information introduced a source of uncertainty in our models that can be greatly reduced in the future by the Life History Program's continued research on this matter.

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7 Tables

Table 7-1 - American Samoa bottomfish management unit species (BMUS).

Species	Samoan name	English common names	Code
Aphareus rutilans	Palu-gutusiliva	Rusty jobfish	APRU
Aprion virescens	Asoama	Green jobfish	APVI
Caranx lugubris	Tafauli	Black jack	CALU
Etelis carbunculus	Palu-malau	Deep-water red snapper	ETCA
Etelis coruscans	Palu-loa	Deepwater longtail red snapper	ETCO
Lethrinus rubrioperculatus	Filoa-paomumu	Spotcheek emperor	LERU
Lutjanus kasmira	Savane	Bluestripe snapper	LUKA
Pristipomoides filamentosus	Palu-‘ena-‘ena	Crimson jobfish	PRFI
Pristipomoides flavipinnis	Palu-sina	Golden eye jobfish	PRFL
Pristipomoides zonatus	Palu-ula, palu-sega	Oblique-banded snapper	PRZO
Variola louti	Velo	Yellow-edged lyretail grouper	VALO

Table 7-2 - Main assumptions and decision points of the American Samoa BMUS Stock Synthesis models with links to relevant report sections.

Model structure and assumptions	Relevant sections
Individual, well-mixed, populations covering Tutuila, the Manu'a Islands, and the banks.	1.2, 2.2.6
No sex differences in life history and abundance for 5 species	2.2.6
Sex-specific differences in life history for *E. coruscans* and *P. zonatus*	2.2.6
Protogynous hermaphroditic but no sex-specific life history for *L. rubrioperculatus* and *V. louti*	2.2.6
Time-invariant life history parameters	2.2.6
Fecundity proportional to female biomass	2.2.6
Single spawning and recruitment period during the first month of the year	2.2.6
Beverton-Holt stock-recruitment curve with no annual deviations	2.2.6, 2.3.4
Steepness (*h*) fixed, not estimated within the model	2.2.6, 2.3.4
Natural mortality (*M*) constant with age and linked to longevity with $S_{max\ age}$ = 0.005	2.2.6, 2.3.4
Initial conditions derived from equilibrium catch and estimated in Stock Synthesis	2.2.6
Time-invariant selectivity	2.2.7
Dirichlet-multinomial error distribution for size-frequency data in Stock Synthesis	2.2.7
Size observations are random and representative of vulnerable population size-frequency	2.2.7
Time-invariant catchability	2.2.7
Fishing mortality estimated as continuous full parameters	2.2.7
Historical catch was reconstructed for 1967 to 1985	2.2.2, 2.3.4
CPUE tied to population abundance	2.2.3, 2.3.4
CPUE time series prior to 2016 is uncertain and not used	2.2.4
Projection recruitment: Beverton-Holt stock-recruitment curve with no annual deviations	2.5

Table 7-3 – Historical catch information, including the total annual catch by year with the source and explanation of how each number was derived.

Year	Catch/effort	Effort	Catch (lb)	Sources	Explanation
1967			6,350	Swerdloff (1972)	Directly from report.
1968			22,399	Swerdloff (1972)	Directly from report.
1969	305	13	6,925	Swerdloff (1972)	Table I provides catch until March 1969. Afterwards, we know there were 21 trips between April 1969 and June 1970. Assign 13 trips to 1969.
1970	305	8	2,440	Swerdloff (1972)	Assign 8 trips to 1970 (see above).
1971	0	0	0	Swerdloff (1972)	Assume no fishing after end of Tautai A'e program.
1972	6,250	6	65,500	Ralston (1979)	Ralston (1979): FY 72 = 28,000 lb FY 73 = 75,000 lb, thus 37,500 lb (6250/month x 6).
1973	6,250	6	91,610	Ralston (1979), OMR (1976)	Ralston (1979): FY 73 = 75,000 lb, thus 37,500 lb (6250/month x 6). OMR 1976: Catch per month for 2nd half of the year.
1974			63,270	OMR (1976)	Directly from report.
1975			83,795	OMR (1976) (catch), Itano (1996) (# active dories), Ralston (1979) (# reporting)	OMR (1976): 51,756 lb caught in 1975. Itano (1996): FY 74 and FY75 had 17 active dories. OMR (1976): FY 74 had 12 and FY 75 had 9 reporting dories.
1976			68,476	OMR (1976) (catch), Itano (1996) (# active dories), Ralston (1979) (# reporting)	OMR 1976: 17,119 lb caught in first half of 1976. Itano (1996): FY 75 and FY 76 had 17 active dories. OMR 1976: FY 75 had 9 and FY 76 had 8 reporting dories. Multiplied by 2 since only data for half the year.
1977	4,028	7.5	30,210	OMR (1976), Itano (1996)	About 7.5 active dories x 4028 lbs/dorie/year from previous year.
1978	4,028	3	12,084	OMR (1976), Itano (1996)	About 3 active dories+other boats x 4028 lbs/dorie/year from previous year.
1979	2,545	4	10,180	Hamm and Quach (1988), Itano (1996)	About 4 active boats x 2545 lbs/dorie/year from previous year. From Hamm and Quach (1988), total bfish 1982-1985 was 379,241 lbs, hence 2545 lb bfish per vessel per year
1980	2,545	10	25,450	Hamm and Quach (1988), Itano (1996)	About 10 active boats x 2545 lbs/boat/year from previous year.
1981	2,545	19	48,355	Hamm and Quach (1988), Itano (1996)	About 19 active boats x 2545 lbs/boat/year from previous year.
1982			62,016	Hamm and Quach (1988)	Directly from report.
1983			125,167	Hamm and Quach (1988)	Directly from report.
1984			92,841	Hamm and Quach (1988)	Directly from report.
1985			99,217	Hamm and Quach (1988)	Directly from report.

Table 7-4 – Species proportion used to break down grouped 1967–1979 historical catches. The 1986–1995 catch compositions are from boat-based creel surveys. The Manu‘a and Tutuila proportions were averaged using bottomfish habitat weights of 0.13 and 0.87, respectively.

Species	Prop. of bottomfish catch (1967-1979)	Explanation
Aphareus rutilans	0.006	- “Etelis/Pristipomoides” were 0.08 of the catch (Ralston 1979). - APRU was 0.05 of “deep snapper” around Manu’a and 0.08 around Tutuila (1986-1995).
Aprion virescens	0.030	Directly from Ralston (1979).
Caranx lugubris	0.022	- “Jacks” were 0.03 of the catch (Ralston 1979). - CALU was 0.67 of jacks around Manu’a and 0.73 around Tutuila (1986-1995).
Etelis carbunculus	0.030	- “Etelis/Pristipomoides” were 0.08 of the catch (Ralston 1979). - ETCA was 0.48 of “etelis/prist.” around Manu’a and 0.38 around Tutuila (1986-1995).
Etelis coruscans	0.027	- “Etelis/Pristipomoides” were 0.08 of the catch (Ralston 1979). - ETCO was 0.31 of “etelis/pristi.” around Manu’a and 0.37 around Tutuila (1986-1995).
Lethrinus rubrioperculatus	0.119	- “Lethrinus sp.” was 0.27 of the catch (Ralston 1979). - LERU is 0.45 of “emperors” around Tutuila in 1986-1995 (Manu’a data unreliable for emperors).
Lutjanus kasmira	0.305	Directly from Ralston (1979).
Pristipomoides filamentosus	0.002	- “Etelis/Pristipomoides” were 0.08 of the catch (Ralston 1979). - PRFI was 0.01 of “etelis/prist.” around Manu’a and 0.03 around Tutuila (1986-1995).
Pristipomoides flavipinnis	0.010	- “Etelis/Pristipomoides” were 0.08 of the catch (Ralston 1979). - PRFL was 0.03 of “etelis/prist.” around Manu’a and 0.15 around Tutuila (1986-1995).
Pristipomoides zonatus	0.006	- “Etelis/Pristipomoides” were 0.08 of the catch (Ralston 1979). - PRZO was 0.16 of “etelis/prist.” around Manu’a and 0.06 around Tutuila (1986-1995).
Variola louti	0.005	- “Groupers” were 0.03 of the catch (Ralston 1979). - VALO was 0.07 of “Groupers” around Manu’a and 0.17 around Tutuila (1986-1995).

Table 7-5 - Species proportion used to break down grouped 1980–1985 historical catches. The 1986–1995 catch compositions are from boat-based creel surveys based on the “bottomfish” group. The Manu‘a I. and Tutuila proportions were averaged using bottomfish habitat weights of 0.13 and 0.87, respectively.

Species	Prop. of bottomfish catch (1980-1985)	Prop. of bottomfish catch (1982-1985) from Hamm and Quach (1988)	Prop. of bottomfish catch (1986-1995) from creel surveys	Note
Aphareus rutilans	0.06	0.08	0.04	Creel prop. was 0.03 around Manu’a and 0.04 around Tutuila.
Aprion virescens	0.09	0.10	0.08	Creel prop. was 0.06 around Manu’a and 0.09 around Tutuila.
Caranx lugubris	0.033	0.003	0.062	Creel prop. was 0.09 around Manu’a and 0.06 around Tutuila.
Etelis carbunculus	0.14	0.19	0.08	Creel prop. was 0.19 around Manu’a and 0.07 around Tutuila.
Etelis coruscans	0.16	0.26	0.07	Creel prop. was 0.13 around Manu’a and 0.06 around Tutuila.
Lethrinus rubrioperculatus	0.13	Not identified	0.13	Creel prop. was 0.13 around Tutuila (Manu’a unreliable).
Lutjanus kasmira	0.12	0.10	0.14	Creel prop. was 0.13 around Manu’a and 0.14 around Tutuila.
Pristipomoides filamentosus	0.02	0.028	0.005	Creel prop. was 0.003 around Manu’a and 0.005 around Tutuila.
Pristipomoides flavipinnis	0.03	0.04	0.03	Creel prop. was 0.01 around Manu’a and 0.03 around Tutuila.
Pristipomoides zonatus	0.03	0.05	0.02	Creel prop. was 0.06 around Manu’a and 0.01 around Tutuila.
Variola louti	0.02	0.02	0.02	Creel prop. was 0.01 around Manu’a and 0.02 around Tutuila.

Table 7-6 - Total catch by species from 1967 to 2021 (continued on next page).

Sp	Yr	MT	CV	Yr	MT	CV	Yr	MT	CV	Yr	MT	CV
APRU	1967	0.017	0.5	1981	1.257	0.5	1995	0.434	0.74	2009	3.253	0.19
APRU	1968	0.06	0.5	1982	1.612	0.5	1996	1.315	0.58	2010	0.678	0.27
APRU	1969	0.019	0.5	1983	3.253	0.5	1997	1.291	0.26	2011	1.189	0.78
APRU	1970	0.007	0.5	1984	2.413	0.5	1998	0.175	0.52	2012	0.531	1.49
APRU	1971	0	0.5	1985	2.579	0.5	1999	0.401	0.72	2013	1.338	1.05
APRU	1972	0.177	0.5	1986	1.566	1.38	2000	0.523	0.51	2014	1.631	0.53
APRU	1973	0.247	0.5	1987	0.466	1.72	2001	0.553	0.35	2015	1.845	0.28
APRU	1974	0.171	0.5	1988	1.153	1.15	2002	2.206	0.51	2016	1.428	0.22
APRU	1975	0.226	0.5	1989	0.586	0.33	2003	0.248	0.31	2017	1.565	0.17
APRU	1976	0.185	0.5	1990	0.065	1.56	2004	0.439	1.47	2018	0.902	0.31
APRU	1977	0.082	0.5	1991	0.122	0.48	2005	0.472	1.43	2019	1.244	0.34
APRU	1978	0.033	0.5	1992	0.324	0.63	2006	0.199	1.58	2020	0.239	0.39
APRU	1979	0.028	0.5	1993	0.182	0.89	2007	1.254	0.79	2021	0.034	0.45
APRU	1980	0.661	0.5	1994	0.689	0.36	2008	1.638	0.58			
APVI	1967	0.086	0.5	1981	1.998	0.5	1995	1.359	0.34	2009	4.395	0.14
APVI	1968	0.305	0.5	1982	2.562	0.5	1996	1.971	0.39	2010	0.771	0.31
APVI	1969	0.094	0.5	1983	5.171	0.5	1997	1.578	0.21	2011	1.515	0.65
APVI	1970	0.033	0.5	1984	3.836	0.5	1998	0.253	0.41	2012	0.463	1.31
APVI	1971	0	0.5	1985	4.099	0.5	1999	0.488	0.65	2013	1.888	0.83

Sp	Yr	MT	CV	Yr	MT	CV	Yr	MT	CV	Yr	MT	CV
APVI	1972	0.891	0.5	1986	3.044	0.96	2000	1.781	0.46	2014	2.195	0.4
APVI	1973	1.246	0.5	1987	0.99	1.27	2001	0.992	0.33	2015	2.553	0.27
APVI	1974	0.861	0.5	1988	1.321	1.06	2002	1.544	0.33	2016	2.993	0.16
APVI	1975	1.14	0.5	1989	1.053	0.25	2003	0.443	0.17	2017	1.911	0.17
APVI	1976	0.932	0.5	1990	0.556	0.44	2004	1.148	0.88	2018	0.946	0.16
APVI	1977	0.411	0.5	1991	1.138	0.23	2005	0.728	1.16	2019	1.25	0.16
APVI	1978	0.165	0.5	1992	0.767	0.36	2006	0.399	1.15	2020	1.33	0.15
APVI	1979	0.138	0.5	1993	0.968	0.33	2007	1.305	0.76	2021	0.123	0.29
APVI	1980	1.051	0.5	1994	1.587	0.2	2008	2.352	0.43			
CALU	1967	0.063	0.5	1981	0.714	0.5	1995	1.297	0.35	2009	1.665	0.34
CALU	1968	0.221	0.5	1982	0.915	0.5	1996	1.077	0.62	2010	0.555	0.3
CALU	1969	0.068	0.5	1983	1.848	0.5	1997	1.742	0.23	2011	0.38	1.48
CALU	1970	0.024	0.5	1984	1.371	0.5	1998	0.379	0.36	2012	0.255	1.73
CALU	1971	0	0.5	1985	1.465	0.5	1999	0.765	0.52	2013	0.44	1.71
CALU	1972	0.647	0.5	1986	2.312	1.13	2000	0.439	0.36	2014	0.274	0.19
CALU	1973	0.904	0.5	1987	0.686	1.5	2001	0.604	0.26	2015	0.565	0.15
CALU	1974	0.625	0.5	1988	1.507	0.97	2002	0.42	0.58	2016	0.76	0.19
CALU	1975	0.827	0.5	1989	1.244	0.22	2003	0.509	0.27	2017	0.675	0.17
CALU	1976	0.676	0.5	1990	0.528	0.44	2004	0.582	1.3	2018	0.633	0.18
CALU	1977	0.298	0.5	1991	0.6	0.19	2005	0.427	1.49	2019	0.577	0.16
CALU	1978	0.119	0.5	1992	0.348	0.57	2006	0.167	1.67	2020	0.338	0.34
CALU	1979	0.101	0.5	1993	0.386	0.51	2007	0.517	1.33	2021	0.037	0.49
CALU	1980	0.376	0.5	1994	0.773	0.24	2008	0.42	1.33			
ETCO	1967	0.078	0.5	1981	3.595	0.5	1995	1.385	0.35	2009	3.25	0.23
ETCO	1968	0.273	0.5	1982	4.61	0.5	1996	1.226	0.55	2010	0.827	0.34
ETCO	1969	0.084	0.5	1983	9.305	0.5	1997	1.952	0.32	2011	2.453	0.53
ETCO	1970	0.03	0.5	1984	6.902	0.5	1998	2.27	0.26	2012	0.512	1.41
ETCO	1971	0	0.5	1985	7.376	0.5	1999	0.969	0.41	2013	1.27	1.07
ETCO	1972	0.798	0.5	1986	3.959	0.81	2000	0.334	0.46	2014	2.308	0.38
ETCO	1973	1.117	0.5	1987	0.797	1.41	2001	2.097	0.35	2015	1.923	0.23
ETCO	1974	0.772	0.5	1988	1.374	1.03	2002	0.673	0.62	2016	3.061	0.21
ETCO	1975	1.021	0.5	1989	0.668	0.41	2003	0.472	0.46	2017	1.514	0.21
ETCO	1976	0.835	0.5	1990	0.143	1.1	2004	0.716	1.17	2018	1.52	0.23
ETCO	1977	0.368	0.5	1991	0.314	0.51	2005	1.306	0.83	2019	0.624	0.29
ETCO	1978	0.147	0.5	1992	0.014	2.32	2006	0.218	1.52	2020	0.633	0.36
ETCO	1979	0.124	0.5	1993	0.837	0.46	2007	1.361	0.74	2021	0.156	0.63
ETCO	1980	1.892	0.5	1994	1.159	0.21	2008	2.041	0.48			
LERU	1967	0.343	0.5	1981	2.742	0.5	1995	1.19	0.46	2009	7.036	0.13
LERU	1968	1.212	0.5	1982	3.516	0.5	1996	2.159	0.42	2010	1.486	0.19
LERU	1969	0.375	0.5	1983	7.097	0.5	1997	1.71	0.3	2011	3.663	0.31
LERU	1970	0.132	0.5	1984	5.264	0.5	1998	0.232	0.75	2012	1.134	0.78
LERU	1971	0	0.5	1985	5.625	0.5	1999	0.29	0.88	2013	2.212	0.74
LERU	1972	3.543	0.5	1986	4.183	0.77	2000	1.439	0.84	2014	1.062	0.34
LERU	1973	4.955	0.5	1987	1.415	1.05	2001	4.288	0.54	2015	3.072	0.26
LERU	1974	3.422	0.5	1988	2.428	0.7	2002	2.884	0.48	2016	0.875	0.18
LERU	1975	4.533	0.5	1989	2.36	0.18	2003	1.158	0.46	2017	0.617	0.21
LERU	1976	3.704	0.5	1990	1.125	0.28	2004	1.386	0.77	2018	0.403	0.14
LERU	1977	1.634	0.5	1991	0.967	0.23	2005	0.849	1.06	2019	0.812	0.15
LERU	1978	0.654	0.5	1992	1.389	0.46	2006	0.391	1.17	2020	0.435	0.12
LERU	1979	0.551	0.5	1993	0.626	0.59	2007	1.612	0.66	2021	0.191	0.41
LERU	1980	1.443	0.5	1994	1.529	0.39	2008	3.325	0.33			
LUKA	1967	0.879	0.5	1981	2.679	0.5	1995	2.074	0.25	2009	4.055	0.1
LUKA	1968	3.099	0.5	1982	3.436	0.5	1996	1.417	0.5	2010	1.135	0.15
LUKA	1969	0.958	0.5	1983	6.935	0.5	1997	2.586	0.18	2011	2.001	0.5

Sp	Yr	MT	CV	Yr	MT	CV	Yr	MT	CV	Yr	MT	CV
LUKA	1970	0.337	0.5	1984	5.144	0.5	1998	0.428	0.34	2012	0.53	1.23
LUKA	1971	0	0.5	1985	5.498	0.5	1999	0.539	0.55	2013	1.649	0.91
LUKA	1972	9.062	0.5	1986	5.009	0.67	2000	2.052	0.28	2014	1.806	0.44
LUKA	1973	12.674	0.5	1987	1.677	0.94	2001	2.889	0.26	2015	1.849	0.17
LUKA	1974	8.753	0.5	1988	3.917	0.47	2002	3.516	0.21	2016	0.564	0.14
LUKA	1975	11.593	0.5	1989	2.772	0.15	2003	1.147	0.23	2017	0.362	0.16
LUKA	1976	9.473	0.5	1990	1.397	0.25	2004	1.483	0.73	2018	0.236	0.13
LUKA	1977	4.179	0.5	1991	1.138	0.22	2005	0.583	1.3	2019	0.342	0.15
LUKA	1978	1.672	0.5	1992	0.563	0.43	2006	0.27	1.39	2020	0.264	0.14
LUKA	1979	1.408	0.5	1993	0.94	0.32	2007	0.866	1.01	2021	0.171	0.48
LUKA	1980	1.41	0.5	1994	1.841	0.17	2008	1.256	0.66			
PRFL	1967	0.03	0.5	1981	0.725	0.5	1995	0.45	0.76	2009	1.241	0.27
PRFL	1968	0.106	0.5	1982	0.929	0.5	1996	0.344	1.31	2010	0.163	0.36
PRFL	1969	0.033	0.5	1983	1.876	0.5	1997	0.989	0.5	2011	0.355	1.52
PRFL	1970	0.011	0.5	1984	1.392	0.5	1998	0.254	0.43	2012	0.286	1.76
PRFL	1971	0	0.5	1985	1.487	0.5	1999	0.36	0.78	2013	0.275	1.96
PRFL	1972	0.309	0.5	1986	1.191	1.55	2000	0.093	0.21	2014	0.292	1.49
PRFL	1973	0.432	0.5	1987	0.327	1.91	2001	1.243	0.46	2015	0.554	0.48
PRFL	1974	0.298	0.5	1988	0.667	1.48	2002	0.735	0.51	2016	0.6	0.29
PRFL	1975	0.395	0.5	1989	0.138	0.32	2003	0.169	1.01	2017	0.093	0.34
PRFL	1976	0.323	0.5	1990	0.015	2.28	2004	0.258	1.78	2018	0.161	0.31
PRFL	1977	0.142	0.5	1991	0.276	0.42	2005	0.379	1.56	2019	0.115	0.38
PRFL	1978	0.057	0.5	1992	0.092	1.35	2006	0.078	2.07	2020	0.075	0.41
PRFL	1979	0.048	0.5	1993	0.205	0.85	2007	0.196	1.89	2021	0.011	0.4
PRFL	1980	0.381	0.5	1994	0.481	0.52	2008	0.537	1.2			
PRZO	1967	0.016	0.5	1981	0.716	0.5	1995	0.176	1.27	2009	0.094	0.33
PRZO	1968	0.056	0.5	1982	0.918	0.5	1996	0.191	1.64	2010	0.086	0.32
PRZO	1969	0.017	0.5	1983	1.852	0.5	1997	0.32	0.64	2011	0.076	2.3
PRZO	1970	0.006	0.5	1984	1.374	0.5	1998	0.171	0.56	2012	0.032	2.8
PRZO	1971	0	0.5	1985	1.468	0.5	1999	0.115	1.44	2013	0.073	2.54
PRZO	1972	0.165	0.5	1986	0.669	1.86	2000	0.059	0	2014	0.127	1.94
PRZO	1973	0.23	0.5	1987	0.136	2.32	2001	0.077	0.78	2015	0.11	1.33
PRZO	1974	0.159	0.5	1988	0.357	1.83	2002	0.058	1.54	2016	0.259	0.17
PRZO	1975	0.21	0.5	1989	0.215	0.47	2003	0.057	1.61	2017	0.245	0.17
PRZO	1976	0.172	0.5	1990	0.158	1.02	2004	0.086	2.31	2018	0.127	0.22
PRZO	1977	0.076	0.5	1991	0.044	0	2005	0.166	2	2019	0.072	0.27
PRZO	1978	0.03	0.5	1992	0.126	1.14	2006	0.061	2.18	2020	0.05	0.42
PRZO	1979	0.025	0.5	1993	0.094	1.24	2007	0.131	2.09	2021	0.006	0.45
PRZO	1980	0.376	0.5	1994	0.298	0	2008	0.256	1.63			
VALO	1967	0.013	0.5	1981	0.409	0.5	1995	0.349	0.86	2009	0.558	0.26
VALO	1968	0.047	0.5	1982	0.525	0.5	1996	0.312	1.37	2010	0.167	0.52
VALO	1969	0.015	0.5	1983	1.06	0.5	1997	0.638	0.8	2011	0.268	1.68
VALO	1970	0.005	0.5	1984	0.786	0.5	1998	0.064	1.12	2012	0.078	2.26
VALO	1971	0	0.5	1985	0.84	0.5	1999	0.215	1.22	2013	0.345	1.84
VALO	1972	0.136	0.5	1986	0.635	1.89	2000	0.205	0.82	2014	0.293	1.01
VALO	1973	0.19	0.5	1987	0.208	2.13	2001	0.273	0.67	2015	0.16	0.67
VALO	1974	0.132	0.5	1988	0.536	1.61	2002	0.552	0.59	2016	0.063	0.31
VALO	1975	0.174	0.5	1989	0.463	0.49	2003	0.724	0.3	2017	0.055	0.35
VALO	1976	0.142	0.5	1990	0.126	1.16	2004	0.277	1.74	2018	0.065	0.18
VALO	1977	0.063	0.5	1991	0.221	0.31	2005	0.135	2.1	2019	0.186	0.11
VALO	1978	0.025	0.5	1992	0.126	1.18	2006	0.117	1.87	2020	0.112	0.25
VALO	1979	0.021	0.5	1993	0.143	1.08	2007	0.277	1.7	2021	0.014	0.47
VALO	1980	0.215	0.5	1994	0.391	0.78	2008	0.395	1.38			

Table 7-7 – Summary of model selection steps for CPUE standardization. The backward selection process started with the full model and iteratively removed the least informative variable until the increase in AIC was > 2. The first line shows the full model, followed by reduced models, and finally, in bold, the best model.

Aphareus rutilans

Model type	Formula	AIC	ΔAIC
Non-zero catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	282.8	
	-SEASON	279.3	-3.6
	-YEAR:AREA	277.5	-1.7
	-HOURS_FISHED	275.8	-1.7
	-PC1	275.8	-0.1
	-WINDSPEED	277.4	1.6
	-AREA	278.0	0.6
	YEAR + NUM_GEAR + PC2 + TYPE_OF_DAY	278.0	
Probability of catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	313.6	
	-YEAR:AREA	311.5	-2.1
	-SEASON	306.7	-4.8
	-TYPE_OF_DAY	304.9	-1.9
	-AREA	303.3	-1.6
	-PC1	303.8	0.5
	YEAR + HOURS_FISHED + NUM_GEAR + WINDSPEED + PC2	303.8	

Aprion virescens

Model type	Formula	AIC	ΔAIC
Non-zero catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	423.4	
	-AREA	423.4	0
	-NUM_GEAR	421.6	-1.8
	-HOURS_FISHED	419.1	-2.5
	-TYPE_OF_DAY	417.3	-1.8
	-PC1	415.4	-1.9
	-YEAR:AREA	411.2	-4.2
	-WINDSPEED	411.1	-0.1
	-SEASON	412.4	1.3
	YEAR + PC2	412.4	
Probability of catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	346.6	
	-YEAR:AREA	342.1	-4.6
	-HOURS_FISHED	340.2	-1.9
	-TYPE_OF_DAY	339.8	-0.4
	-WINDSPEED	340.1	0.3
	-SEASON	340.5	0.4
	YEAR + AREA + NUM_GEAR + PC1 + PC2	340.5	

Table 7-7 (continued)

Caranx lugubris

Model type	Formula	AIC	ΔAIC
Non-zero catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	215.8	
	-NUM_GEAR	213.8	-2
	-PC2	211.8	-2
	-TYPE_OF_DAY	209.9	-1.9
	-PC1	208.5	-1.3
	-SEASON	205.3	-3.2
	-HOURS_FISHED	205.1	-0.3
	-WINDSPEED	204.3	-0.8
	-YEAR:AREA	203.9	-0.4
	YEAR + AREA	203.9	
Probability of catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	293.2	
	-YEAR:AREA	294.4	1.2
	-WINDSPEED	291.9	-2.4
	-NUM_GEAR	290.1	-1.9
	-AREA	288.1	-2
	-SEASON	284.1	-4
	YEAR + HOURS_FISHED + PC1 + PC2 + TYPE_OF_DAY	284.1	

Etelis coruscans

Model type	Formula	AIC	ΔAIC
Non-zero catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	201.9	
	-NUM_GEAR	200.1	-1.8
	-HOURS_FISHED	198.4	-1.7
	-TYPE_OF_DAY	197	-1.4
	-WINDSPEED	195.6	-1.5
	-YEAR:AREA	194.3	-1.3
	-AREA	193.8	-0.4
	-PC1	195	1.2
	YEAR + SEASON + PC2	195	
Probability of catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	263.8	
	-YEAR:AREA	261.1	-2.7
	-PC1	259.2	-1.9
	-TYPE_OF_DAY	257.4	-1.8
	-AREA	256.3	-1.2
	-SEASON	257.2	0.9
	YEAR + HOURS_FISHED + NUM_GEAR + WINDSPEED + PC2	257.2	

Table 7-7 (continued)

Lethrinus rubrioperculatus

Model type	Formula	AIC	ΔAIC
Non-zero catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	500.4	
	-YEAR:AREA	498.5	-1.9
	-HOURS_FISHED	496.7	-1.8
	-TYPE_OF_DAY	495.1	-1.5
	-AREA	493.9	-1.3
	-PC1	492.9	-1
	-PC2	492	-0.8
	-NUM_GEAR	491.6	-0.4
	YEAR + SEASON + WINDSPEED	491.6	
Probability of catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	287	
	-YEAR:AREA	288	1.1
	-NUM_GEAR	286	-2
	-AREA	284.1	-2
	-SEASON	279.5	-4.5
	-HOURS_FISHED	278.9	-0.6
	-TYPE_OF_DAY	278.3	-0.6
	-WINDSPEED	278.4	0.1
	YEAR + PC1 + PC2	278.4	

Lutjanus kasmira

Model type	Formula	AIC	ΔAIC
Non-zero catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	522.8	
	-HOURS_FISHED	520.8	-2
	-YEAR:AREA	515.5	-5.3
	-PC1	513.1	-2.4
	-NUM_GEAR	511.3	-1.8
	-TYPE_OF_DAY	509.6	-1.7
	-PC2	508.3	-1.3
	-SEASON	506.4	-1.9
	-AREA	505.9	-0.5
	-WINDSPEED	505.8	-0.1
	YEAR	505.8	
Probability of catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	298.4	
	-YEAR:AREA	298.8	0.4
	-TYPE_OF_DAY	297.2	-1.6
	-WINDSPEED	294.8	-2.5
	-PC2	295.1	0.3
	-HOURS_FISHED	295	-0.1
	YEAR + AREA + NUM_GEAR + SEASON + PC1	295	

Table 7-7 (continued)

Pristipomoides flavipinnis

Model type	Formula	AIC	ΔAIC
Non-zero catch	YEAR + AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	120.8	
	-SEASON	116.3	-4.6
	-NUM_GEAR	114.3	-1.9
	-TYPE_OF_DAY	112.5	-1.8
	-HOURS_FISHED	111	-1.5
	-PC1	109.1	-1.9
	-PC2	107.9	-1.2
	-WINDSPEED	108.9	1
	YEAR + AREA	108.9	
Probability of catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	250.7	0
	-YEAR:AREA	247.4	-3.3
	-HOURS_FISHED	245.4	-2
	-AREA	243.5	-2
	-SEASON	238.3	-5.2
	-TYPE_OF_DAY	236.4	-1.8
	-WINDSPEED	234.9	-1.6
	-PC1	233.3	-1.6
	YEAR + NUM_GEAR + PC2	233.3	

Pristipomoides zonatus

Model type	Formula	AIC	ΔAIC
Non-zero catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	152.8	
	-NUM_GEAR	150.8	-2
	-SEASON	145	-5.8
	-AREA	145	0
	-YEAR:AREA	141.2	-3.9
	-TYPE_OF_DAY	140.1	-1.1
	-WINDSPEED	141.8	1.7
	-PC1	143.5	1.7
	-PC2	142.9	-0.6
	-HOURS_FISHED	143.8	0.9
	YEAR	143.8	
Probability of catch	YEAR + AREA + YEAR:AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	262.4	
	-YEAR:AREA	256.8	-5.6
	-WINDSPEED	255	-1.8
	-SEASON	251.3	-3.7
	-AREA	249.6	-1.7
	-TYPE_OF_DAY	248.2	-1.5
	-HOURS_FISHED	247.5	-0.7
	-NUM_GEAR	247.5	0
	YEAR + PC1 + PC2	247.5	

Table 7-7 (continued)

Variola louti

Model type	Formula	AIC	ΔAIC
Non-zero catch	YEAR + HOURS_FISHED + NUM_GEAR + PC2 + TYPE_OF_DAY	76.6	
	-PC2	75	-1.6
	-NUM_GEAR	73.7	-1.3
	-HOURS_FISHED	72.3	-1.4
	-TYPE_OF_DAY	70.7	-1.6
	YEAR	70.7	
Probability of catch	YEAR + AREA + HOURS_FISHED + NUM_GEAR + SEASON + WINDSPEED + PC1 + PC2 + TYPE_OF_DAY	153.3	
	-AREA	151.4	-1.9
	-TYPE_OF_DAY	150	-1.4
	-PC2	149.5	-0.5
	-WINDSPEED	149.2	-0.2
	-SEASON	147.8	-1.4
	-HOURS_FISHED	148.5	0.7
	-NUM_GEAR	148.3	-0.3
	YEAR + PC1	148.3	

Table 7-8. Standardized catch-per-unit-effort for all species from 2016 to 2021.

Sp	Yr	CPUE	CV	Sp	Yr	CPUE	CV
APRU	2016	2.286	0.33	LUKA	2016	1.788	0.20
APRU	2017	4.494	0.27	LUKA	2017	1.149	0.21
APRU	2018	3.662	0.34	LUKA	2018	1.383	0.20
APRU	2019	2.764	0.32	LUKA	2019	1.836	0.20
APRU	2020	2.542	0.49	LUKA	2020	1.126	0.20
APRU	2021	6.163	0.645	LUKA	2021	1.786	0.41
APVI	2016	9.82	0.20	PRFL	2016	1.410	0.43
APVI	2017	7.16	0.20	PRFL	2017	0.491	0.45
APVI	2018	6.46	0.20	PRFL	2018	1.273	0.32
APVI	2019	8.35	0.20	PRFL	2019	0.697	0.41
APVI	2020	9.43	0.20	PRFL	2020	0.907	0.45
APVI	2021	8.88	0.35	PRZO	2016	0.864	0.26
CALU	2016	2.103	0.28	PRZO	2017	0.765	0.28
CALU	2017	1.686	0.27	PRZO	2018	0.495	0.30
CALU	2018	1.733	0.28	PRZO	2019	0.195	0.54
CALU	2019	3.193	0.22	PRZO	2020	0.241	0.59
CALU	2020	1.082	0.66	VALO	2016	0.072	0.555
ETCO	2016	6.978	0.37	VALO	2017	0.088	0.765
ETCO	2017	3.397	0.44	VALO	2018	0.037	1.028
ETCO	2018	6.094	0.37	VALO	2019	0.208	0.481
ETCO	2019	3.471	0.49	VALO	2020	0.196	0.598
ETCO	2020	10.71	0.61				
ETCO	2021	2.665	0.21				
LERU	2016	2.378	0.21				
LERU	2017	2.568	0.20				
LERU	2018	3.645	0.20				
LERU	2019	2.520	0.20				
LERU	2020	5.681	0.39				
LERU	2021	2.665	0.21				

Table 7-9 – Summary of selected metrics for the BMUS. Overfishing is defined by $F/F_{MSY} > 1$ and overfished status is defined by $SSB/SSB_{MSST} < 1$. Life history sources are indicated by S (StepwiseLH), E (external, or non-local) study, and L (local study).

BMUS	Samoan name	LH source	F/F_{MSY} 2021	SSB/SSB_{MSST} 2021	*SSB* 2021 (mt)	Catch 2019-2021 (mt)	OFL 2028 (mt)	Status in 2021
Aphareus rutilans	Palu-gutusiliva	S	<0.01	3.1	14.2	0.5	4.1	No overfishing , not overfished
Aprion virescens	Asoama	E	0.05	1.7	5.0	0.9	2.2	No overfishing , not overfished
Caranx lugubris	Tafauli	S	0.02	4.4	2.1	0.3	1.3	No overfishing , not overfished
Etelis carbunculus	Palu-malau	-	-	-	-	-	-	Unknown
Etelis coruscans	Palu-loa	E	0.05	1.7	12.9	0.5	2.4	No overfishing , not overfished
Lethrinus rubrioperculatus	Filoa-paomumu	E	0.02	2.8	9.6	0.5	3.4	No overfishing , not overfished
Lutjanus kasmira	Savane	E	<0.01	7.6	12.5	0.3	8.0	No overfishing , not overfished
Pristipomoides filamentosus	Palu-‘ena-‘ena	-	-	-	-	-	-	Unknown
Pristipomoides flavipinnis	Palu-sina	L	<0.01	3.2	3.2	0.1	1.1	No overfishing , not overfished
Pristipomoides zonatus	Palu-ula	E	<0.01	3.3	2.0	<0.1	0.6	No overfishing , not overfished
Variola louti	Velo	S	<0.01	4.1	2.1	0.1	0.9	No overfishing , not overfished

Table 7-10 – Base models sensitivity to the L_{inf} parameter from various sources: other studies, estimates from Stock Synthesis (SS), and the StepwiseLH tool. Base models are in bold.

Species	Source	L_{inf} (cm)	N	SSB_{2021}/ SSB_{MSST}	SSB_{MSST}
APRU	**Stepwise**	**83.3**		3.1	5.0
	Fry (2006) - New Guinea	87.2	14	2.1	3.0
	SS estimated	85.7		2.4	3.4
APVI	**O'Malley (2021) - All regions**	**76.9**	450	1.7	2.8
	O'Malley (2021) - NW Hawaiian I.	74.1	248	1.4	2.7
	O'Malley (2021) - Main Hawaiian I.	77.7	139	1.2	2.7
	O'Malley (2021) - E. Indian Ocean	81.1	63	1.9	2.9
	SS estimated	74.8		2.0	3.0
	Stepwise	72.1		2.8	3.5
CALU	**Stepwise**	**68.8**		4.0	0.5
	SS estimated	66.6		4.4	0.5
	Fry (2006) - New Guinea	57.5	12	7.0	87.5
ETCO	**Andrews (2021) - Hawaii pooled**	**86.8**	187	1.8	7.6
	Uehara (2020) - Japan Pooled	82.1	760	3.5	85.5
	SS	83.5		3.5	72.9
	Stepwise	86.2		2.1	8.4
LERU	**Loubens (1980) - New Caledonia**	**33.9**	29	3.4	2.9
	Trianni (2011) - Mariana	31.5	275	4.2	4.5
	Ebisawa (2009) - Japan	38.3	635	3.0	3.4
	SS estimated	33.3		3.8	3.3
	Stepwise	33.9		3.4	2.9
LUKA	**Loubens (1980) - New Caledonia**	**24.6**	29	7.6	1.7
	Morales-Nin (1990) - Hawaii	32.9	171	5.7	0.5
	SS estimated	24.0		7.7	3.1
	Stepwise	24.7		7.7	1.6
PRFL	**O'Malley (2019) - American Samoa**	**41.2**	373	3.3	1.0
	SS estimated	43.8		2.2	0.8
	Stepwise	45.3		1.7	0.8
PRZO	**Schemmel (2021) - Guam pooled**	**36.9**	316	3.5	0.6
	Andrews (2021) - Hawaii	42.5	39	2.3	0.9
	SS estimated	36.9		3.4	0.7
	Stepwise	37.0		3.3	0.7
VALO	**Stepwise**	**46.1**		4.2	0.5
	Schemmel (2023) - Guam	43.8	287	4.6	0.7
	SS estimated	52.2		3.8	0.4

Table 7-11 - Base models sensitivity to the natural mortality parameter, derived directly from longevity (A_{max}) from different studies and the StepwiseLH tool. Base models are in bold.

Species	Source	A_{max} (yr)	N	SSB_{2021}/ SSB_{MSST}	SSB_{MSST}
APRU	**Stepwise**	**30**		3.1	5.0
	Fry (2006) - New Guinea	16	14	3.7	25.1
APVI	**O'Malley (2021) - All regions**	**32**	450	1.7	2.8
	O'Malley (2021) - NW Hawaiian I.	32	248	1.7	2.8
	O'Malley (2021) - Main Hawaiian I.	27	139	2.5	2.6
	O'Malley (2021) - E. Indian Ocean	32	63	1.7	2.8
	Loubens (1980) - New Caledonia	26	22	3.3	2.8
	Stepwise	24		3.4	2.8
CALU	**Fry (2006) - New Guinea**	**12**	12	4.0	0.5
	Stepwise	10		5.7	0.4
ETCO	**Andrews (2021) - Hawaii pooled**	**55**	187	1.8	7.6
	Uehara (2020) - Japan Pooled	55	760	1.8	7.6
	Stepwise	30		4.0	34.4
LERU	**Loubens (1980) - New Caledonia**	**15**	532	3.4	2.9
	Trianni (2011) - Mariana	8	275	6.3	2.4
	Ebisawa (2009) - Japan	13	635	4.1	2.5
	Stepwise	15		3.4	2.9
LUKA	**Loubens (1980) - New Caledonia**	**8**	29	7.6	1.7
	Morales-Nin (1990) - Hawaii	6	171	8.3	2.3
	Stepwise	13		7.6	4.4
PRFL	**O'Malley (2019) - American Samoa**	**28**	373	3.3	1.0
	Stepwise	21		4.7	4.4
PRZO	**Schemmel (2021) - Guam pooled**	**30**	316	3.5	0.6
	Andrews (2021) - Hawaii	30	39	3.5	0.6
	Stepwise	19		4.5	0.3
VALO	**Grandcourt (2005) - Seychelles**	**15**	101	4.2	0.5
	Schemmel (2023) - Guam	14	287	4.6	0.5
	Stepwise	18		3.5	0.5

Table 7-12 – Summary of life history information for the two un-assessed BMUS and two potential indicator species.

Species	Type	Amax (yr)	Linf (cm)	Depth (m)	Sources
E. carbunculus	Un-assessed	39	57	200 - 400	Andrews (2011), DeMartini (2017)
P. filamentosus	Un-assessed	45	70	100 - 400	Andrews (2012), Uehara (2020)
E. coruscans	Indicator	55	82-87	200 - 400	Andrews (2021), Uehara (2020)
P. flavipinnis	Indicator	28	41	100 - 400	O’Malley (2019)

8 Figures

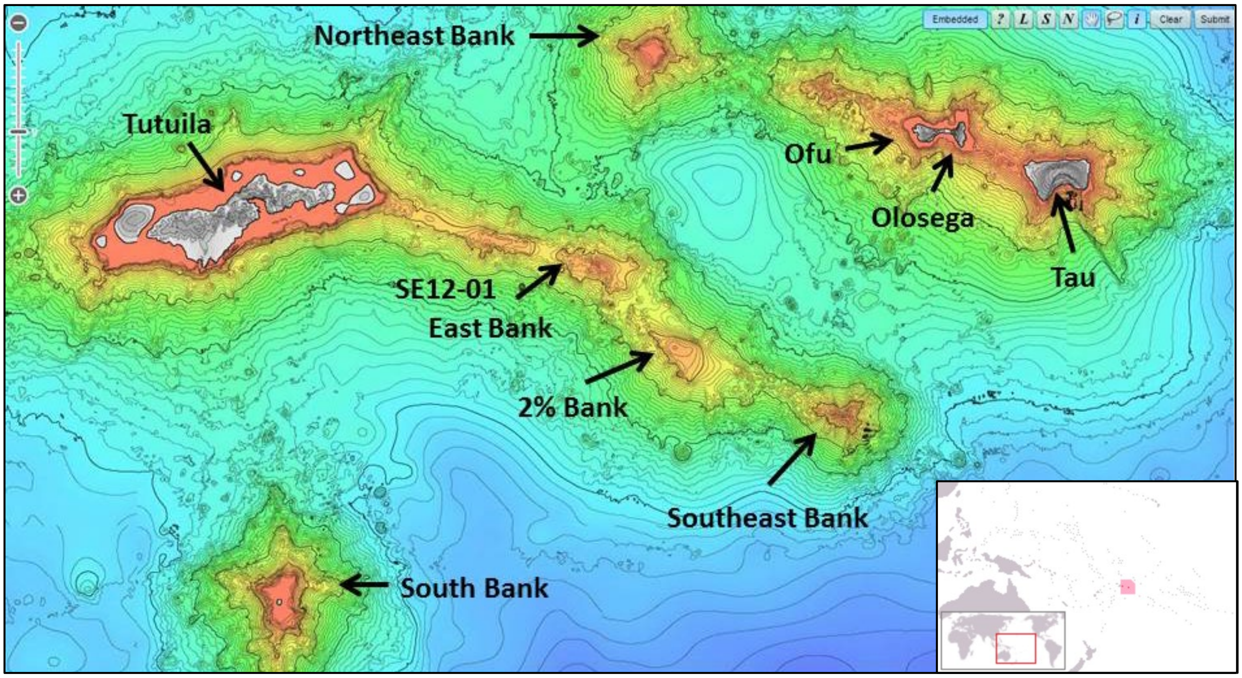


Figure 8-1 – Map of the American Samoa archipelago, with its location on a world map in inset. Ofu-Olosega and Ta'u form the Manu'a Islands.

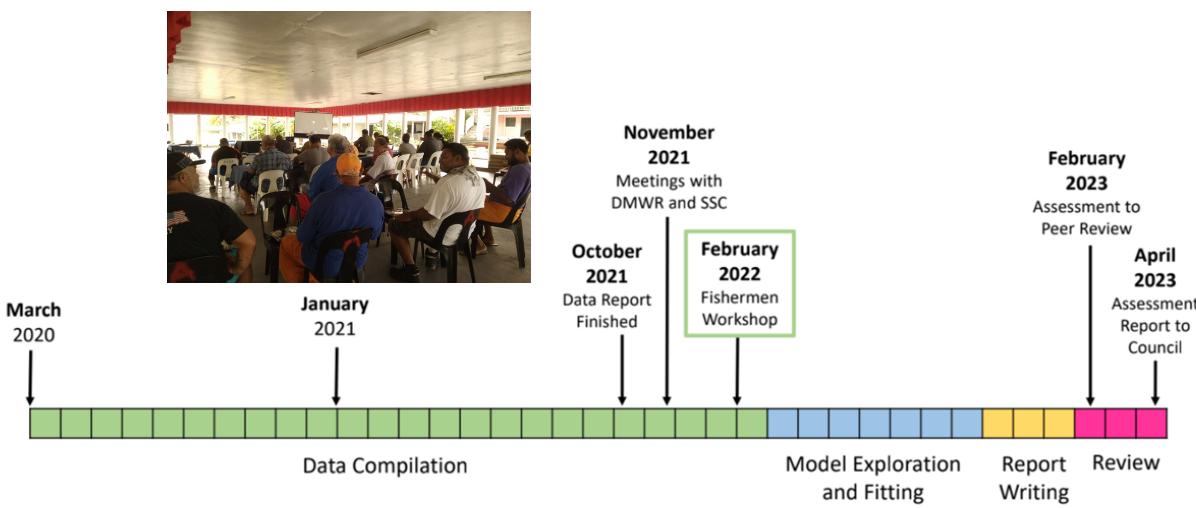


Figure 8-2 – Timeline of the 2023 benchmark assessment process, including the data exploration, model exploration, and report phase. The top picture is from the Manu'a Island fishermen data workshop held in early February 2022.

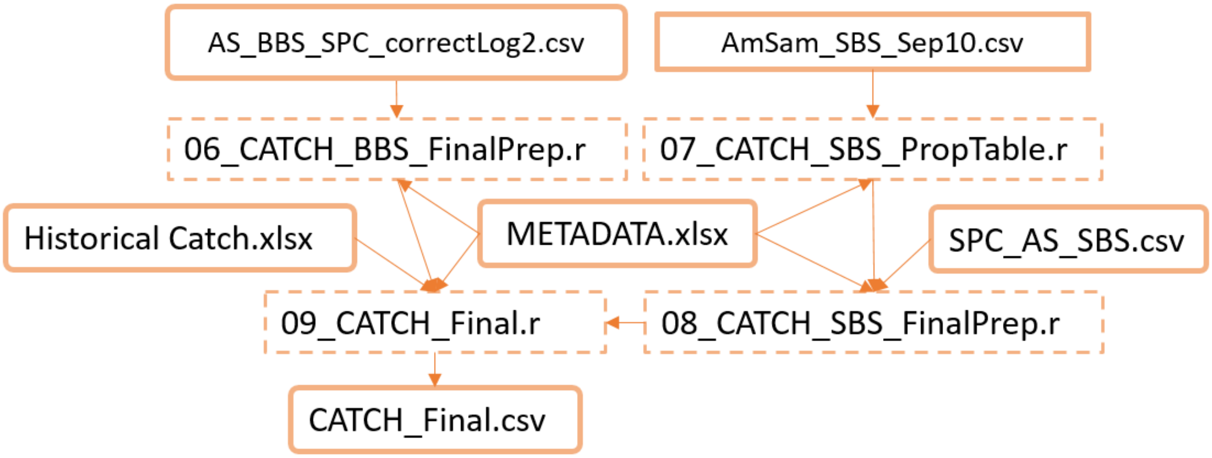


Figure 8-3 – Data (solid boxes) and scripts (dashed boxes) used to generate the final catch data used in our SS models.

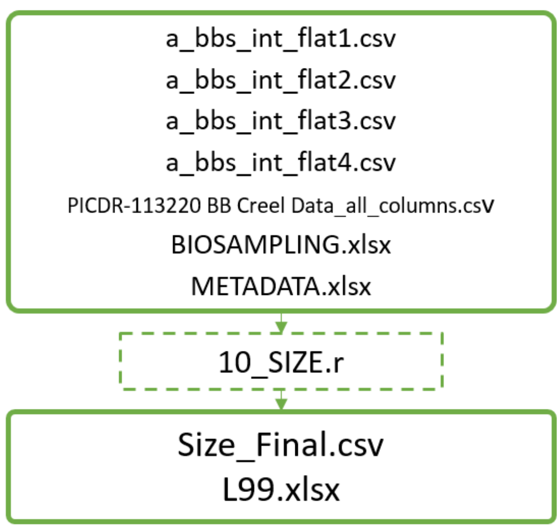


Figure 8-4 - Data (solid boxes) and scripts (dashed boxes) used to generate the final size data used in our SS models.

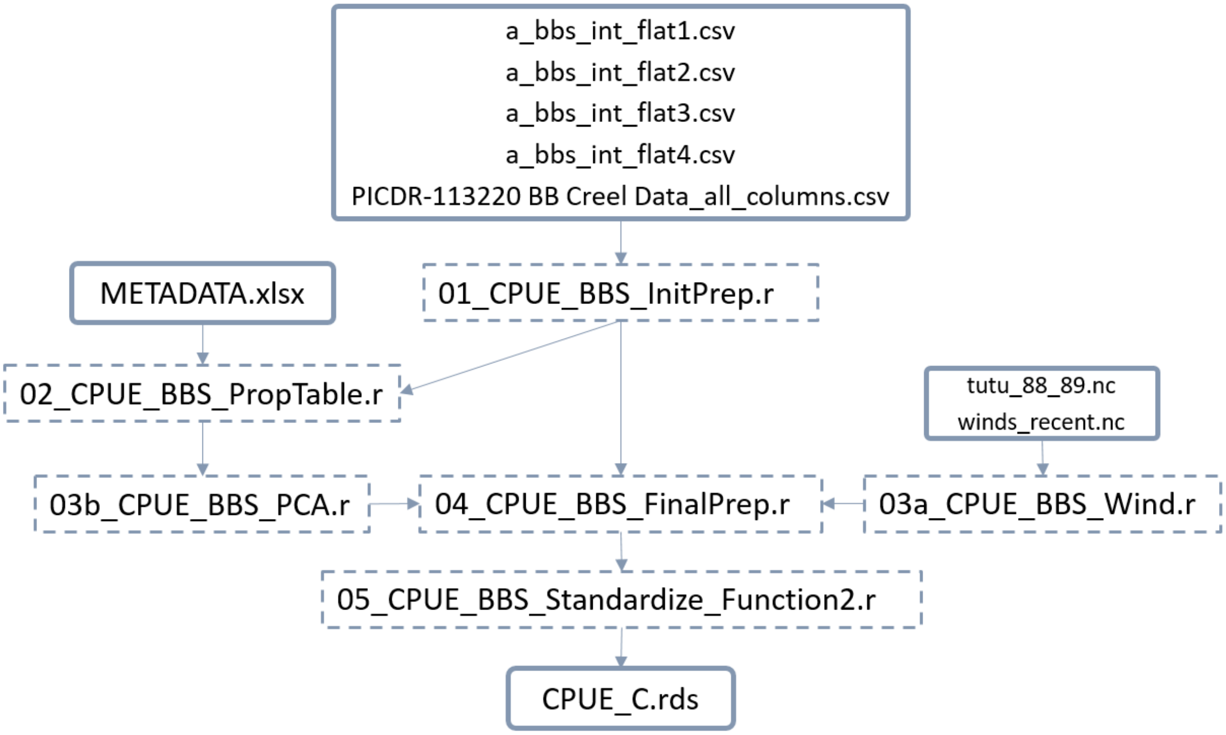


Figure 8-5 – Data (solid boxes) and scripts (dashed boxes) used to generate the final CPUE data used in our SS models.

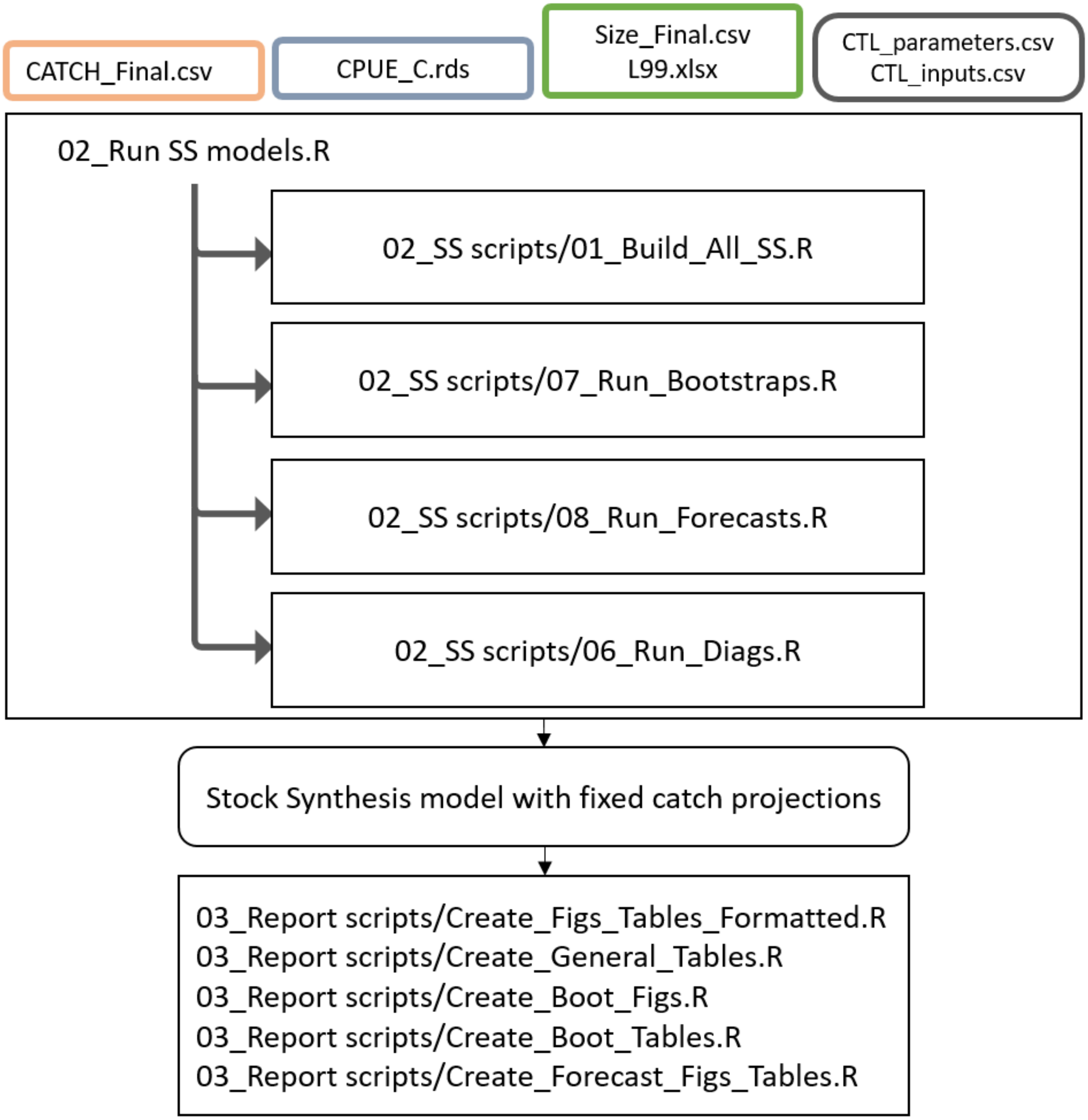


Figure 8-6 – Steps for incorporating processed data files (catch, CPUE, and size) into SS models, running parametric bootstrap and forecasting with SS, and output processing to generate the final figures and tables used in the current report.

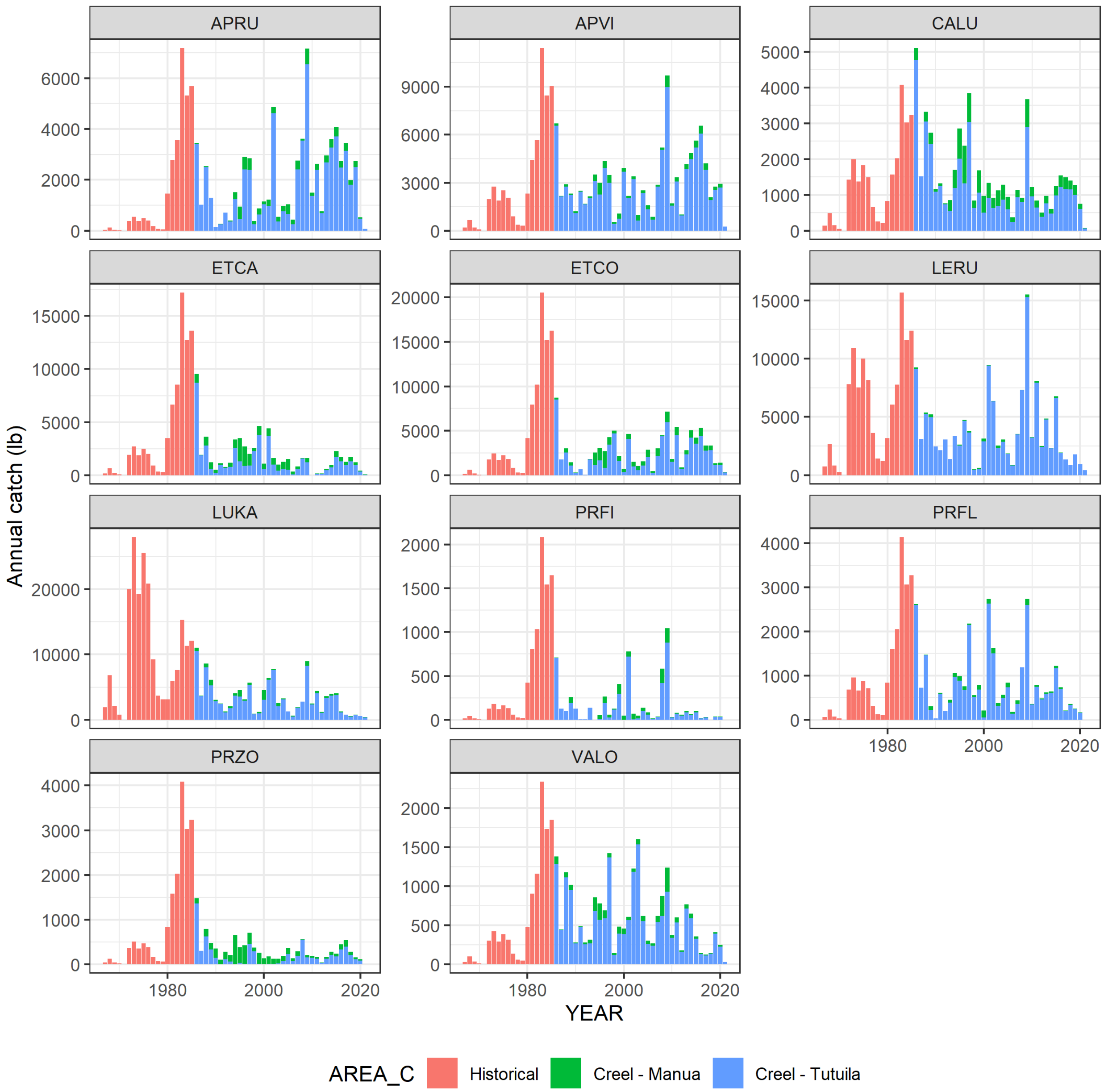


Figure 8-7 – Total catch by species by year from historical reports and creel surveys (split by area). Species code represents the first two letters of the genus and species name (see table Table 7-1).

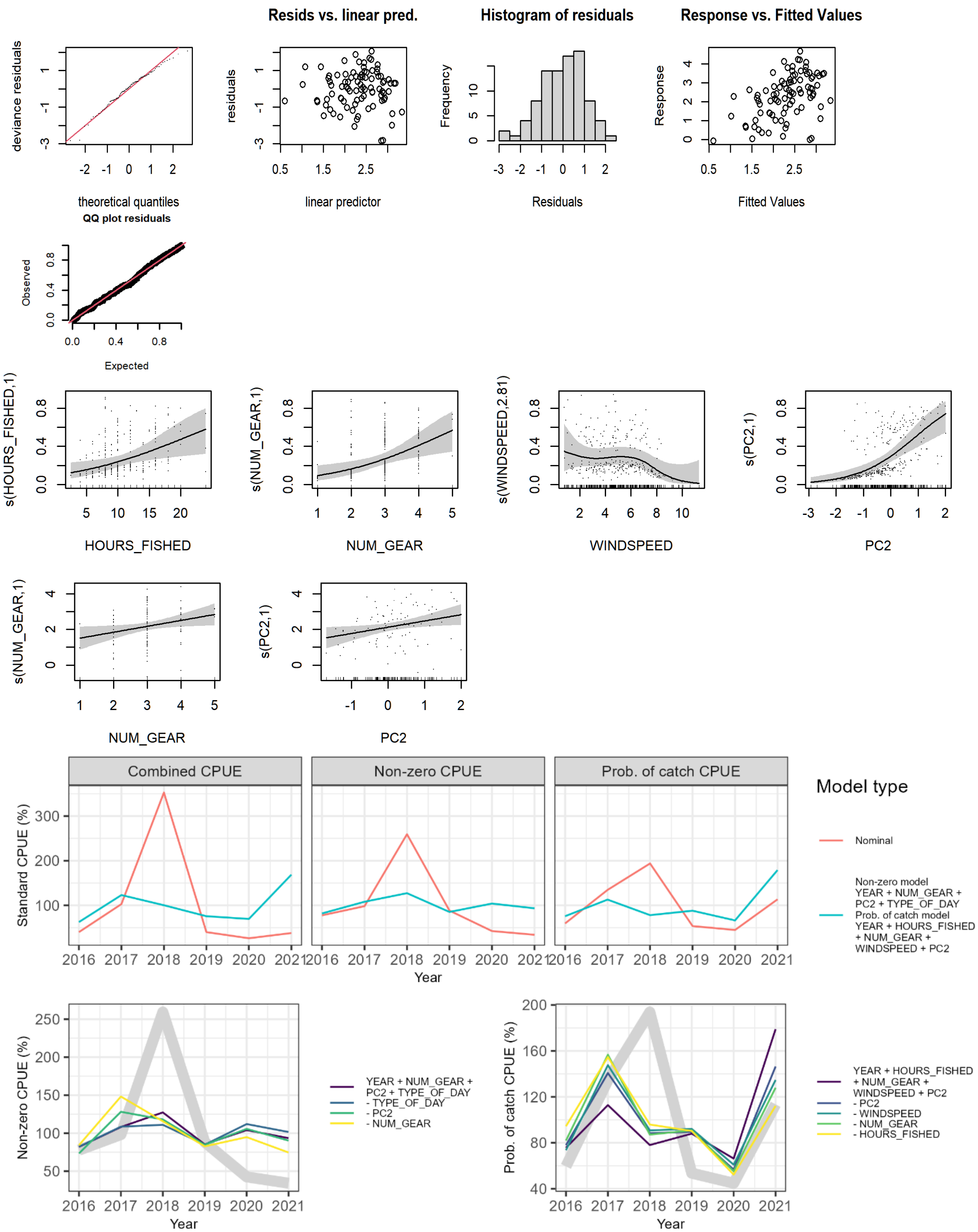


Figure 8-8 - CPUE model diagnostics for *Aphareus rutilans*. The first two rows contain residual plots followed by partial effect plots of smooth terms for the non-zero catch and probability of catch models. Row 5 shows plots comparing nominal CPUE vs. the best CPUE model, while the last row shows plots comparing progressively simpler version of the best model.

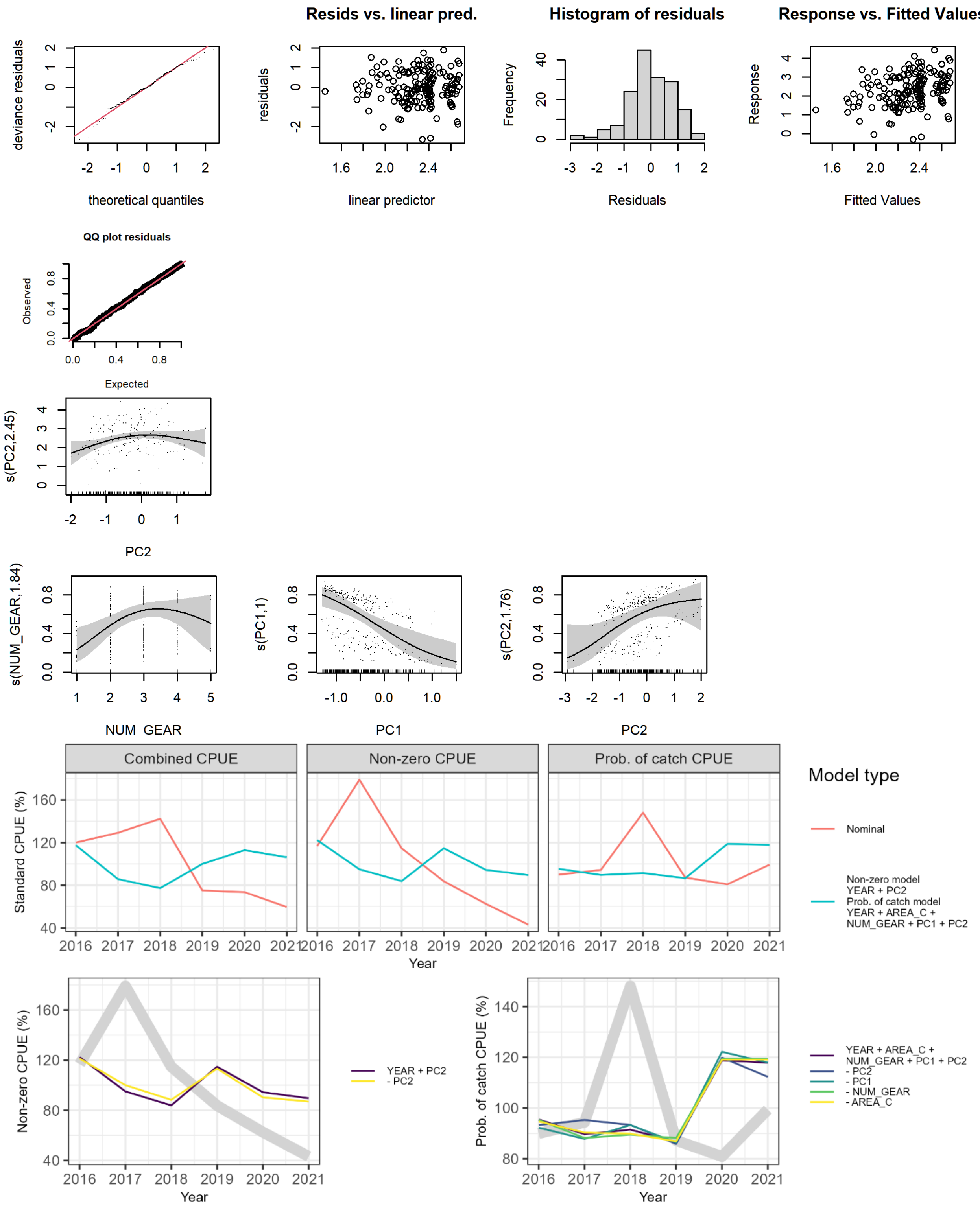


Figure 8-9 CPUE model diagnostics for *Aprion virescens*. The first two rows contain residual plots followed by partial effect plots of smooth terms for the non-zero catch and probability of catch models. Row 5 shows plots comparing nominal CPUE vs. the best CPUE model, the last row shows plots comparing progressively simpler version of the best model.

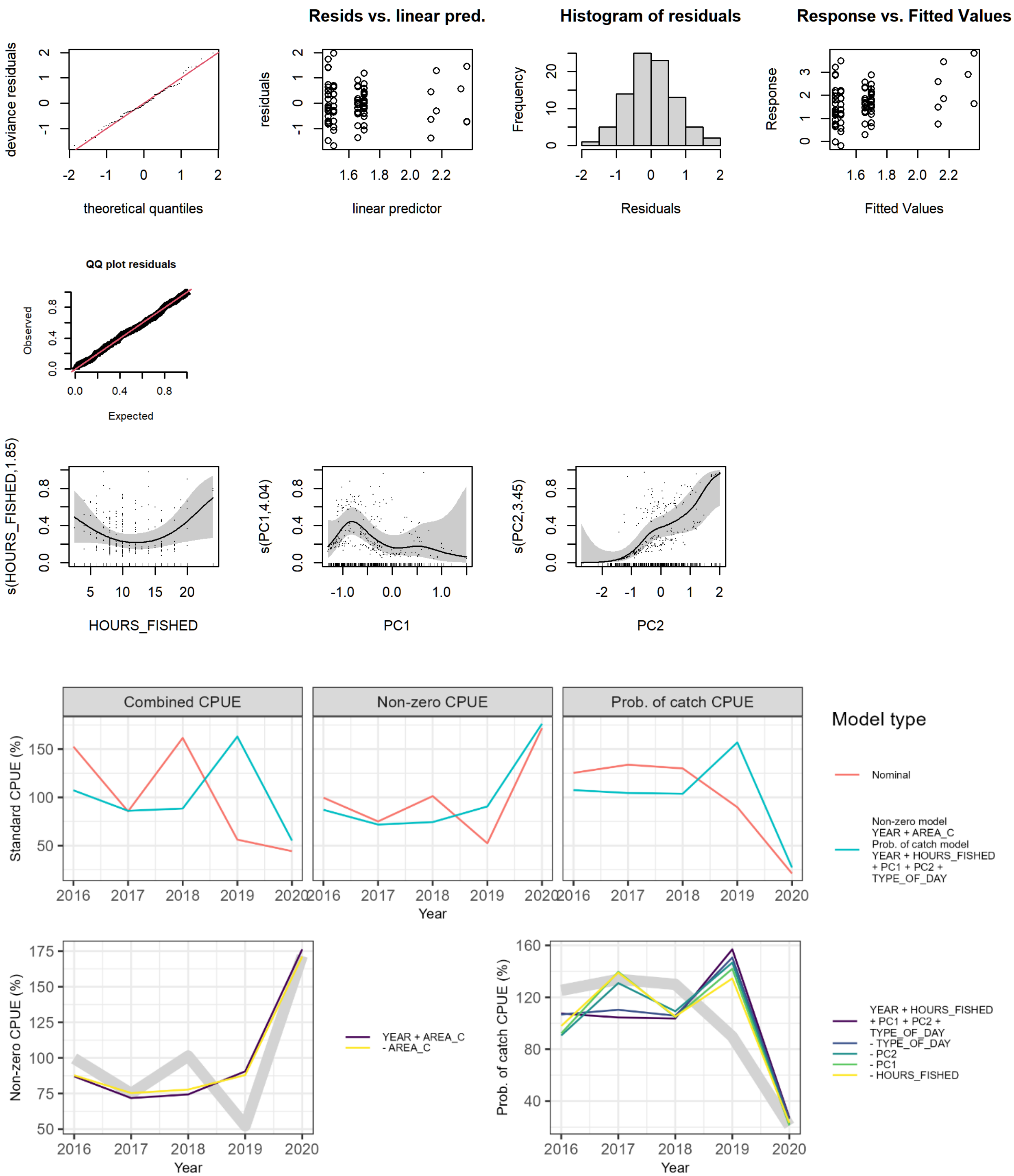


Figure 8-10 CPUE model diagnostics for *Caranx lugubris*. The first two rows contain residual plots for the non-zero and probability of catch models, followed by partial effect plots of smooth terms for the probability of catch model. Row 4 shows plots comparing nominal CPUE vs. the best CPUE model, while the last row shows plots comparing progressively simpler version of the best model.

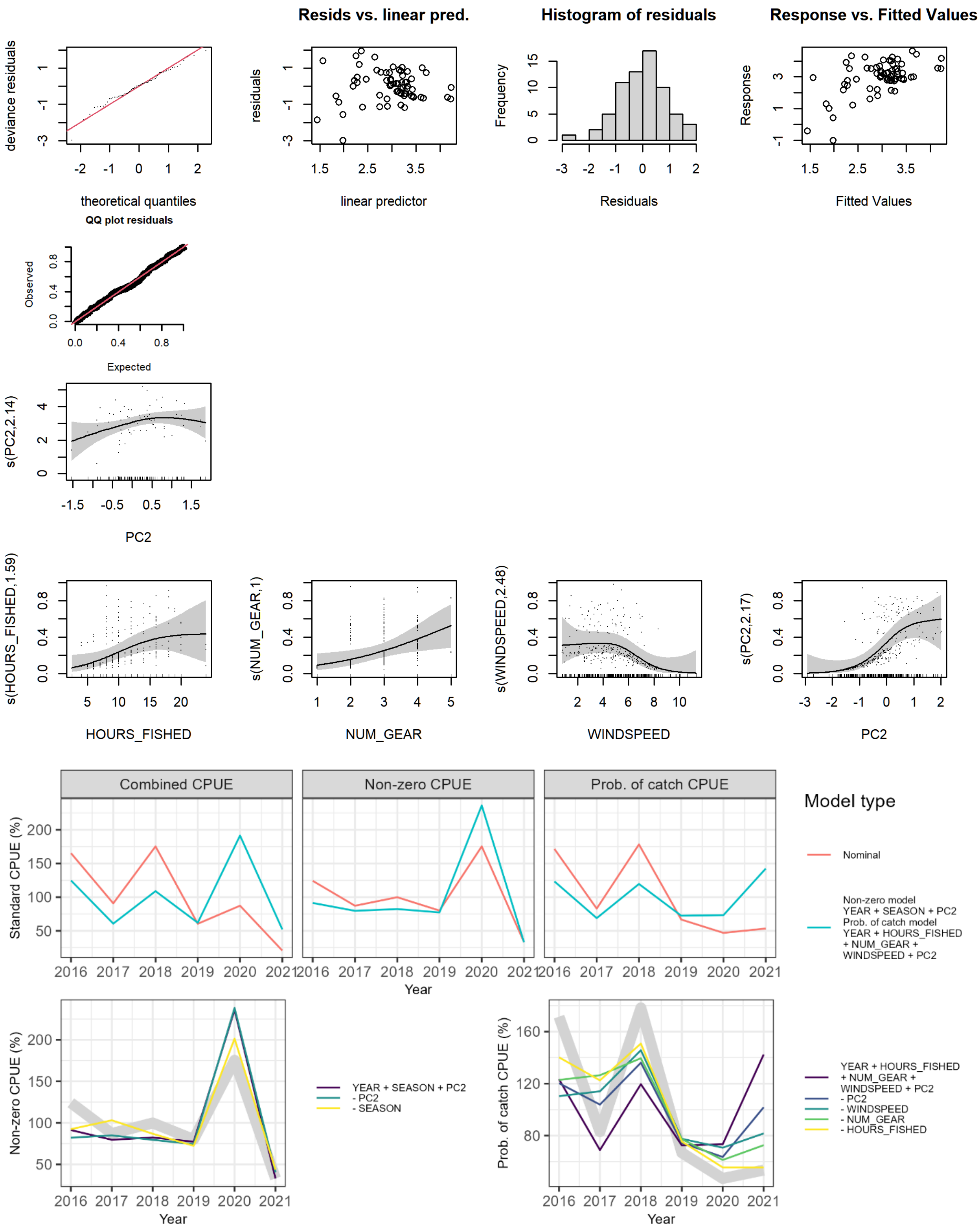


Figure 8-11 CPUE model diagnostics for *Etelis coruscans*. The first two rows contain residual plots followed by partial effect plots of smooth terms for the non-zero catch and probability of catch models. Row 5 shows plots comparing nominal CPUE vs. the best CPUE model, while the last row shows plots comparing progressively simpler version of the best model.

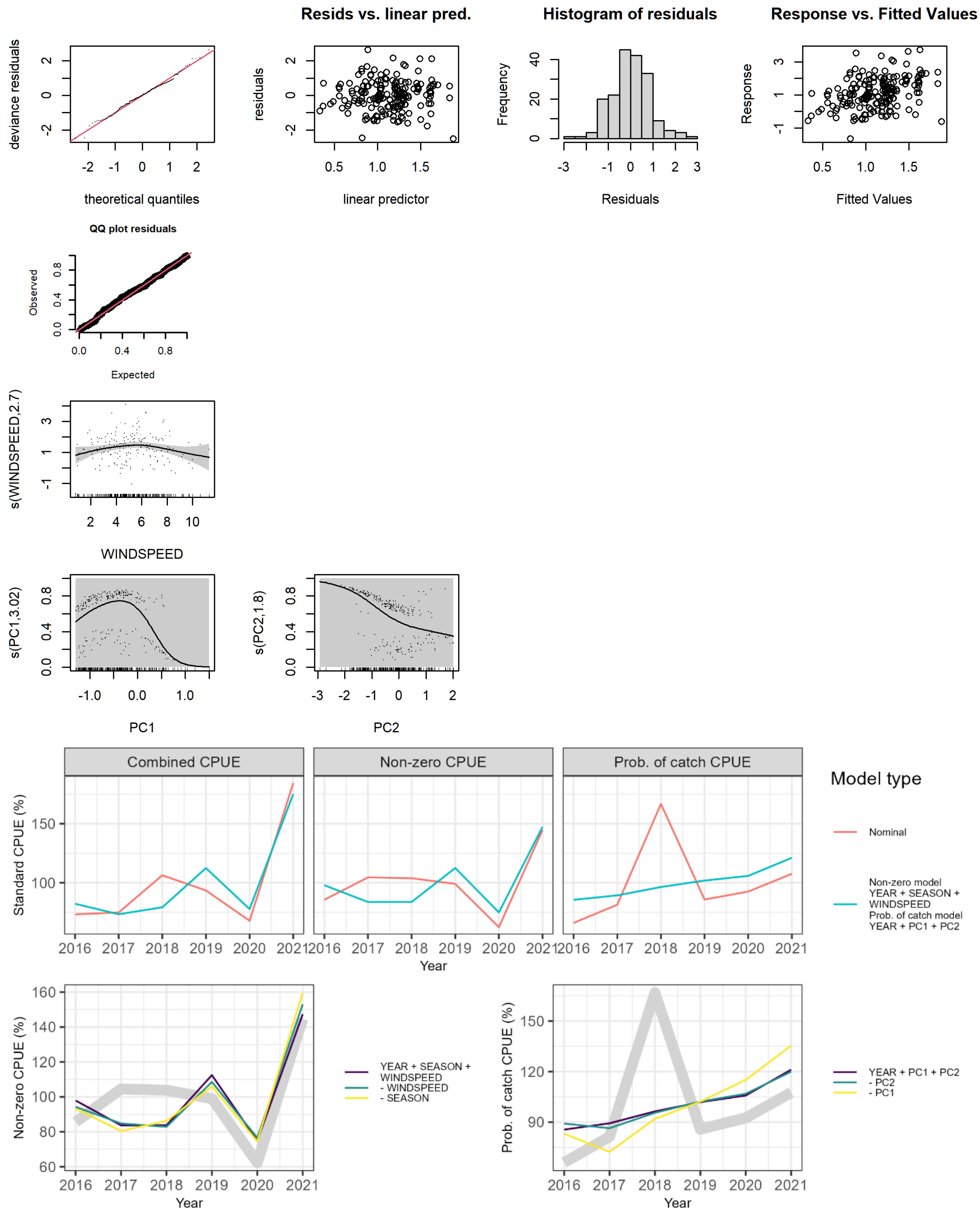


Figure 8-12 CPUE model diagnostics for *Lethrinus rubrioperculatus*. The first two rows contain residual plots followed by partial effect plots of smooth terms for the non-zero catch and probability of catch models. Row 5 shows plots comparing nominal CPUE vs. the best CPUE model, while the last row shows plots comparing progressively simpler version of the best model.

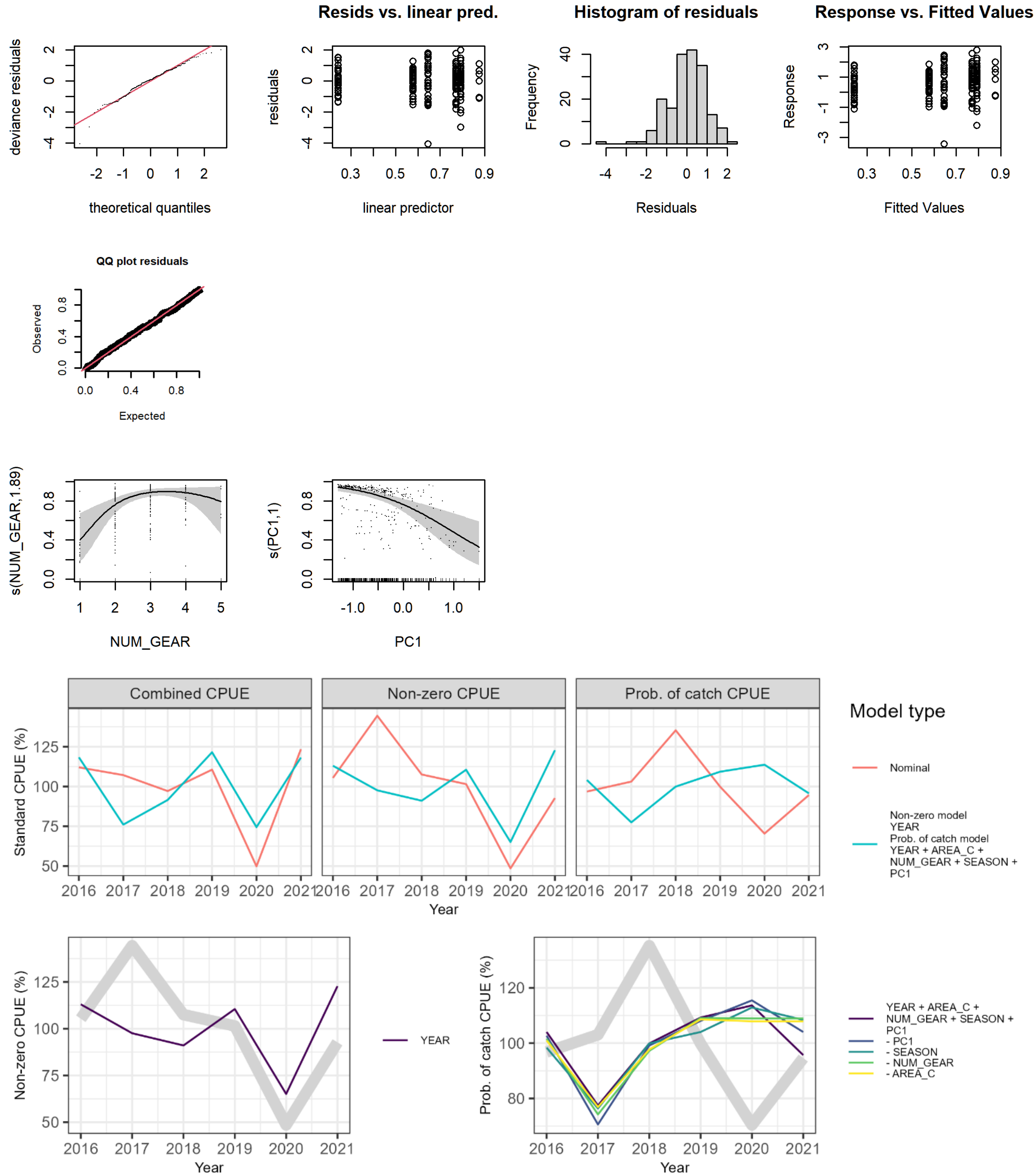


Figure 8-13 CPUE model diagnostics for *Lutjanus kasmira*. The first two rows contain residual plots for the non-zero and probability of catch models, followed by partial effect plots of smooth terms for the probability of catch model. Row 4 shows plots comparing nominal CPUE vs. the best CPUE model, while the last row shows plots comparing progressively simpler version of the best model.

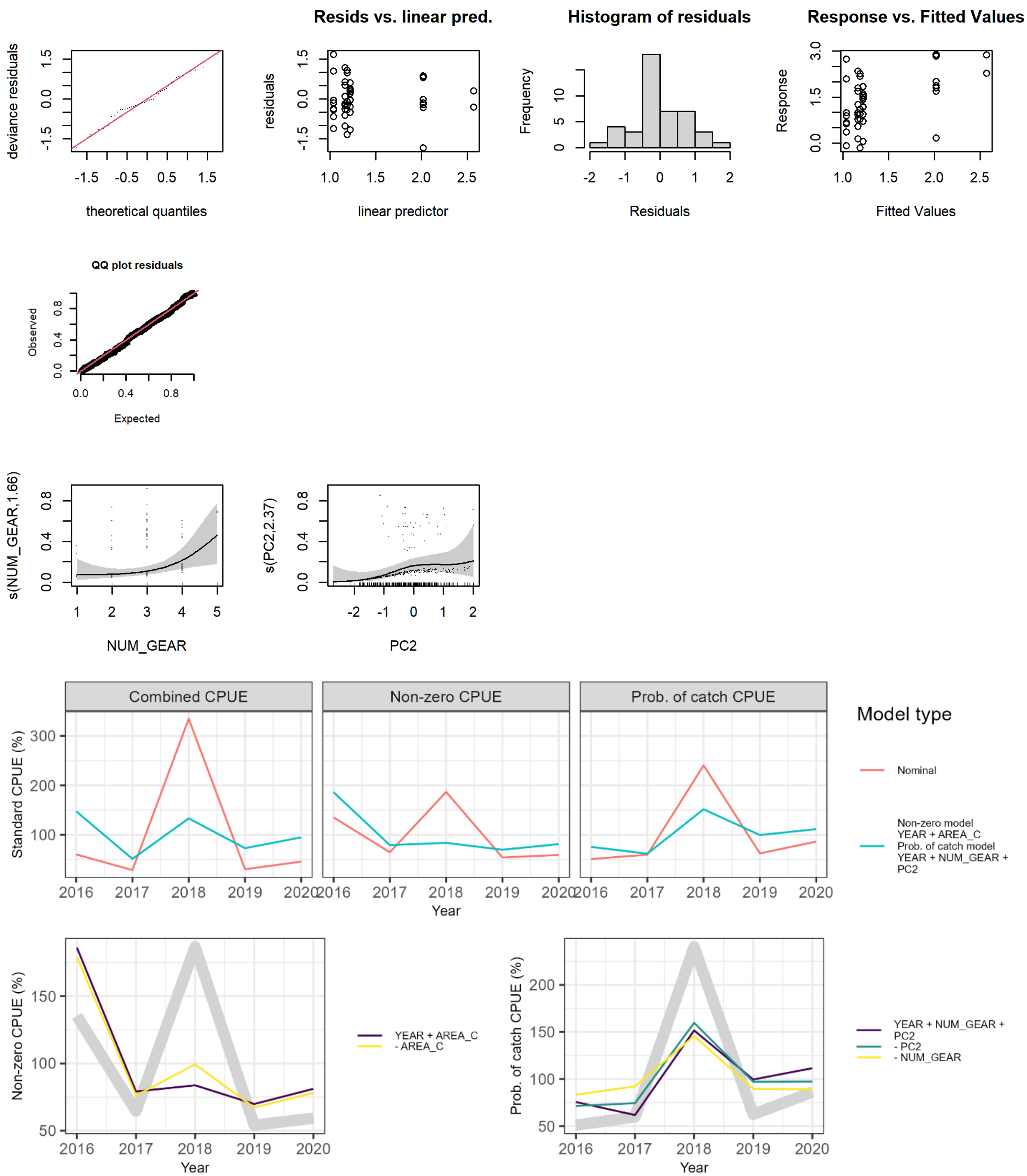


Figure 8-14 CPUE model diagnostics for *Pristipomoides flavipinnis*. The first two rows contain residual plots for the non-zero and probability of catch models, followed by partial effect plots of smooth terms for the probability of catch model. Row 4 shows plots comparing nominal CPUE vs. the best CPUE model, while the last row shows plots comparing progressively simpler version of the best model.

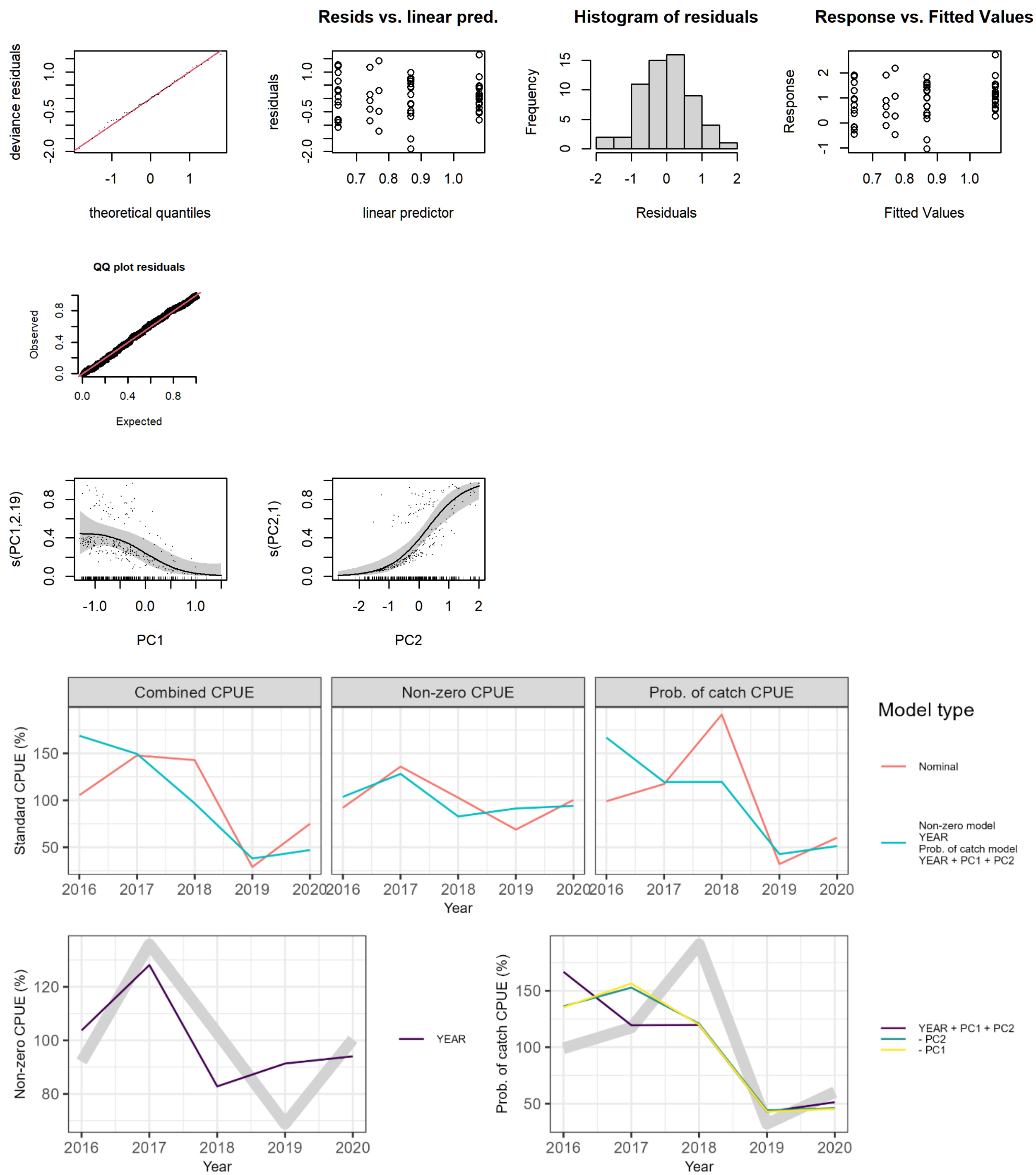


Figure 8-15 CPUE model diagnostics for *Pristipomoides zonatus*. The first two rows contain residual plots for the non-zero and probability of catch models, followed by partial effect plots of smooth terms for the probability of catch model. Row 4 shows plots comparing nominal CPUE vs. the best CPUE model, while the last row shows plots comparing progressively simpler version of the best model.

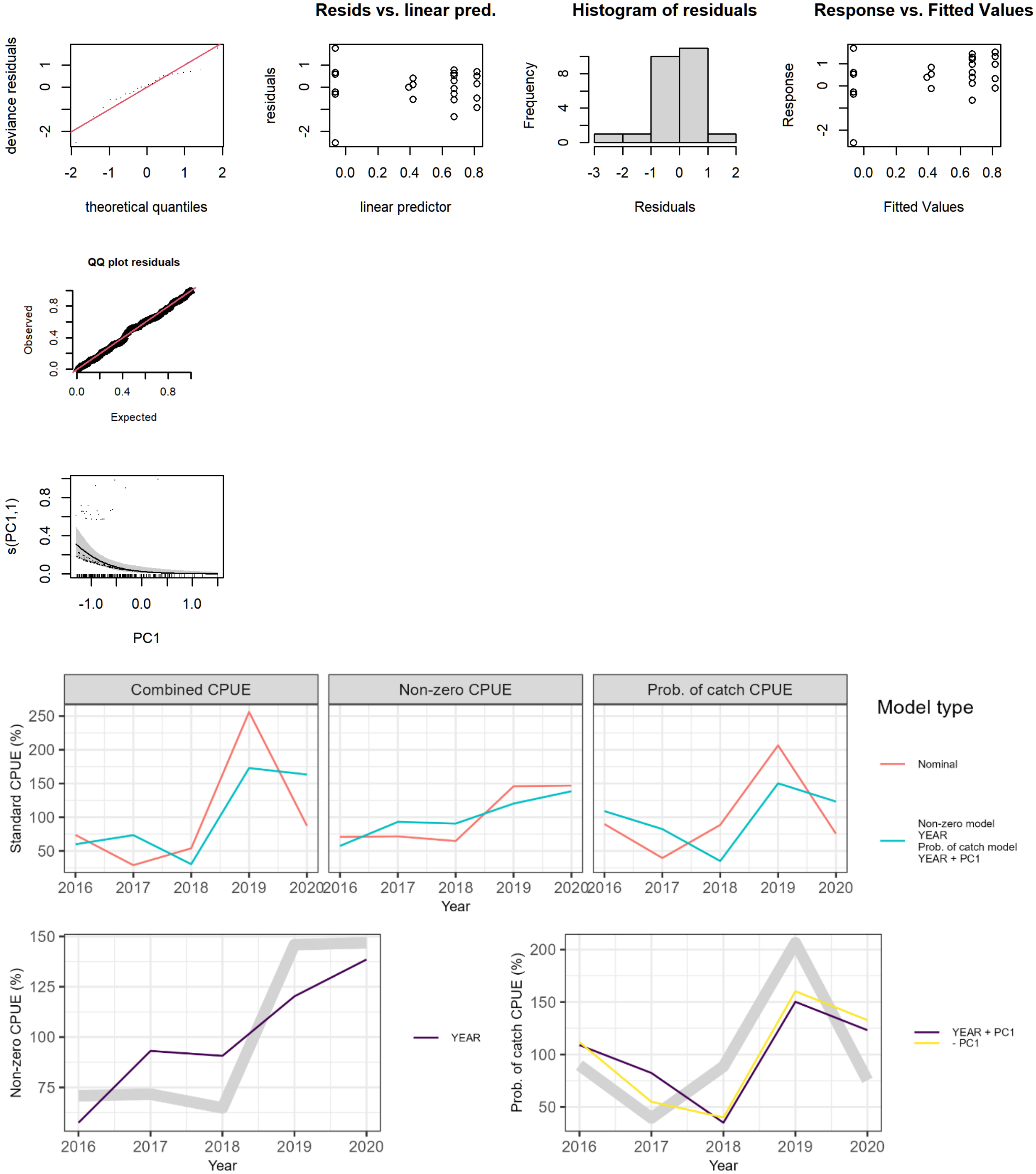


Figure 8-16 CPUE model diagnostics for *Variola louti*. The first two rows contain residual plots for the non-zero and probability of catch models, followed by partial effect plots of smooth terms for the probability of catch model. Row 4 shows plots comparing nominal CPUE vs. the best CPUE model, while the last row shows plots comparing progressively simpler version of the best model.

MFMT	MSST	B_{FLAG}
$F(B) = \frac{F_{MSY} B}{c\, B_{MSY}}$ for $B \le c\, B_{MSY}$ $F(B) = F_{MSY}$ for $B > c\, B_{MSY}$	$c\, B_{MSY}$	B_{MSY}
where c = max (1-M, 0.5)		

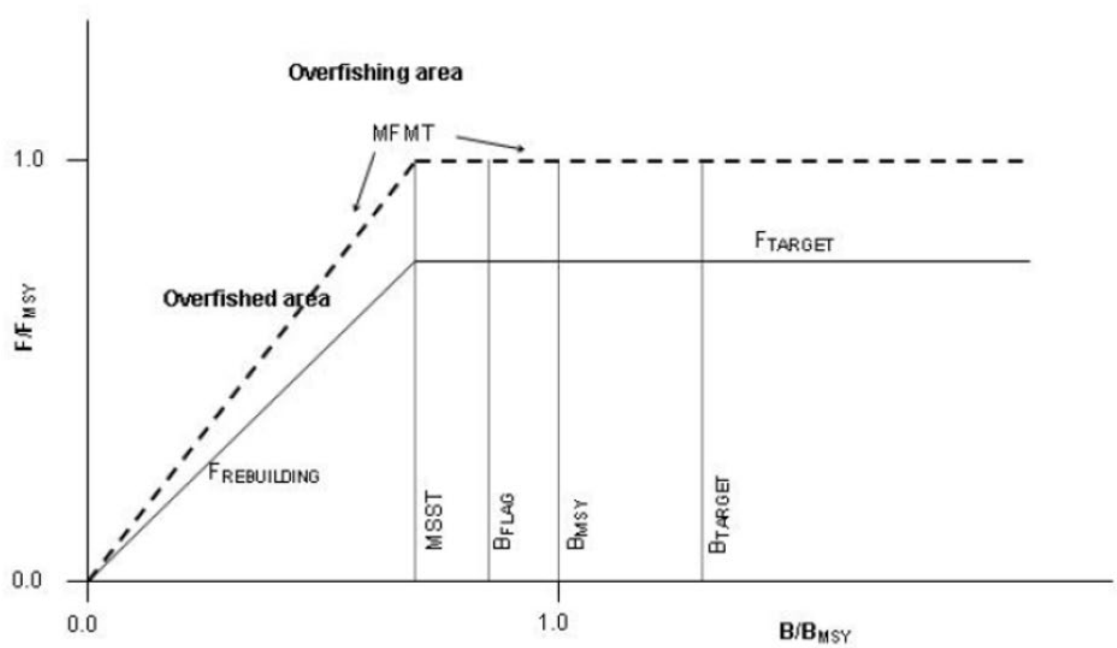
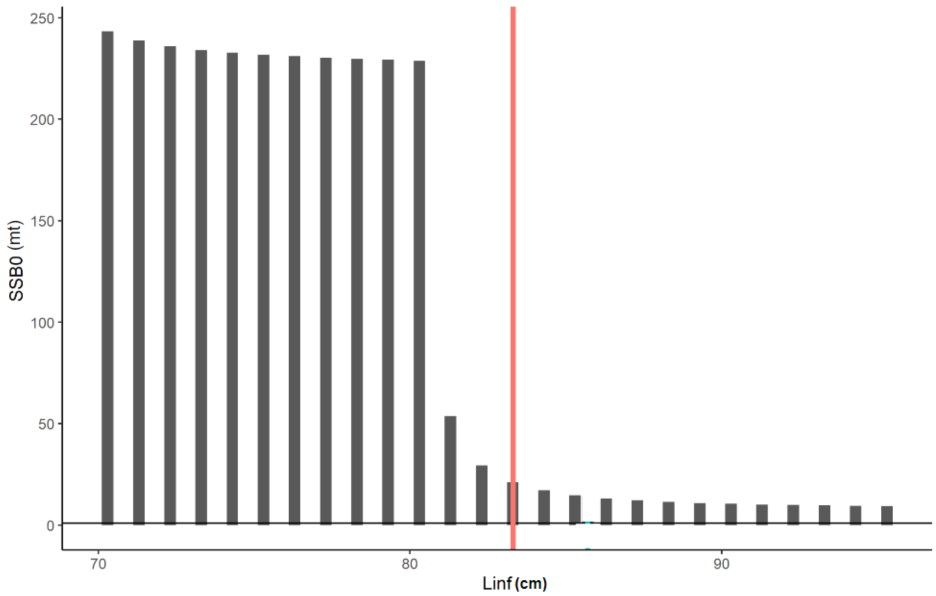


Figure 8-17 – Fishery management control rules used for bottomfish management in American Samoa.



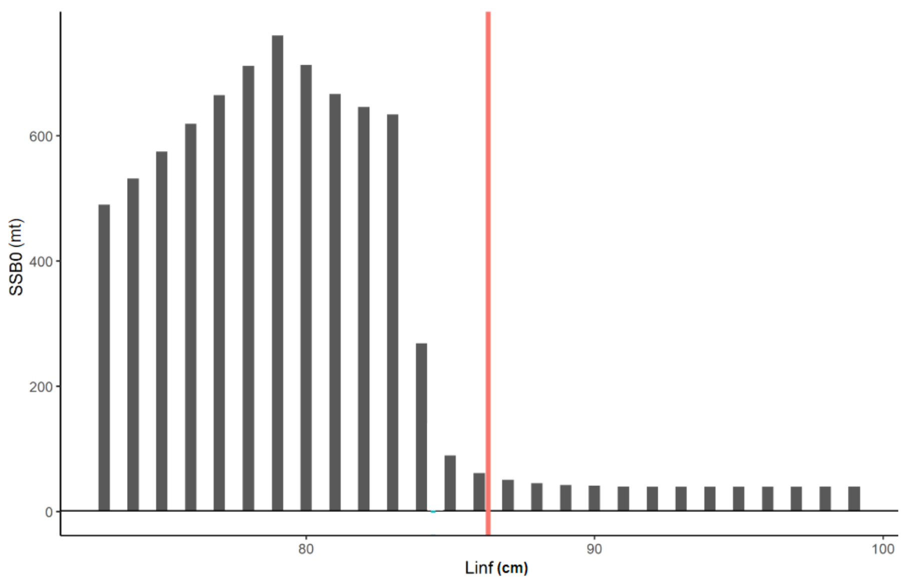


Figure 8-18 – Impact of modifying the L_{inf} parameter on population scale (represented by SSB_0) for *Aphareus rutilans* (top) and *Etelis coruscans* (bottom). Red lines represent base case parameter value.

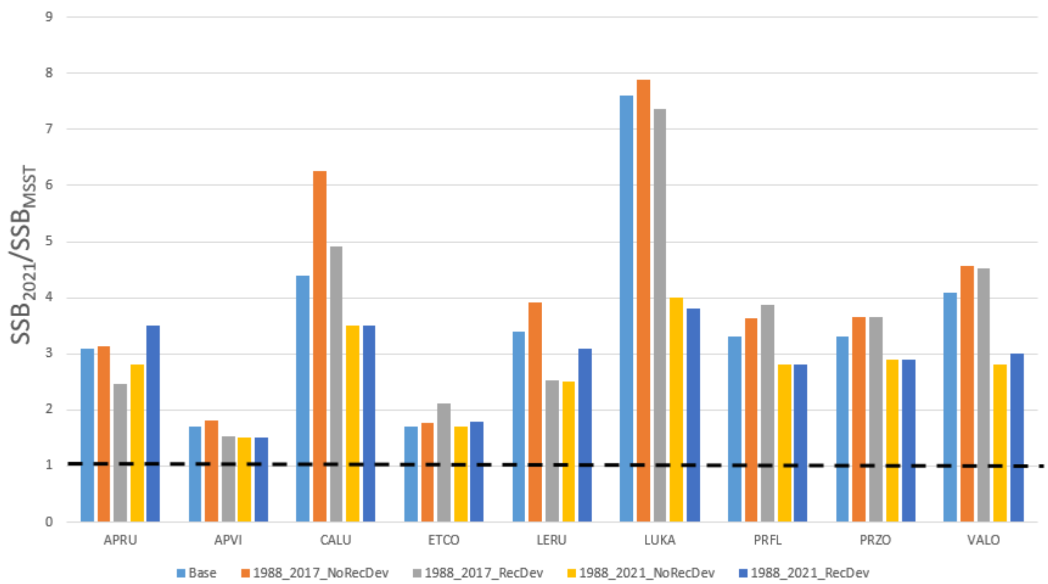


Figure 8-19 – Stock status in 2021 for the base model and for models that included either the full 1988-2021 CPUE time series (with separate catchability parameters for 1988-2015 and 2016-2021) or the 1988-2017 CPUE time series (same period as the 2019 assessment). Models were run with and without recruitment deviations.

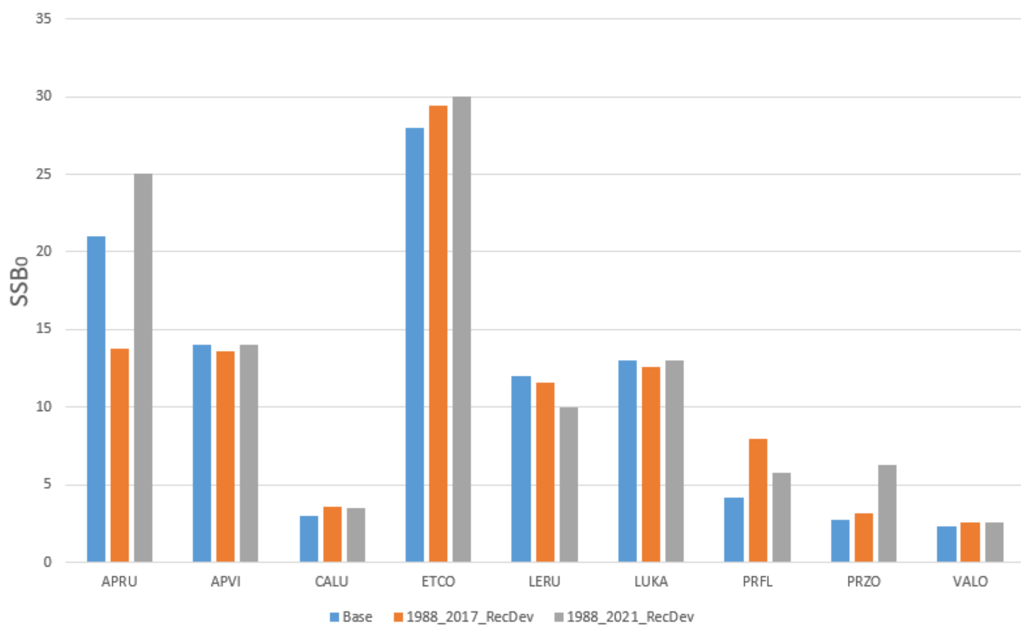


Figure 8-20 – Pristine population scale (SSB_0) for the base model and for models that included either the full 1988-2021 CPUE time series (with separate catchability parameters for 1988-2015 and 2016-2021) or the 1988-2017 CPUE time series (same period as the 2019 assessment). Models were run with recruitment deviations.

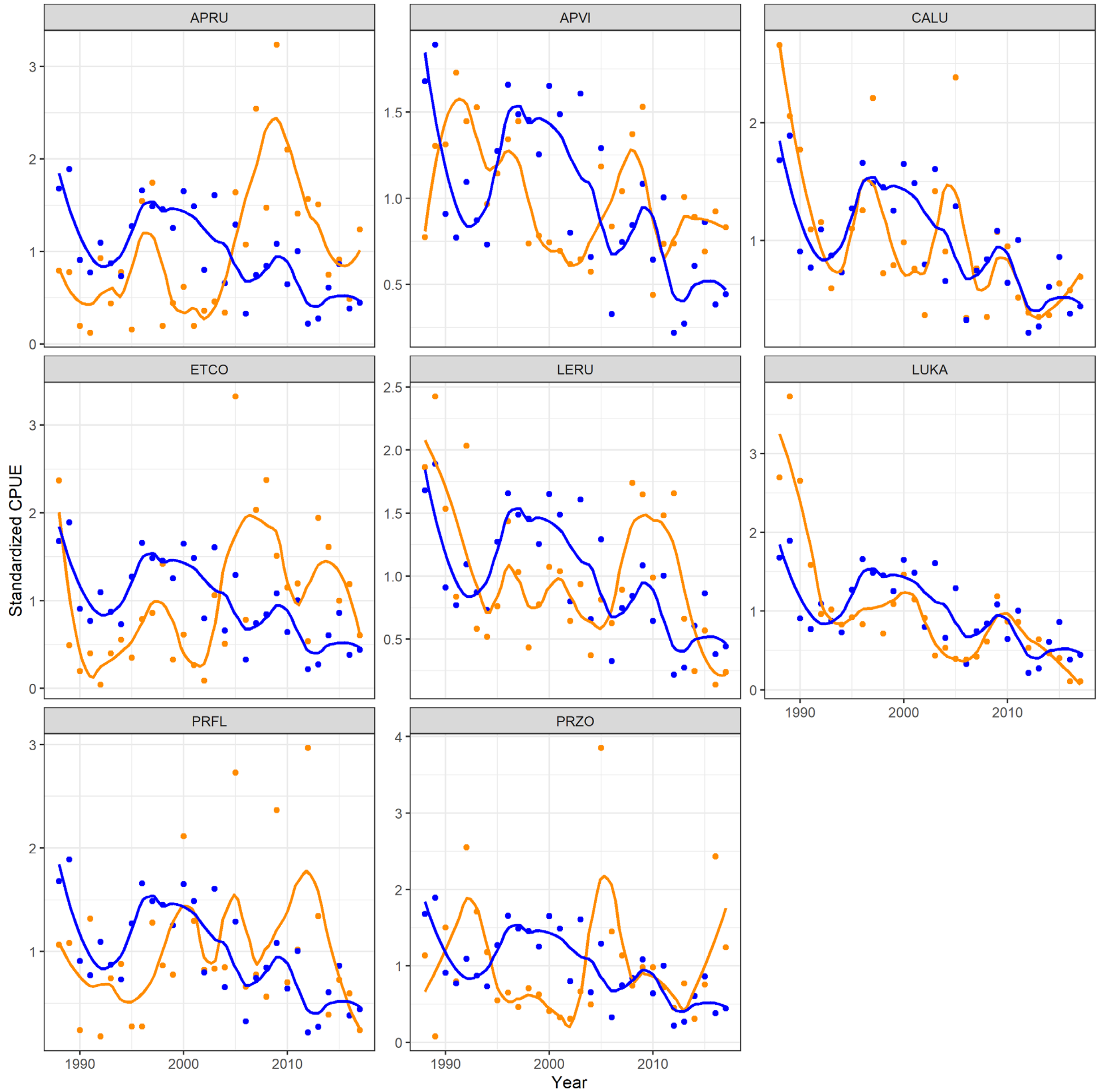


Figure 8-21 – Standardized CPUE trends comparison between the BMUS complex (2019 assessment; blue line) and individual species (orange line). Loess fits (span=0.3) are plotted for ease of comparison.

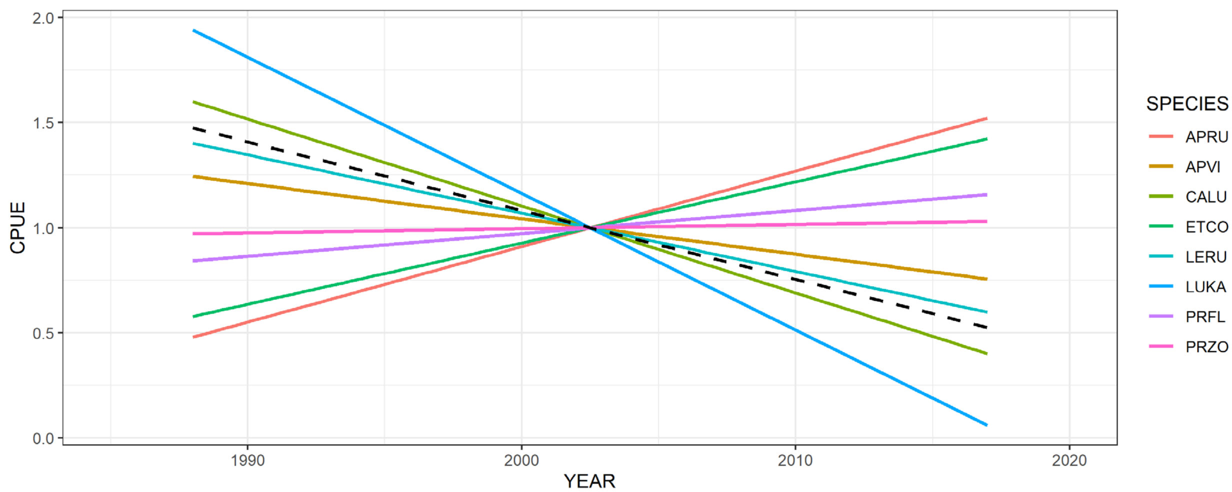


Figure 8-22 – Linear regression trends on standardized CPUE data points for the BMUS complex (dashed black line) and the individual species from 1988 to 2017.

9 Species reports

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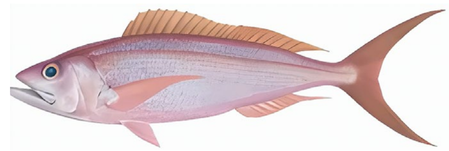
9.1 *Aphareus rutilans*



Palu-gutusiliva, *Rusty jobfish*
Lutjanidae (snappers)

Key model parameters

Parameter	Value	Phase	Source
Natural mortality, M (yr^{-1})	0.18	-2	5.4/A_{max} (Hamel and Cope 2022)
Reference age, A_{min} (yr)	0	-2	StepwiseLH. L_{99}: 85.2 cm (creel+biosampling)
Maximum age, A_{max} (yr)	30	-2	-
Length at A_{min}, L_{Amin} (cm)	6.2	-2	-
Length at A_{max}, L_{Amax} (cm)	83.3	-2	-
Growth rate, K (yr^{-1})	0.129	-2	-
CV of length < L_{Amin}	0.1	-2	-
CV of length > L_{Amin}	0.1	-2	-
Length-weight α	5.82e-5	-2	Kamikawa et al. (2015)
Length-weight β	2.77	-2	-
Length 50% maturity, L_{mat50} (cm)	46.2	-2	StepwiseLH. L_{99}: 85.2 cm (creel+biosampling)
Slope of maturity ogive	-0.98	-2	-
Spawner-recruit steepness (h)	0.72	-2	FishLife 2.0 (Thorson 2019)
Number of platoons	3	-	Fixed
Unfished recruitment (Log R_0)	1.31 (0.31)	1	Estimated
Initial fishing mortality	-	-	Set to zero
Catchability (Log Q)	-2.32 (0.45)	1	Estimated
Extra Q SD	-	-	Set to zero
Length at 50% selectivity (cm)	38.6 (0.87)	2	Estimated
Width to 95% selectivity (cm)	10.6 (1.1)	2	Estimated
Dirichlet parameter (Log theta)	1.25 (0.41)	2	Estimated (note: 1.182, 0.255 normal prior used)

General comments

Data: Catch data are available from 1967 to 2021, CPUE from 2016 to 2021, and size composition observations are available in sufficient numbers from 2006 to 2020 (Figure 9-1). The size data from 2019 (n=78) and 2020 (n=23) were combined into a super-period.

Life history: We found two published growth curves but no maturity studies (Ralston and Williams 1988 in the Mariana I. and Fry et al. 2006 in New Guinea). Both had very low sample sizes (n=14) and low maximum age (< 16 years) relative to other snappers (Nadon and Ault 2016). Given these concerns, we used the StepwiseLH approach with an L_{99} from the combined creel and biosampling length data. This resulted in an L_{inf} of 83.3 cm, an L_{mat50} of 46.2 cm, and a longevity of 30 years, which is closer to other deep snappers (Figure 9-2 and Figure 9-3). An alternative model was run using the Fry (2006) A_{max} of 16 years. There is no evidence of sex-specific growth patterns for this species. Therefore, life history parameters were the same for both sexes and recruitment was split evenly between sexes.

Fishery: The re-created historical catch (1967–1985) suggests that few *A. rutilans* were caught during the dory project years in the 1970s, with a noticeable fishery for this species only starting with the ʻalia program in the early 1980s (Figure 9-4). Catches in these early years was around 2.5 mt per year, while catches in recent years have been around 2 mt, before tapering off in 2020 and 2021. We first ran a model with an equilibrium catch in the first year (1967), but this resulted in a very low initial F estimate, which suggests that this species was very lightly exploited pre-1967. This is reasonable given the history of the fishery, where deeper areas were hard to access for the local fishermen. We therefore started the model in an unfished state (initial F set to 0). The model estimated length at

50% selectivity at approximately 39 cm and full selectivity at approximately 55 cm, with small differences in selectivity-at-age between platoons (Figure 9-5).

Model diagnostics: All estimated parameters converged within the set bounds, with the final likelihood gradient of the model being less than 0.0001 and the associated Hessian matrix being positive definite. A jitter analysis of 100 model runs with different random initial starting values also supported that the model converged on a global minimum (Figure 9-6). Further, goodness-of-fit diagnostics indicated that the model fitted both the CPUE index and the size composition reasonably well, with an RMSE slightly above 0.3 for CPUE and around 0.05 for mean length (Figure 9-7 and Figure 9-8). The model was originally fitted with the “extra SD” parameter, which allowed for an increase in the SD of the CPUE index, but this parameter was estimated close to zero and was turned off in subsequent runs. Both index and mean length fits passed the runs test ($p>0.05$). The model fitted well to the overall (Figure 9-9) and yearly (Figure 9-10) size composition data, with little patterns in the size composition residuals. The change in negative log-likelihoods at different fixed $\log(R_0)$ values indicated that this parameter’s estimate was entirely driven by the length composition data, with a clear minimum reached at 1.3 (~3,700 recruits; Figure 9-11). The results of the retrospective analysis, which progressively removed one year of data from 2021 to 2017, showed some pattern for *SSB* and *F* associated with removing 2018 data. This is likely related to anomalous size composition in 2016-2017 (left skew; higher *F* and lower *SSB*) vs 2018 (right skew; lower *F* and higher *SSB*). However, the Mohn’s rho values were around -0.07 and 0.09 for both *SSB* and *F*, respectively (suggested limits are between -0.15 and 0.2; Figure 9-12).

Stock status: Population biomass declined from a SSB_0 around 20 mt prior to 1967 to about 14 mt in the late 1980s, following the increased catch associated with the ‘alia program (Figure 9-13 and Table 9-1). It has remained stable since then, staying between 14 and 16 mt throughout the time series (the MSST was estimated at 4.6 mt; Figure 9-13). Recruitment stayed close to R_0, varying between 3,300 and 3,500 recruits per year (Figure 9-14). The current stock status (SSB/SSB_{MSST}) is equal to 3.1 (not overfished) with no overfishing having occurred in the time series (Figure 9-15; Table 9-2). Fishing mortality varied around 0.03, hitting maximum values in the 80s and in 2009 at around 0.07 (F_{MSY} was estimated at 0.14). Equilibrium catches at F_{MSY} (i.e., the *MSY*) were estimated at 2.2 mt. Catches in recent years have averaged around 0.5 mt (Table 9-2).

Alternate scenarios: We ran 7 alternative models: *M* and steepness plus and minus 10%, no historical catch, with recruitment deviations, and alternate LH source. The alternate specifications with the largest impact were increasing *M* and the alternate longevity value of 16 years (Fry et al. 2006) vs. the original 30 years, which also resulted in a much higher *M* (Table 9-3, Figure 9-16, and Figure 9-17). Both of these scenarios resulted in unrealistically low *F* values, approaching absolute zero (given that $F=Z-M$), which resulted in very elevated *SSB*. None of the alternative models resulted in overfishing or overfished status in 2021.

Projections: The projection analysis showed the distribution of outcomes in the probability of overfishing and overfished status that would occur in various final years (2024-2028) under various fixed-catch scenarios (Table 9-4; Figure 9-18, and Figure 9-19). The projections indicated low probability of overfished status occurring between 2024 and 2028 for the range of fixed catch explored (< 5.5 mt per year).

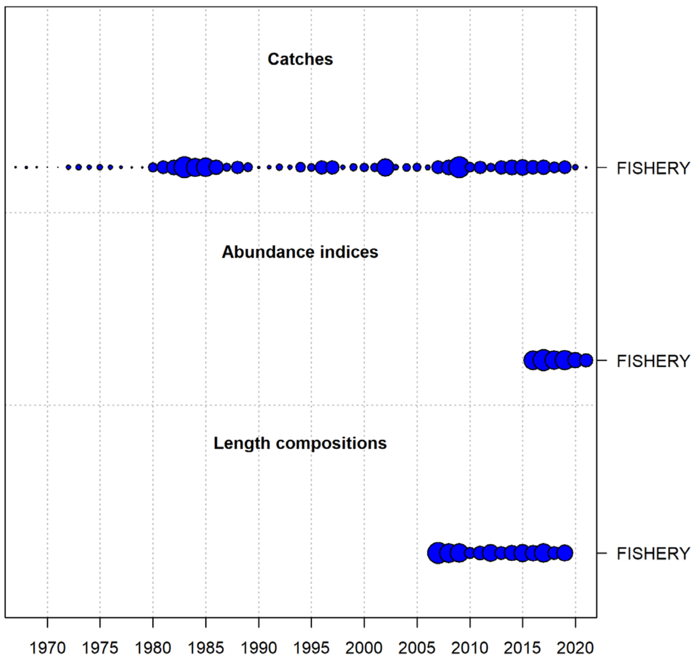


Figure 9-1- Summary of data types used in the Stock Synthesis model. Catches include boat-based and shore-based landings from creel surveys (1986-2021), as well as historical catches from reports (1967-1985). The abundance index is from boat-based creel survey 'bottomfishing" gear type. Length compositions are from creel surveys (all years) and the biosampling program (2010-2015), filtered for the "bottomfishing" gear.

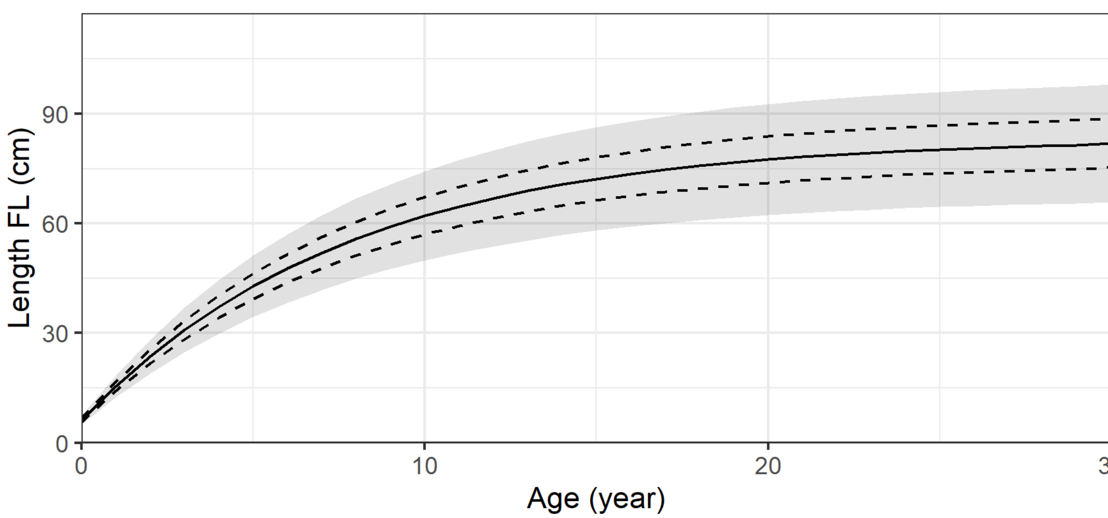


Figure 9-2 – Growth curve following a Von Bertalanffy model with 95% confidence intervals associated with the CV L_{inf} parameter. The central growth platoon (solid line) and the two secondary ones (dashed lines) used in the model are also displayed.

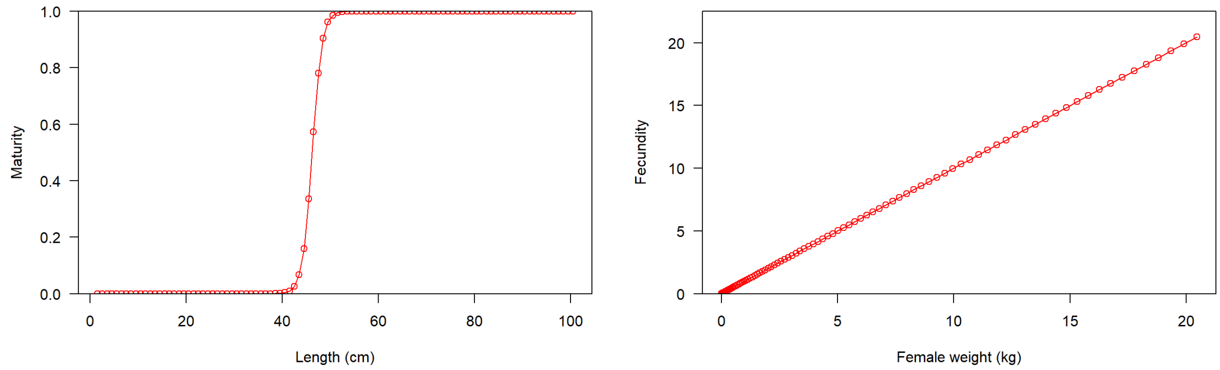


Figure 9-3 – Maturity-at-length (FL; left) and fecundity-at-weight (right) used in the stock assessment model.

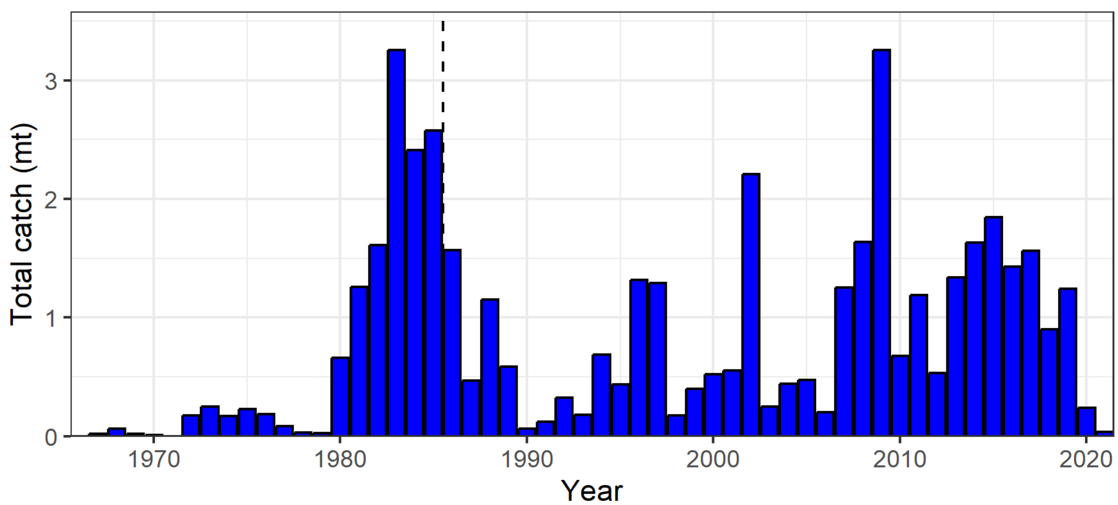


Figure 9-4 – Annual total catch in metric tons (mt). The vertical dashed line indicates the start of the creel survey program (1986), with older data coming from historical catch reports.

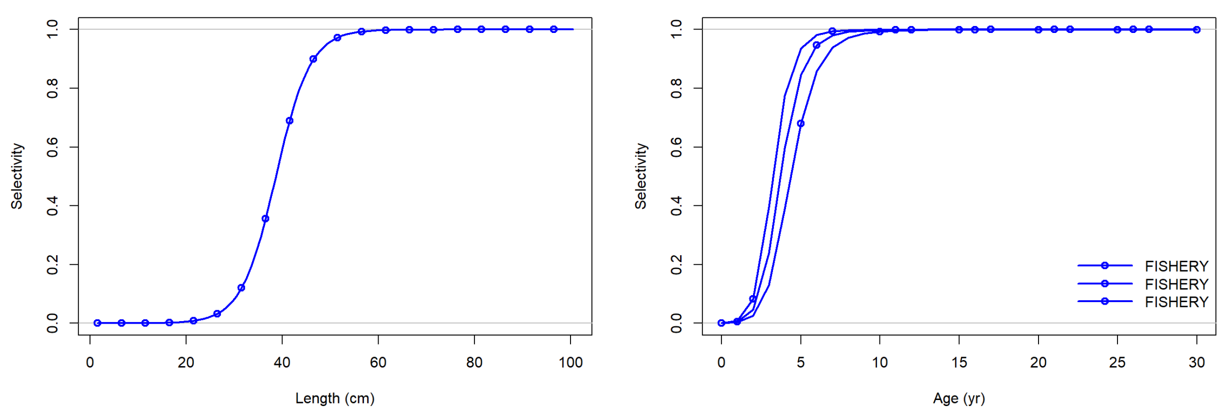


Figure 9-5 – Length-based selectivity estimated by the Stock Synthesis model (left) and the resulting selectivity-at-age for all 3 growth platoons (right).

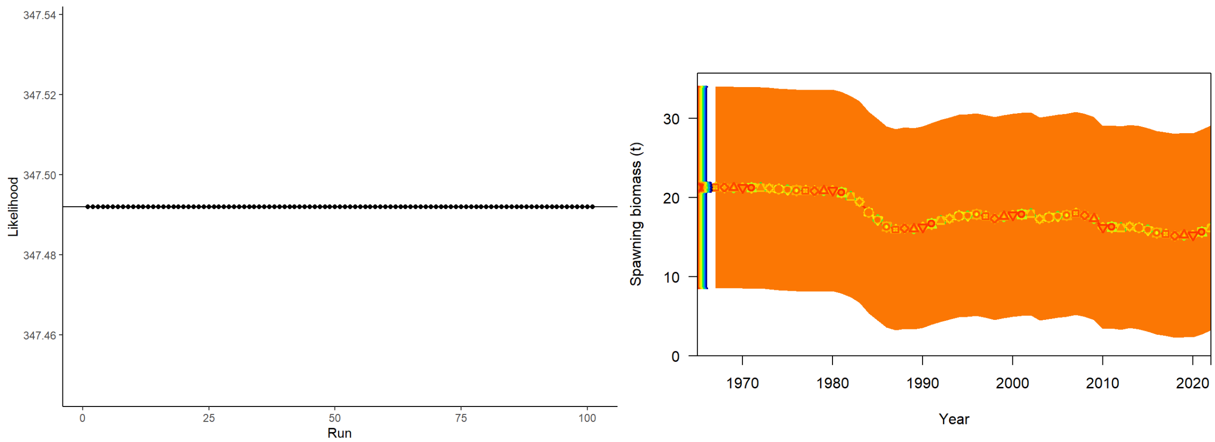


Figure 9-6 – Results of jitter analysis where 100 models were run with randomly varying initial parameter values. Left panel shows the variation in minimum model likelihood value for all 100 model runs. Right panel shows the variation in SSB time series for all 100 model runs.

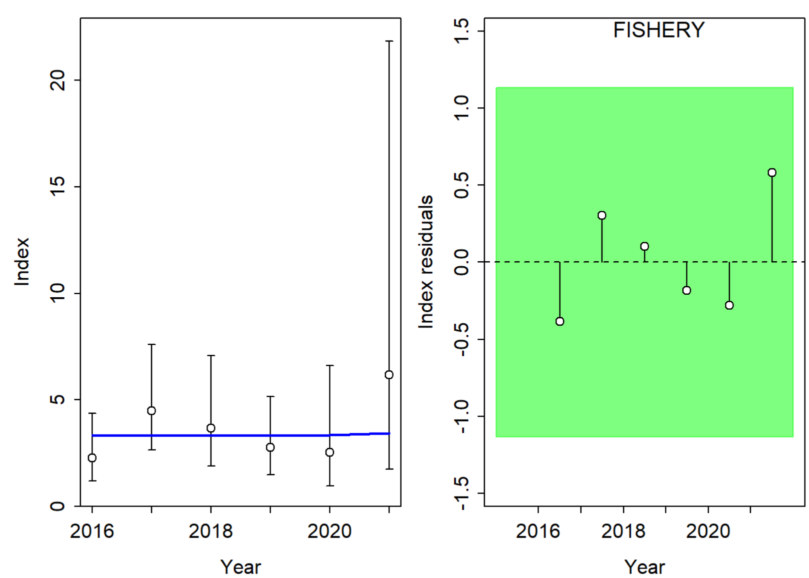


Figure 9-7 – Observed (open dots) vs expected (blue line) CPUE abundance index by year with standard deviations intervals (left). CPUE index residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.34.

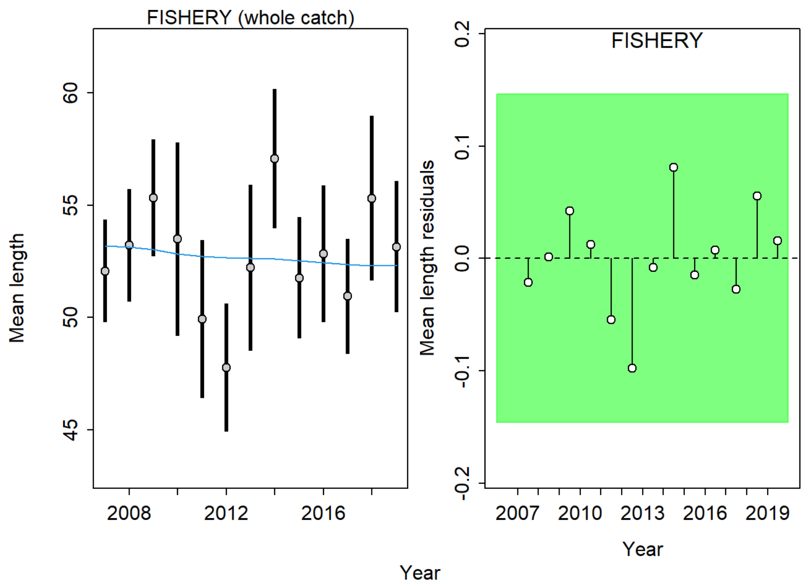


Figure 9-8 – Observed (open dots) vs expected (blue line) mean length by year with standard deviations intervals (left). Mean length residuals by year, with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.05.

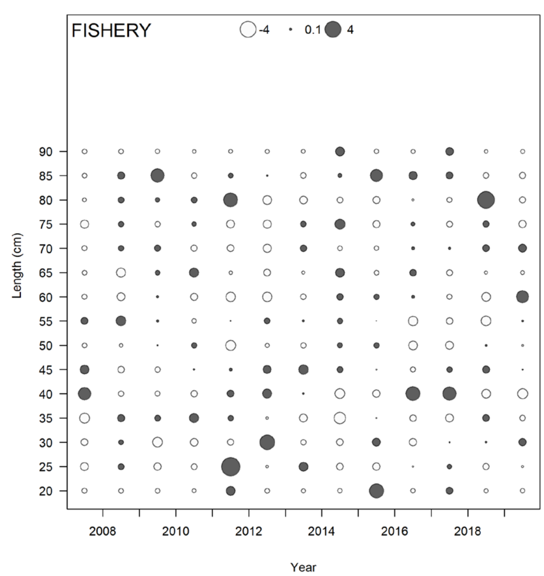


Figure 9-9 – Pearson residual plot of observed vs. expected size frequency data by size bin and year.

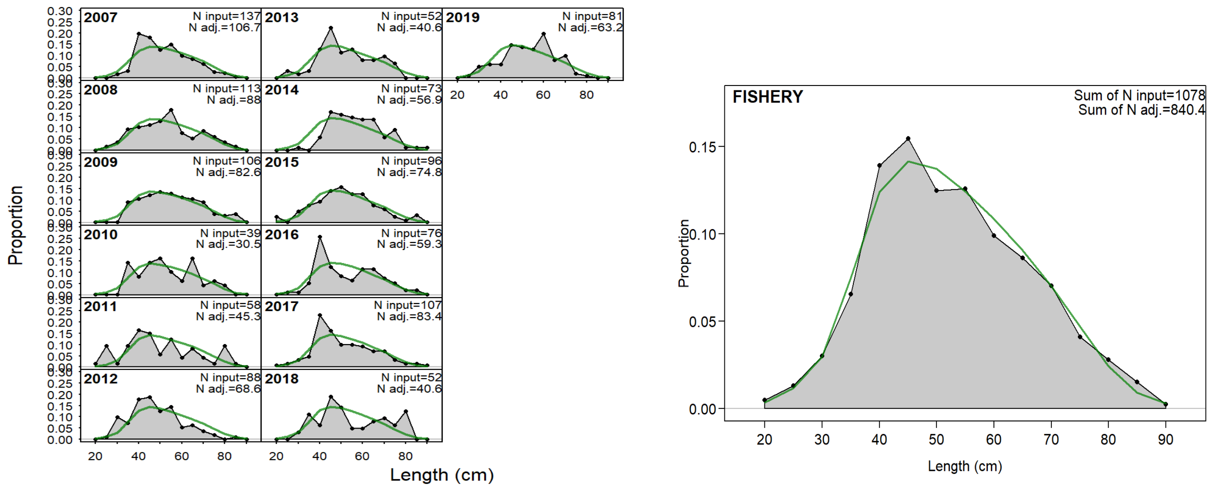


Figure 9-10 – Observed (gray area) vs. expected (green line) abundance-at-length from bottomfishing catch by year (left) and overall (right).

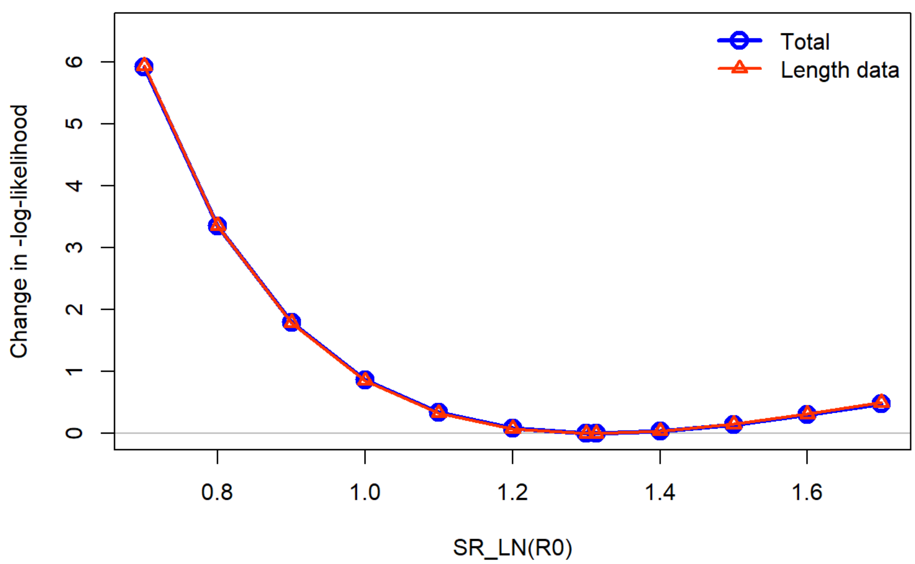


Figure 9-11 – Profiles of the change in negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter (R_0) in log-scale.

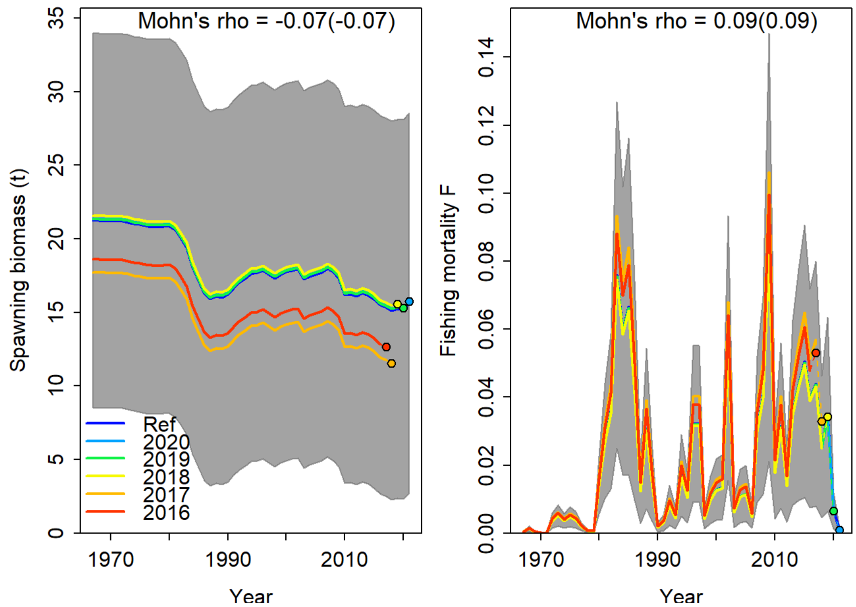


Figure 9-12 – Retrospective analysis of spawning biomass (left) and fishing mortality (right) consisting of 5 reruns of the base case model each fitted with one less year of data from the base case model (blue line).

Table 9-1 – Time series of spawning biomass (SSB, mt), age-0 recruitment (Rec., 1000s of recruits), and instantaneous fishing mortality (F, yr^{-1}) estimated by the Stock Synthesis model. CV is the coefficient of variation.

Year	SSB	CV	Rec.	CV	F	CV	Year	SSB	CV	Rec.	CV	F	CV
1969	20.0	0.31	3.46	0.31	0.000	0.71	1996	16.4	0.39	3.41	0.32	0.027	0.63
1970	19.7	0.32	3.50	0.31	0.000	0.62	1997	16.3	0.39	3.41	0.33	0.029	0.53
1971	19.7	0.31	3.46	0.32	0.000	0.49	1998	15.6	0.39	3.41	0.33	0.004	0.63
1972	19.9	0.31	3.47	0.32	0.003	0.59	1999	16.1	0.39	3.39	0.33	0.008	0.60
1973	19.6	0.32	3.49	0.32	0.004	0.60	2000	16.1	0.39	3.39	0.33	0.010	0.70
1974	19.7	0.31	3.51	0.32	0.003	0.64	2001	16.4	0.39	3.40	0.33	0.013	0.48
1975	19.8	0.34	3.47	0.32	0.004	0.51	2002	16.6	0.38	3.42	0.32	0.040	0.67
1976	19.7	0.32	3.48	0.33	0.004	0.51	2003	15.4	0.40	3.39	0.32	0.005	0.51
1977	19.4	0.32	3.51	0.30	0.001	0.74	2004	16.2	0.39	3.39	0.33	0.009	0.61
1978	19.7	0.33	3.49	0.32	0.001	0.61	2005	16.3	0.38	3.44	0.32	0.010	0.64
1979	19.3	0.33	3.54	0.33	0.001	0.79	2006	16.4	0.37	3.41	0.34	0.004	0.56
1980	19.4	0.32	3.41	0.32	0.011	0.64	2007	16.9	0.38	3.40	0.32	0.026	0.64
1981	19.3	0.32	3.41	0.31	0.025	0.67	2008	16.2	0.39	3.40	0.33	0.033	0.55
1982	18.7	0.35	3.51	0.32	0.037	0.62	2009	15.7	0.39	3.41	0.33	0.074	0.44
1983	17.8	0.33	3.42	0.32	0.066	0.61	2010	14.7	0.41	3.37	0.33	0.016	0.50
1984	16.5	0.37	3.39	0.31	0.048	0.58	2011	14.7	0.41	3.37	0.33	0.025	0.63
1985	15.6	0.39	3.40	0.33	0.055	0.49	2012	14.4	0.40	3.36	0.33	0.011	0.61
1986	14.8	0.41	3.41	0.34	0.038	0.57	2013	14.7	0.41	3.38	0.32	0.028	0.57
1987	14.2	0.43	3.38	0.32	0.013	0.66	2014	14.7	0.41	3.45	0.34	0.043	0.60
1988	14.5	0.43	3.35	0.33	0.027	0.74	2015	14.3	0.43	3.38	0.32	0.044	0.52
1989	14.8	0.43	3.33	0.33	0.015	0.60	2016	13.9	0.44	3.29	0.33	0.036	0.49
1990	14.6	0.42	3.31	0.33	0.002	0.65	2017	14.0	0.43	3.31	0.33	0.040	0.47
1991	15.4	0.43	3.46	0.32	0.003	0.57	2018	13.8	0.46	3.34	0.33	0.023	0.48
1992	15.4	0.41	3.45	0.33	0.006	0.64	2019	13.7	0.46	3.30	0.33	0.030	0.58
1993	15.8	0.41	3.46	0.33	0.004	0.58	2020	13.3	0.44	3.28	0.35	0.006	0.65
1994	16.1	0.37	3.41	0.34	0.015	0.66	2021	14.2	0.41	3.35	0.32	0.001	0.63
1995	16.3	0.38	3.41	0.33	0.009	0.62							

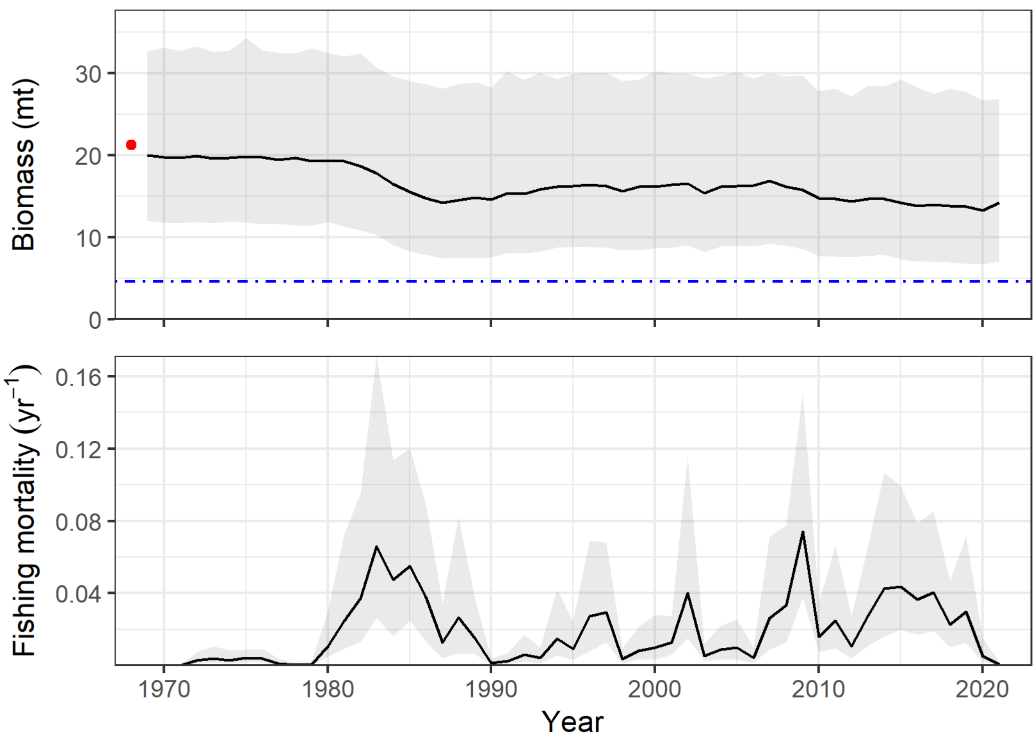


Figure 9-13 – Time series of spawning biomass (solid line) with its 95% confidence interval and SSB_0 estimate (red dot; top panel). The dot-and-dash blue line shows the spawning biomass at the MSST reference point (SSB_{MSST}). Time series of fishing mortality rate with its 95% confidence intervals (bottom panel).

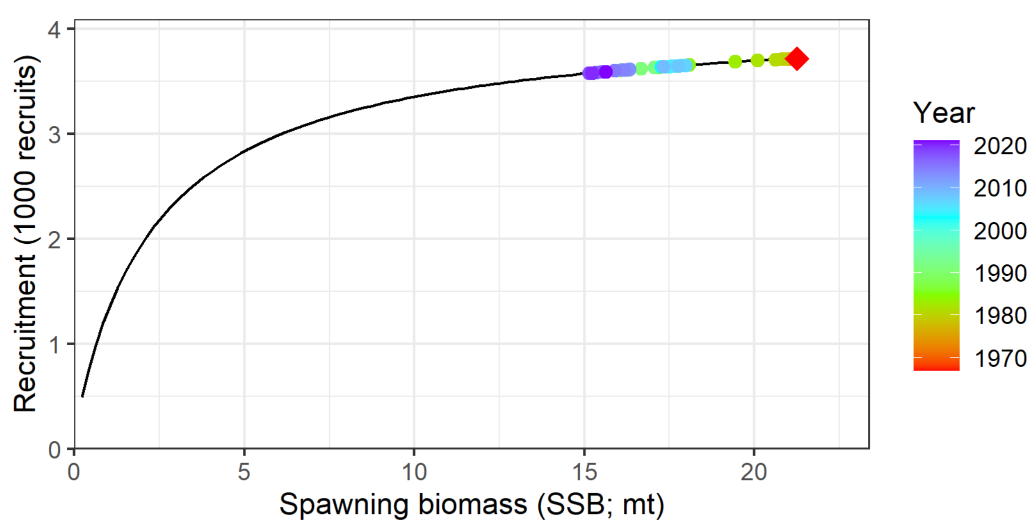


Figure 9-14 – Expected recruitment from the stock-recruitment relationship (black line) and estimated annual recruitment (dots) from Stock Synthesis. Estimated virgin SSB and recruitment is indicated with a red diamond.

Table 9-2 – Estimated biological reference points with 95% confidence interval (SD) derived from the Stock Synthesis base-case model where *F* is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield (2021 is the terminal year of the model).

Reference point	Value
F_{MSY} (yr^{-1})	0.136 (0.127 - 0.146)
F_{2021} (yr^{-1})	0.001 (0 - 0.002)
F_{2021}/F_{MSY}	0.006 (0.003 - 0.014)
SSB_{MSST} (mt)	4.6 (2.47 - 8.55)
SSB_{2021} (mt)	14.2 (7.06 - 26.88)
SSB_{2021}/SSB_{MSST}	3.12 (2.56 - 3.8)
MSY (mt)	2.16 (0.89 - 3.43)
$\text{Catch}_{2019\text{-}2021}$ (mt)	0.51 (0.11 - 0.9)
SPR_{MSY}	0.36 (0.36 - 0.36)
SPR_{2021}	0.99 (0.98 - 1)

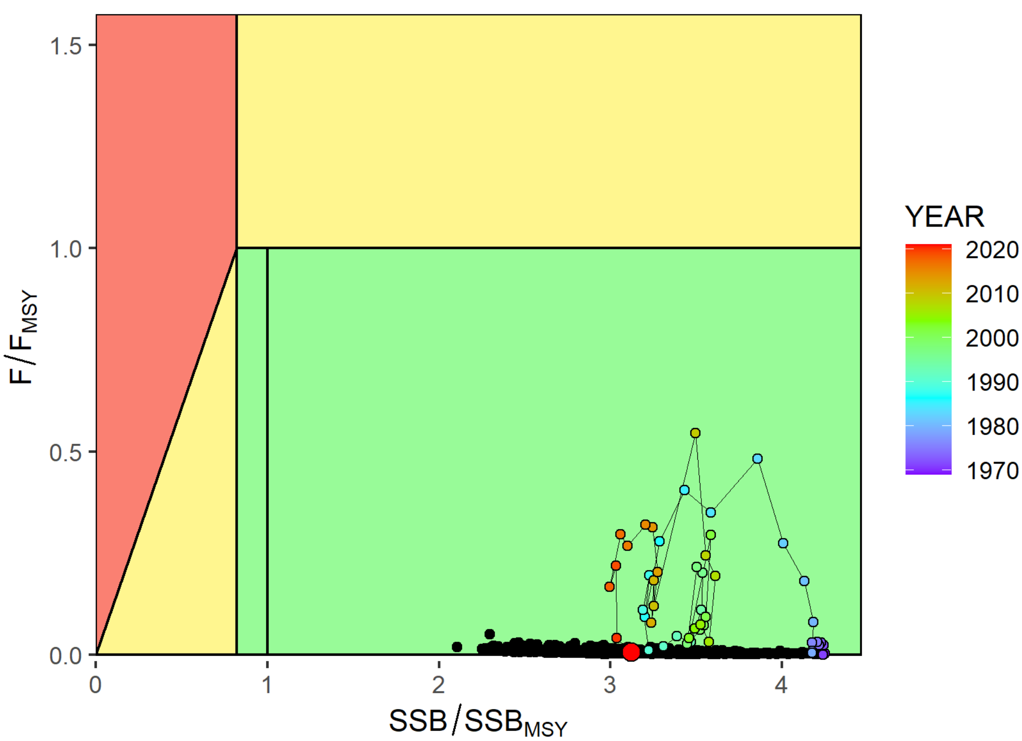


Figure 9-15 – Kobe plot representing the trend in relative fishing mortality and spawning stock biomass between 1969 and 2021 with their associated biological reference areas (red: overfished and overfishing, yellow: overfishing or overfished, green: no overfishing and not overfished). The large red dot indicates median stock status in 2021 and the black dots are one thousand Monte Carlo draws from the stock status distribution to represent the uncertainty around the final year status.

Table 9-3 – Summary table of key model output for all alternative model runs where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield.

Model	F_{2021}	F_{MSY}	F_{2021}/F_{MSY}	SSB_{MSY}	SSB_{MSST}	SSB_{2021}	SSB_{2021}/SSB_{MSY}	SSB_{2021}/SSB_{MSST}	Catch MSY
Base	0.001	0.14	0.01	6.1	5	15.6	2.6	3.1	2.2
M - 10%	0.002	0.12	0.02	4.3	3.6	8.2	1.9	2.3	1.3
M + 10%	0	0.15	0	19.2	15.3	63	3.3	4.1	7.7
Steep. - 10%	0.001	0.12	0.01	6.6	5.4	15.4	2.3	2.9	2
Steep. + 10%	0.001	0.16	0.01	5.5	4.5	15.8	2.9	3.5	2.4
Rec. dev.	0.001	0.14	0.01	5.9	4.9	14.5	2.5	3	2.1
No hist. catch	0.001	0.14	0.01	6.2	5.1	15.9	2.6	3.1	2.2
Alternate LH	0	0.25	0	38	25.1	141.8	3.7	5.6	32.8

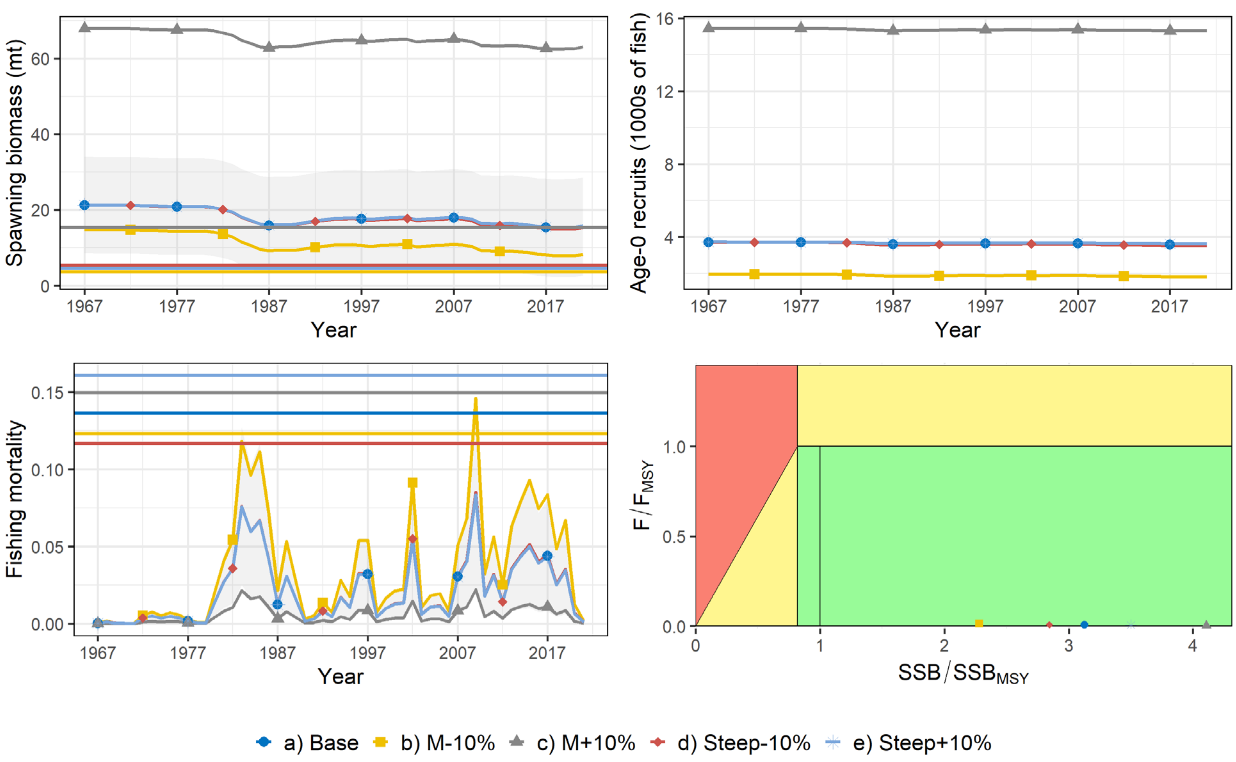


Figure 9-16 – Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) under moderate life-history parameter variation (plus and minus 10% of base parameter values).

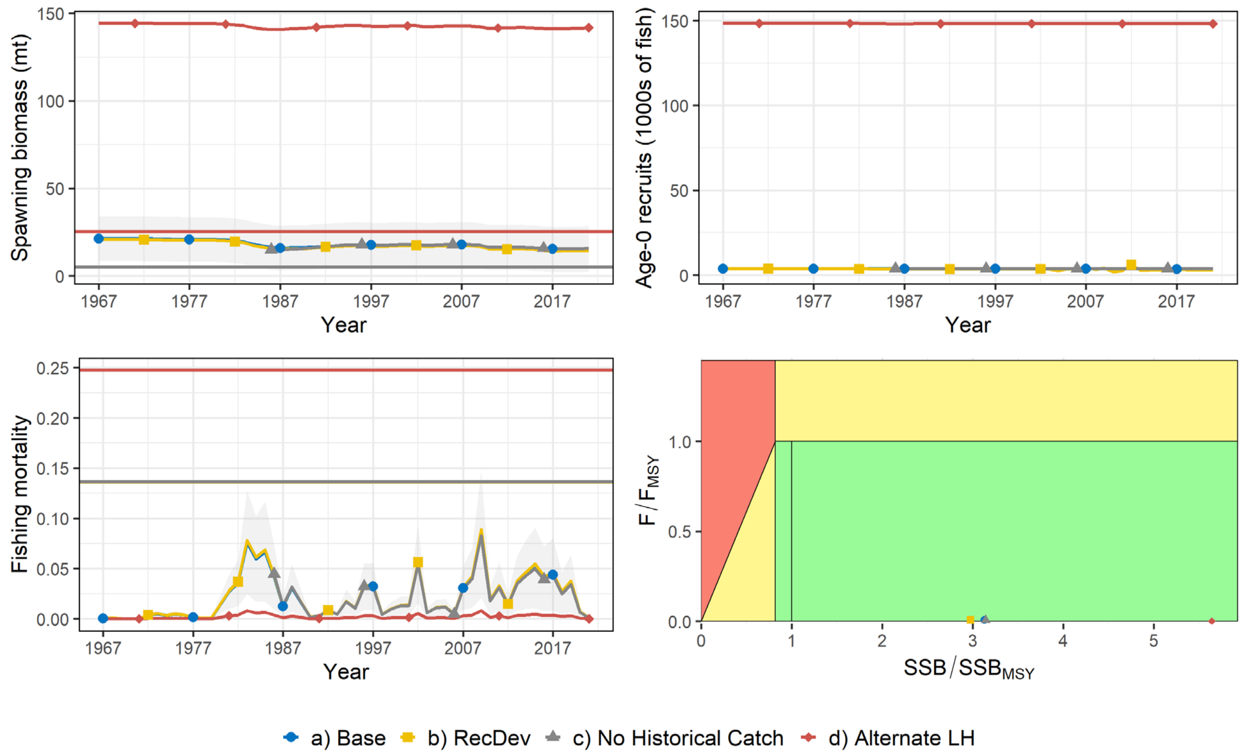


Figure 9-17 - Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) b) with recruitment deviations, c) without historical catch data (model starts in 1986), and d) an alternate life history parameter source (longevity from Fry 2006).

Table 9-4 – The annual fixed catch values (metric tons) applied from 2024 to a final projection year resulting in a given probability of overfishing (F/F_{MSY}>1) in that final year. Catches for years prior to the start of the new catch guidance (2022 and 2023) were fixed at the mean of the last 3 years of catch data (2019 to 2021).

Probability of	Fixed catch (mt) from 2024 to:				
$F > F_{MSY}$	2024	2025	2026	2027	2028
0.50	5.27	4.78	4.54	4.28	4.08
0.49	5.23	4.73	4.50	4.24	4.04
0.48	5.18	4.69	4.45	4.20	4.00
0.47	5.14	4.65	4.41	4.16	3.96
0.46	5.09	4.61	4.37	4.13	3.92
0.45	5.05	4.57	4.32	4.09	3.88
0.44	5.00	4.52	4.28	4.05	3.84
0.43	4.96	4.48	4.24	4.01	3.80
0.42	4.91	4.44	4.19	3.97	3.76
0.41	4.86	4.40	4.15	3.93	3.72
0.40	4.82	4.35	4.10	3.89	3.69
0.39	4.77	4.31	4.06	3.85	3.65
0.38	4.72	4.27	4.02	3.81	3.61
0.37	4.67	4.23	3.97	3.77	3.57
0.36	4.63	4.19	3.93	3.73	3.53
0.35	4.58	4.14	3.88	3.69	3.50
0.34	4.53	4.10	3.84	3.65	3.46
0.33	4.48	4.06	3.80	3.61	3.42
0.32	4.43	4.02	3.75	3.58	3.39
0.31	4.38	3.97	3.71	3.54	3.35
0.30	4.33	3.93	3.66	3.50	3.31
0.29	4.28	3.89	3.62	3.46	3.28
0.28	4.23	3.85	3.57	3.42	3.24
0.27	4.18	3.80	3.53	3.38	3.20
0.26	4.13	3.76	3.49	3.34	3.17
0.25	4.07	3.72	3.44	3.30	3.13
0.24	4.02	3.67	3.40	3.26	3.10
0.23	3.97	3.63	3.35	3.22	3.06
0.22	3.92	3.59	3.31	3.18	3.03
0.21	3.86	3.55	3.26	3.15	2.99
0.20	3.81	3.50	3.22	3.11	2.96
0.19	3.76	3.46	3.17	3.07	2.92
0.18	3.70	3.42	3.13	3.03	2.89
0.17	3.65	3.37	3.09	2.99	2.85
0.16	3.59	3.33	3.04	2.95	2.82
0.15	3.54	3.29	3.00	2.91	2.79
0.14	3.48	3.24	2.95	2.87	2.75
0.13	3.43	3.20	2.91	2.83	2.72
0.12	3.37	3.16	2.86	2.79	2.69
0.11	3.31	3.11	2.82	2.76	2.65
0.10	3.26	3.07	2.77	2.72	2.62

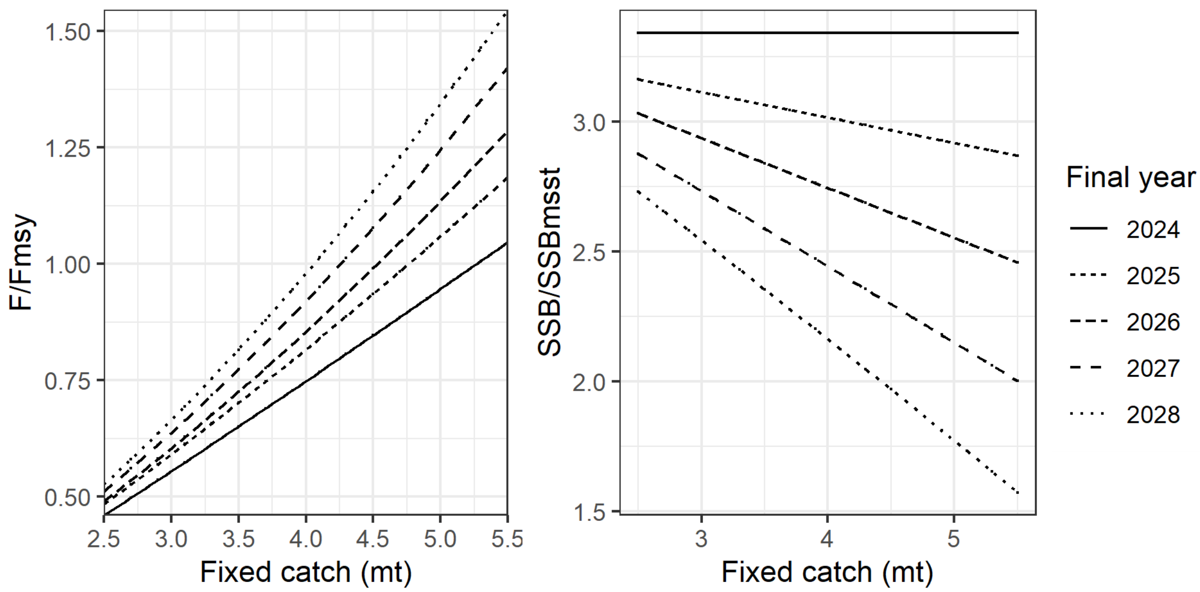


Figure 9-18 – Median stock status for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status is for the final projection year.

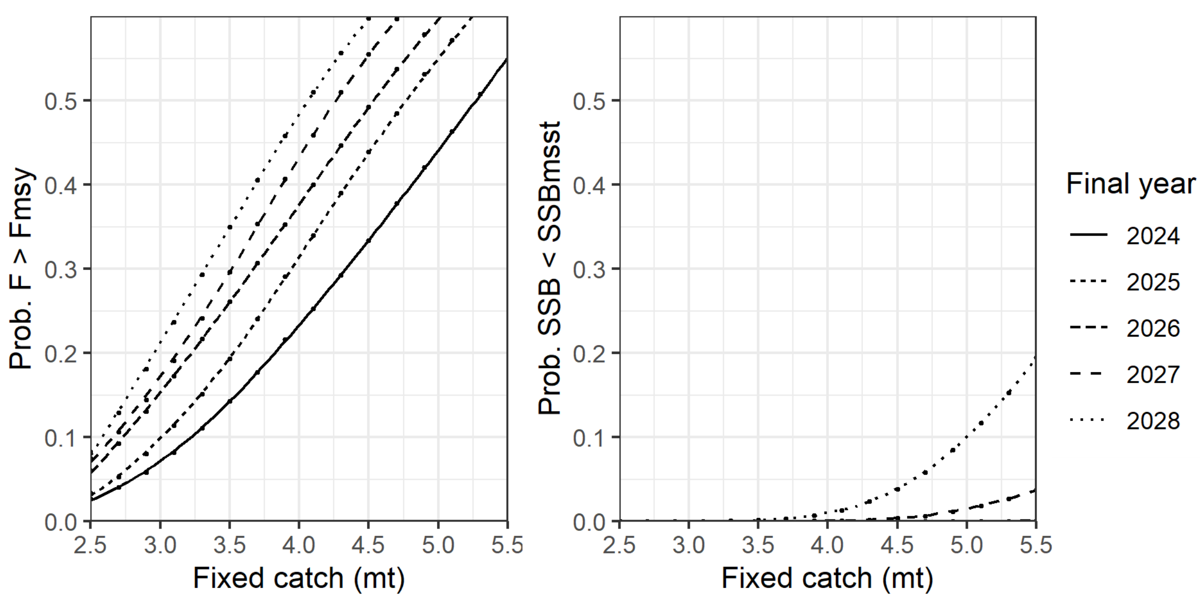


Figure 9-19– Probability of overfishing (left panel) and of stock being overfished (right panel) for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status probabilities are for the final projection year.

9.2 *Aprion virescens*

Asoama, G*reen jobfish*
Lutjanidae (snappers)

Key model parameters

Parameter	Value	Phase	Source
Natural mortality, M (yr^{-1})	0.17	-2	5.4/A_{max} (Hamel and Cope 2022)
Reference age, A_{min} (yr)	3	-2	O'Malley (2021)
Maximum age, A_{max} (yr)	32	-2	-
Length at A_{min}, L_{Amin} (cm)	34.0	-2	-
Length at A_{max}, L_{Amax} (cm)	76.9	-2	-
Growth rate, K (yr^{-1})	0.13	-2	-
CV of length < L_{Amin}	0.09	-2	-
CV of length > L_{Amin}	0.09	-2	-
Length-weight α	2.41e-5	-2	Kamikawa et al. (2015)
Length-weight β	2.89	-2	-
Length 50% maturity, L_{mat50} (cm)	44.8	-2	Everson (1989)
Slope of maturity ogive	-3.44	-2	-
Spawner-recruit steepness (h)	0.81	-2	FishLife 2.0 (Thorson 2019)
Number of platoons	3	-	Fixed
Unfished recruitment (Log R_0)	1.02 (0.04)	1	Estimated
Initial fishing mortality	-	-	Set to zero
Catchability (Log Q)	-0.11 (0.17)	1	Estimated
Extra Q SD	-	-	Set to zero
Length at 50% selectivity (cm)	43.1 (0.9)	2	Estimated
Width to 95% selectivity (cm)	13.4 (1.2)	2	Estimated
Dirichlet parameter (Log theta)	0.89 (0.32)	2	Estimated (note: 1.182, 0.255 normal prior used)

General comments

Data: Catch data are available from 1967 to 2021, CPUE from 2016 to 2021, and size composition observations are available in sufficient numbers from 2004 to 2020 (Figure 9-20). The size data from 2004 to 2006 (n=152) and 2010 to 2012 (n=126) were combined into two super-periods.

Life history: We found two growth studies: Loubens (1980a) in New Caledonia and O'Malley et al. (2021) in Hawaii and several Eastern Indian Ocean islands. Remarkably, all areas from both studies shared similar growth curves, with A_{max} between 28 years (New Caledonia) and 32 years (Hawaii and Indian Ocean) and L_{inf} values at 70 cm (New Caledonia) and 72 cm (Hawaii and Indian Ocean). Given these similarities, we selected the larger O'Malley (2021) dataset and fitted our own two-part von Bertalanffy curve. A single maturity study was found, from Hawaii, which provided a reasonable L_{mat50} estimate of 44.8 cm, or 59% of L_{inf}, which is reasonable based on Nadon and Ault (2016). The resulting growth and maturity curves are presented in Figure 9-21 and Figure 9-22. No alternative growth parametrization was run for this species, given the stability of these LH parameters, but an alternate model run with an L_{mat50} equal to 40 cm from the StepwiseLH tool was tested. There is no evidence of sex-specific growth patterns for this species (O'Malley 2021).

Fishery: The re-created historical catch (1967–1985) suggests that few *A. virescens* were caught during the dory project years in the 1970s (< 1 mt), with a noticeable fishery for this species only starting with the ‘alia program in the early 1980s (Figure 9-23). Catch in these early years was around 3 mt per year while catch in recent years have been around 1.5 mt before tapering off in 2020 and 2021. We first ran a model with an equilibrium catch in the first year (1967) but this resulted in a very low initial F estimate, which suggests that this species was very lightly exploited pre-1967. This is reasonable given the history of the fishery, where deeper areas were hard to access for the local fishermen. We therefore started the model in an unfished state (initial F set to 0). The model estimated length at 50% selectivity at approximately 43 cm and full selectivity at approximately 56 cm (or age 8), with small differences in selectivity-at-age between platoons (Figure 9-24).

Model diagnostics: All estimated parameters converged within the set bounds, with the final likelihood gradient of the model being less than 0.0001 and the associated Hessian matrix being positive definite. A jitter analysis of 100 model runs with different random initial starting values also supported that the model converged on a global minimum (Figure 9-25). Further, goodness-of-fit diagnostics indicated that the model fitted the CPUE index well with an RMSE of 0.11 and successful Runs test (Figure 9-26). The model was originally fitted with the “extra SD” parameter, which allowed for an increase in the SD of the CPUE index, but this parameter was estimated close to zero and was turned off in subsequent runs. The model fitted the mean length observations worst in the early years versus recent ones, which resulted in a failed Runs test (Figure 9-27). However, the RMSE for the mean length model fit was low at 0.05 and the model fitted well to the yearly and overall size composition data with little patterns in the size composition residuals (Figure 9-28 and Figure 9-29). The change in negative log-likelihoods at different fixed log(R_0) values indicated that this parameter’s estimate was mainly driven by the length composition data with a clear minimum reached at 1.0 (~2,700 recruits; Figure 9-30). The results of the retrospective analysis, which progressively removed one year of data from 2021 to 2017, showed no significant pattern for *SSB* and *F*, with Mohn’s rho values around -0.07 and 0.09, respectively (suggested limits are between -0.15 and 0.2; Figure 9-31).

Stock status: Population biomass declined from a SSB_0 around 14 mt prior to 1967 to about 5 mt in the late 1980s following the increased catch associated with the ‘alia program (Figure 9-32 and Table 9-5). Biomass increased consistently between 1990 and 2008 but fell again between 2009 and 2016 following years with increased catch (the MSST was estimated at 2.9 mt; Figure 9-32). Recruitment stayed close to R_0, varying between 2,600 and 2,800 recruits per year (Figure 9-33). The current stock status (SSB/SSB_{MSST}) is equal to 1.7 (not overfished) with no overfishing occurring. The stock came close to being overfished in 1987 before rebounding. Overfishing occurred consistently between 1983 and 1986 but only sporadically since then (Figure 9-34; Table 9-6) with fishing mortality varying around 0.1, hitting maximum values in the 80s and in 2009 at around 0.3 (F_{MSY} was estimated at 0.19). Equilibrium catches at F_{MSY} (i.e., the *MSY*) were estimated at 1.6 mt. Catches in recent years have averaged around 0.9 mt (Table 9-6).

Alternate scenarios: We ran 7 alternative models: *M* and steepness plus and minus 10%, no historical catch, with recruitment deviations, and alternate LH source. The alternate specifications did not have major impacts on the model results (Table 9-7, Figure 9-35, and Figure 9-36). There was little impact of starting the model in 1986. The recruitment deviation model resulted in some lower recruitment in 2015-2020 which decreased *SSB*. None of the alternative models resulted in overfishing or overfished status in 2021.

Projections: The projection analysis showed the distribution of outcomes in the probability of overfishing and overfished status that would occur in various final years (2024-2028) under various fixed-catch scenarios (Figure 9-36 ; Figure 9-37, and Figure 9-38). The projections indicated very low probability of overfished status occurring between 2024 and 2028 for the range of fixed catch explored (< 3 mt per year).

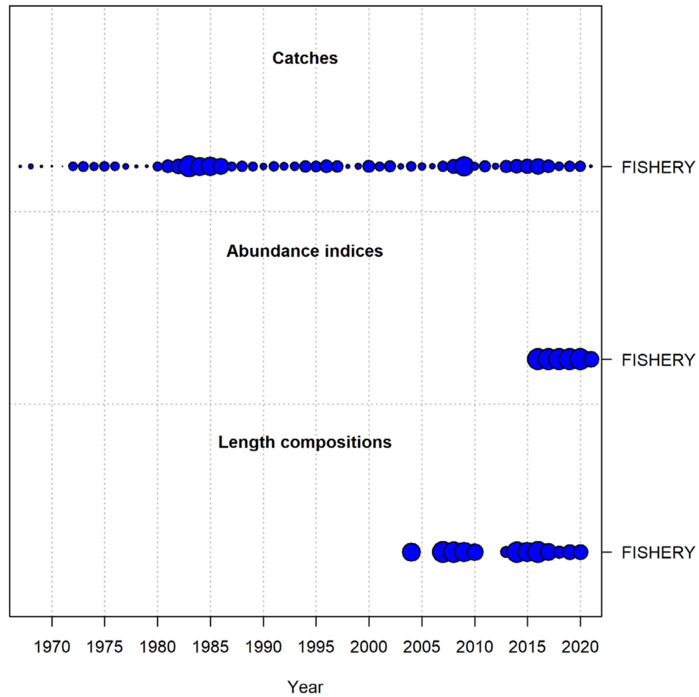


Figure 9-20- Summary of data types used in the Stock Synthesis model. Catches include boat-based and shore-based landings from creel surveys (1986-2021), as well as historical catches from reports (1967-1985). The abundance index is from boat-based creel survey ‘bottomfishing” gear type. Length compositions are from creel surveys (all years) and the biosampling program (2010-2015), filtered for the “bottomfishing” gear.

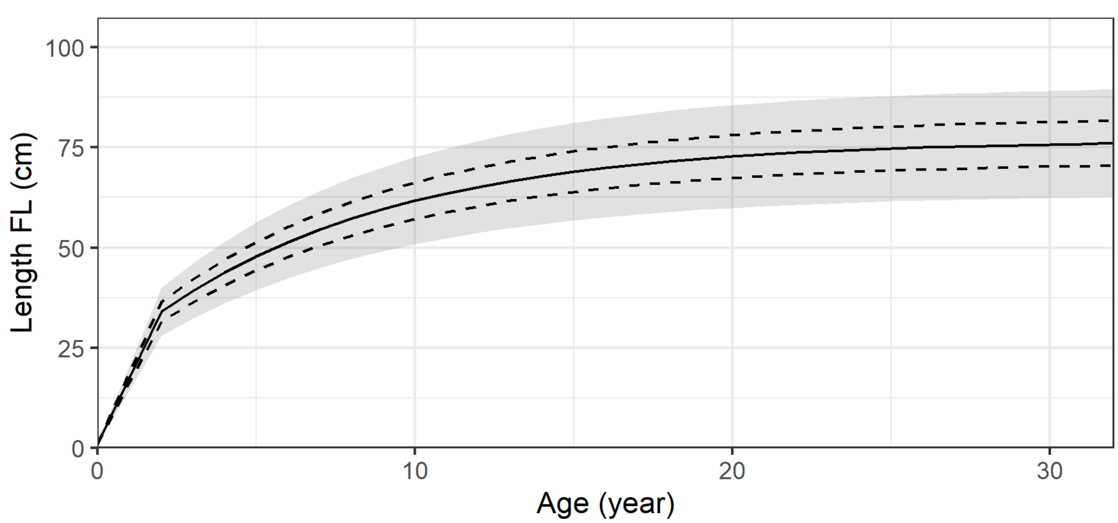


Figure 9-21 – Growth curve following a Von Bertalanffy model with 95% confidence intervals associated with the CV Linf parameter. The central growth platoon (solid line) and the two secondary ones (dashed lines) used in the model are also displayed.

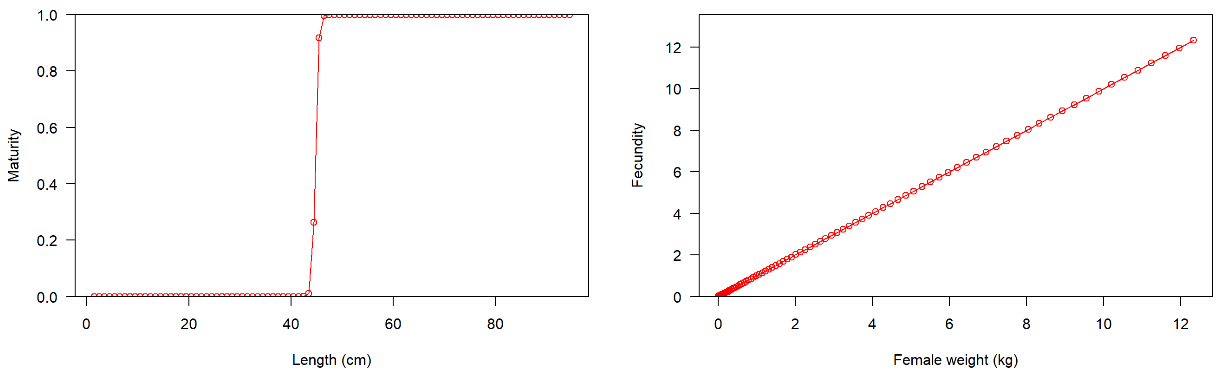


Figure 9-22 – Maturity-at-length (FL; left) and fecundity-at-weight (right) used in the stock assessment model.

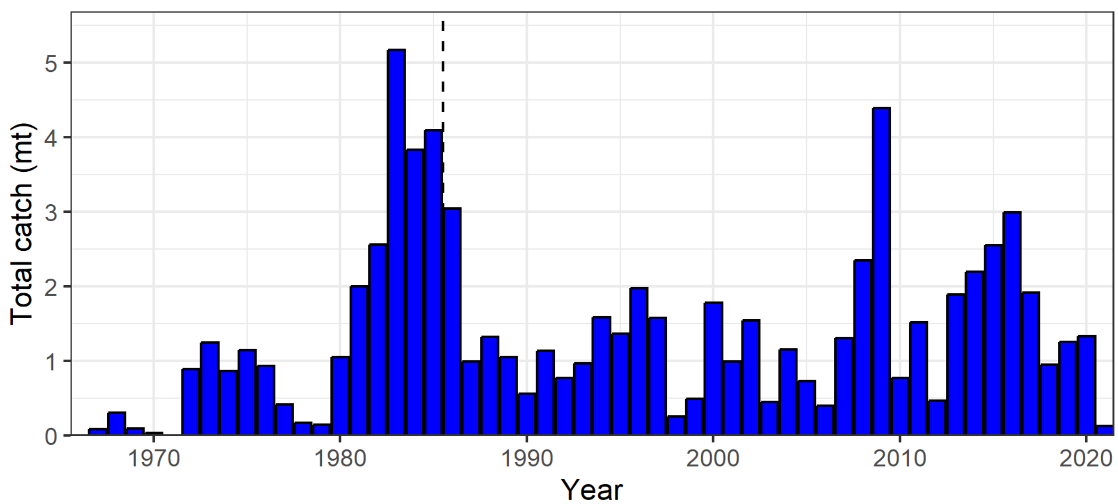


Figure 9-23 – Annual total catch in metric tons (mt). The vertical dashed line indicates the start of the creel survey program (1986), with older data coming from historical catch reports.

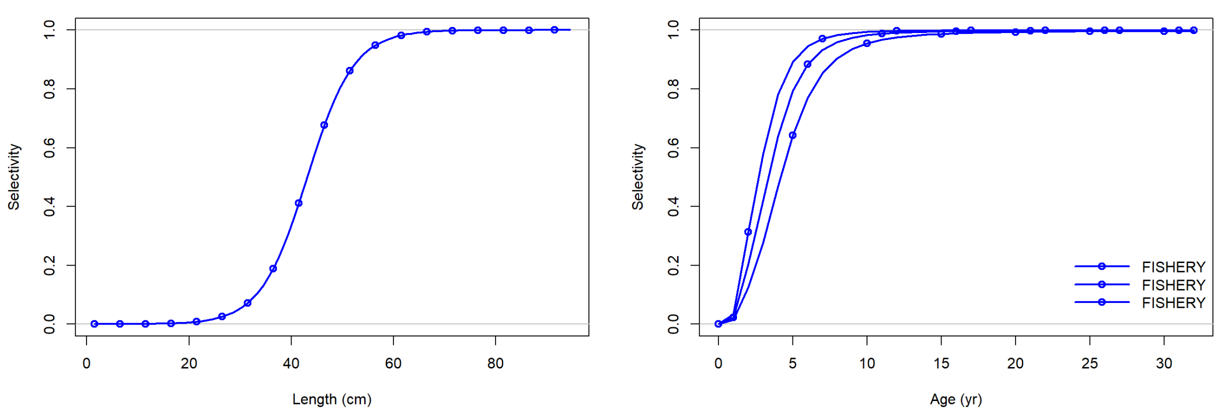


Figure 9-24 – Length-based selectivity estimated by the Stock Synthesis model (left) and the resulting selectivity-at-age for all 3 growth platoons (right).

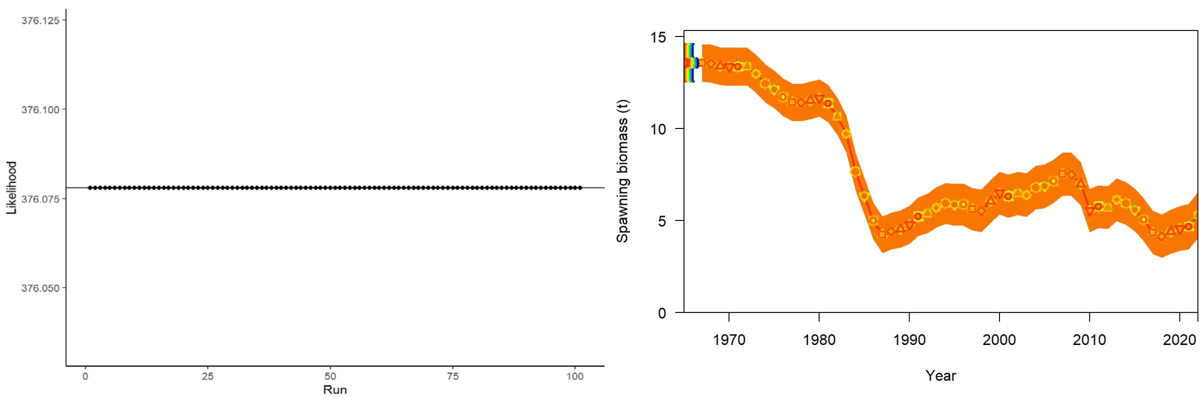


Figure 9-25 - Results of jitter analysis where 100 models were run with randomly varying initial parameter values. Left panel shows the variation in minimum model likelihood value for all 100 model runs. Right panel shows the variation in SSB time series for all 100 model runs.

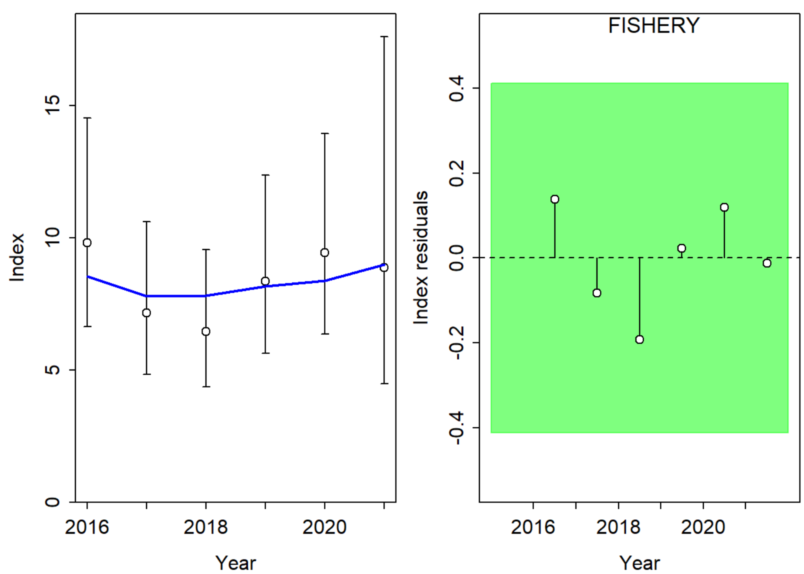


Figure 9-26 – Observed (open dots) vs expected (blue line) CPUE abundance index by year with standard deviations intervals (left). CPUE index residuals by year, with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.11.

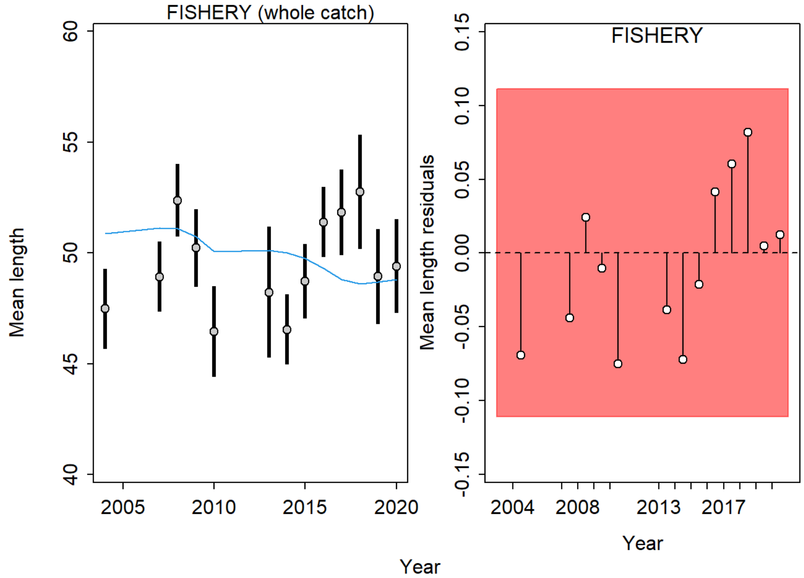


Figure 9-27 – Observed (open dots) vs expected (blue line) mean length by year with standard deviations intervals (left). Mean length residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.05.

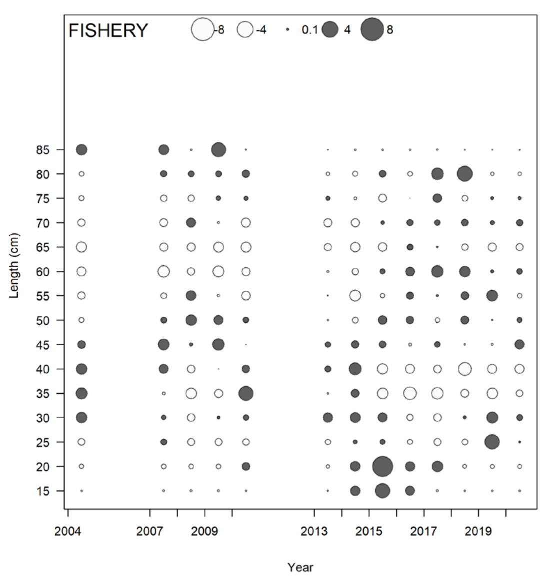


Figure 9-28 – Pearson residual plot of observed vs. expected size frequency data by size bin and year.

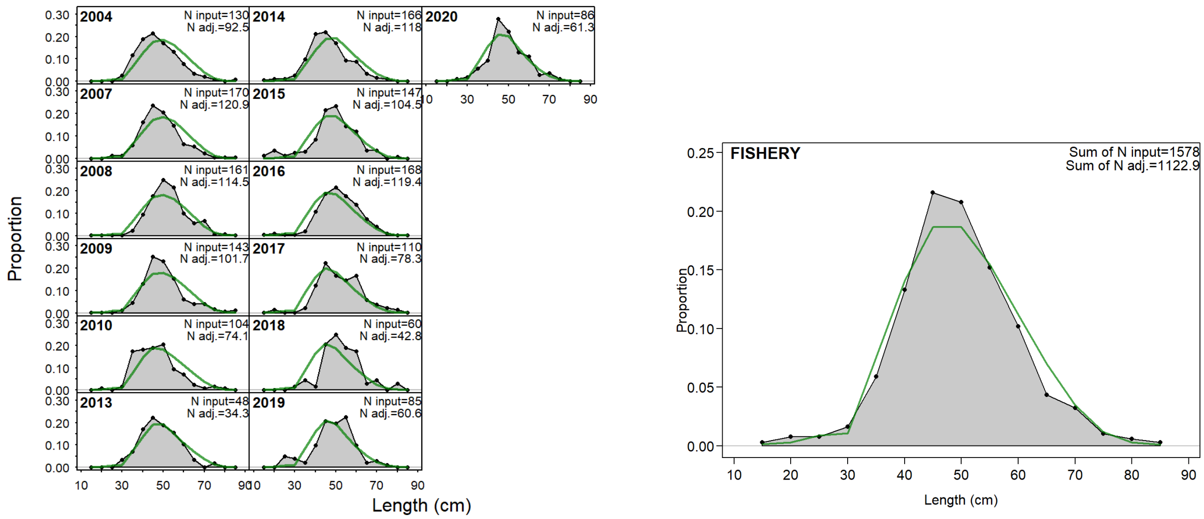


Figure 9-29 – Observed (gray area) vs. expected (green line) abundance-at-length from bottomfishing catch by year (left) and overall (right).

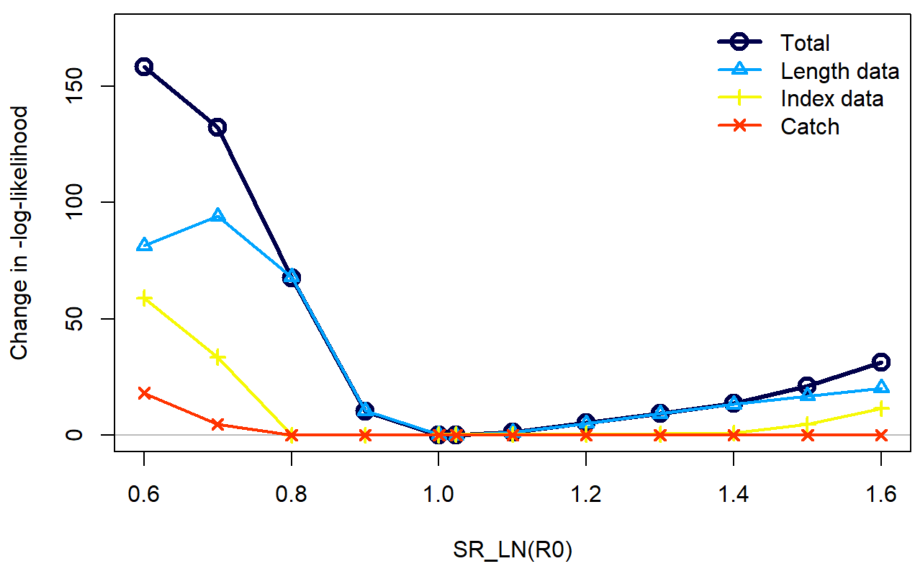


Figure 9-30 – Profiles of the change in negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter (R_0) in log-scale.

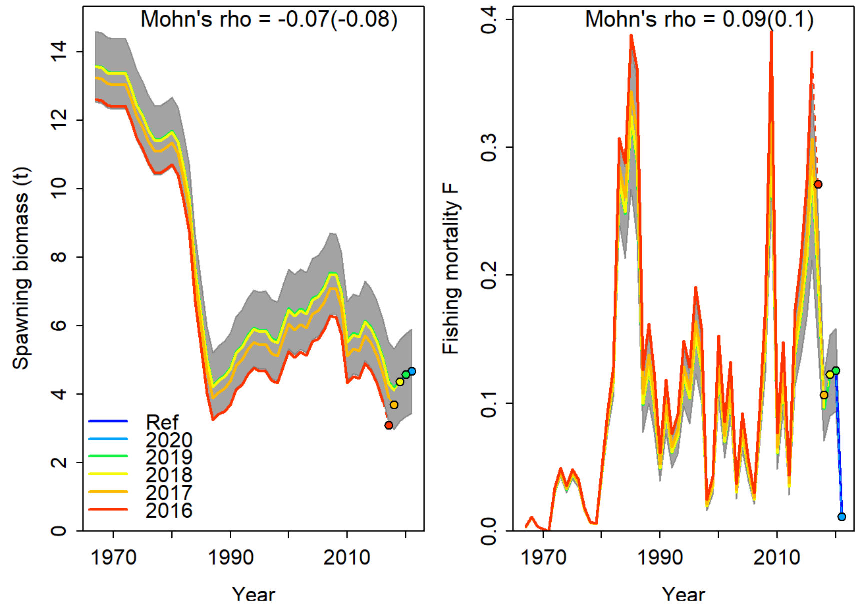


Figure 9-31 – Retrospective analysis of spawning biomass (left) and fishing mortality (right) consisting of 5 reruns of the base case model each fitted with one less year of data from the base case model (blue line).

Table 9-5 – Time series of spawning biomass (SSB, mt), age-0 recruitment (Rec., 1000s of recruits), and instantaneous fishing mortality (F, yr^{-1}) estimated by the Stock Synthesis model. CV is the coefficient of variation.

Year	SSB	CV	Rec.	CV	F	CV	Year	SSB	CV	Rec.	CV	F	CV
1969	13.7	0.09	2.85	0.09	0.003	0.48	1996	6.0	0.32	2.63	0.10	0.166	0.60
1970	13.7	0.09	2.85	0.09	0.001	0.46	1997	5.7	0.34	2.62	0.11	0.115	0.45
1971	13.7	0.09	2.85	0.09	0.000	0.39	1998	5.7	0.34	2.62	0.11	0.019	0.55
1972	13.7	0.09	2.85	0.09	0.028	0.54	1999	6.2	0.30	2.65	0.10	0.030	0.53
1973	13.2	0.09	2.84	0.09	0.048	0.46	2000	6.6	0.28	2.67	0.10	0.099	0.55
1974	12.6	0.10	2.83	0.09	0.027	0.59	2001	6.5	0.27	2.66	0.10	0.071	0.41
1975	12.3	0.10	2.83	0.09	0.038	0.50	2002	6.6	0.26	2.67	0.10	0.096	0.48
1976	11.9	0.11	2.83	0.09	0.033	0.44	2003	6.5	0.26	2.66	0.10	0.029	0.36
1977	11.6	0.11	2.82	0.09	0.013	0.54	2004	7.0	0.24	2.68	0.10	0.056	0.65
1978	11.7	0.11	2.82	0.09	0.005	0.45	2005	7.0	0.23	2.70	0.10	0.041	0.50
1979	11.8	0.11	2.83	0.09	0.006	0.51	2006	7.3	0.21	2.70	0.10	0.026	0.46
1980	11.9	0.11	2.82	0.09	0.033	0.52	2007	7.7	0.19	2.72	0.10	0.067	0.65
1981	11.7	0.11	2.82	0.09	0.094	0.59	2008	7.5	0.19	2.71	0.10	0.145	0.46
1982	10.8	0.14	2.81	0.09	0.093	0.57	2009	7.1	0.18	2.70	0.09	0.324	0.23
1983	10.0	0.17	2.79	0.09	0.300	0.87	2010	5.6	0.21	2.63	0.10	0.057	0.42
1984	7.6	0.28	2.70	0.09	0.199	0.71	2011	5.8	0.20	2.64	0.10	0.080	0.54
1985	6.3	0.35	2.64	0.11	0.273	0.74	2012	5.9	0.20	2.65	0.10	0.033	0.48
1986	4.9	0.44	2.56	0.13	0.281	0.70	2013	6.3	0.18	2.67	0.09	0.118	0.58
1987	4.2	0.48	2.49	0.16	0.095	0.87	2014	6.1	0.14	2.66	0.09	0.161	0.33
1988	4.5	0.45	2.50	0.14	0.106	0.79	2015	5.6	0.14	2.63	0.09	0.191	0.30
1989	4.8	0.44	2.52	0.13	0.098	0.55	2016	5.2	0.14	2.60	0.09	0.264	0.26
1990	5.0	0.41	2.53	0.12	0.046	0.49	2017	4.5	0.16	2.54	0.10	0.168	0.24
1991	5.5	0.37	2.58	0.11	0.090	0.47	2018	4.4	0.18	2.54	0.10	0.090	0.24
1992	5.6	0.36	2.60	0.11	0.055	0.61	2019	4.6	0.17	2.56	0.10	0.111	0.26
1993	5.9	0.34	2.62	0.10	0.069	0.58	2020	4.8	0.17	2.57	0.10	0.109	0.28
1994	6.1	0.32	2.63	0.10	0.110	0.50	2021	5.0	0.17	2.58	0.10	0.009	0.30
1995	6.1	0.33	2.63	0.10	0.094	0.59							

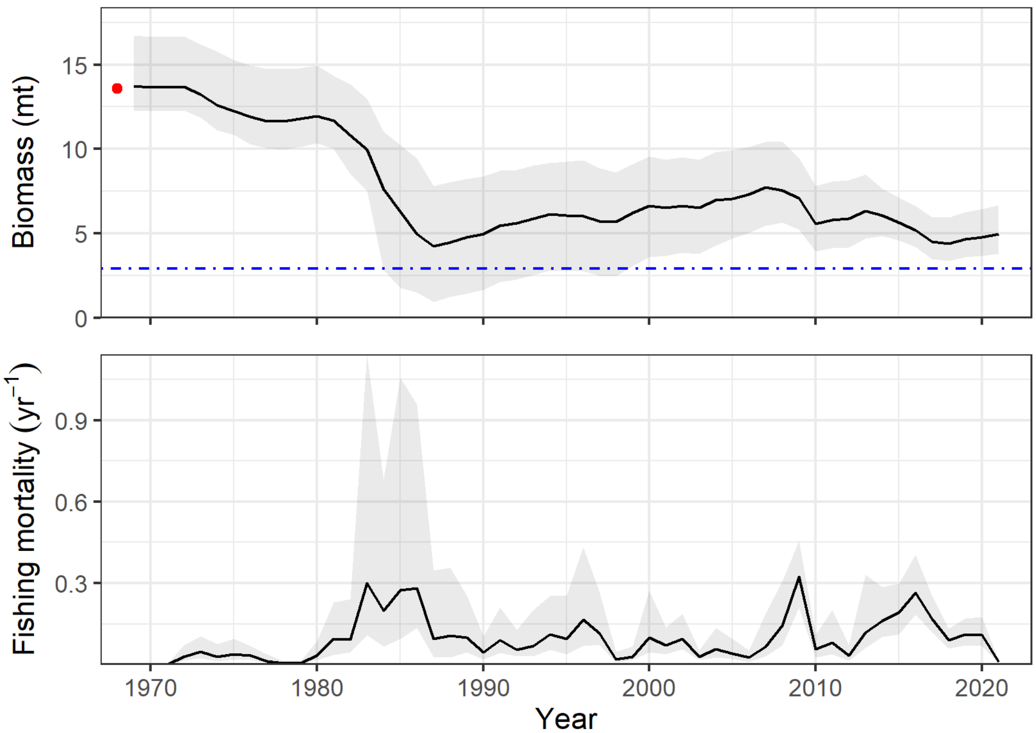


Figure 9-32 – Time series of spawning biomass (solid line) with its 95% confidence interval and SSB_0 estimate (red dot; top panel). The dot-and-dash blue line shows the spawning biomass at the MSST reference point (SSB_{MSST}). Time series of fishing mortality rate with its 95% confidence intervals (bottom panel).

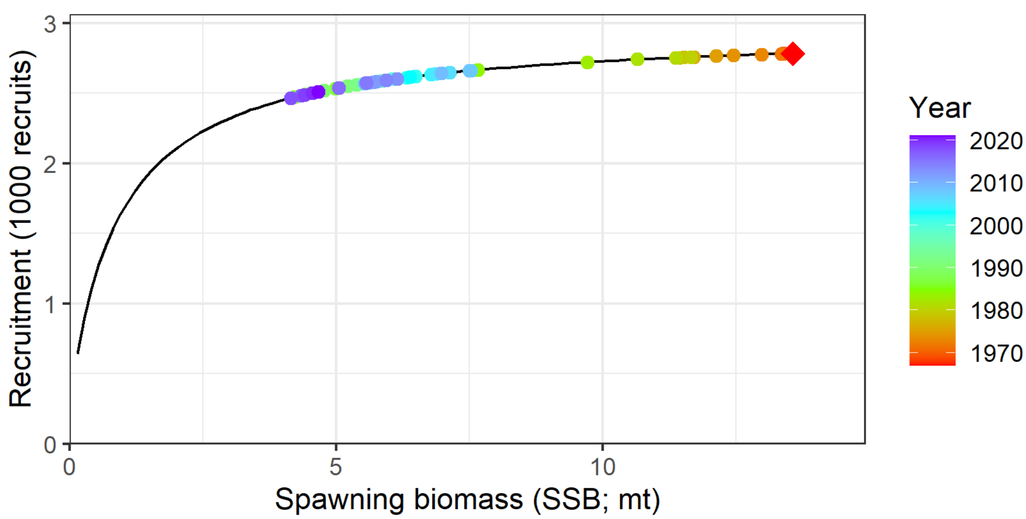


Figure 9-33 – Expected recruitment from the stock-recruitment relationship (black line) and estimated annual recruitment (dots) from SS. Estimated virgin SSB and recruitment is indicated with a red diamond.

Table 9-6 – Estimated biological reference points with 95% confidence interval (SD) derived from the SS base-case model where *F* is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield (2021 is the terminal year of the model).

Reference point	Value
F_{MSY} (yr^{-1})	0.196 (0.187 - 0.203)
F_{2021} (yr^{-1})	0.009 (0.006 - 0.015)
F_{2021}/F_{MSY}	0.048 (0.03 - 0.073)
SSB_{MSST} (mt)	2.91 (2.35 - 3.7)
SSB_{2021} (mt)	4.96 (3.8 - 6.66)
SSB_{2021}/SSB_{MSST}	1.72 (1.43 - 2.03)
MSY (mt)	1.56 (1.46 - 1.67)
$Catch_{2019-2021}$ (mt)	0.9 (0.49 - 1.31)
SPR_{MSY}	0.3 (0.29 - 0.3)
SPR_{2021}	0.91 (0.88 - 0.93)

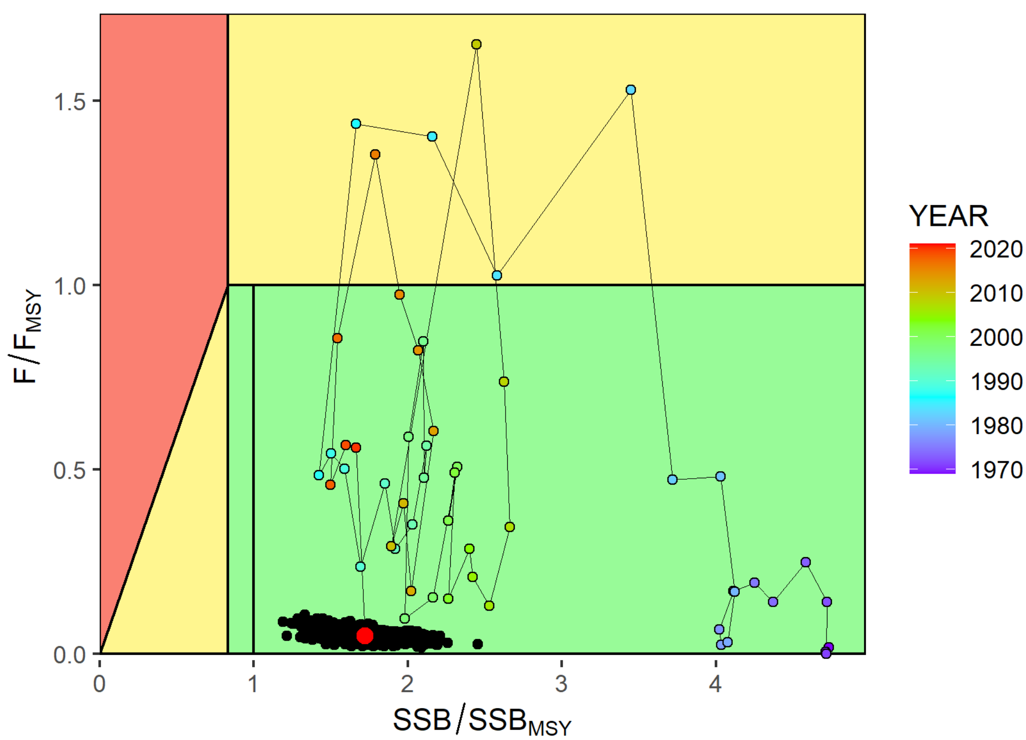


Figure 9-34 – Kobe plot representing the trend in relative fishing mortality and spawning stock biomass between 1969 and 2021 with their associated biological reference areas (red: overfished and overfishing, yellow: overfishing or overfished, green: no overfishing and not overfished). The large red dot indicates median stock status in 2021 and the black dots are one thousand Monte Carlo draws from the stock status distribution to represent the uncertainty around the final year status.

Table 9-7 – Summary table of key model output for all alternative model runs where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield.

Model	F_{2021}	F_{MSY}	F_{2021}/F_{MSY}	SSB_{MSY}	SSB_{MSST}	SSB_{2021}	SSB_{2021}/SSB_{MSY}	SSB_{2021}/SSB_{MSST}	Catch MSY
Base	0.011	0.2	0.05	3.4	2.8	4.7	1.4	1.7	1.6
M - 10%	0.013	0.17	0.08	3.6	3.1	3.9	1.1	1.3	1.4
M + 10%	0.009	0.22	0.04	3.3	2.7	5.8	1.8	2.1	1.8
Steep. - 10%	0.011	0.16	0.07	4	3.3	4.6	1.1	1.4	1.5
Steep. + 10%	0.011	0.24	0.05	2.9	2.4	4.7	1.6	2	1.7
Rec. dev.	0.015	0.19	0.08	3.2	2.6	3.4	1.1	1.3	1.4
No hist. catch	0.01	0.19	0.05	3.4	2.8	4.9	1.4	1.8	1.6
Alternate LH	0.011	0.22	0.05	3.8	3.2	5.5	1.4	1.7	1.6

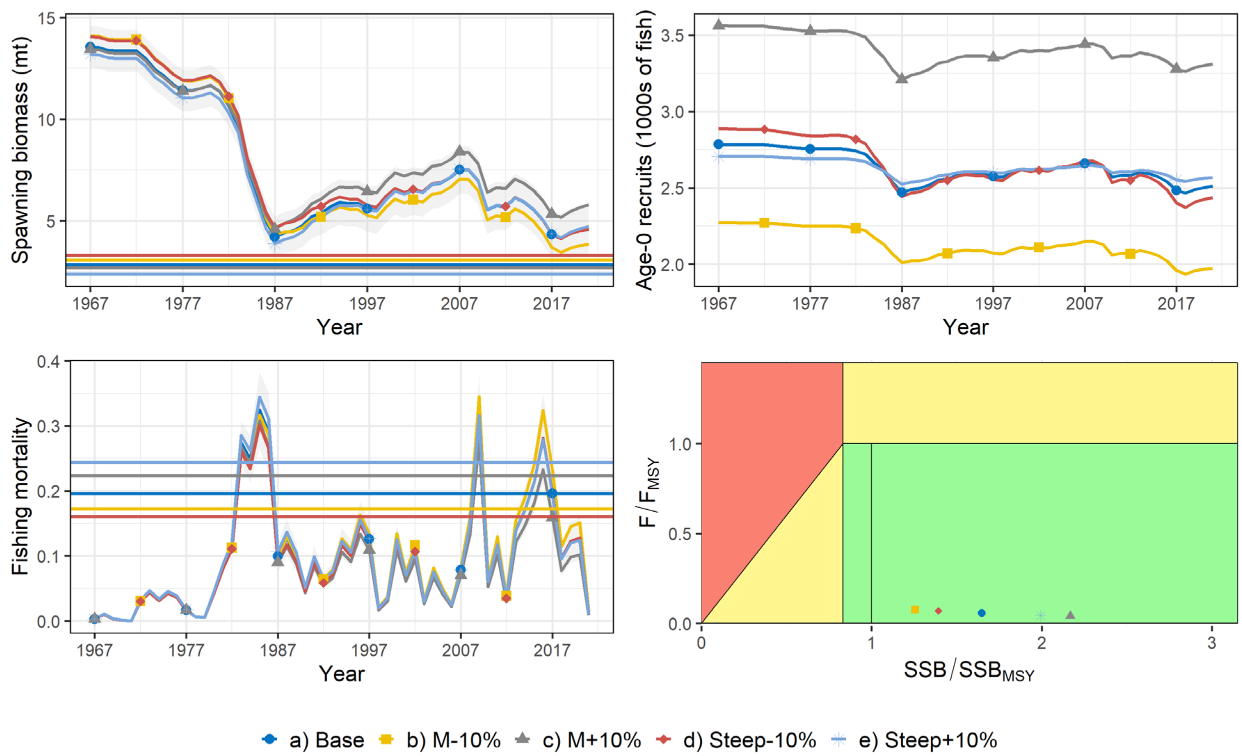


Figure 9-35 – Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) under moderate life-history parameter variation (plus and minus 10% of base parameter values).

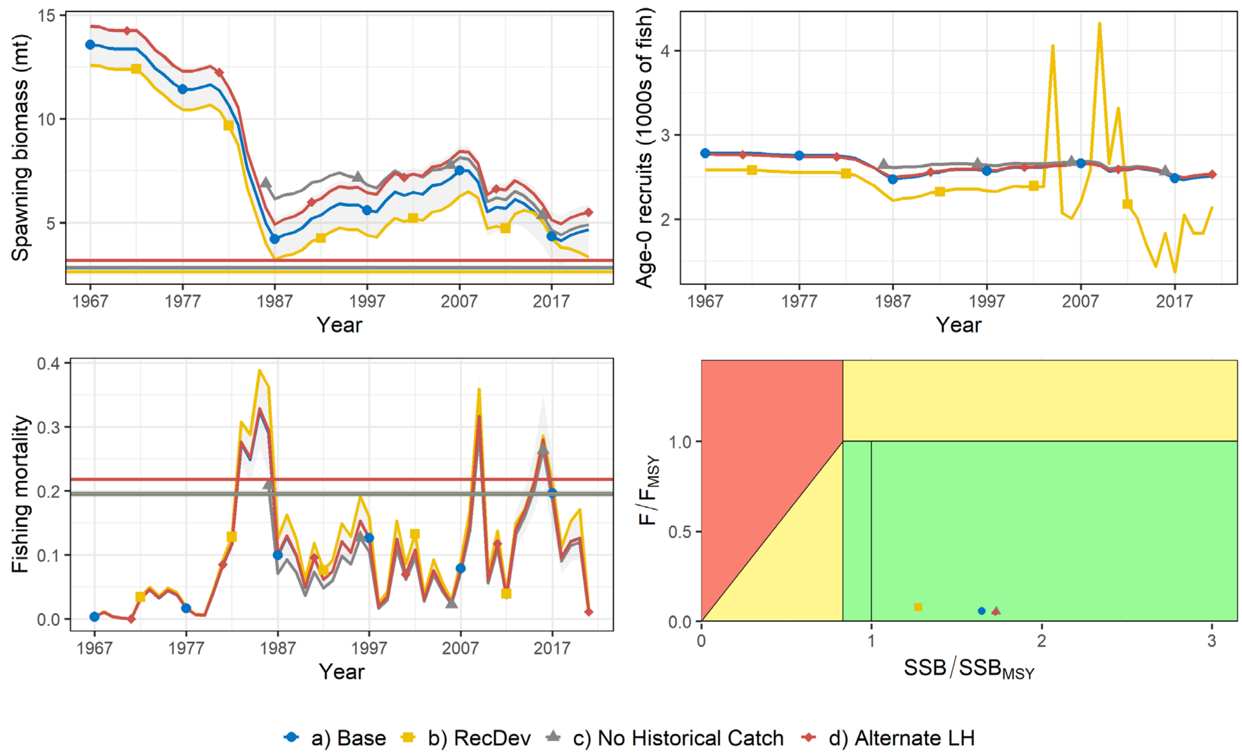


Figure 9-36 - Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) b) with recruitment deviations, c) without historical catch data (model starts in 1986), and d) with an alternate life history parameter source (L_{mat} from StepwiseLH).

Table 9-8 - The annual fixed catch values (metric tons) applied from 2024 to a final projection year resulting in a given probability of overfishing (F/F_{MSY}>1) in that final year. Catches for years prior to the start of the new catch guidance (2022 and 2023) were fixed at the mean of the last 3 years of catch data (2019 to 2021).

Probability of	Fixed catch (mt) from 2024 to:				
$F > F_{MSY}$	2024	2025	2026	2027	2028
0.50	2.63	2.45	2.32	2.22	2.15
0.49	2.62	2.44	2.32	2.22	2.15
0.48	2.61	2.43	2.31	2.21	2.14
0.47	2.60	2.42	2.30	2.20	2.14
0.46	2.59	2.41	2.29	2.20	2.13
0.45	2.58	2.41	2.29	2.19	2.12
0.44	2.57	2.40	2.28	2.18	2.12
0.43	2.56	2.39	2.27	2.18	2.11
0.42	2.55	2.38	2.26	2.17	2.10
0.41	2.54	2.37	2.25	2.16	2.10
0.40	2.53	2.36	2.25	2.16	2.09
0.39	2.52	2.36	2.24	2.15	2.08
0.38	2.51	2.35	2.23	2.14	2.08
0.37	2.50	2.34	2.22	2.14	2.07
0.36	2.49	2.33	2.21	2.13	2.06
0.35	2.48	2.32	2.21	2.12	2.06
0.34	2.47	2.31	2.20	2.12	2.05
0.33	2.46	2.30	2.19	2.11	2.04
0.32	2.45	2.29	2.18	2.10	2.04
0.31	2.44	2.29	2.17	2.10	2.03
0.30	2.43	2.28	2.16	2.09	2.02
0.29	2.42	2.27	2.16	2.08	2.02
0.28	2.41	2.26	2.15	2.07	2.01
0.27	2.40	2.25	2.14	2.07	2.00
0.26	2.39	2.24	2.13	2.06	2.00
0.25	2.38	2.23	2.12	2.05	1.99
0.24	2.37	2.22	2.11	2.04	1.98
0.23	2.35	2.21	2.10	2.04	1.98
0.22	2.34	2.20	2.10	2.03	1.97
0.21	2.33	2.19	2.09	2.02	1.96
0.20	2.32	2.18	2.08	2.01	1.96
0.19	2.31	2.17	2.07	2.01	1.95
0.18	2.30	2.16	2.06	2.00	1.94
0.17	2.28	2.15	2.05	1.99	1.93
0.16	2.27	2.14	2.04	1.98	1.93
0.15	2.26	2.13	2.03	1.98	1.92
0.14	2.25	2.12	2.02	1.97	1.91
0.13	2.24	2.11	2.02	1.96	1.90
0.12	2.22	2.10	2.01	1.95	1.90
0.11	2.21	2.09	2.00	1.94	1.89
0.10	2.20	2.08	1.99	1.94	1.88

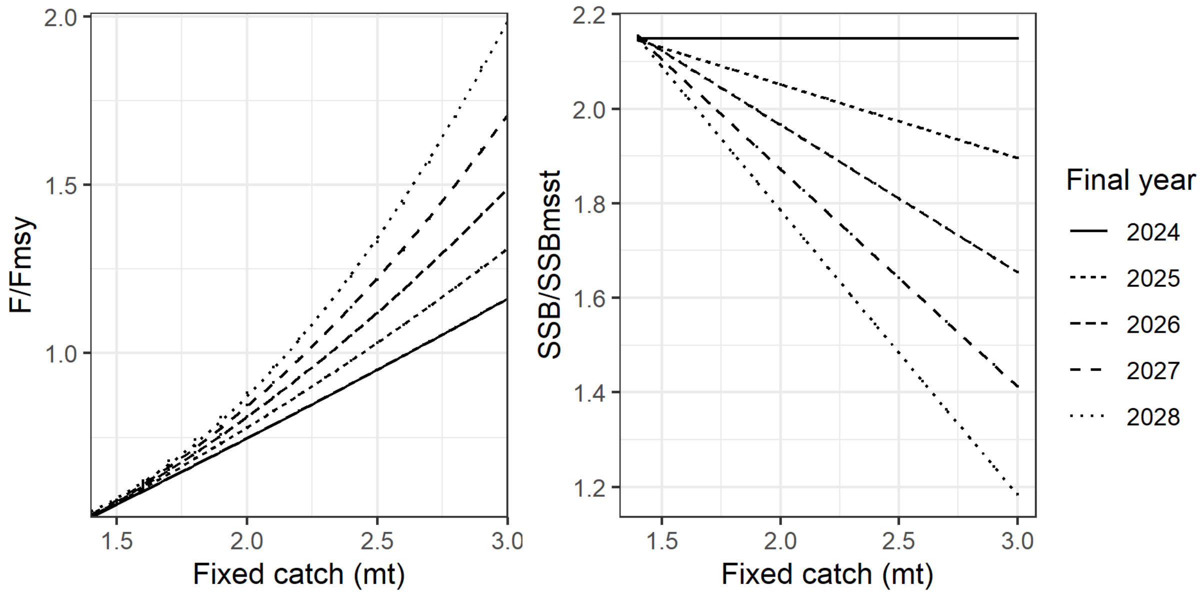


Figure 9-37 – Median stock status for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status is for the final projection year.

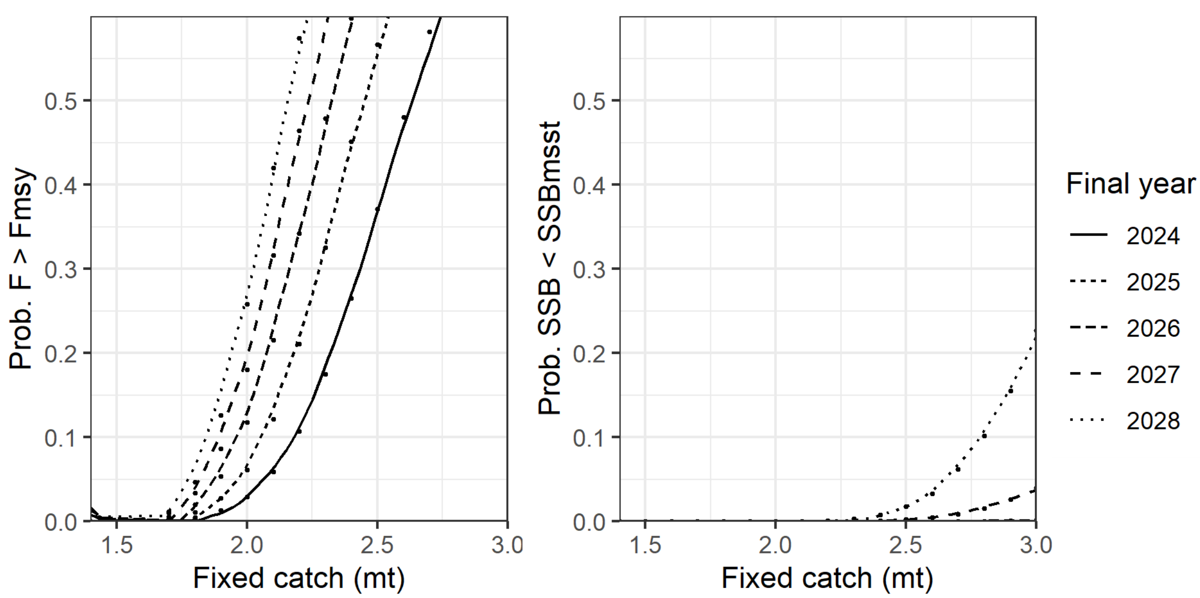
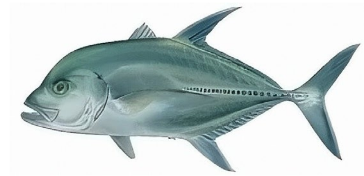


Figure 9-38– Probability of overfishing (left panel) and of stock being overfished (right panel) for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status probabilities are for the final projection year.

9.3 *Caranx lugubris*



Tafauli, *Black jack*
Carangidae (jacks and trevallies)

Key model parameters

Parameter	Value	Phase	Source
Natural mortality, M (yr^{-1})	0.45	-2	5.4/A_{max} (Hamel and Cope 2022)
Reference age, A_{min} (yr)	0	-2	-
Maximum age, A_{max} (yr)	12	-2	Fry (2016)
Length at A_{min}, L_{Amin} (cm)	8.9	-2	StepwiseLH. L_{99}: 66.0 cm (creel+biosampling)
Length at A_{max}, L_{Amax} (cm)	68.8	-2	-
Growth rate, K (yr^{-1})	0.23	-2	-
CV of length < L_{Amin}	0.09	-2	-
CV of length > L_{Amin}	0.09	-2	-
Length-weight α	2.87e-5	-2	Kamikawa (2015)
Length-weight β	2.94	-2	-
Length 50% maturity, L_{mat50} (cm)	37.9	-2	StepwiseLH. L_{99}: 66.0 cm (creel+biosampling)
Slope of maturity ogive	-1.47	-2	-
Spawner-recruit steepness (h)	0.73	-2	FishLife 2.0 (Thorson 2019)
Number of platoons	3	-	Fixed
Unfished recruitment (Log R_0)	1.26 (0.02)	1	Estimated
Initial fishing mortality	-	-	Set to zero
Catchability (Log Q)	-0.26 (0.17)	1	Estimated
Extra Q SD	0.04 (0.10)	1	Estimated
Length at 50% selectivity (cm)	43.9 (1.5)	2	Estimated
Width to 95% selectivity (cm)	16.4 (1.3)	2	Estimated
Dirichlet parameter (Log theta)	0.29 (0.37)	2	Estimated (note: 1.182, 0.255 normal prior used)

General comments

Data: Catch data are available from 1967 to 2021, CPUE from 2016 to 2021, and size composition observations are available in sufficient numbers from 2007 to 2020 (Figure 9-39). The size data from 2009 to 2011 (n=132), 2016 to 2017 (n=103), and 2018 to 2020 (n=84) were combined into three super-periods.

Life history: We found a single growth study (Fry 2006 in New Guinea) but no maturity studies. Fry (2016) had a very low sample size (n=12). As a result, we decided to use the StepwiseLH approach using an L_{99} from creel survey and biosampling programs which provided an L_{inf} of 69 cm and similar max age (10 years) to Fry (2016; 12 years). The higher max age was selected for our model. The resulting growth and maturity curves are presented in Figure 9-40 and Figure 9-41. We ran a model with the StepwiseLH maximum age as an alternate scenario. There is no evidence of sex-specific growth patterns for this species.

Fishery: The re-created historical catch (1967–1985) suggests that contrary to deeper-occurring species, a fair amount of *C. lugubris* were caught during the dory project years in the 1970s (0.5 mt per year), with a noticeable increase in catch during the ‘alia program in the 1980s Figure 9-42). Catch in recent years have been around 0.5 mt. We first ran a model with an equilibrium catch in the first year (1967) but this resulted in a very low initial F estimate, which suggests that this species was very lightly exploited pre-1967. Thus, we started the model in an unfished state (initial F set to 0). The model estimated length at 50% selectivity at approximately 44 cm and full selectivity at approximately 60 cm (or age 8) with some small differences in selectivity-at-age between platoons (Figure 9-43).

Model diagnostics: All estimated parameters converged within the set bounds with the final likelihood gradient of the model being less than 0.0001 and the associated Hessian matrix being positive definite. A jitter analysis of 100 model runs with different random initial starting values also supported that the model converged on a global minimum (Figure 9-44). Further, goodness-of-fit diagnostics indicated that the model fitted the CPUE index well with a successful Runs test but with a large RMSE of 0.39 (Figure 9-45). The model was fitted with the “extra SD” parameter, which allowed for an increase in the SD of the CPUE index by a small amount (0.04). The mean length model fit passed the Runs test and had a RMSE of 0.06 (Figure 9-46). The yearly and overall size composition data was fitted relatively well with some residual pattern in 2012-2015 likely due to some oddly shaped size composition data in those 3 years (Figure 9-47 and Figure 9-48). The change in negative log-likelihoods at different fixed log(R_0) values indicated that this parameter’s estimate was mainly driven by the length composition data with a clear minimum reached at 1.3 (~3,600 recruits; Figure 9-49). The results of the retrospective analysis, which progressively removed one year of data from 2021 to 2017, showed no significant pattern for *SSB* or *F*, with Mohn’s rho values around 0 for both (suggested limits are between -0.15 and 0.2; Figure 9-50).

Stock status: Population biomass declined from an SSB_0 around 3 mt prior to 1967 to about 0.5 mt in the late 1980s, following the increased catch associated with the ‘alia program (Figure 9-51 and Table 9-9). Following this program, biomass started to increase but declined again in the late 1990s. However, it has been increasing consistently since then, reaching values around 2 mt in recent years (the MSST was estimated at 0.8 mt; Figure 9-51). Recruitment started near $R_{0,}$ at around 3,600 recruits but fell as low as 2,300 recruits in the late 1990s (Figure 9-52). The current stock status (SSB/SSB_{MSST}) is equal to 4.4 (not overfished) with no overfishing occurring. The stock was overfished sporadically in the late 1980s and 1990s before rebounding. Overfishing occurred during those early years (Figure 9-53; Table 9-10), hitting maximum values in the 1990s at around 1.07 (F_{MSY} was estimated at 0.41). Equilibrium catches at F_{MSY} (i.e., the *MSY*) were estimated at 0.9 mt. Catches in recent years have been low, averaging only 0.3 mt (Table 9-10).

Alternate scenarios: We ran 7 alternative models: *M* and steepness plus and minus 10%, no historical catch, with recruitment deviations, and alternate LH source. The alternate specifications did not have major impacts on the model results (Table 9-11, Figure 9-54, and Figure 9-55). There was little impact of starting the model in 1986. Adding recruitment deviations did not significantly change model results. We used the StepwiseLH tool as an alternative LH parameter source to obtain a different A_{max} (10 years vs 12 years) which scaled the *SSB* higher (by increasing *M*, decreasing *F*, which scaled the population higher). None of the alternative models resulted in overfishing or overfished status in 2021.

Projections: The projection analysis showed the distribution of outcomes in the probability of overfishing and overfished status that would occur in various final years (2024-2028) under various fixed-catch scenarios (Table 9-12; Figure 9-56, and Figure 9-57). The projections indicated very low probability of overfished status occurring between 2024 and 2028 for the range of fixed catch explored (< 2 mt per year).

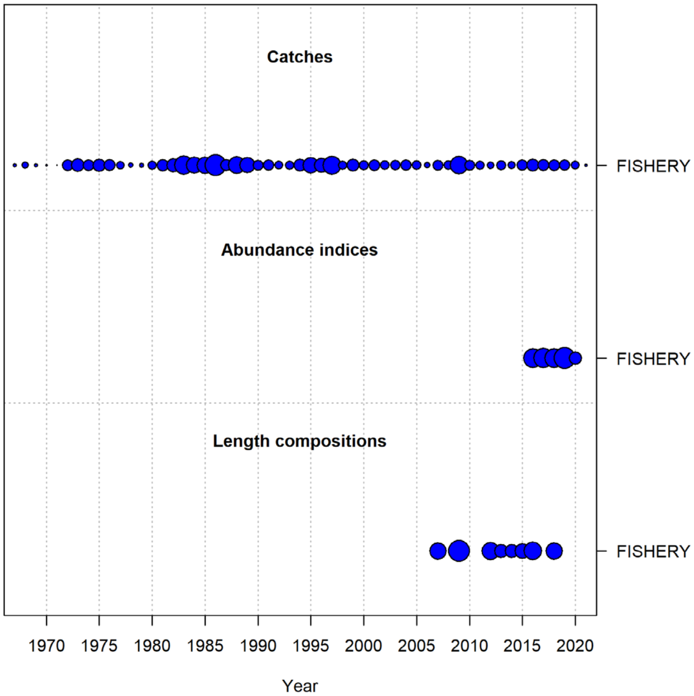


Figure 9-39- Summary of data types used in the Stock Synthesis model. Catches include boat-based and shore-based landings from creel surveys (1986-2021), as well as historical catches from reports (1967-1985). The abundance index is from boat-based creel survey 'bottomfishing" gear type. Length compositions are from creel surveys (all years) and the biosampling program (2010-2015), filtered for the "bottomfishing" gear.

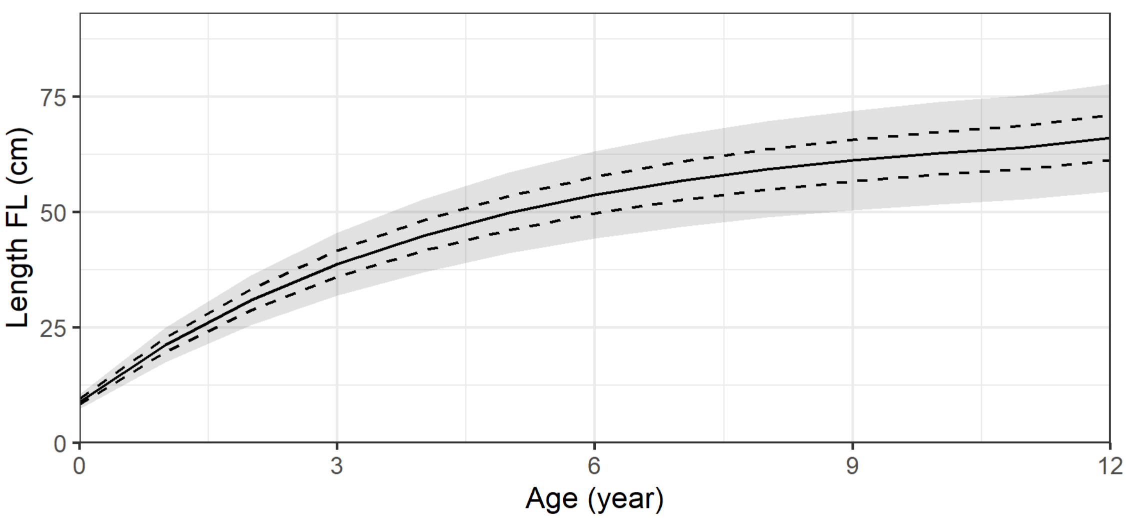


Figure 9-40 – Growth curve following a Von Bertalanffy model with 95% confidence intervals associated with the CV Linf parameter. The central growth platoon (solid line) and the two secondary ones (dashed lines) used in the model are also displayed.

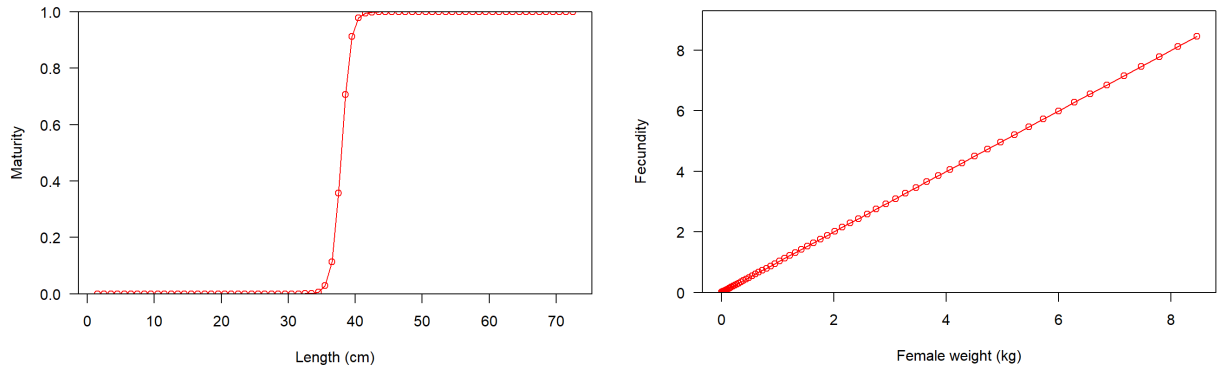


Figure 9-41 – Maturity-at-length (FL; left) and fecundity-at-weight (right) used in the stock assessment model.

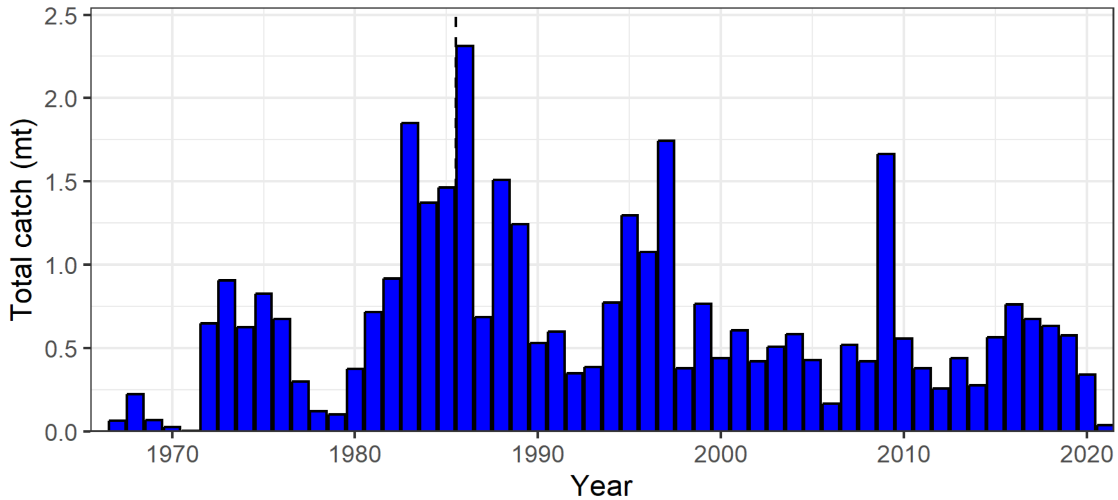


Figure 9-42 – Annual total catch in metric tons (mt). The vertical dashed line indicates the start of the creel survey program (1986) with older data coming from historical catch reports.

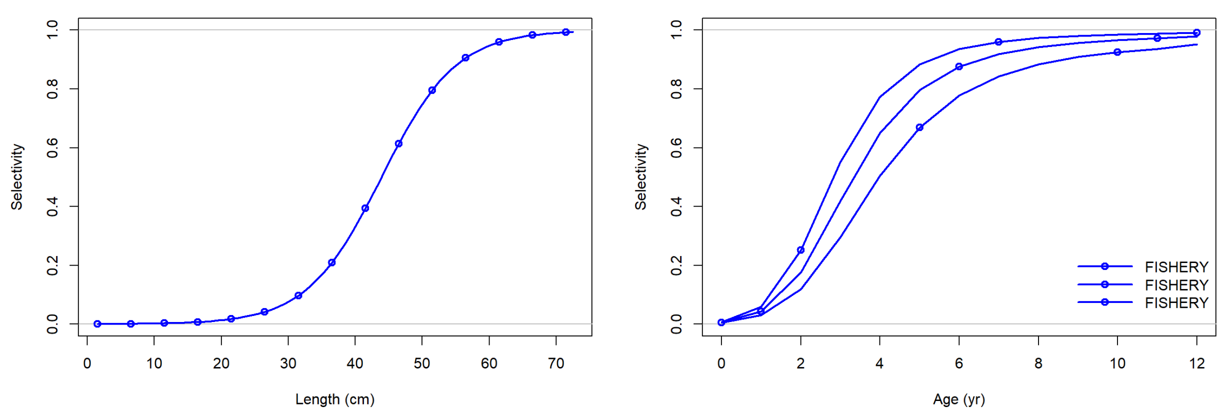


Figure 9-43 – Length-based selectivity estimated by the Stock Synthesis model (left) and the resulting selectivity-at-age for all 3 growth platoons (right).

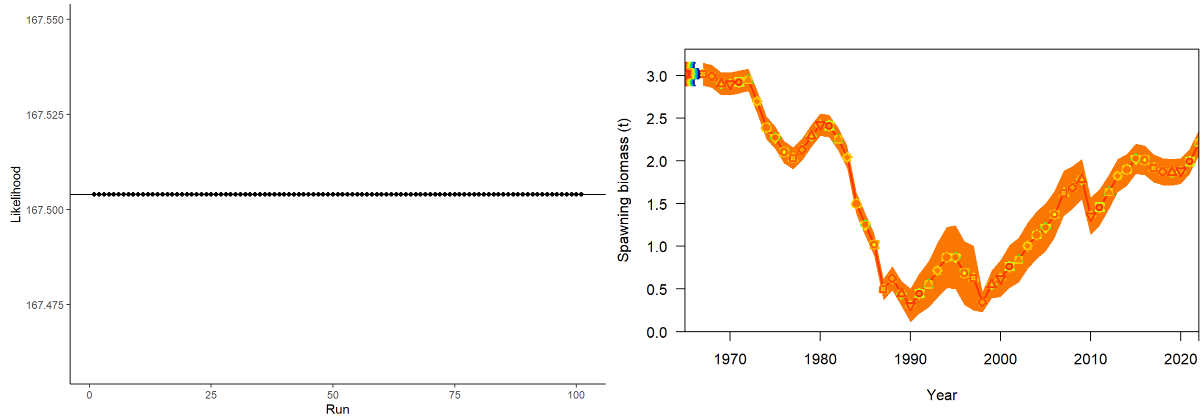


Figure 9-44 - Results of jitter analysis where 100 models were run with randomly varying initial parameter values. Left panel shows the variation in minimum model likelihood value for all 100 model runs. Right panel shows the variation in SSB time series for all 100 model runs.

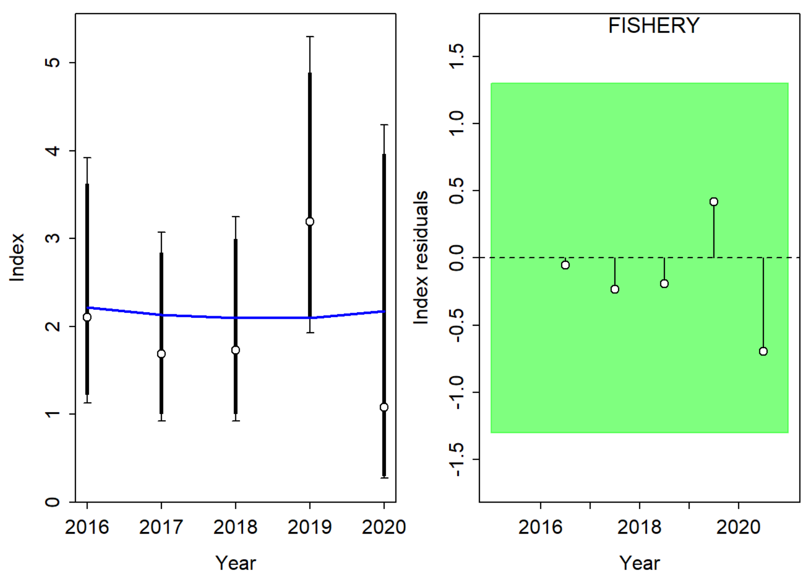


Figure 9-45 – Observed (open dots) vs expected (blue line) CPUE abundance index by year with standard deviations intervals (left). CPUE index residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.39.

Caranx lugubris

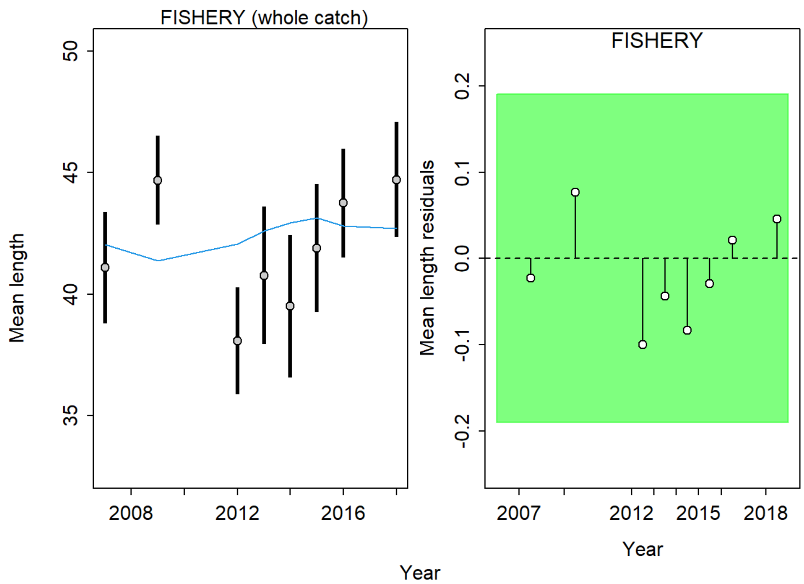


Figure 9-46 – Observed (open dots) vs expected (blue line) mean length by year with standard deviations intervals (left). Mean length residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.06.

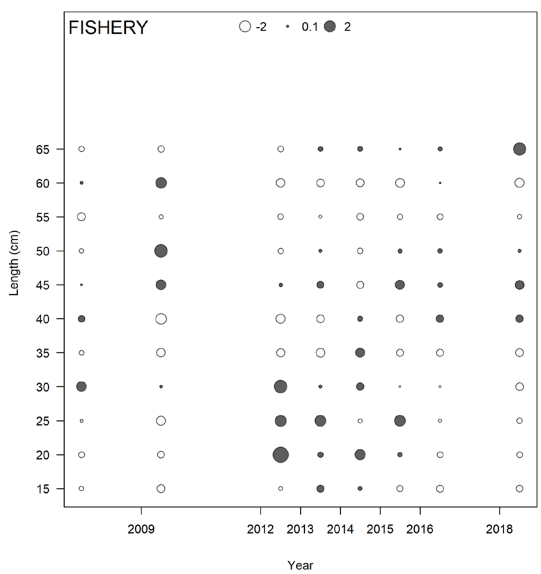


Figure 9-47 – Pearson residual plot of observed vs. expected size frequency data by size bin and year.

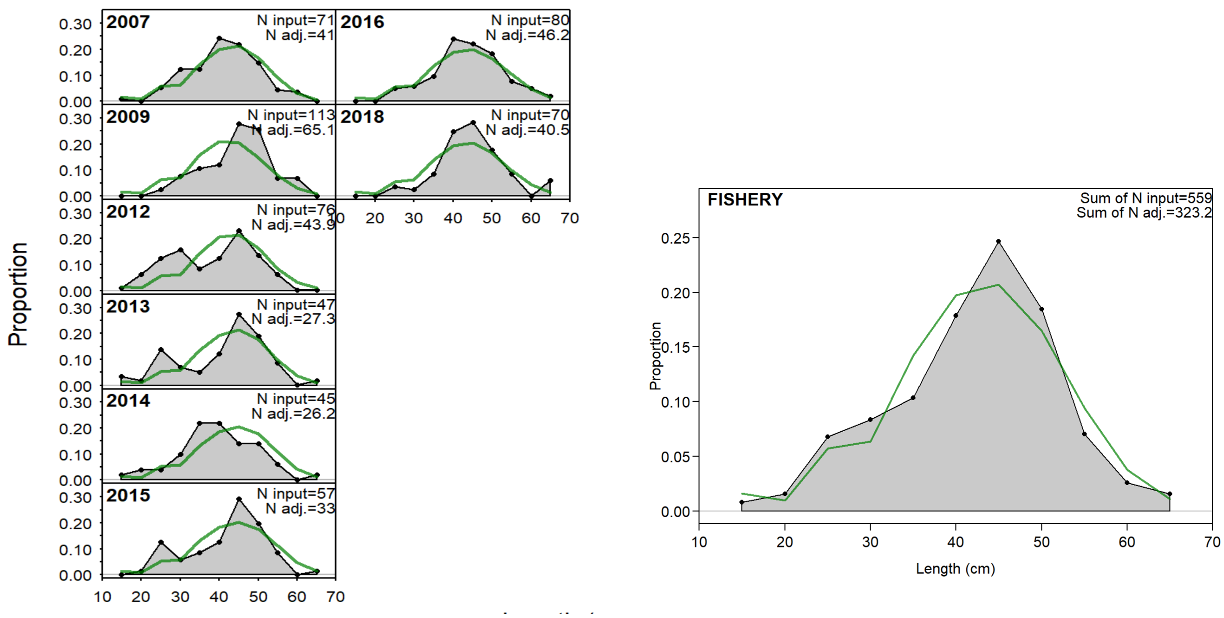


Figure 9-48 – Observed (gray area) vs. expected (green line) abundance-at-length from bottomfishing catch by year (left) and overall (right).

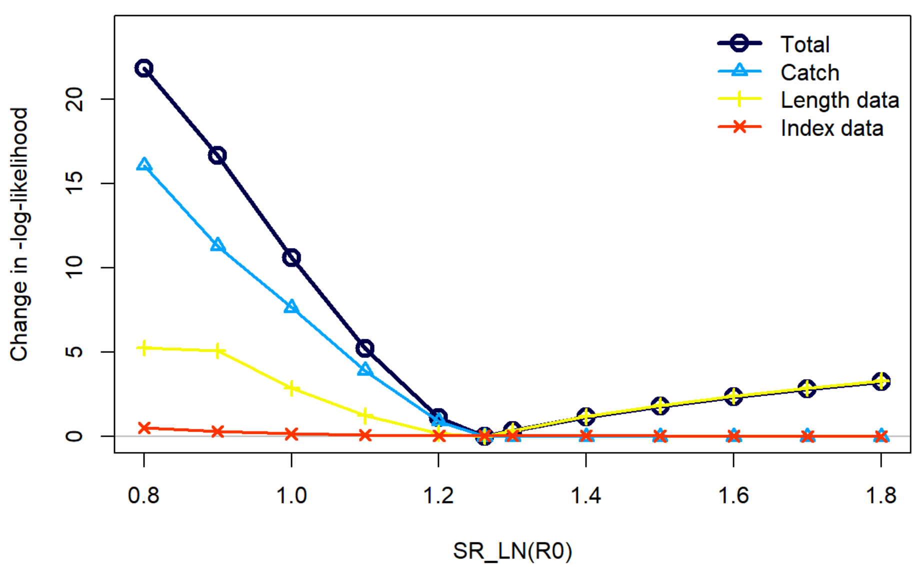


Figure 9-49 – Profiles of the change in negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter (R_0) in log-scale.

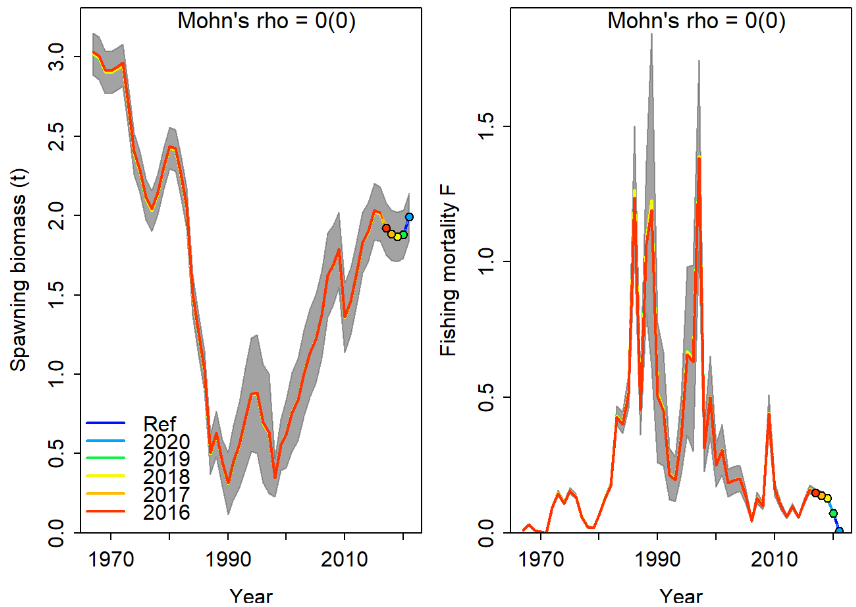


Figure 9-50 – Retrospective analysis of spawning biomass (left) and fishing mortality (right) consisting of 5 reruns of the base case model each fitted with one less year of data from the base case model (blue line).

Table 9-9 – Time series of spawning biomass (SSB, mt), age-0 recruitment (Rec., 1000s of recruits), and instantaneous fishing mortality (F, yr^{-1}) estimated by the Stock Synthesis model. CV is the coefficient of variation.

Year	SSB	CV	Rec.	CV	F	CV	Year	SSB	CV	Rec.	CV	F	CV
1969	3.0	0.16	3.61	0.15	0.009	0.53	1996	0.9	0.53	3.01	0.20	0.453	0.66
1970	3.0	0.16	3.61	0.15	0.003	0.40	1997	0.8	0.59	2.91	0.21	1.019	0.49
1971	3.0	0.15	3.61	0.15	0.000	0.48	1998	0.4	0.80	2.53	0.25	0.206	0.57
1972	3.0	0.15	3.62	0.15	0.093	0.56	1999	0.7	0.61	2.84	0.21	0.337	0.75
1973	2.8	0.18	3.59	0.15	0.136	0.57	2000	0.8	0.60	2.91	0.21	0.167	0.54
1974	2.5	0.20	3.55	0.15	0.098	0.63	2001	0.9	0.53	3.03	0.19	0.222	0.53
1975	2.3	0.23	3.52	0.16	0.125	0.50	2002	1.0	0.50	3.09	0.19	0.122	0.60
1976	2.2	0.23	3.50	0.16	0.098	0.53	2003	1.2	0.44	3.20	0.18	0.164	0.44
1977	2.1	0.23	3.50	0.16	0.045	0.77	2004	1.3	0.41	3.25	0.17	0.140	0.57
1978	2.3	0.23	3.52	0.16	0.020	0.52	2005	1.4	0.37	3.31	0.17	0.119	0.61
1979	2.4	0.21	3.55	0.16	0.015	0.40	2006	1.5	0.34	3.33	0.17	0.039	0.61
1980	2.5	0.19	3.54	0.15	0.058	0.62	2007	1.8	0.30	3.40	0.16	0.112	0.51
1981	2.5	0.21	3.54	0.15	0.102	0.55	2008	1.8	0.29	3.40	0.16	0.079	0.48
1982	2.3	0.22	3.53	0.16	0.166	0.48	2009	1.9	0.26	3.44	0.16	0.395	0.32
1983	2.1	0.22	3.47	0.16	0.424	0.58	2010	1.5	0.29	3.32	0.16	0.145	0.39
1984	1.5	0.31	3.31	0.16	0.377	0.72	2011	1.5	0.28	3.35	0.16	0.077	0.56
1985	1.3	0.40	3.25	0.19	0.509	0.66	2012	1.7	0.26	3.40	0.16	0.049	0.55
1986	1.0	0.49	3.08	0.19	0.869	0.52	2013	1.9	0.23	3.45	0.16	0.093	0.69
1987	0.6	0.67	2.73	0.22	0.340	0.64	2014	2.0	0.24	3.48	0.16	0.051	0.33
1988	0.7	0.58	2.86	0.20	0.937	0.50	2015	2.1	0.23	3.49	0.16	0.108	0.29
1989	0.5	0.68	2.57	0.21	1.068	0.43	2016	2.1	0.23	3.48	0.16	0.158	0.31
1990	0.3	0.87	2.34	0.25	0.329	0.72	2017	2.0	0.23	3.46	0.16	0.147	0.30
1991	0.5	0.69	2.69	0.21	0.356	0.46	2018	2.0	0.25	3.45	0.16	0.122	0.27
1992	0.6	0.60	2.83	0.20	0.154	0.58	2019	1.9	0.24	3.45	0.16	0.112	0.25
1993	0.8	0.54	3.00	0.19	0.126	0.73	2020	2.0	0.23	3.45	0.16	0.061	0.37
1994	1.0	0.44	3.12	0.18	0.291	0.46	2021	2.1	0.21	3.48	0.16	0.006	0.43
1995	1.0	0.45	3.13	0.18	0.449	0.59							

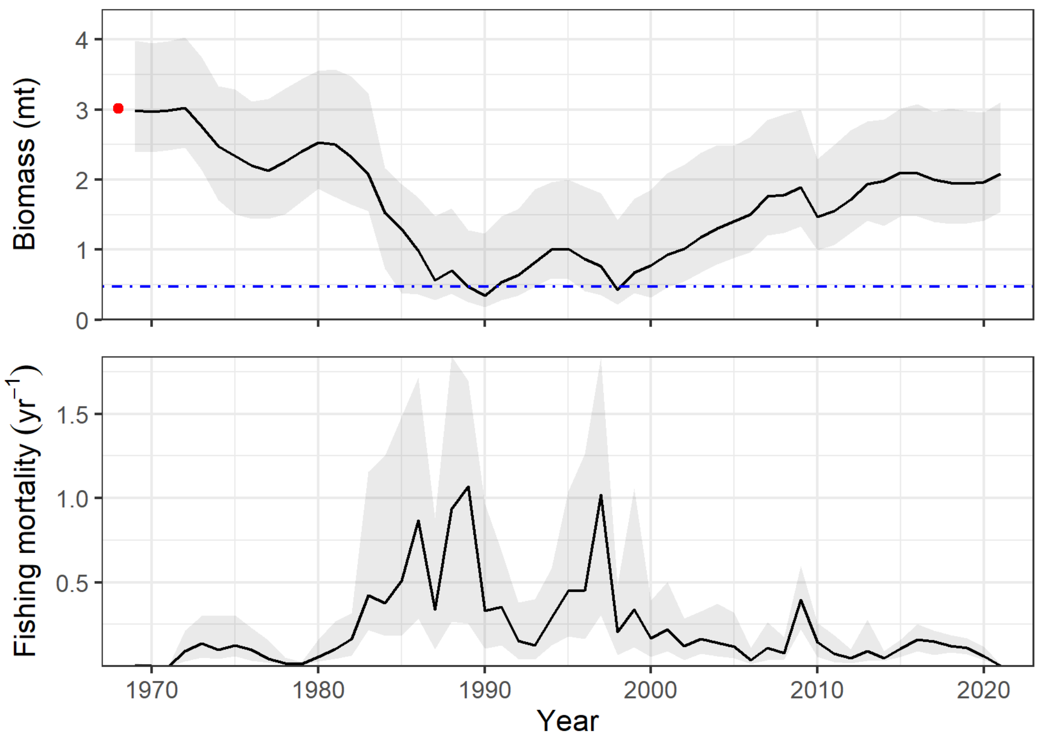


Figure 9-51 – Time series of spawning biomass (solid line) with its 95% confidence interval and SSB_0 estimate (red dot; top panel). The dot-and-dash blue line shows the spawning biomass at the MSST reference point (SSB_{MSST}). Time series of fishing mortality rate with its 95% confidence intervals (bottom panel).

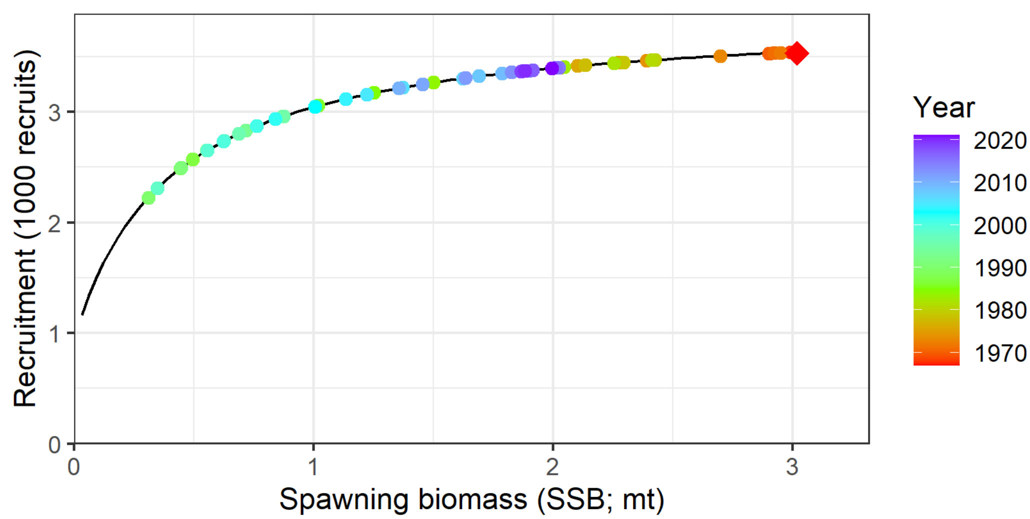


Figure 9-52 – Expected recruitment from the stock-recruitment relationship (black line) and estimated annual recruitment (dots) from SS. Estimated virgin SSB and recruitment is indicated with a red diamond.

Table 9-10 – Estimated biological reference points with 95% confidence interval (SD) derived from the SS base-case model where *F* is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield (2021 is the terminal year of the model).

Reference point	Value
F_{MSY} (yr^{-1})	0.407 (0.389 - 0.425)
F_{2021} (yr^{-1})	0.006 (0.003 - 0.011)
F_{2021}/F_{MSY}	0.015 (0.007 - 0.027)
SSB_{MSST} (mt)	0.48 (0.31 - 0.74)
SSB_{2021} (mt)	2.08 (1.55 - 3.11)
SSB_{2021}/SSB_{MSST}	4.4 (3.91 - 4.97)
MSY (mt)	0.86 (0.83 - 0.9)
$Catch_{2019-2021}$ (mt)	0.32 (0.11 - 0.53)
SPR_{MSY}	0.35 (0.34 - 0.35)
SPR_{2021}	0.97 (0.97 - 0.97)

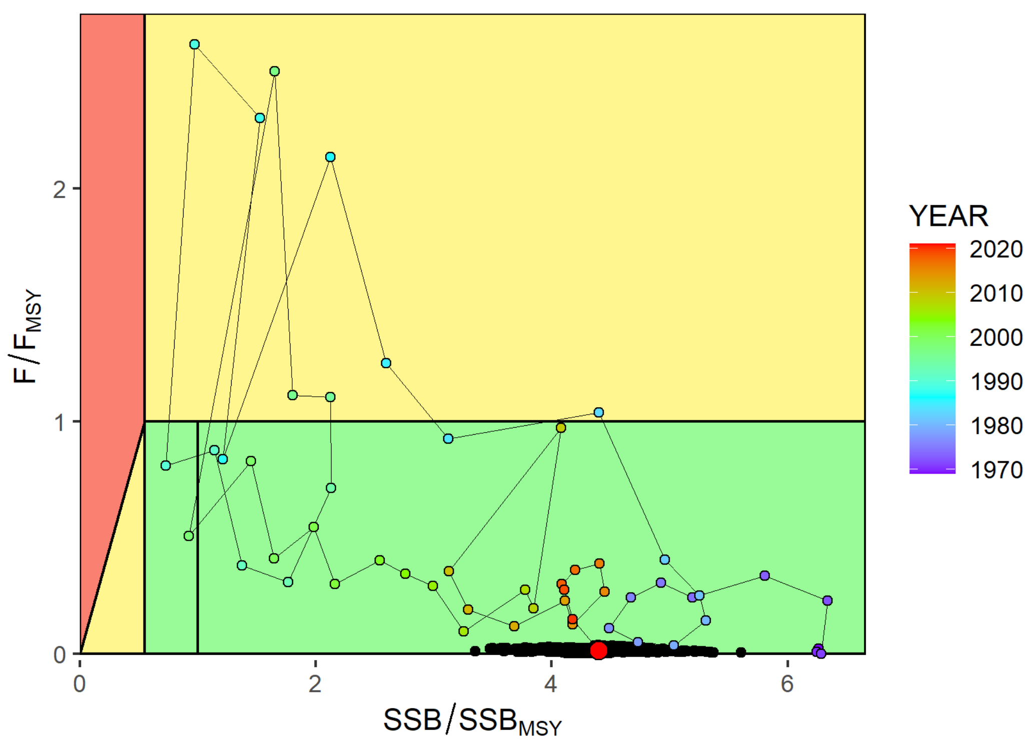


Figure 9-53 – Kobe plot representing the trend in relative fishing mortality and spawning stock biomass between 1969 and 2021 with their associated biological reference areas (red: overfished and overfishing, yellow: overfishing or overfished, green: no overfishing and not overfished). The large red dot indicates median stock status in 2021 and the black dots are one thousand Monte Carlo draws from the stock status distribution to represent the uncertainty around the final year status.

Table 9-11 – Summary table of key model output for all alternative model runs where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield.

Model	F_{2021}	F_{MSY}	F_{2021}/F_{MSY}	SSB_{MSY}	SSB_{MSST}	SSB_{2021}	SSB_{2021}/SSB_{MSY}	SSB_{2021}/SSB_{MSST}	Catch MSY
Base	0.007	0.41	0.02	0.8	0.5	2	2.5	4	0.9
M - 10%	0.007	0.36	0.02	0.9	0.6	2.1	2.3	3.5	0.8
M + 10%	0.007	0.47	0.01	0.8	0.4	1.9	2.4	4.7	0.9
Steep. - 10%	0.007	0.34	0.02	1	0.5	2.1	2.1	4.2	0.8
Steep. + 10%	0.007	0.48	0.01	0.7	0.4	1.9	2.7	4.7	0.9
Rec. dev.	0.008	0.41	0.02	0.8	0.5	1.9	2.4	3.8	0.9
No hist. catch	0.008	0.41	0.02	0.8	0.4	1.9	2.4	4.7	0.8
Alternate LH	0.006	0.52	0.01	0.8	0.4	2.3	2.9	5.7	1.1

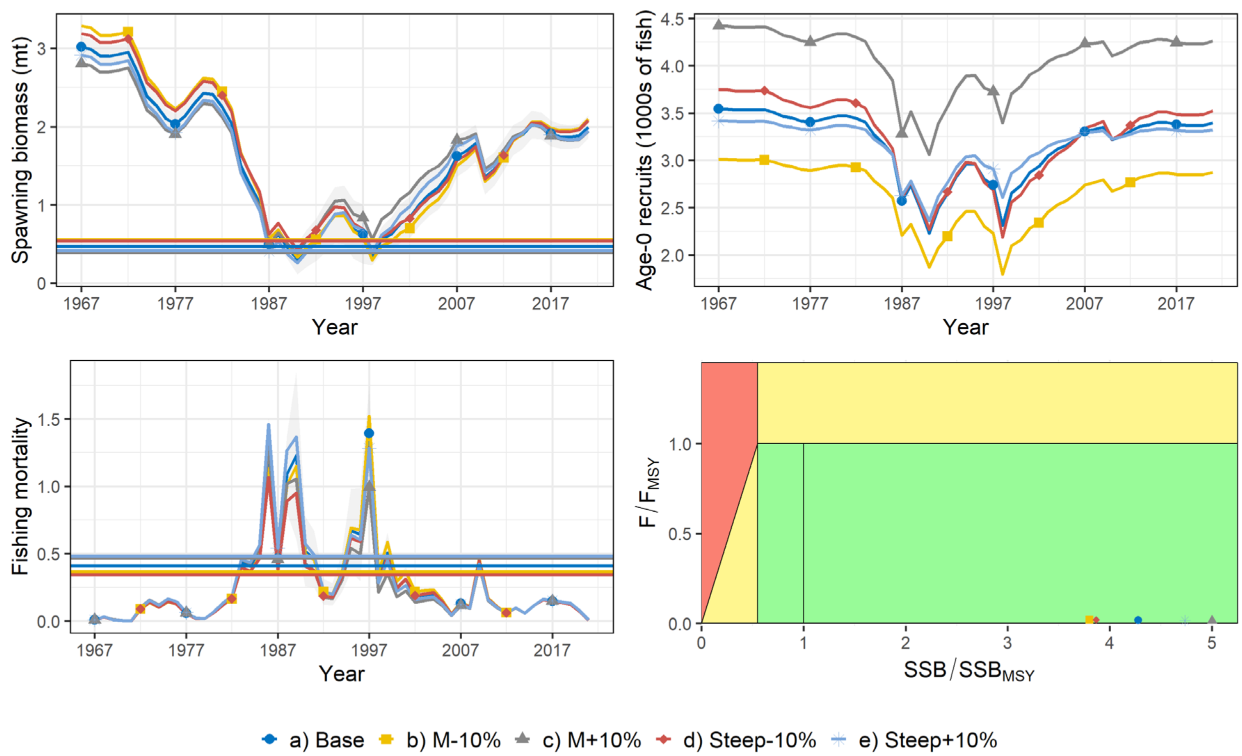


Figure 9-54 – Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) under moderate life-history parameter variation (plus and minus 10% of base parameter values).

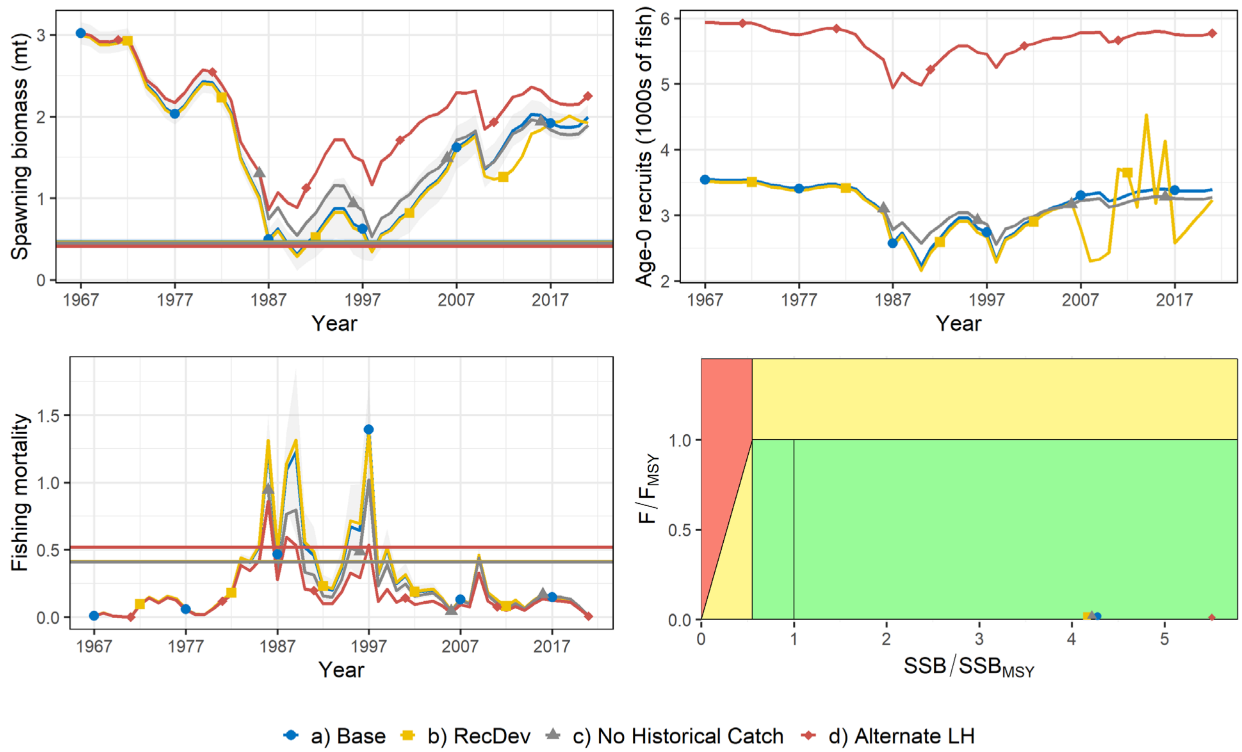


Figure 9-55 - Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) b) with recruitment deviations, c) without historical catch data (model starts in 1986), and d) with an alternate life history parameter source (longevity from StepwiseLH).

Table 9-12 - The annual fixed catch values (metric tons) applied from 2024 to a final projection year resulting in a given probability of overfishing ($F/F_{MSY}>1$) in that final year. Catches for years prior to the start of the new catch guidance (2022 and 2023) were fixed at the mean of the last 3 years of catch data (2019 to 2021).

Probability of	Fixed catch (mt) from 2024 to:				
$F > F_{MSY}$	2024	2025	2026	2027	2028
0.50	2.02	1.64	1.46	1.34	1.26
0.49	2.01	1.63	1.46	1.34	1.26
0.48	2.00	1.63	1.45	1.33	1.26
0.47	2.00	1.63	1.45	1.33	1.25
0.46	1.99	1.62	1.44	1.33	1.25
0.45	1.98	1.62	1.44	1.32	1.25
0.44	1.98	1.61	1.43	1.32	1.24
0.43	1.97	1.61	1.43	1.31	1.24
0.42	1.96	1.60	1.42	1.31	1.24
0.41	1.95	1.60	1.42	1.31	1.23
0.40	1.95	1.59	1.41	1.30	1.23
0.39	1.94	1.59	1.41	1.30	1.22
0.38	1.93	1.58	1.40	1.29	1.22
0.37	1.92	1.58	1.40	1.29	1.22
0.36	1.91	1.57	1.39	1.28	1.21
0.35	1.91	1.57	1.39	1.28	1.21
0.34	1.90	1.56	1.38	1.28	1.20
0.33	1.89	1.55	1.38	1.27	1.20
0.32	1.88	1.55	1.37	1.27	1.19
0.31	1.87	1.54	1.37	1.26	1.19
0.30	1.87	1.54	1.36	1.26	1.19
0.29	1.86	1.53	1.35	1.25	1.18
0.28	1.85	1.52	1.35	1.25	1.18
0.27	1.84	1.52	1.34	1.24	1.17
0.26	1.83	1.51	1.34	1.24	1.17
0.25	1.82	1.50	1.33	1.23	1.16
0.24	1.81	1.50	1.33	1.22	1.16
0.23	1.80	1.49	1.32	1.22	1.15
0.22	1.80	1.48	1.31	1.21	1.15
0.21	1.79	1.48	1.31	1.21	1.14
0.20	1.78	1.47	1.30	1.20	1.14
0.19	1.77	1.46	1.30	1.20	1.13
0.18	1.76	1.45	1.29	1.19	1.12
0.17	1.75	1.44	1.28	1.18	1.12
0.16	1.74	1.44	1.28	1.18	1.11
0.15	1.73	1.43	1.27	1.17	1.11
0.14	1.72	1.42	1.26	1.17	1.10
0.13	1.71	1.41	1.26	1.16	1.10
0.12	1.70	1.40	1.25	1.15	1.09
0.11	1.69	1.40	1.25	1.15	1.08
0.10	1.68	1.39	1.24	1.14	1.08

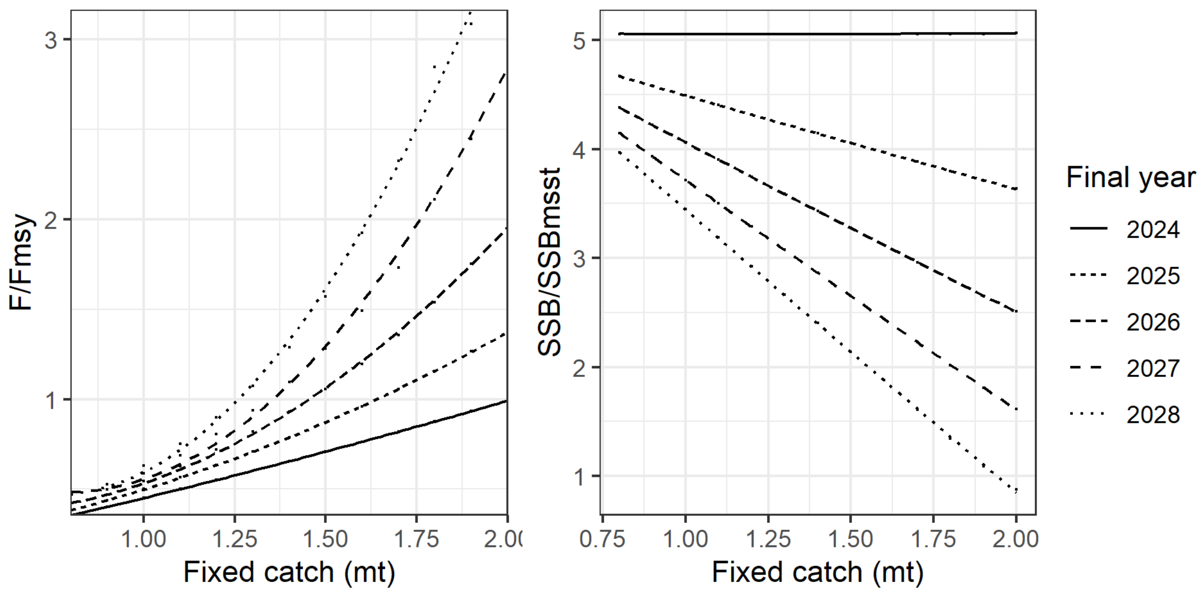


Figure 9-56 – Median stock status for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status is for the final projection year.

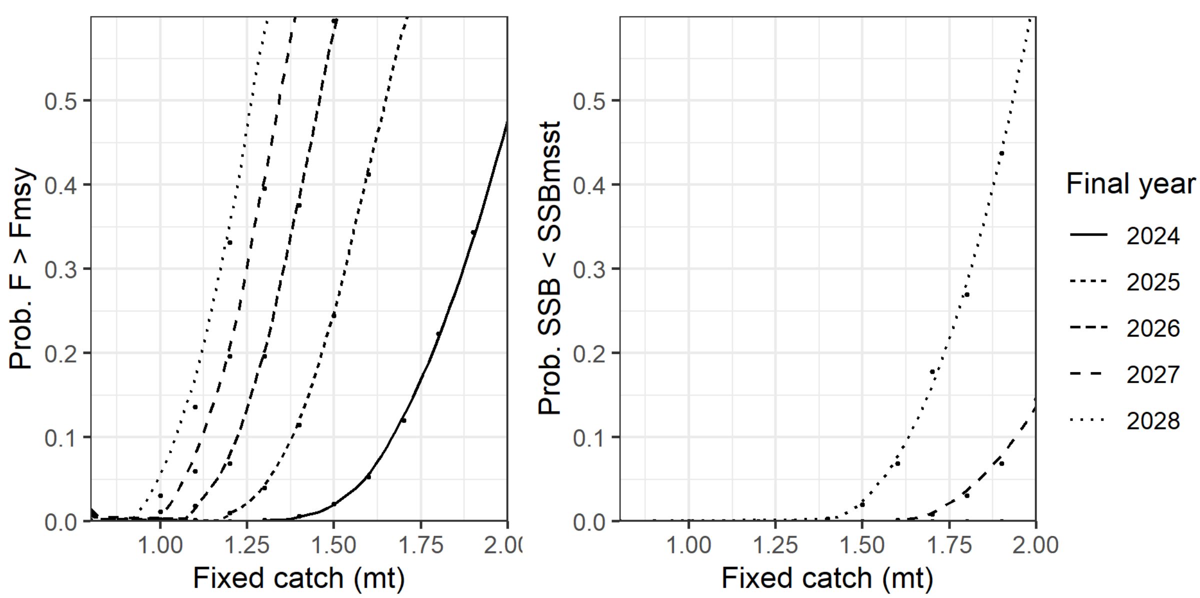
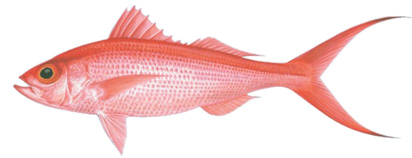


Figure 9-57– Probability of overfishing (left panel) and of stock being overfished (right panel) for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status probabilities are for the final projection year.

9.4 *Etelis coruscans*



Palu-loa, *Deepwater longtail red snapper*
Lutjanidae (snappers)

Key model parameters

Parameter	Value	Phase	Source
Natural mortality, M (yr^{-1})	0.10	-2	5.4/A_{max} (Hamel and Cope 2022)
Reference age, A_{min} (yr)	0	-2	Andrews (2021)
Maximum age, A_{max} (yr)	55	-2	-
Length at A_{min}, L_{Amin} (cm)	12.7 – 14.1	-2	Andrews (2021), females - males
Length at A_{max}, L_{Amax} (cm)	89.9 – 84.0	-2	-
Growth rate, K (yr^{-1})	0.105 – 0.116	-2	-
CV of length < L_{Amin}	0.07	-2	-
CV of length > L_{Amin}	0.07	-2	-
Length-weight α	4.25e-5	-2	Kamikawa (2015)
Length-weight β	2.75	-2	-
Length 50% maturity, L_{mat50} (cm)	62.2	-2	Reed (2021)
Slope of maturity ogive	-0.16	-2	-
Spawner-recruit steepness (h)	0.64	-2	FishLife 2.0 (Thorson 2019)
Number of platoons	3	-	Fixed
Unfished recruitment (Log R_0)	0.81 (0.17)	1	Estimated
Initial fishing mortality	-	-	Set to zero
Catchability (Log Q)	-1.69 (0.51)	1	Estimated
Extra Q SD	-	1	Set to zero
Length at 50% selectivity (cm)	52.4 (5.7)	2	Estimated
Width to 95% selectivity (cm)	31.2 (5.1)	2	Estimated
Dirichlet parameter (Log theta)	0.39 (0.28)	2	Estimated (note: 1.182, 0.255 normal prior used)

General comments

Data: Catch data are available from 1967 to 2021, CPUE from 2016 to 2021, and size composition observations are available in sufficient numbers from 2007 to 2020 (Figure 9-58). The size data from 2018 to 2020 (n=104) were combined into a super-period.

Life history: We found three recent growth studies with high sample sizes: Uehara et al. (2020) in Japan, Williams et al. (2013) in New Caledonia, and Andrews et al. (2021a) in Hawaii. A single maturity study from Hawaii was found (Reed 2021). Of these studies, Williams et al. (2013) seemed the weakest with low sample size and max age (18 years). The Hawaii and Japan curves had similar L_{inf} (86.8 cm and 82.1 cm) and A_{max} (55 years). We selected the Hawaii curve from Andrews (2021) and tested the Uehara et al. (2020) as an alternate model. The resulting growth and maturity curves are presented in Figure 9-59 and Figure 9-60. There is evidence of sex-specific growth patterns for this species and we fitted different curves for the 2 sexes.

Fishery: The re-created historical catch (1967–1985) suggests that few *E. coruscans* were caught during the dory project years in the 1970s, with a noticeable fishery for this species only starting with the ‘alia program in the early 1980s (Figure 9-61). Catch in these early years was around 5 mt per year, while catch in recent years have been around 2 mt before tapering off in 2020 and 2021. We first ran a model with an equilibrium catch in the first year (1967), but this resulted in a very low initial F estimate, which suggests that this species was very lightly exploited pre-1967. This is reasonable given the history of the fishery, where deeper areas were hard to access for the local fishermen. We therefore started the model in an unfished state (initial F set to 0). The model estimated length at 50% selectivity at approximately 52 cm and full selectivity at approximately 85 cm (or age 20), following a noticeably shallow selectivity curve (Figure 9-62).

Model diagnostics: All estimated parameters converged within the set bounds with the final likelihood gradient of the model being less than 0.0001 and the associated Hessian matrix being positive definite. A jitter analysis of 100 model runs with different random initial starting values also supported that the model converged on a global minimum (Figure 9-63). Further, goodness-of-fit diagnostics indicated that the model fitted the CPUE index well with a successful Runs test but with a large RMSE of 0.47 (Figure 9-64). The mean length model fit passed the Runs test and had a RMSE of 0.07 (Figure 9-65). The yearly and overall size composition data was fitted relatively well, despite some anomalous peaks occurring in certain years like 2011 (Figure 9-66 and Figure 9-67). The change in negative log-likelihoods at different fixed log(R_0) values indicated that this parameter's estimate was mainly driven by the length composition data with a clear minimum reached at 0.8 (~2,200 recruits; Figure 9-68). The results of the retrospective analysis, which progressively removed one year of data from 2021 to 2017, showed some patterns for *SSB* and *F* associated with removing 2018 data. This is likely related to anomalous size composition in 2015-2016 (right skew; lower *F* and higher *SSB*) vs 2018. However, the Mohn's rho values were around 0.09 and -0.06 for *SSB* and *F*, respectively (suggested limits are between -0.15 and 0.2; Figure 9-69).

Stock status: Population biomass declined from an SSB_0 around 28 mt prior to 1967 to about 10 mt in the late 1980s following the increased catch associated with the ‘alia program (Figure 9-70 and Table 9-13). Biomass increased steadily afterwards, reaching values around 14 mt in 2014 before declining slightly in recent years to around 12 mt (the MSST was estimated at 7.6 mt; Figure 9-70). Recruitment stayed close to R_0, varying between 1,800 and 2,200 recruits per year (Figure 9-71). The current stock status (SSB/SSB_{MSST}) is equal to 1.7 (not overfished) with no overfishing currently occurring. The stock came close to being overfished in the late 1980s before rebounding. Overfishing did occur in the 1980s and the stock came near to being overfished in the late 1980s (Figure 9-72; Table 9-14) with *F* hitting maximum values at around 0.17 (F_{MSY} was estimated at 0.05). Equilibrium catches at F_{MSY} (i.e., the *MSY*) were estimated at 1.6 mt. Catches in recent years have been low, averaging only 0.5 mt (Table 9-14).

Alternate scenarios: We ran 7 alternative models: M and steepness plus and minus 10%, no historical catch, with recruitment deviations, and alternate LH source. The alternate specification with the largest impact was the alternate LH source, which used a growth curve from Japan (Uehara et al. 2020) (Table 9-15, Figure 9-73, and Figure 9-74). This scenario resulted in unrealistically low *F* values, close to absolute zero, resulting in very high *SSB* estimated. There was little impact of starting the model in 1986. Adding recruitment deviations did not significantly change model results. None of the alternative models resulted in overfishing or overfished status in 2021.

Projections: The projection analysis showed the distribution of outcomes in the probability of overfishing and overfished status that would occur in various final years (2024-2028) under various fixed-catch scenarios (Table 9-16; Figure 9-75, and Figure 9-76). The projections indicated very low probability of overfished status occurring between 2024 and 2028 for the range of fixed catch explored (< 2.5 mt per year).

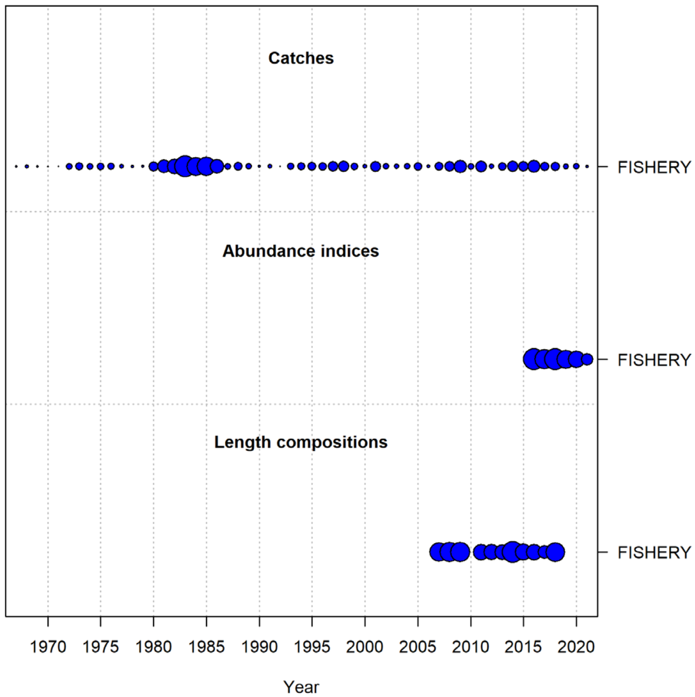


Figure 9-58- Summary of data types used in the Stock Synthesis model. Catches include boat-based and shore-based landings from creel surveys (1986-2021), as well as historical catches from reports (1967-1985). The abundance index is from boat-based creel survey ‘bottomfishing” gear type. Length compositions are from creel surveys (all years) and the biosampling program (2010-2015), filtered for the “bottomfishing” gear.

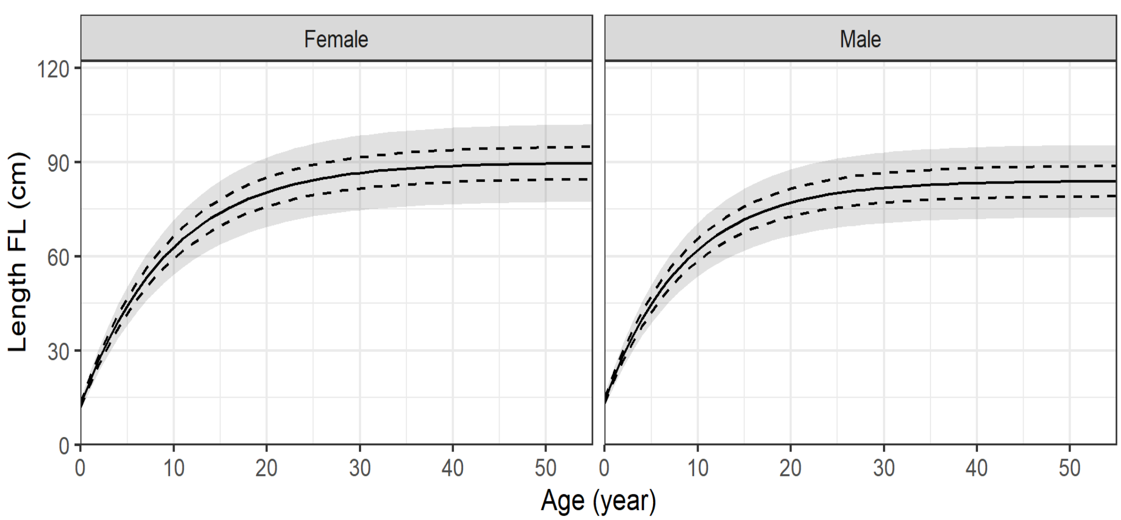


Figure 9-59 – Growth curve following a Von Bertalanffy model with 95% confidence intervals associated with the CV Linf parameter. The central growth platoon (solid line) and the two secondary ones (dashed lines) used in the model are also displayed.

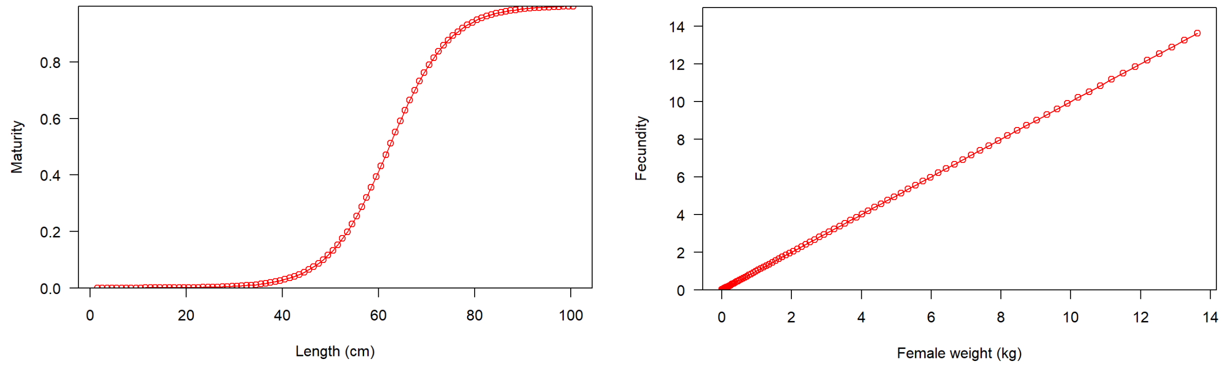


Figure 9-60 – Maturity-at-length (FL; left) and fecundity-at-weight (right) used in the stock assessment model.

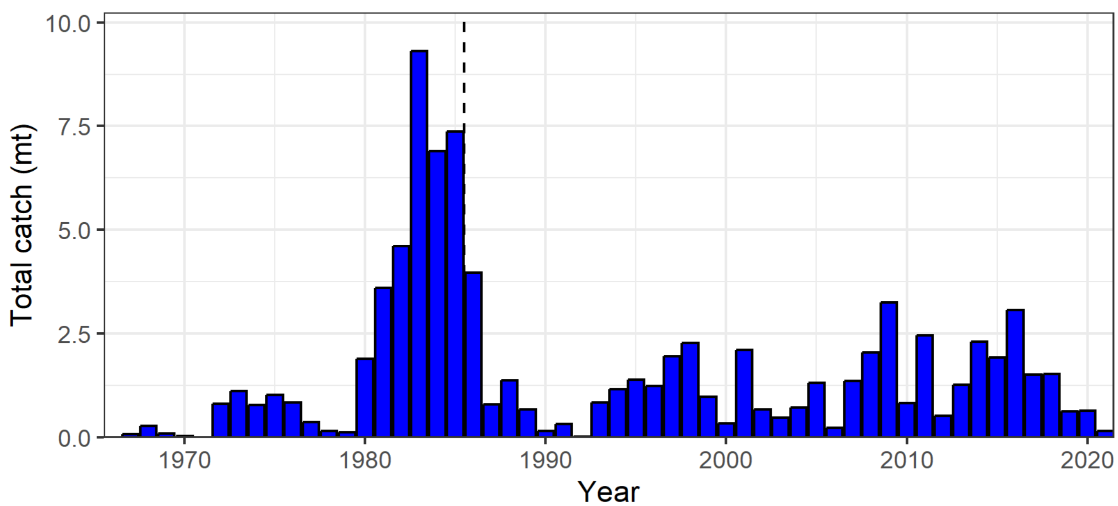


Figure 9-61 – Annual total catch in metric tons (mt). The vertical dashed line indicates the start of the creel survey program (1986), with older data coming from historical catch reports.

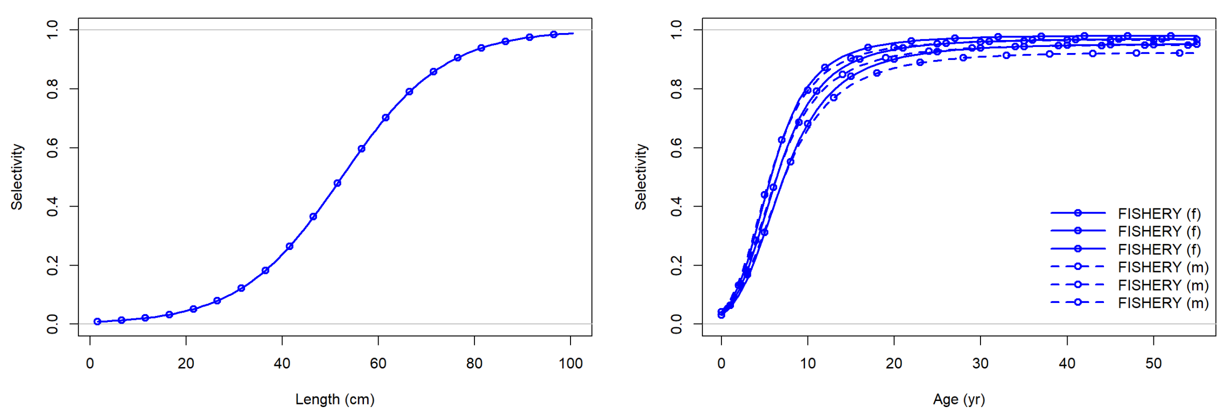


Figure 9-62 – Length-based selectivity estimated by the Stock Synthesis model (left) and the resulting selectivity-at-age for all 3 growth platoons (right).

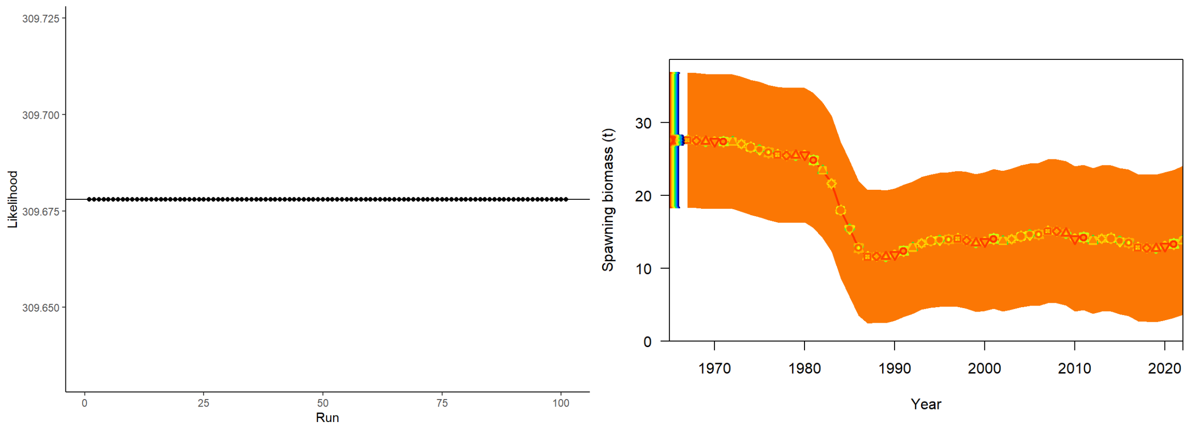


Figure 9-63 - Results of jitter analysis where 100 models were run with randomly varying initial parameter values. Left panel shows the variation in minimum model likelihood value for all 100 model runs. Right panel shows the variation in SSB time series for all 100 model runs.

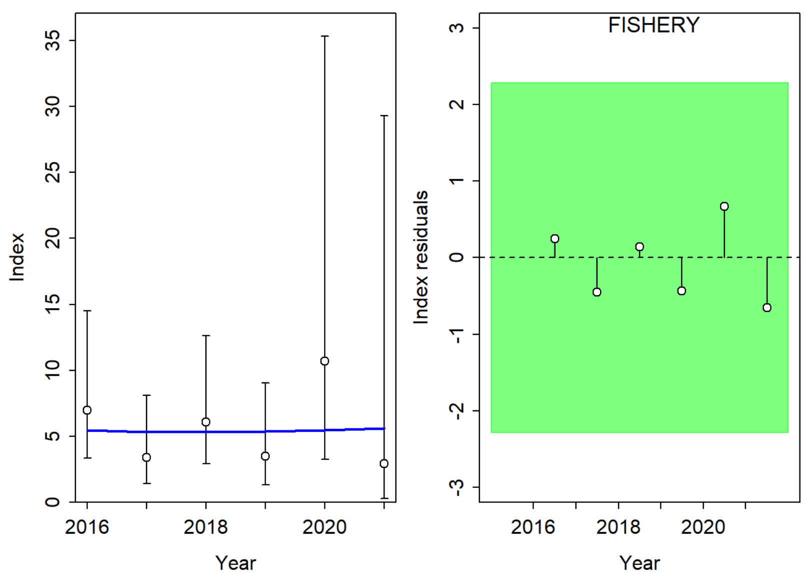


Figure 9-64 – Observed (open dots) vs expected (blue line) CPUE abundance index by year with standard deviations intervals (left). CPUE index residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.47.

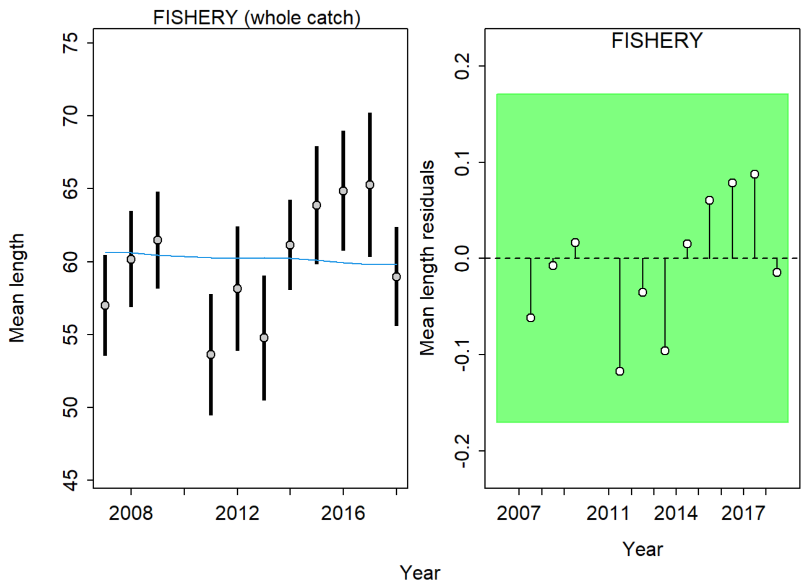


Figure 9-65 – Observed (open dots) vs expected (blue line) mean length by year with standard deviations intervals (left). Mean length residuals by year, with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.07.

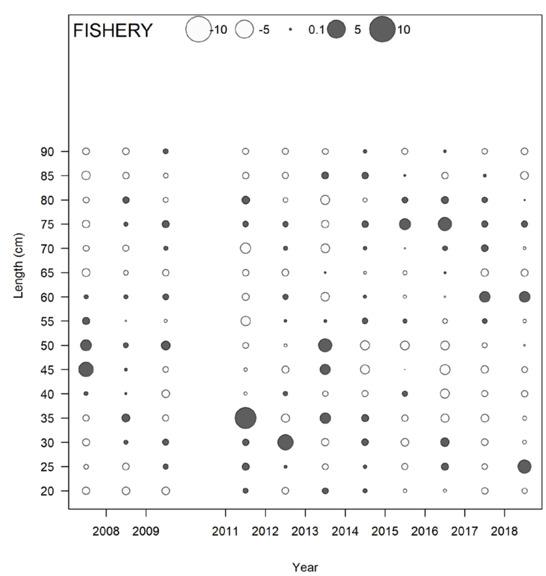


Figure 9-66 – Pearson residual plot of observed vs. expected size frequency data by size bin and year.

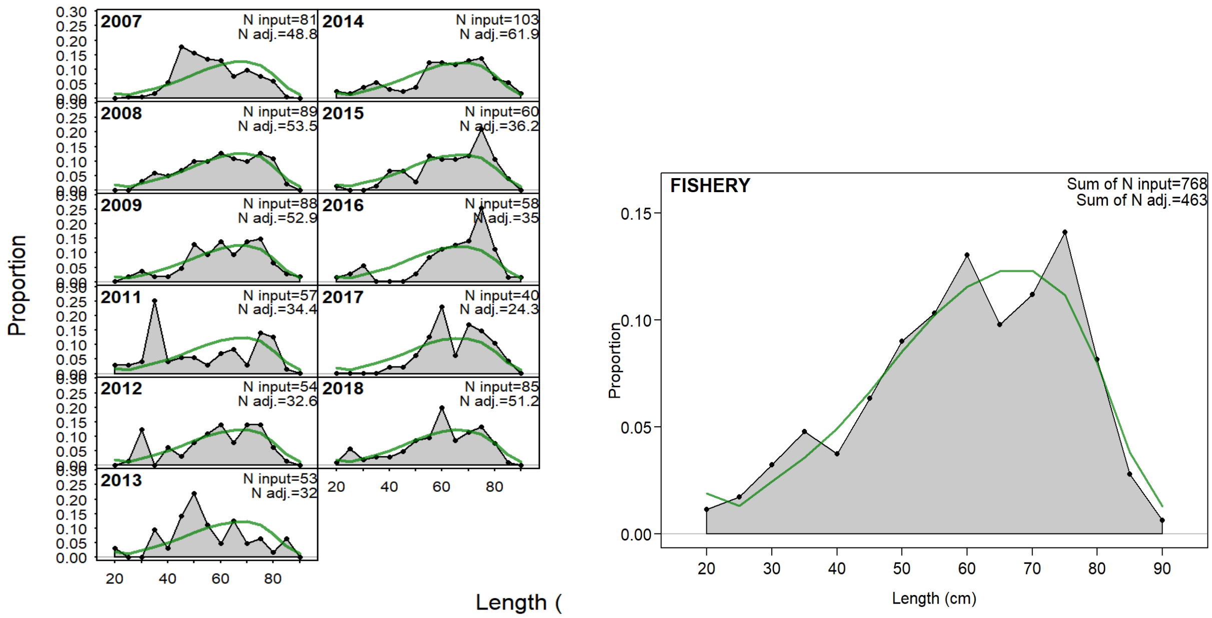


Figure 9-67 – Observed (gray area) vs. expected (green line) abundance-at-length from bottomfishing catch by year (left) and overall (right).

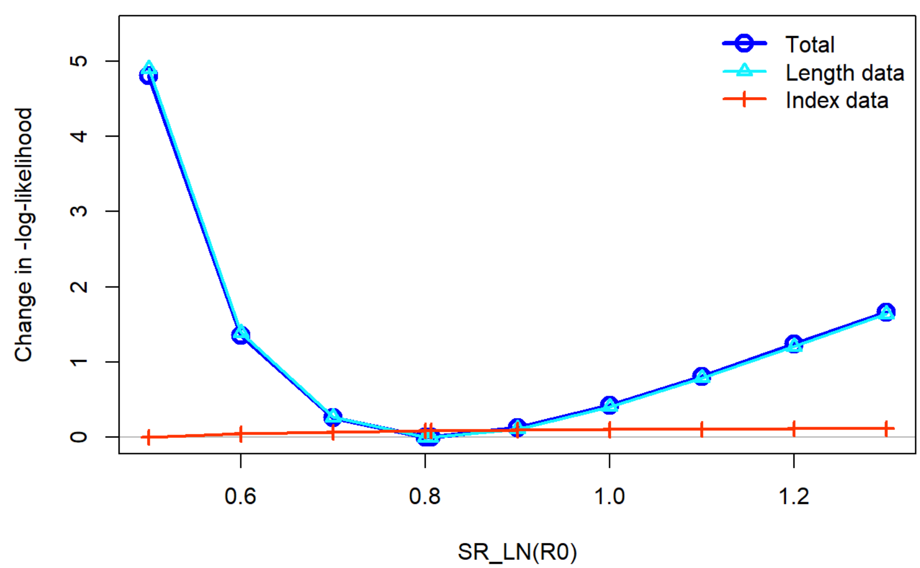


Figure 9-68 – Profiles of the change in negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter (R_0) in log-scale.

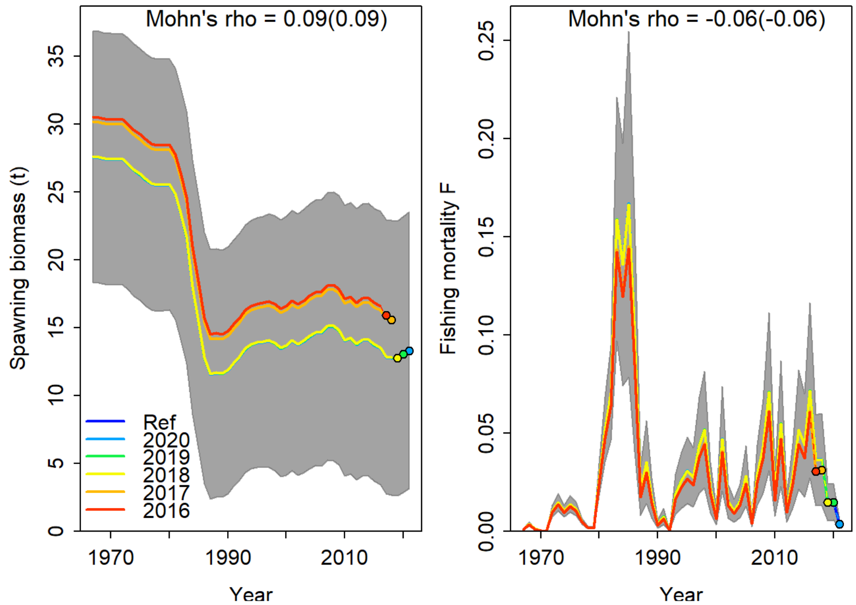


Figure 9-69 – Retrospective analysis of spawning biomass (left) and fishing mortality (right) consisting of 5 reruns of the base case model each fitted with one less year of data from the base case model (blue line).

Table 9-13 – Time series of spawning biomass (SSB, mt), age-0 recruitment (Rec., 1000s of recruits), and instantaneous fishing mortality (F, yr-1) estimated by the Stock Synthesis model. CV is the coefficient of variation.

Year	SSB	CV	Rec.	CV	F	CV	Year	SSB	CV	Rec.	CV	F	CV
1969	27.8	0.20	2.25	0.20	0.001	0.52	1996	13.4	0.36	1.96	0.23	0.025	0.54
1970	27.5	0.20	2.26	0.20	0.000	0.69	1997	13.5	0.36	1.97	0.23	0.038	0.41
1971	27.5	0.20	2.25	0.20	0.000	0.47	1998	13.1	0.36	1.96	0.24	0.048	0.41
1972	27.7	0.20	2.25	0.20	0.008	0.56	1999	12.9	0.37	1.94	0.24	0.020	0.63
1973	27.1	0.20	2.25	0.20	0.013	0.39	2000	12.9	0.38	1.94	0.24	0.006	0.54
1974	26.9	0.20	2.26	0.20	0.010	0.44	2001	13.4	0.37	1.96	0.24	0.042	0.47
1975	26.8	0.21	2.24	0.20	0.011	0.54	2002	13.2	0.37	1.96	0.24	0.014	0.59
1976	26.3	0.21	2.24	0.20	0.012	0.52	2003	13.0	0.38	1.96	0.23	0.009	0.62
1977	25.8	0.21	2.25	0.19	0.005	0.42	2004	13.8	0.37	1.97	0.23	0.010	0.75
1978	25.8	0.22	2.24	0.20	0.002	0.46	2005	14.1	0.36	2.00	0.23	0.024	0.68
1979	25.6	0.22	2.26	0.20	0.002	0.43	2006	14.1	0.35	1.99	0.24	0.004	0.51
1980	25.7	0.21	2.21	0.20	0.028	0.47	2007	14.8	0.36	2.00	0.23	0.026	0.55
1981	24.9	0.21	2.20	0.20	0.040	0.53	2008	14.4	0.36	2.00	0.23	0.035	0.52
1982	23.7	0.23	2.22	0.20	0.056	0.64	2009	14.2	0.37	2.00	0.23	0.063	0.35
1983	21.8	0.24	2.17	0.21	0.135	0.62	2010	13.5	0.37	1.97	0.24	0.018	0.44
1984	17.8	0.29	2.08	0.21	0.112	0.61	2011	13.6	0.37	1.98	0.24	0.046	0.56
1985	15.1	0.33	2.02	0.22	0.169	0.54	2012	13.1	0.38	1.96	0.24	0.009	0.61
1986	11.9	0.40	1.91	0.25	0.085	0.62	2013	13.5	0.38	1.98	0.23	0.021	0.61
1987	10.5	0.44	1.84	0.25	0.017	0.69	2014	13.6	0.37	2.01	0.24	0.049	0.47
1988	10.7	0.43	1.83	0.26	0.033	0.59	2015	13.1	0.40	1.97	0.24	0.039	0.37
1989	10.9	0.44	1.83	0.26	0.013	0.56	2016	12.9	0.41	1.93	0.24	0.066	0.39
1990	11.0	0.42	1.83	0.25	0.003	0.50	2017	12.5	0.41	1.92	0.25	0.033	0.41
1991	11.8	0.42	1.91	0.24	0.006	0.64	2018	12.5	0.43	1.93	0.25	0.033	0.44
1992	11.9	0.39	1.93	0.24	0.000	0.91	2019	12.3	0.43	1.91	0.25	0.014	0.47
1993	12.7	0.39	1.95	0.23	0.013	0.60	2020	12.2	0.41	1.92	0.26	0.015	0.53
1994	13.1	0.35	1.95	0.24	0.026	0.35	2021	12.9	0.39	1.95	0.24	0.003	0.56
1995	13.3	0.35	1.95	0.23	0.026	0.48							

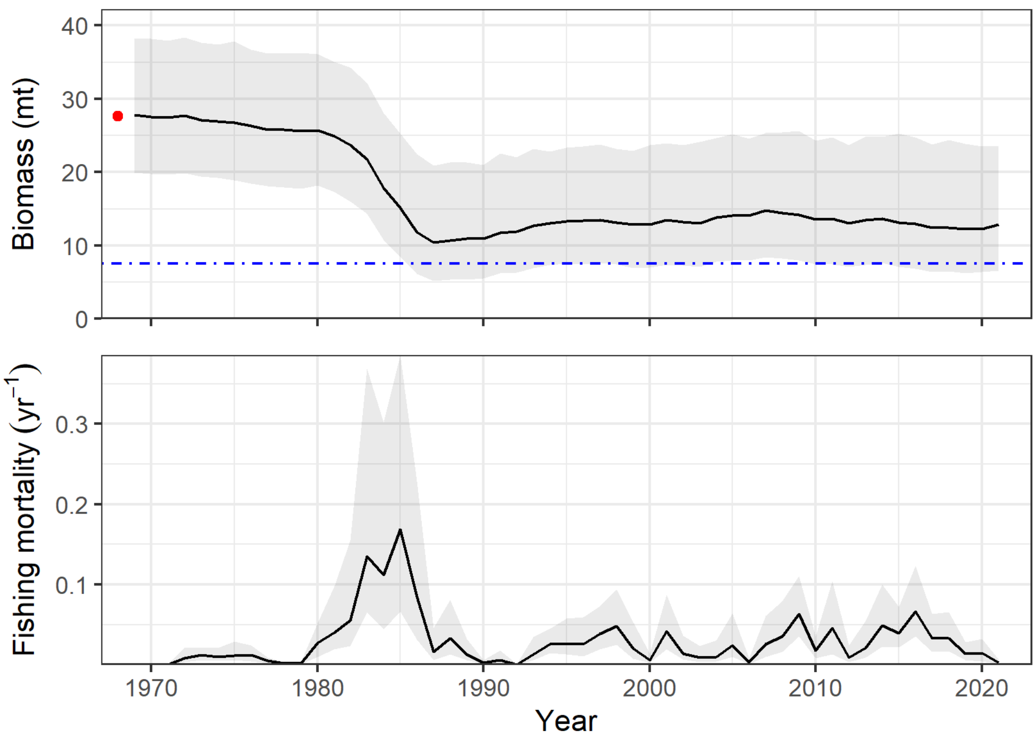


Figure 9-70 – Time series of spawning biomass (solid line) with its 95% confidence interval and SSB_0 estimate (red dot; top panel). The dot-and-dash blue line shows the spawning biomass at the MSST reference point (SSBMSST). Time series of fishing mortality rate with its 95% confidence intervals (bottom panel).

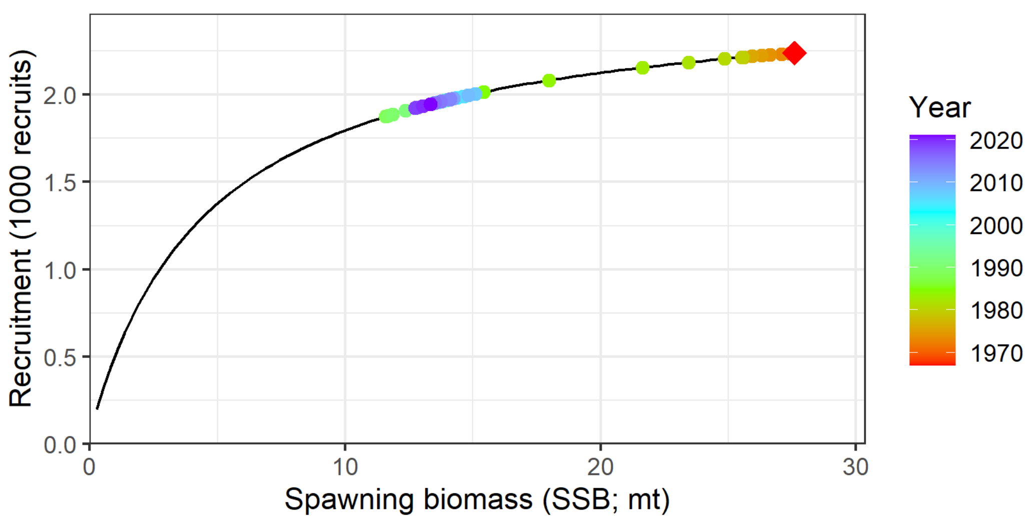


Figure 9-71 – Expected recruitment from the stock-recruitment relationship (black line) and estimated annual recruitment (dots) from SS. Estimated virgin SSB and recruitment is indicated with a red diamond.

Table 9-14 – Estimated biological reference points with 95% confidence interval (SD) derived from the SS base-case model where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield (2021 is the terminal year of the model).

Reference point	Value
F_{MSY} (yr^{-1})	0.053 (0.049 - 0.057)
F_{2021} (yr^{-1})	0.003 (0.001 - 0.006)
F_{2021}/F_{MSY}	0.052 (0.023 - 0.115)
SSB_{MSST} (mt)	7.56 (4.04 - 13.9)
SSB_{2021} (mt)	12.87 (6.61 - 23.6)
SSB_{2021}/SSB_{MSST}	1.74 (1.2 - 2.46)
MSY (mt)	1.57 (1.08 - 2.05)
$Catch_{2019-2021}$ (mt)	0.47 (0.12 - 0.82)
SPR_{MSY}	0.41 (0.4 - 0.41)
SPR_{2021}	0.93 (0.88 - 0.98)

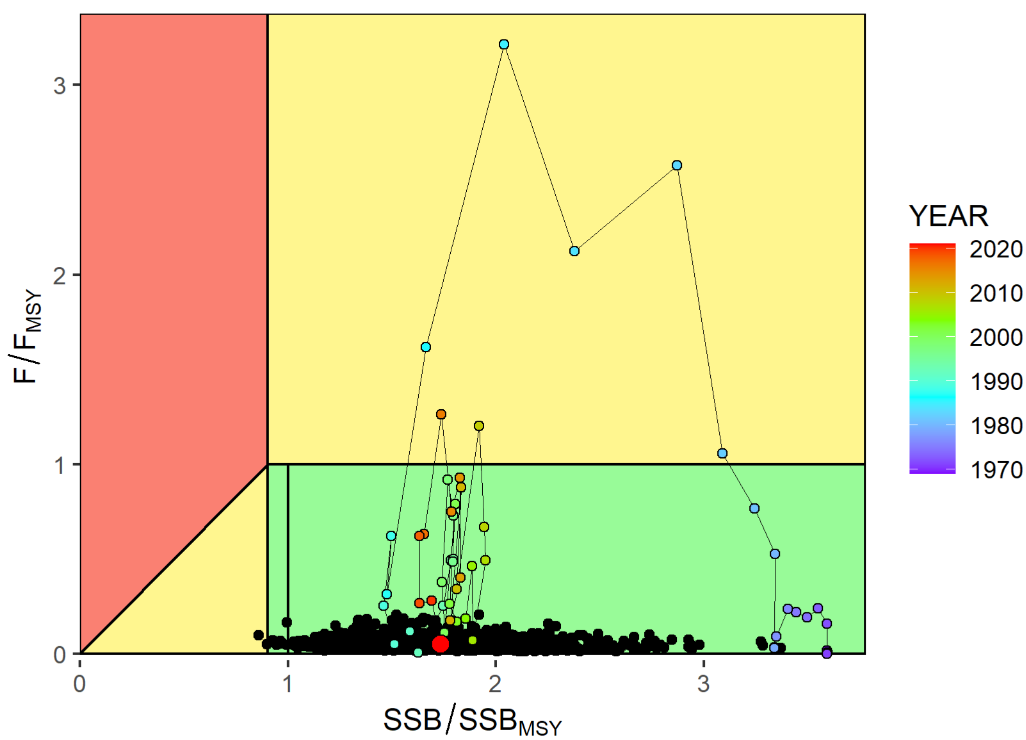


Figure 9-72 – Kobe plot representing the trend in relative fishing mortality and spawning stock biomass between 1969 and 2021 with their associated biological reference areas (red: overfished and overfishing, yellow: overfishing or overfished, green: no overfishing and not overfished). The large red dot indicates median stock status in 2021 and the black dots are one thousand Monte Carlo draws from the stock status distribution to represent the uncertainty around the final year status.

Table 9-15 – Summary table of key model output for all alternative model runs where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield.

Model	F_{2021}	F_{MSY}	F_{2021}/F_{MSY}	SSB_{MSY}	SSB_{MSST}	SSB_{2021}	SSB_{2021}/SSB_{MSY}	SSB_{2021}/SSB_{MSST}	Catch MSY
Base	0.004	0.05	0.08	8.5	7.6	13.3	1.6	1.8	1.6
M - 10%	0.004	0.05	0.08	8.6	7.8	11.4	1.3	1.5	1.4
M + 10%	0.003	0.06	0.05	8.6	7.8	16.6	1.9	2.1	1.9
Steep. - 10%	0.004	0.04	0.1	9.3	8.4	13	1.4	1.5	1.4
Steep. + 10%	0.003	0.06	0.05	7.7	6.9	13.5	1.8	2	1.7
Rec. dev.	0.004	0.05	0.08	8.5	7.6	12.2	1.4	1.6	1.5
No hist. catch	0.002	0.05	0.04	17.3	15.6	32	1.8	2.1	3.2
Alternate LH	0	0.06	0	190.8	172.1	596.6	3.1	3.5	19.3

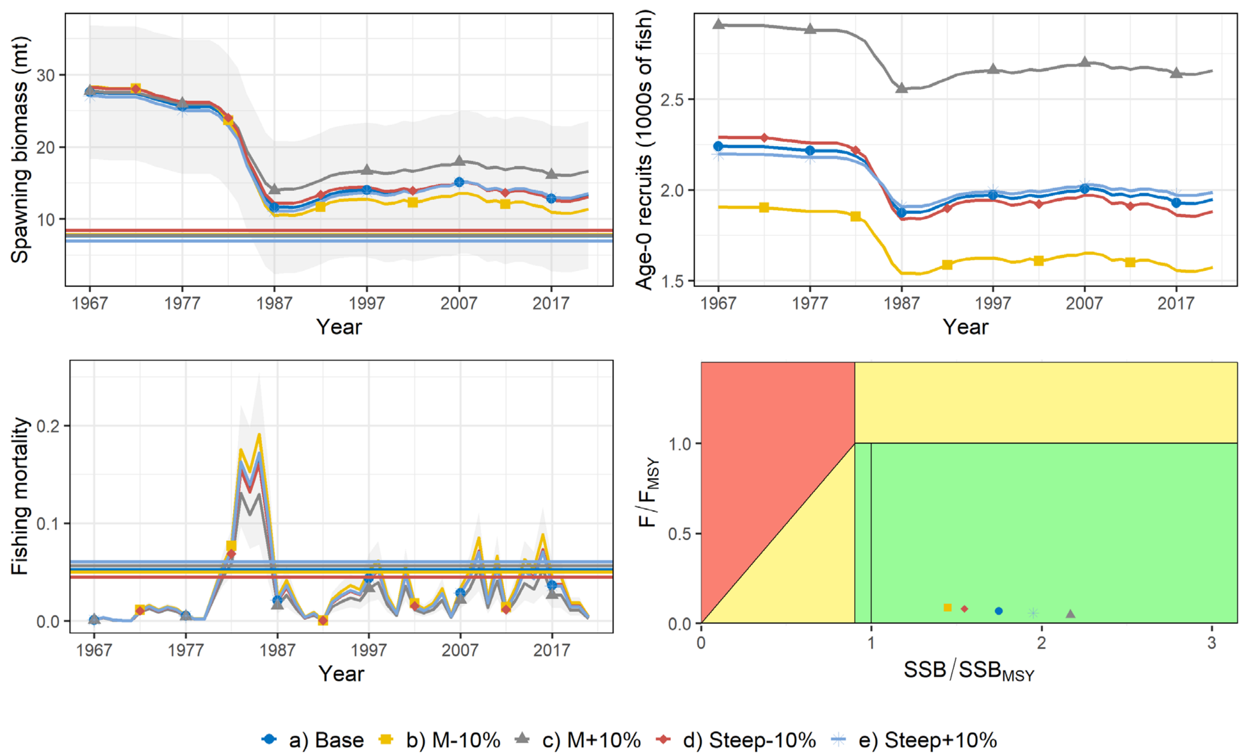


Figure 9-73 – Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) under moderate life-history parameter variation (plus and minus 10% of base parameter values).

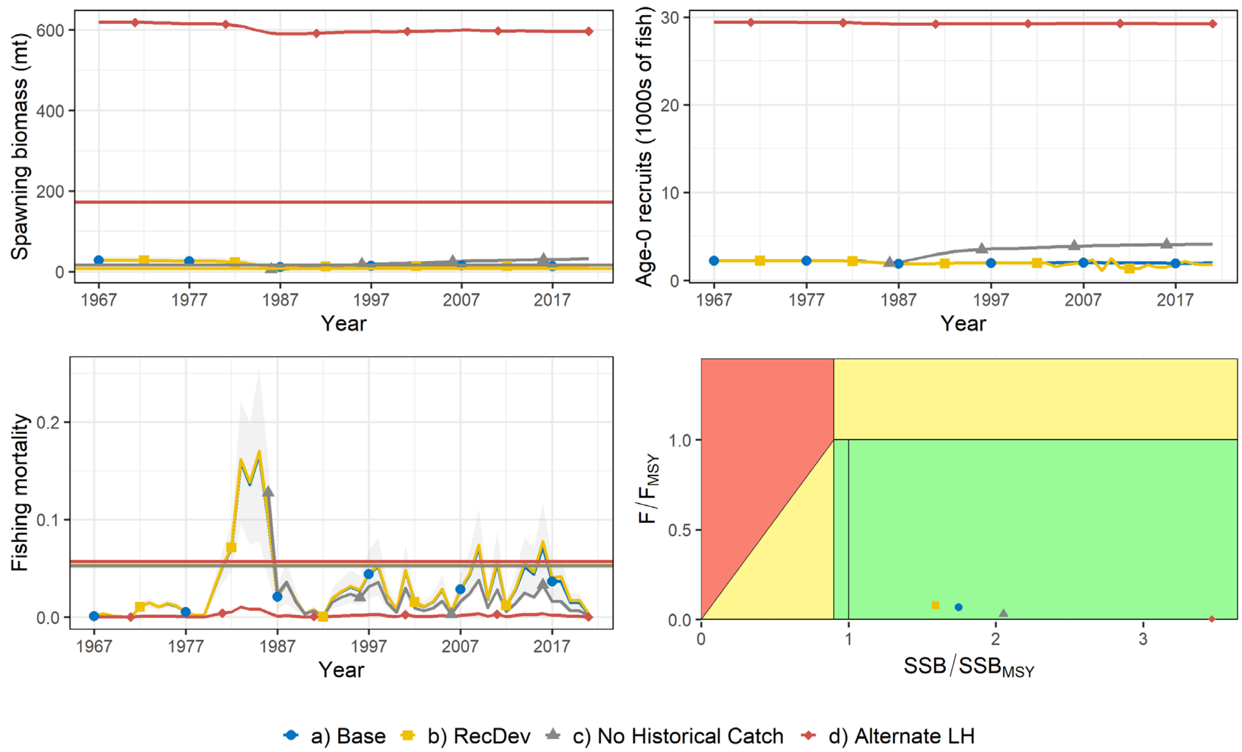


Figure 9-74 - Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) b) with recruitment deviations, c) without historical catch data (model starts in 1986), and d) with an alternate life history parameter source (growth curve from Uehara et al. 2020).

Table 9-16 - The annual fixed catch values (metric tons) applied from 2024 to a final projection year resulting in a given probability of overfishing ($F/F_{MSY}>1$) in that final year. Catches for years prior to the start of the new catch guidance (2022 and 2023) were fixed at the mean of the last 3 years of catch data (2019 to 2021).

Probability of	Fixed catch (mt) from 2024 to:				
$F > F_{MSY}$	2024	2025	2026	2027	2028
0.50	2.57	2.49	2.47	2.42	2.38
0.49	2.56	2.47	2.45	2.41	2.36
0.48	2.54	2.46	2.44	2.39	2.34
0.47	2.53	2.44	2.42	2.38	2.33
0.46	2.51	2.42	2.40	2.36	2.31
0.45	2.49	2.41	2.39	2.34	2.30
0.44	2.48	2.39	2.37	2.33	2.28
0.43	2.46	2.37	2.35	2.31	2.26
0.42	2.44	2.36	2.33	2.29	2.25
0.41	2.43	2.34	2.32	2.28	2.23
0.40	2.41	2.32	2.30	2.26	2.21
0.39	2.39	2.31	2.28	2.25	2.20
0.38	2.37	2.29	2.26	2.23	2.18
0.37	2.35	2.27	2.24	2.21	2.16
0.36	2.34	2.26	2.22	2.19	2.15
0.35	2.32	2.24	2.21	2.18	2.13
0.34	2.30	2.22	2.19	2.16	2.11
0.33	2.28	2.20	2.17	2.14	2.10
0.32	2.26	2.19	2.15	2.12	2.08
0.31	2.24	2.17	2.13	2.11	2.06
0.30	2.22	2.15	2.11	2.09	2.05
0.29	2.20	2.13	2.09	2.07	2.03
0.28	2.18	2.11	2.07	2.05	2.01
0.27	2.16	2.09	2.05	2.03	1.99
0.26	2.14	2.08	2.03	2.01	1.98
0.25	2.12	2.06	2.01	1.99	1.96
0.24	2.10	2.04	1.99	1.98	1.94
0.23	2.07	2.02	1.97	1.96	1.92
0.22	2.05	2.00	1.95	1.94	1.91
0.21	2.03	1.98	1.93	1.92	1.89
0.20	2.01	1.96	1.91	1.90	1.87
0.19	1.99	1.94	1.88	1.88	1.85
0.18	1.96	1.92	1.86	1.86	1.84
0.17	1.94	1.90	1.84	1.84	1.82
0.16	1.92	1.88	1.82	1.82	1.80
0.15	1.90	1.86	1.80	1.80	1.78
0.14	1.87	1.84	1.78	1.78	1.76
0.13	1.85	1.82	1.75	1.76	1.75
0.12	1.82	1.80	1.73	1.74	1.73
0.11	1.80	1.78	1.71	1.72	1.71
0.10	1.78	1.76	1.69	1.70	1.69

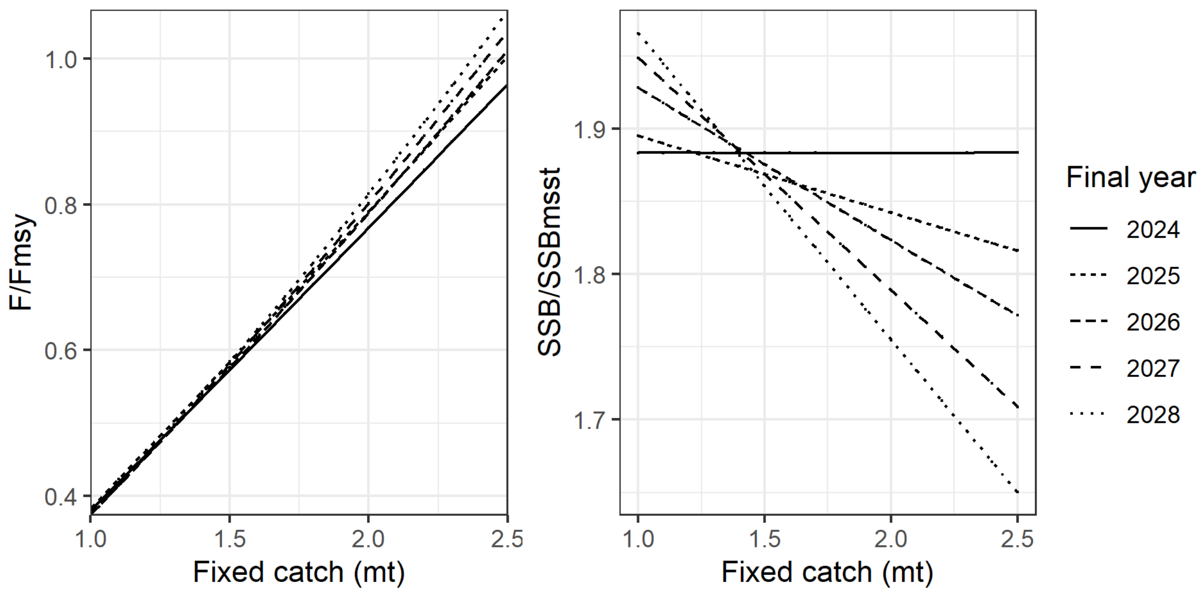


Figure 9-75 – Median stock status for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status is for the final projection year.

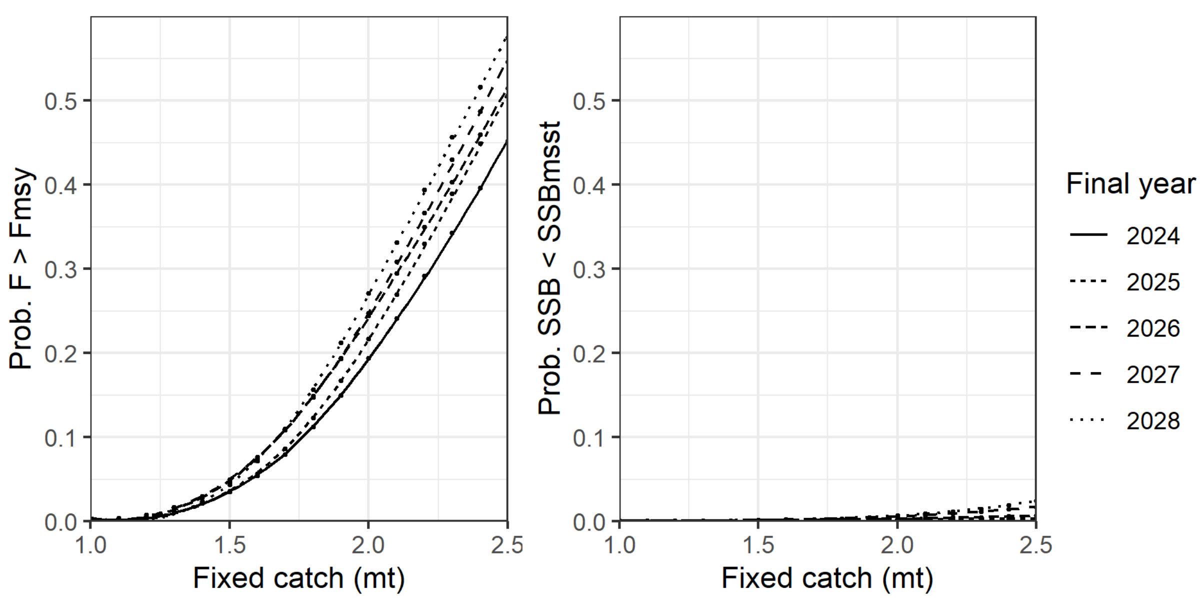


Figure 9-76– Probability of overfishing (left panel) and of stock being overfished (right panel) for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status probabilities are for the final projection year.

9.5 *Lethrinus rubrioperculatus*

Filoa-paomumu, *Spotcheek emperor*
Lethrinidae (emperors)

Key model parameters

Parameter	Value	Phase	Source
Natural mortality, M (yr^{-1})	0.36	-2	5.4/A_{max} (Hamel and Cope 2022)
Reference age, A_{min} (yr)	0	-2	-
Maximum age, A_{max} (yr)	15	-2	Loubens (1980a)
Length at A_{min}, L_{Amin} (cm)	5.5	-2	-
Length at A_{max}, L_{Amax} (cm)	33.9	-2	Loubens (1980a)
Growth rate, K (yr^{-1})	0.431	-2	-
CV of length < L_{Amin}	0.1	-2	-
CV of length > L_{Amin}	0.1	-2	-
Length-weight α	2.28e-5	-2	Kamikawa et al. (2015)
Length-weight β	2.94	-2	-
Length 50% maturity, L_{mat50} (cm)	21.9	-2	Loubens (1980b)
Slope of maturity ogive	-1.47	-2	-
Hermaph. inflection age (yr)	5.5	-2	Loubens (1980b)
Spawner-recruit steepness (h)	0.66	-2	FishLife 2.0 (Thorson 2019)
Number of platoons	3	-	Fixed
Unfished recruitment (Log R_0)	3.34 (0.03)	1	Estimated
Initial fishing mortality	0.02	1	Estimated
Catchability (Log Q)	-1.09 (0.12)	1	Estimated
Extra Q SD	-	1	Set to zero
Length at 50% selectivity (cm)	23.5 (0.3)	2	Estimated
Width to 95% selectivity (cm)	3.6 (0.3)	2	Estimated
Dirichlet parameter (Log theta)	-1.11 (0.15)	2	Estimated (note: 1.182, 0.255 normal prior used)

General comments

Data: Catch data are available from 1967 to 2021, CPUE from 2016 to 2021, and size composition observations are available in sufficient numbers from 2004 to 2021 (Figure 9-77). No super-period was used for length data in the SS model.

Life history: There are multiple published growth curves. The main ones are Loubens (1980a) in New Caledonia (as *L. variegatus*), Trianni et al. (2011) in the Mariana Islands, and Ebisawa and Ozawa (2009) in Japan. The parameters from New Caledonia appeared most appropriate, the Trianni A_{max} was low at 8 years compared to Loubens and Ebisawa at around 15 years. The L_{inf} from New Caledonia was close to Trianni at around 33.9 cm vs. 31.5 cm. We tested the Trianni (2011) curve as an alternate model run. The selected growth and maturity curves are presented in Figure 9-78 and Figure 9-79. Although no significant difference growth curves were found between sexes, this species is known to be a protogynous hermaphrodite with an inflection age for sex change at around 5.5 years (Loubens 1980b), which was included in our model (Figure 9-82). We also tested an alternative model with no hermaphroditism.

Fishery: The re-created historical catch (1967–1985) suggests that contrary to deeper-occurring species, a fair amount of *L. rubrioperculatus* were caught during the dory project years in the 1970s (~4 mt per year) with an increase in catch during the ‘alia program in the 1980s Figure 9-80). Catches since then have peaked occasionally, but have typically remained below 2 mt. The early catches were slightly adjusted by the model. The model estimated an initial F around 0.02. The model estimated length at 50% selectivity at approximately 24 cm and full selectivity at approximately 27 cm (or age 2), with some slight differences in selectivity-at-age between platoons (Figure 9-81).

Model diagnostics: All estimated parameters converged within the set bounds with the final likelihood gradient of the model being less than 0.0001 and the associated Hessian matrix being positive definite. A jitter analysis of 100 model runs with different random initial starting values also supported that the model converged on a global minimum (Figure 9-83). Further, goodness-of-fit diagnostics indicated that the model fitted the CPUE index well with a successful Runs test and with a RMSE of 0.25 (Figure 9-84). The mean length model fit also passed the Runs test and had a RMSE of 0.02 (Figure 9-85). The yearly and overall size composition data was fitted relatively well, except for some of the early years between 2004 and 2008 (Figure 9-86 and Figure 9-87). The change in negative log-likelihoods at different fixed log(R_0) values indicated that this parameter's estimate was mainly driven by the length composition data with a clear minimum reached at 3.3 (~27,000 recruits; Figure 9-88). The results of the retrospective analysis, which progressively removed one year of data from 2021 to 2017, showed no significant pattern for SSB or F with Mohn's rho values around -0.02 to 0.03 for both (suggested limits are between -0.15 and 0.2; Figure 9-89).

Stock status: Population biomass declined from an SSB_0 around 11 mt prior to 1967 to as low as 1.8 mt in the late 1980s, following the sustained high catch associated with both the dory and ‘alia programs (Figure 9-90 and Table 9-17). Biomass increased from this very low value to around 9 mt in 2008 before dropping significantly again following increased catches between 2009 and 2015. It has since recovered to ~10 mt following a slowdown in fishing activity with recent catches around 0.5 mt (the MSST was estimated at 2.8 mt; Figure 9-90). Recruitment changed drastically throughout the time series —reaching low points in the late 1980s at around 16,000 recruits —before rebounding to 20,000 to 26,000 afterwards (Figure 9-91). The current stock status (SSB/SSB_{MSST}) is equal to 3.4 (not overfished) with no overfishing occurring. The stock was overfished in the late 1980s but rebounded by the early 1990s. In 2010 the stock did come close to being overfished again due to increased fishing activity but has since recovered. Overfishing also occurred in the 1970s and 1980s as well as in 2009-2012 (Figure 9-92; Table 9-18). F_{MSY} was estimated at 0.59. Equilibrium catches at F_{MSY} (i.e., the *MSY*) were estimated at 2.4 mt. Catches in recent years have been low, averaging only 0.5 mt (Table 9-18).

Alternate scenarios: We ran 7 alternative models: *M* and steepness plus and minus 10%, no historical catch, with recruitment deviations, and alternate LH source. The alternate specification with the largest impact was the alternate LH source, which used a growth curve from the Mariana Islands (Trianni et al. 2011) (Table 9-19, Figure 9-93, and Figure 9-94). This scenario resulted in low *F* values, resulting in elevated *SSB*. Starting the model in 1986 led to the SSB being higher from 1986 to 2000 but similar to the base model afterwards. Adding recruitment deviations did not significantly change model results. None of the alternative models resulted in overfishing or overfished status in 2021.

Projections: The projection analysis showed the distribution of outcomes in the probability of overfishing and overfished status that would occur in various final years (2024-2028) under various fixed-catch scenarios (Table 9-20; Figure 9-95, and Figure 9-96). The projections indicated very low probability of overfished status occurring between 2024 and 2028 for the range of fixed catch explored (< 5 mt per year).

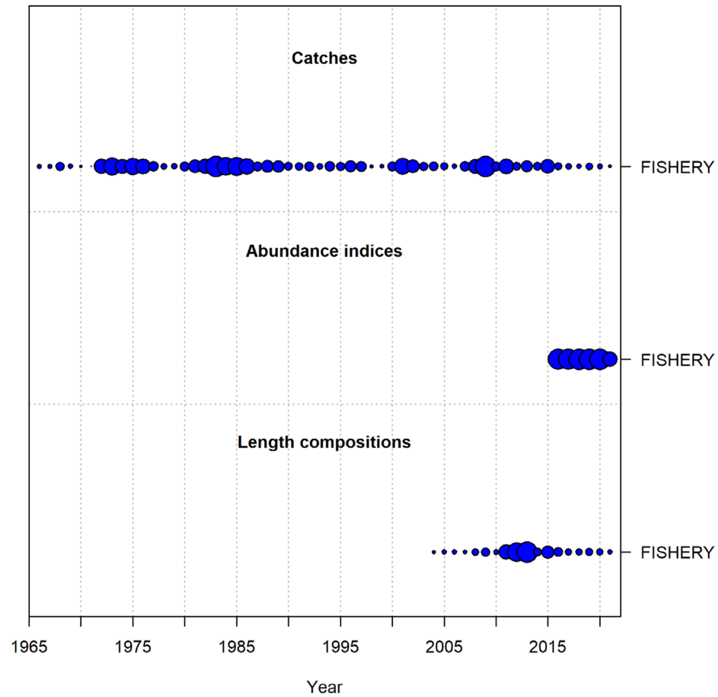


Figure 9-77- Summary of data types used in the Stock Synthesis model. Catches include boat-based and shore-based landings from creel surveys (1986-2021) as well as historical catches from reports (1967-1985). The abundance index is from boat-based creel survey 'bottomfishing" gear type. Length compositions are from creel surveys (all years) and the biosampling program (2010-2015) filtered for the "bottomfishing" gear.

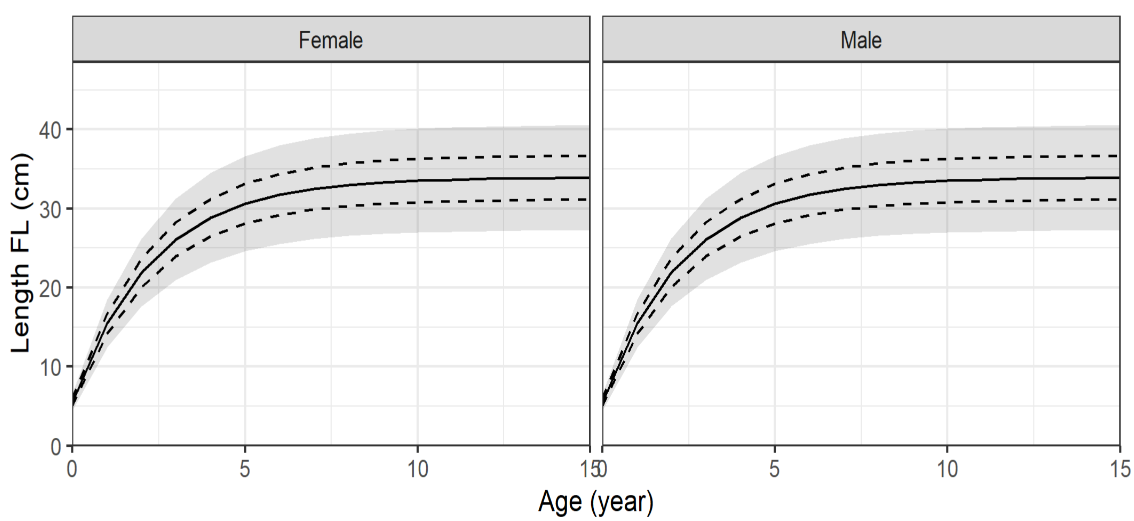


Figure 9-78 – Growth curve following a Von Bertalanffy model with 95% confidence intervals associated with the CV Linf parameter. The central growth platoon (solid line) and the two secondary ones (dashed lines) used in the model are also displayed.

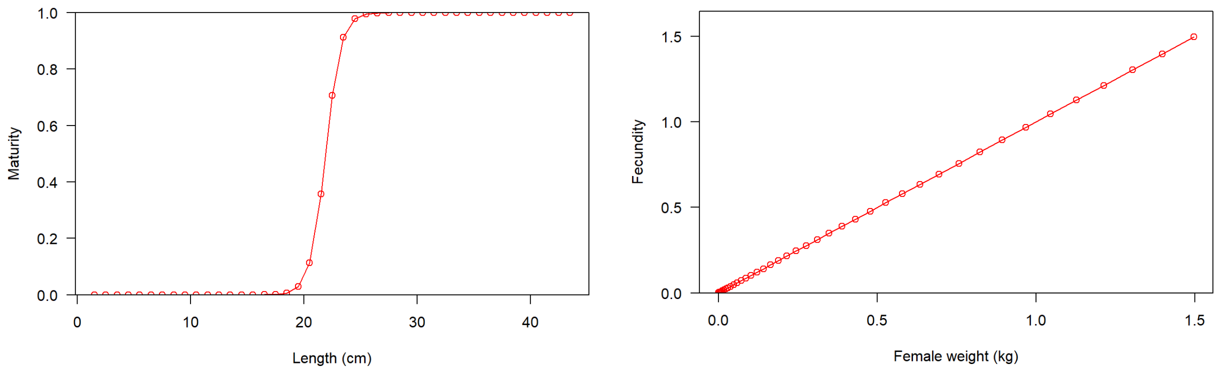


Figure 9-79 – Maturity-at-length (FL; left) and fecundity-at-weight (right) used in the stock assessment model.

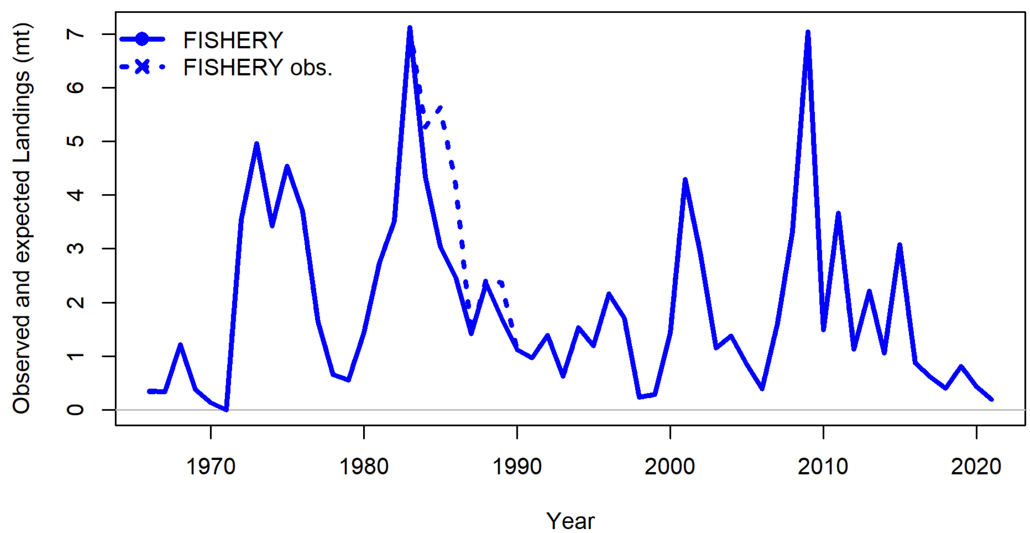


Figure 9-80 – Annual total catch in metric tons (mt). The dashed line represent the observed median catch while the solid line represent the catch as adjusted in the model.

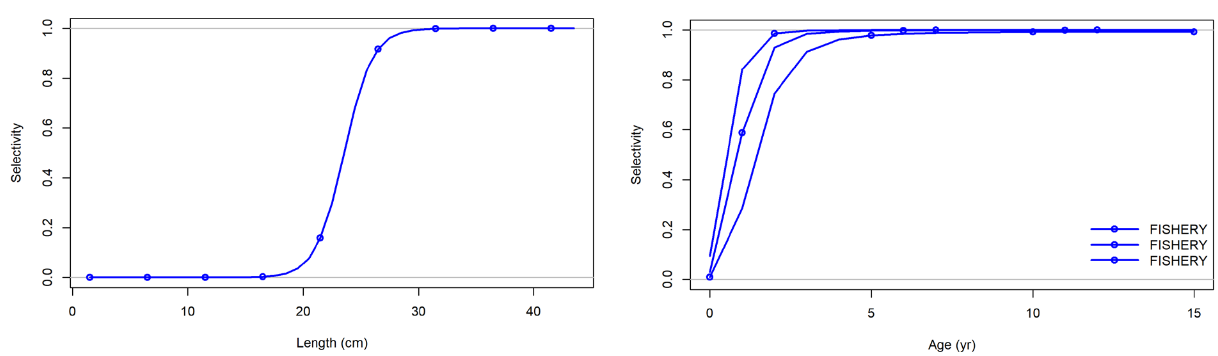


Figure 9-81 – Length-based selectivity estimated by the Stock Synthesis model (left) and the resulting selectivity-at-age for all 3 growth platoons (right).

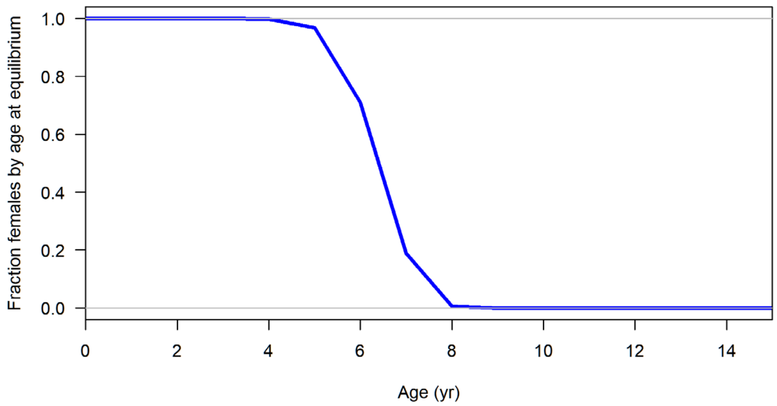


Figure 9-82 – Proportion of females transitioned to males by age (protogynous hermaphrodite).

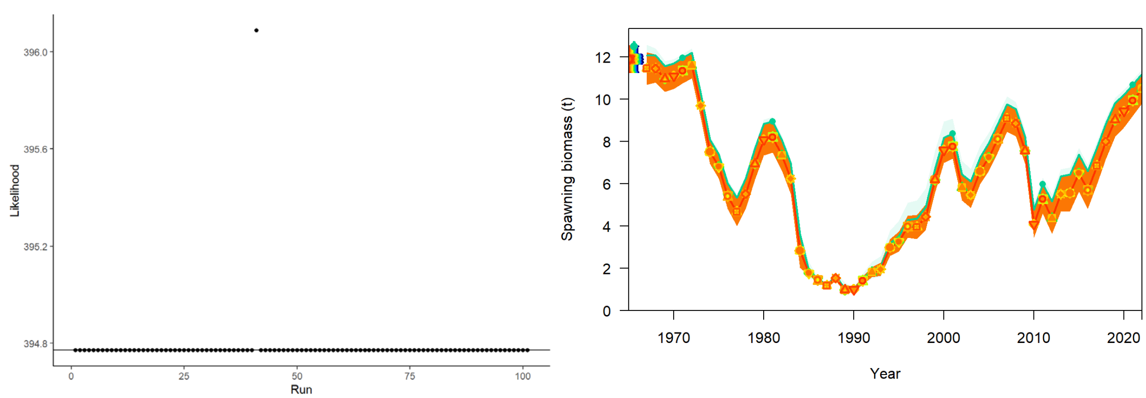


Figure 9-83 - Results of jitter analysis where 100 models were run with randomly varying initial parameter values. Left panel shows the variation in minimum model likelihood value for all 100 model runs. Right panel shows the variation in SSB time series for all 100 model runs.

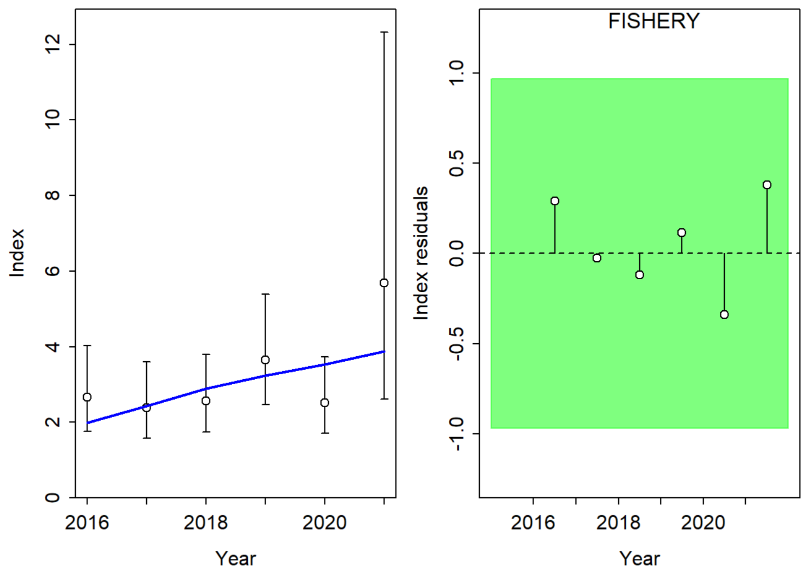


Figure 9-84 – Observed (open dots) vs expected (blue line) CPUE abundance index by year with standard deviations intervals (left). CPUE index residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.25.

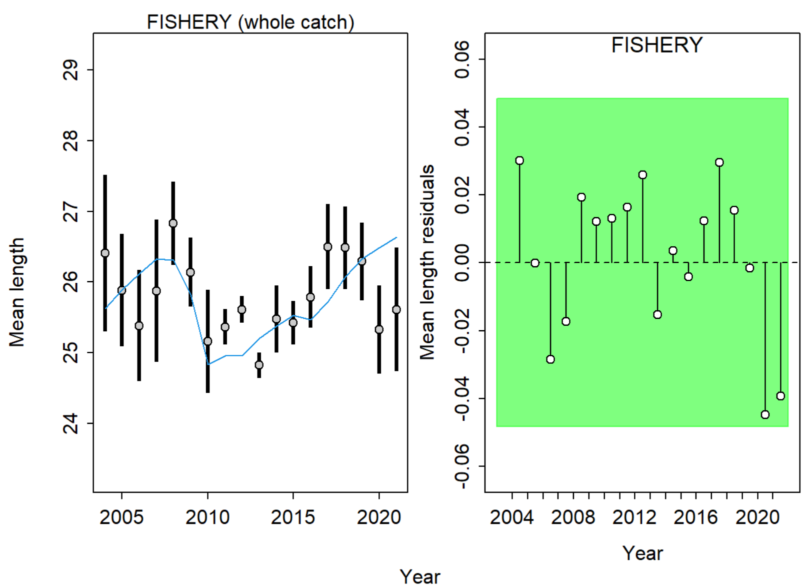


Figure 9-85 – Observed (open dots) vs expected (blue line) mean length by year with standard deviations intervals (left). Mean length residuals by year, with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.02.

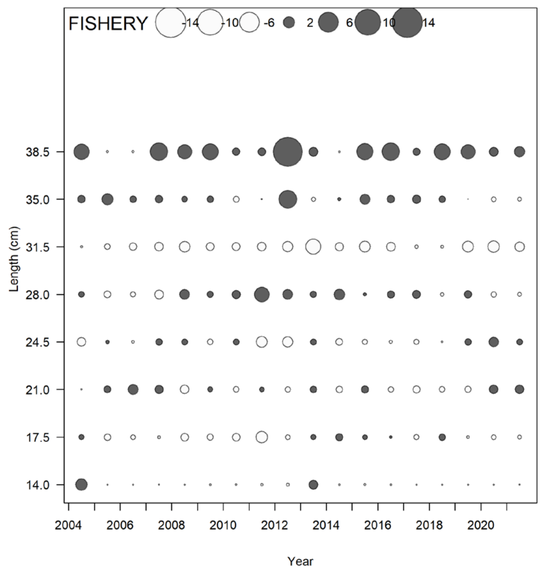


Figure 9-86 – Pearson residual plot of observed vs. expected size frequency data by size bin and year.

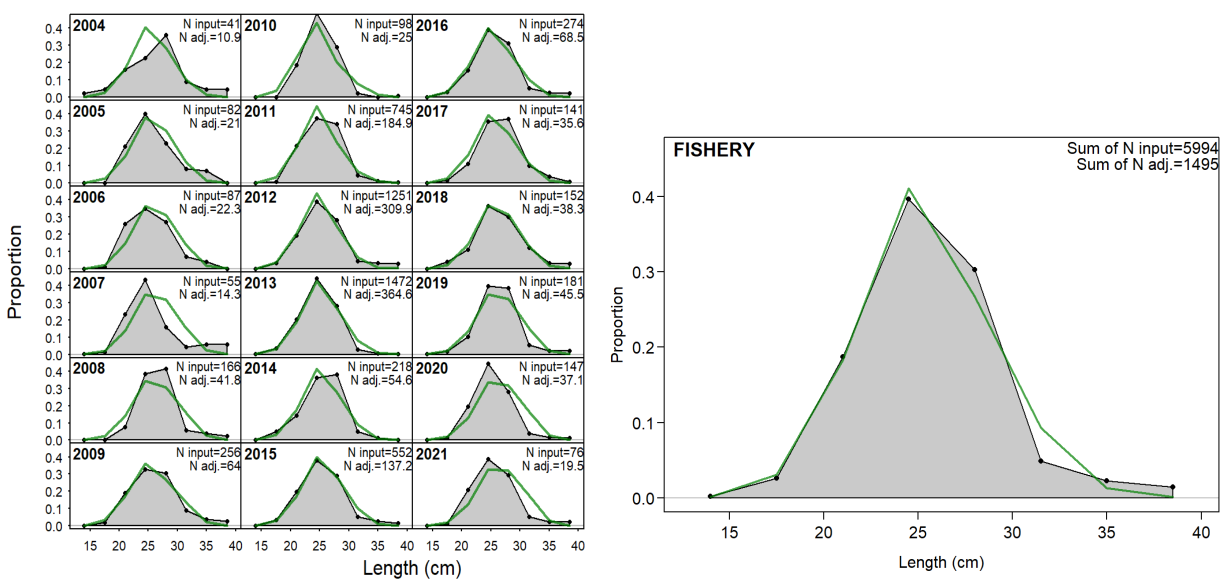


Figure 9-87 – Observed (gray area) vs. expected (green line) abundance-at-length from bottomfishing catch by year (left) and overall (right).

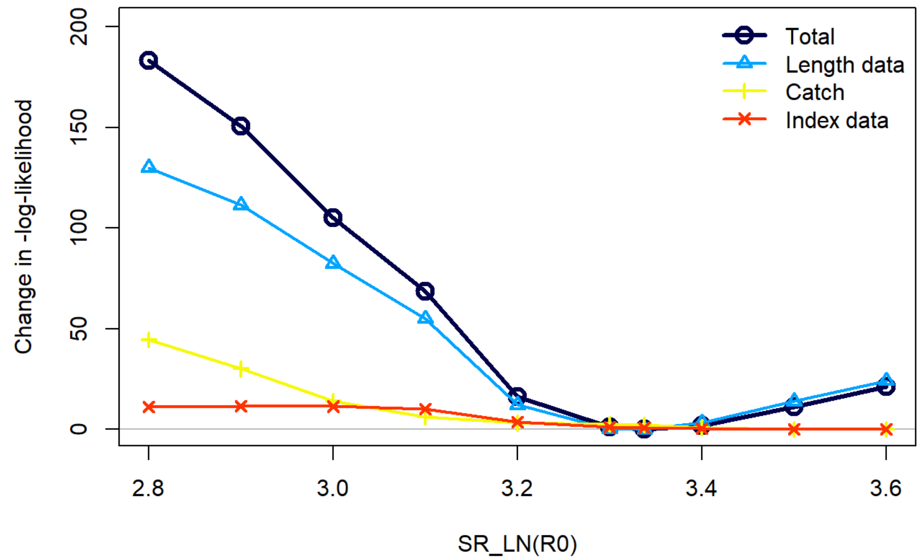


Figure 9-88 – Profiles of the change in negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter (R_0) in log-scale.

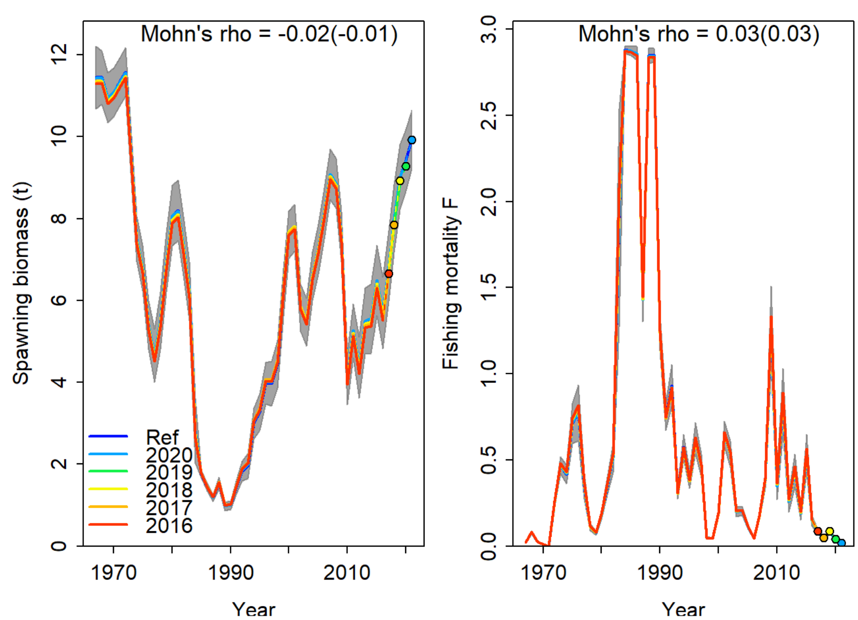


Figure 9-89 – Retrospective analysis of spawning biomass (left) and fishing mortality (right) consisting of 5 reruns of the base case model each fitted with one less year of data from the base case model (blue line).

Table 9-17 – Time series of spawning biomass (SSB, mt), age-0 recruitment (Rec., 1000s of recruits), and instantaneous fishing mortality (F, yr-1) estimated by the SS model. CV is the coefficient of variation.

Year	SSB	CV	Rec.	CV	F	CV	Year	SSB	CV	Rec.	CV	F	CV
1969	10.5	0.10	26.97	0.09	0.022	0.40	1996	6.3	0.30	24.34	0.12	0.324	0.75
1970	10.7	0.10	27.02	0.09	0.009	0.50	1997	6.0	0.32	23.99	0.13	0.258	0.52
1971	10.9	0.09	27.13	0.08	0.000	0.47	1998	6.4	0.28	24.47	0.12	0.025	0.68
1972	11.2	0.09	27.20	0.08	0.301	0.56	1999	7.7	0.22	25.55	0.10	0.034	0.56
1973	9.1	0.15	26.43	0.09	0.416	0.65	2000	8.7	0.17	26.12	0.10	0.142	0.54
1974	7.3	0.20	25.23	0.09	0.353	0.81	2001	8.7	0.16	26.13	0.09	0.436	0.85
1975	6.9	0.22	24.93	0.10	0.653	0.90	2002	6.8	0.24	24.88	0.09	0.357	0.57
1976	5.9	0.40	23.67	0.17	0.697	0.76	2003	6.4	0.24	24.54	0.09	0.172	0.60
1977	4.6	0.41	22.80	0.17	0.334	0.98	2004	7.0	0.19	25.27	0.09	0.146	0.66
1978	5.4	0.39	23.62	0.16	0.098	0.89	2005	7.7	0.18	25.69	0.09	0.076	0.53
1979	6.8	0.31	24.79	0.12	0.081	0.66	2006	8.6	0.14	26.09	0.08	0.039	0.54
1980	7.7	0.26	25.44	0.11	0.162	0.64	2007	9.3	0.11	26.48	0.08	0.130	0.48
1981	7.6	0.24	25.45	0.10	0.280	0.51	2008	9.0	0.12	26.42	0.09	0.365	0.38
1982	7.0	0.24	25.02	0.11	0.613	0.51	2009	7.6	0.14	25.68	0.08	1.201	0.22
1983	5.5	0.29	24.07	0.12	2.188	0.48	2010	4.1	0.20	22.03	0.10	0.336	0.24
1984	2.3	0.56	18.66	0.21	2.746	0.35	2011	5.2	0.16	23.56	0.09	0.766	0.33
1985	1.8	0.54	16.37	0.20	1.550	0.50	2012	4.4	0.14	22.58	0.09	0.196	0.53
1986	1.9	0.58	16.99	0.21	1.423	0.65	2013	5.6	0.12	24.15	0.09	0.408	0.50
1987	1.8	0.67	16.40	0.27	0.783	0.76	2014	5.5	0.18	24.07	0.09	0.175	0.43
1988	2.2	0.63	18.36	0.24	1.084	0.67	2015	6.5	0.16	24.87	0.09	0.514	0.38
1989	2.1	0.72	17.16	0.28	0.989	0.69	2016	5.6	0.21	24.13	0.11	0.147	0.28
1990	2.2	0.70	17.86	0.28	0.546	0.67	2017	6.7	0.17	25.07	0.10	0.085	0.29
1991	2.9	0.61	19.75	0.23	0.354	0.75	2018	7.8	0.14	25.75	0.09	0.044	0.28
1992	3.7	0.55	21.59	0.21	0.405	0.56	2019	8.7	0.12	26.27	0.09	0.087	0.30
1993	4.1	0.48	22.23	0.19	0.117	0.70	2020	9.1	0.12	26.45	0.09	0.043	0.26
1994	5.4	0.39	23.59	0.15	0.268	0.70	2021	9.6	0.11	26.62	0.09	0.013	0.50
1995	5.6	0.37	23.76	0.14	0.191	0.60							

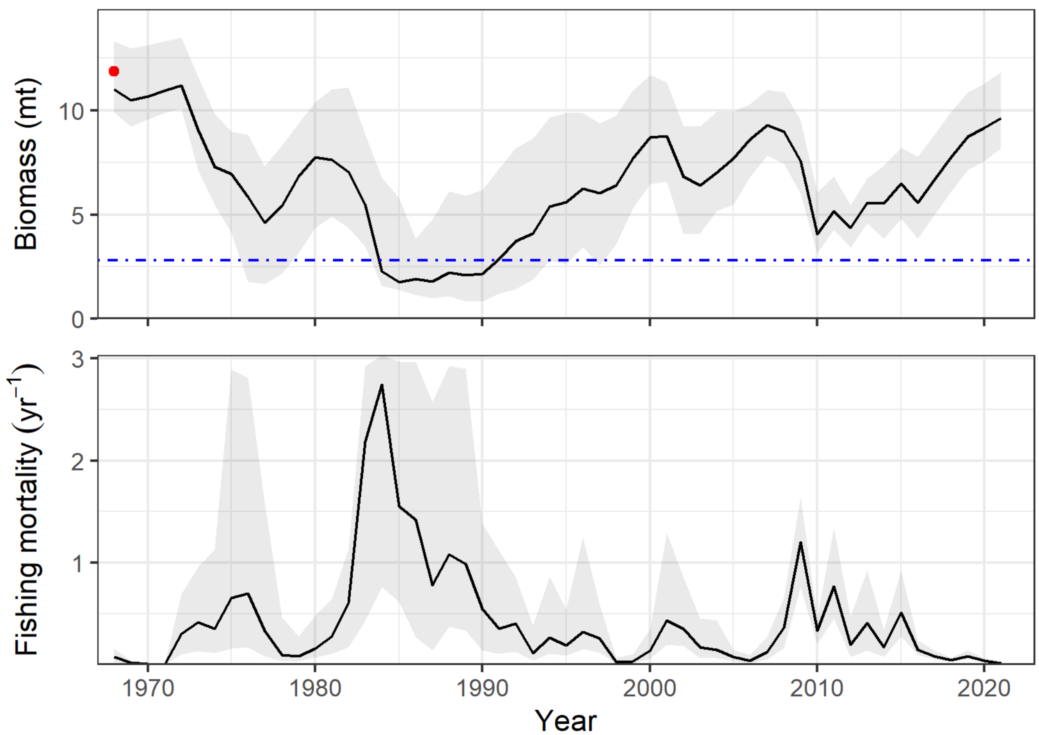


Figure 9-90 – Time series of spawning biomass (solid line) with its 95% confidence interval and SSB_0 estimate (red dot; top panel). The dot-and-dash blue line shows the spawning biomass at the MSST reference point (SSBMSST). Time series of fishing mortality rate with its 95% confidence intervals (bottom panel).

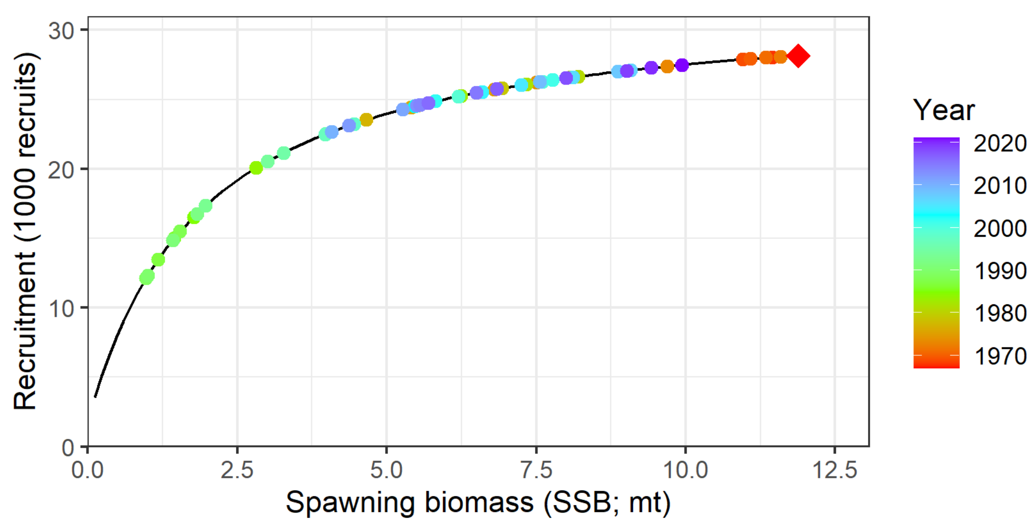


Figure 9-91 – Expected recruitment from the stock-recruitment relationship (black line) and estimated annual recruitment (dots) from SS. Estimated virgin SSB and recruitment is indicated with a red diamond.

Table 9-18 – Estimated biological reference points with 95% confidence interval (SD) derived from the SS base-case model where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield (2021 is the terminal year of the model).

Reference point	Value
F_{MSY} (yr^{-1})	0.592 (0.549 - 0.641)
F_{2021} (yr^{-1})	0.013 (0.008 - 0.033)
F_{2021}/F_{MSY}	0.022 (0.014 - 0.051)
SSB_{MSST} (mt)	2.8 (2.35 - 3.44)
SSB_{2021} (mt)	9.63 (8.18 - 11.82)
SSB_{2021}/SSB_{MSST}	3.42 (3.14 - 3.71)
MSY (mt)	2.38 (2.28 - 2.48)
$Catch_{2019-2021}$(mt)	0.48 (0.23 - 0.73)
SPR_{MSY}	0.46 (0.46 - 0.46)
SPR_{2021}	0.97 (0.97 - 0.97)

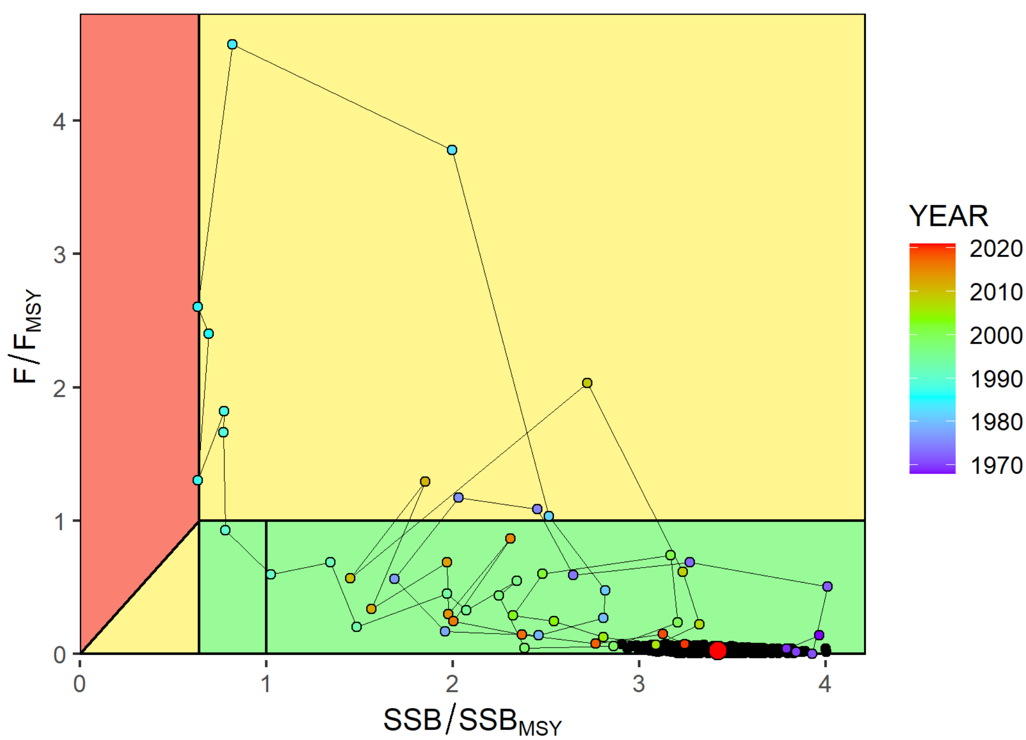


Figure 9-92 – Kobe plot representing the trend in relative fishing mortality and spawning stock biomass between 1969 and 2021 with their associated biological reference areas (red: overfished and overfishing, yellow: overfishing or overfished, green: no overfishing and not overfished). The large red dot indicates median stock status in 2021 and the black dots are one thousand Monte Carlo draws from the stock status distribution to represent the uncertainty around the final year status.

Table 9-19 – Summary table of key model output for all alternative model runs where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield.

Model	F_{2021}	F_{MSY}	F_{2021}/F_{MSY}	SSB_{MSY}	SSB_{MSST}	SSB_{2021}	SSB_{2021}/SSB_{MSY}	SSB_{2021}/SSB_{MSST}	Catch MSY
Base	0.017	0.6	0.03	4.5	2.9	9.9	2.2	3.4	2.4
M - 10%	0.016	0.54	0.03	4.7	3.2	9.9	2.1	3.1	2.4
M + 10%	0.016	0.66	0.02	4.4	2.8	10.2	2.3	3.6	2.5
Steep. - 10%	0.015	0.5	0.03	5.3	3.4	10.8	2	3.2	2.4
Steep. + 10%	0.017	0.71	0.02	4	2.6	9.8	2.5	3.8	2.4
Rec. dev.	0.021	0.61	0.03	4.8	3	8.1	1.7	2.7	2.5
No hist. catch	0.018	0.6	0.03	4.3	2.7	9.3	2.2	3.4	2.3
Alternate LH	0.008	0.45	0.02	7.1	4.5	19.1	2.7	4.2	3.7

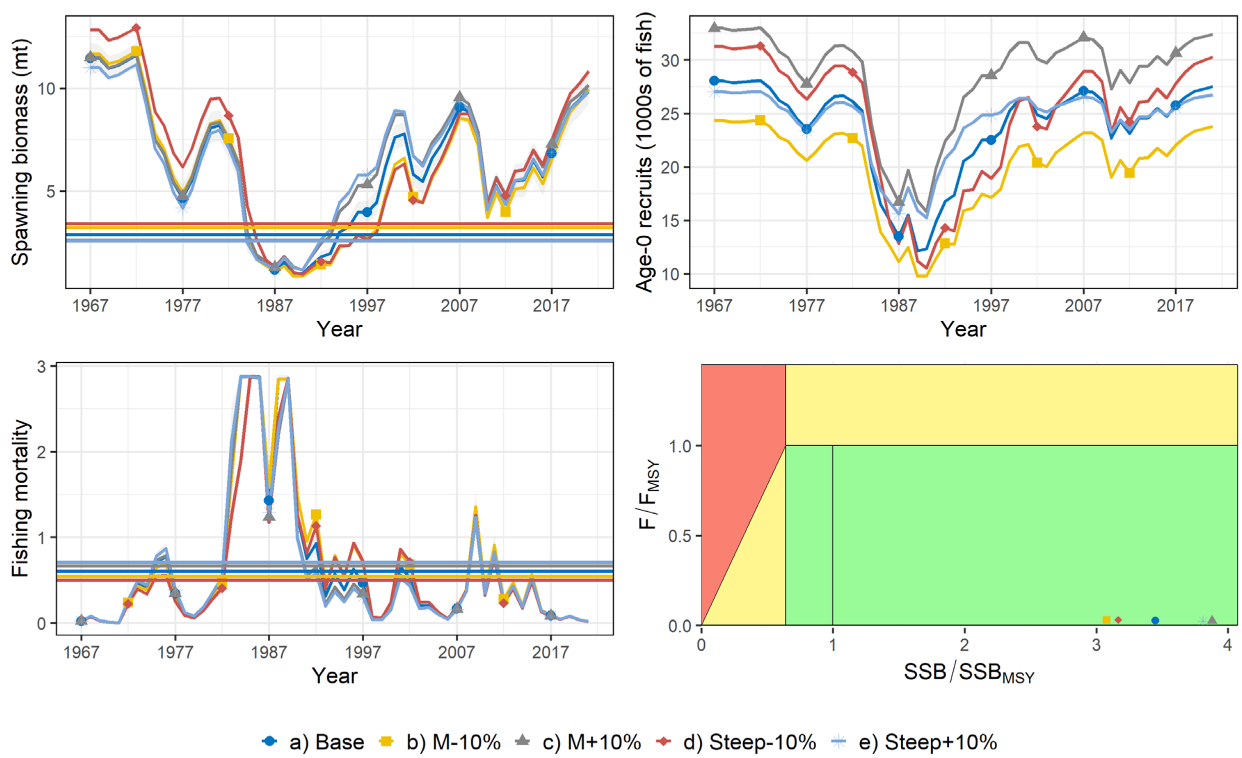


Figure 9-93 – Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) under moderate life-history parameter variation (plus and minus 10% of base parameter values).

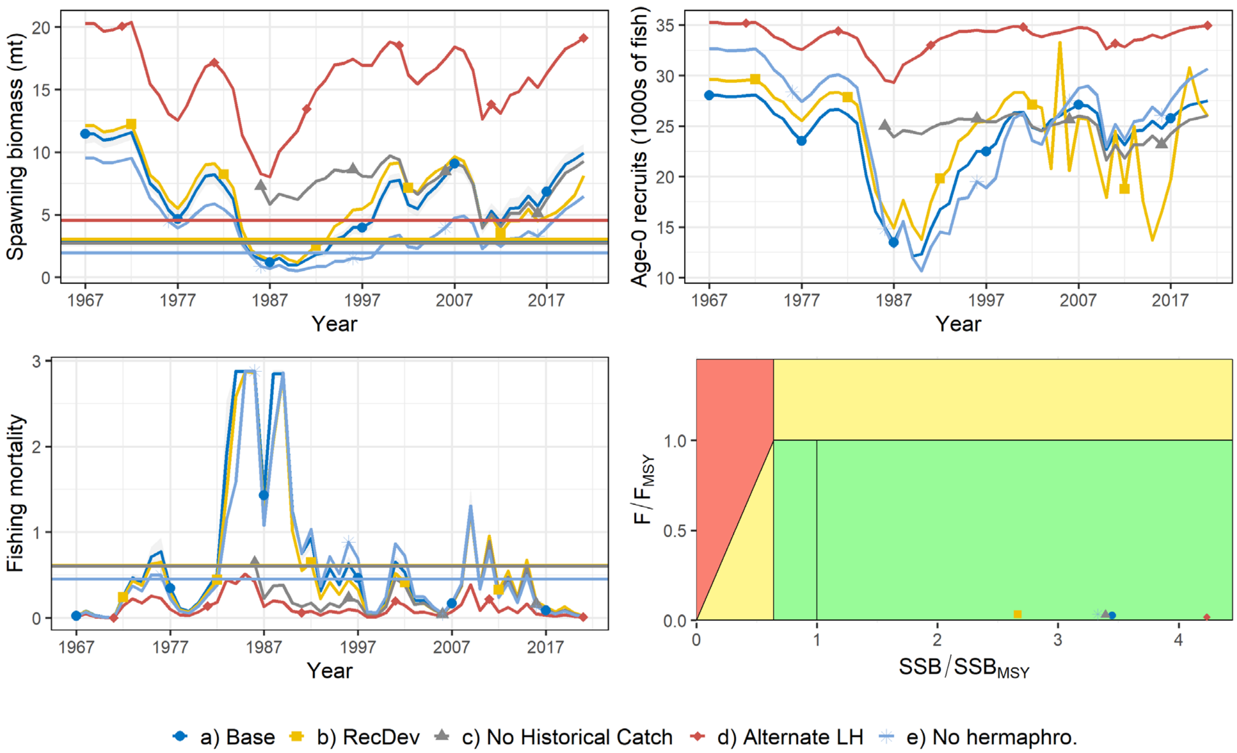


Figure 9-94 - Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) b) with recruitment deviations, c) without historical catch data (model starts in 1986), and d) with an alternate life history parameter source (growth curve from Trianni et al. 2011).

Table 9-20 - The annual fixed catch values (metric tons) applied from 2024 to a final projection year resulting in a given probability of overfishing ($F/F_{MSY}>1$) in that final year. Catches for years prior to the start of the new catch guidance (2022 and 2023) were fixed at the mean of the last 3 years of catch data (2019 to 2021).

Probability of	Fixed catch (mt) from 2024 to:			
$F > F_{MSY}$	2025	2026	2027	2028
0.50	4.70	4.02	3.61	3.36
0.49	4.68	4.01	3.61	3.35
0.48	4.67	3.99	3.60	3.34
0.47	4.66	3.98	3.59	3.33
0.46	4.65	3.97	3.58	3.33
0.45	4.63	3.96	3.57	3.32
0.44	4.62	3.95	3.56	3.31
0.43	4.61	3.94	3.55	3.30
0.42	4.60	3.93	3.54	3.29
0.41	4.58	3.92	3.53	3.28
0.40	4.57	3.91	3.52	3.28
0.39	4.56	3.90	3.52	3.27
0.38	4.54	3.89	3.51	3.26
0.37	4.53	3.88	3.50	3.25
0.36	4.52	3.87	3.49	3.25
0.35	4.51	3.86	3.48	3.24
0.34	4.49	3.85	3.47	3.23
0.33	4.48	3.84	3.46	3.22
0.32	4.47	3.83	3.45	3.21
0.31	4.45	3.82	3.45	3.21
0.30	4.44	3.81	3.44	3.20
0.29	4.43	3.80	3.43	3.19
0.28	4.41	3.79	3.42	3.18
0.27	4.40	3.78	3.41	3.18
0.26	4.39	3.77	3.40	3.17
0.25	4.38	3.76	3.39	3.16
0.24	4.36	3.75	3.38	3.15
0.23	4.35	3.74	3.38	3.15
0.22	4.34	3.72	3.37	3.14
0.21	4.32	3.71	3.36	3.13
0.20	4.31	3.70	3.35	3.12
0.19	4.30	3.69	3.34	3.12
0.18	4.28	3.68	3.33	3.11
0.17	4.27	3.67	3.32	3.10
0.16	4.26	3.66	3.32	3.10
0.15	4.24	3.65	3.31	3.09
0.14	4.23	3.64	3.30	3.08
0.13	4.22	3.63	3.29	3.07
0.12	4.20	3.62	3.28	3.07
0.11	4.19	3.61	3.27	3.06
0.10	4.18	3.60	3.27	3.05

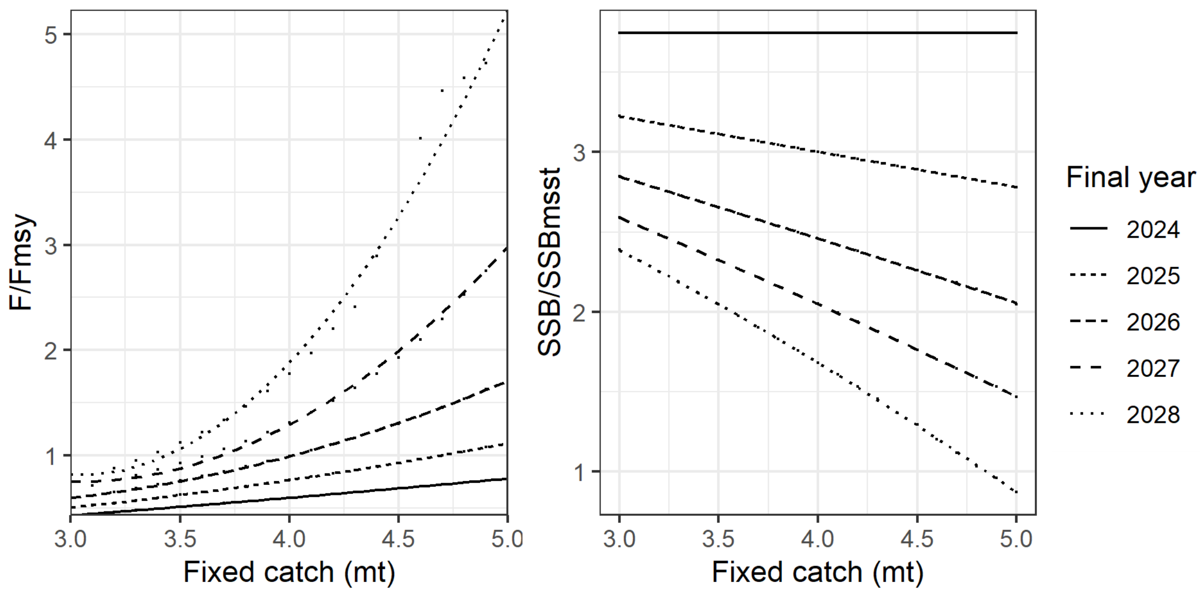


Figure 9-95 – Median stock status for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status is for the final projection year.

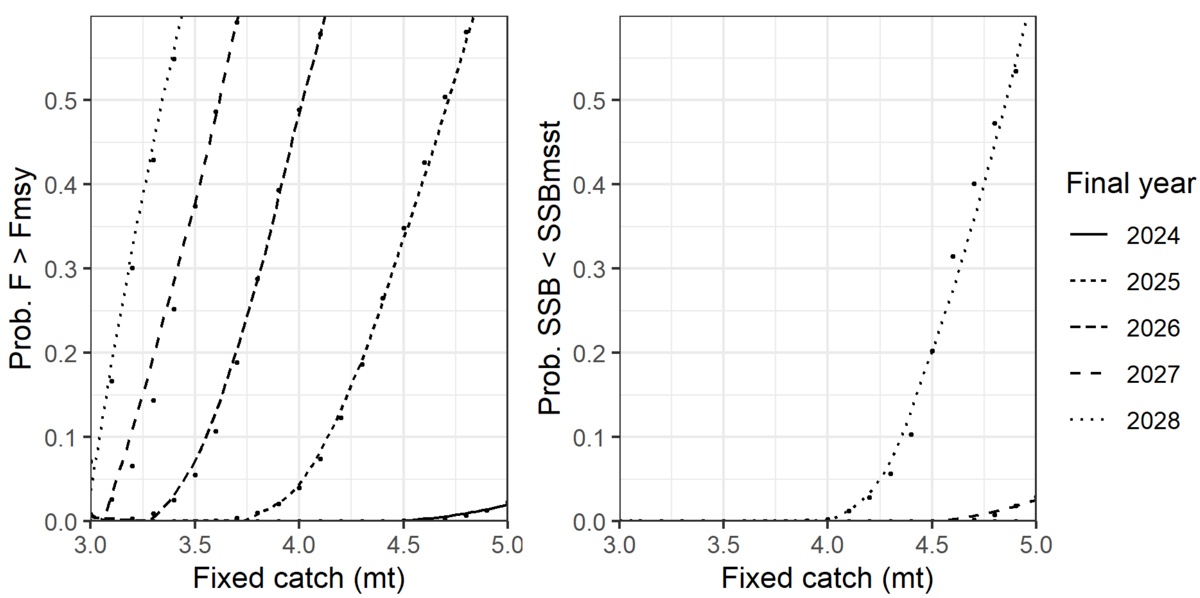


Figure 9-96– Probability of overfishing (left panel) and of stock being overfished (right panel) for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status probabilities are for the final projection year.

9.6 *Lutjanus kasmira*

Savane, *Bluestripe snapper*
Lutjanidae (snappers)

Key model parameters

Parameter	Value	Phase	Source
Natural mortality, M (yr^{-1})	0.68	-2	5.4/A_{max} (Hamel and Cope 2022)
Reference age, A_{min} (yr)	1	-2	-
Maximum age, A_{max} (yr)	8	-2	Loubens (1980a)
Length at A_{min}, L_{Amin} (cm)	11.2	-2	-
Length at A_{max}, L_{Amax} (cm)	24.6	-2	-
Growth rate, K (yr^{-1})	0.38	-2	-
CV of length < L_{Amin}	0.07	-2	-
CV of length > L_{Amin}	0.07	-2	-
Length-weight α	1.28e-5	-2	Kamikawa et al. (2015)
Length-weight β	3.12	-2	-
Length 50% maturity, L_{mat50} (cm)	18	-2	StepwiseLH. L_{99}: 26.4 cm (creel+biosampling)
Slope of maturity ogive	-3	-2	-
Spawner-recruit steepness (h)	0.69	-2	FishLife 2.0 (Thorson 2019)
Number of platoons	3	-	Fixed
Unfished recruitment (Log R_0)	6.64 (0.18)	1	Estimated
Initial fishing mortality	0.11 (0.07)	-	Estimated
Catchability (Log Q)	-1.69 (0.27)	1	Estimated
Extra Q SD	-	1	Set to zero
Length at 50% selectivity (cm)	22.1 (0.16)	2	Estimated
Width to 95% selectivity (cm)	2.9 (0.1)	2	Estimated
Dirichlet parameter (Log theta)	-1.11 (0.16)	2	Estimated (note: 1.182, 0.255 normal prior used)

General comments

Data: Catch data are available from 1967 to 2021, CPUE from 2016 to 2021, and size composition observations are available in sufficient numbers from 2004 to 2021 (Figure 9-97). No super-period was used for size data.

Life history: We found two growth studies: one in Hawaii (Morales-Nin and Ralston 1990) and one in New Caledonia (Loubens 1980a). We did not find maturity studies. The Hawaii *L. kasmira* snappers appear larger than the ones found in Samoa (mean length 27 cm vs. 22 cm), which precluded us from considering the Hawaii growth curve. Therefore, we selected Loubens (1980a; Figure 9-98), which has an L_{inf} parameter similar to the one derived from the StepwiseLH tool using an L_{99} of 27.5 cm from the biosampling and creel data (24.6 cm vs. 24.7 cm). The StepwiseLH tool estimated a higher A_{max} than the one found in Loubens (1980a), at 13 years vs. 8 years (the latter is identical to the Hawaii A_{max}). We tested this longer longevity in an alternate model run. The maturity curve derived from the StepwiseLH tool is presented in Figure 9-99. There was no evidence of sex-specific patterns for this species.

Fishery: The re-created historical catch (1967–1985) suggests that contrary to deeper-occurring species, a fair amount of *L. kasmira* were caught, especially during the dory project years in the 1970s (~9 mt per year) with a lower but still significant catch during the ‘alia program in the 1980s (~ 5 mt; Figure 9-100). After those initial peaks, catch has been hovering between 1 and 7 mt per year, with a reduction in recent years. The early catches were slightly adjusted by the model. The model estimated an initial F in 1967 at 0.11. The model estimated length at 50% selectivity at approximately 22.1 cm and full selectivity at approximately 24 cm (or age 7), with clear differences in selectivity-at-age between platoons (Figure 9-101). This fishery is noteworthy in that only the largest individuals in the stock are selected by bottomfish gear, which leaves a significant proportion of the spawning biomass unfished.

Model diagnostics: All estimated model parameters converged within the set bounds with the final likelihood gradient of the model being less than 0.0001 and the associated Hessian matrix being positive definite. However, due to the late selectivity in the fishery, the model could not appropriately estimate $F_{MSY.}$ In other words, the high proportion of the spawning biomass that is not vulnerable is large enough to insure a SSB_{MSST} of 1.6 mt regardless of fishing pressure. A jitter analysis of 100 model runs with different random initial starting values also supported that the model converged on a global minimum (Figure 9-102). Further, goodness-of-fit diagnostics indicated that the model fitted the CPUE index well with a successful Runs test and a relatively small RMSE of 0.22 (Figure 9-103). The mean length model failed the Runs test but had a very low RMSE of 0.01 (Figure 9-104). The yearly and overall size composition data was fitted well by our model, with minimal residual patterns (Figure 9-105 and Figure 9-106). The change in negative log-likelihoods at different fixed log(R_0) values indicated that this parameter's estimate was mainly driven by the catch and length composition data, with a clear minimum reached at 6.6 (~735,000 recruits; Figure 9-107). The results of the retrospective analysis, which progressively removed one year of data from 2021 to 2017, showed no significant pattern for SSB or F, with Mohn's rho values around 0.01 for both (suggested limits are between -0.15 and 0.2; Figure 9-108).

Stock status: Population biomass declined from an SSB_0 around 13 mt prior to 1967 to as low as 8 mt in the late 1970s, following the sustained high catch associated with the dory program (this was by far the most caught species during this program). Another bump in catch associated with the ‘alia program in the 1980s kept the biomass around 9 mt (Figure 9-109 and Table 9-21). Biomass has been increasing consistently since then returning to 12.5 mt in recent years (the MSST was estimated at 1.6 mt; Figure 9-109). Recruitment stayed near R_0 for the entire period, varying around 710,000 recruits per year (Figure 9-110). The current stock status (SSB/SSB_{MSST}) is equal to 7.6 (not overfished) with no overfishing occurring. No overfishing or overfished status occurred throughout the time series (Figure 9-111; Table 9-22). F_{MSY} was estimated at 1.2 (a harvest rate of 0.70). No fishing rate will lead to SSB falling below the SSB_{MSST} of 1.6 mt. Equilibrium catches at F_{MSY} (i.e., the *MSY*) were estimated at 8.3 mt. Catches in recent years have been low, averaging only 0.3 mt (Table 9-22).

Alternate scenarios: We ran 7 alternative models: *M* and steepness plus and minus 10%, no historical catch, with recruitment deviations, and alternate LH source. The alternate specification with the largest impact was the alternate LH source, which used the StepwiseLH tool (Table 9-23, Figure 9-112, and Figure 9-113). This scenario resulted in elevated *SSB*. There was little impact of starting the model in 1986 or adding recruitment deviations. None of the alternative models resulted in overfishing or overfished status in 2021.

Projections: Given the low proportion of the stock that is vulnerable to bottomfishing, it is impossible to determine fixed catch values that would result in either overfishing or overfished status. We therefore set the OFL to the MSY estimate from our model (8 mt). See the Methods projection section for more details.

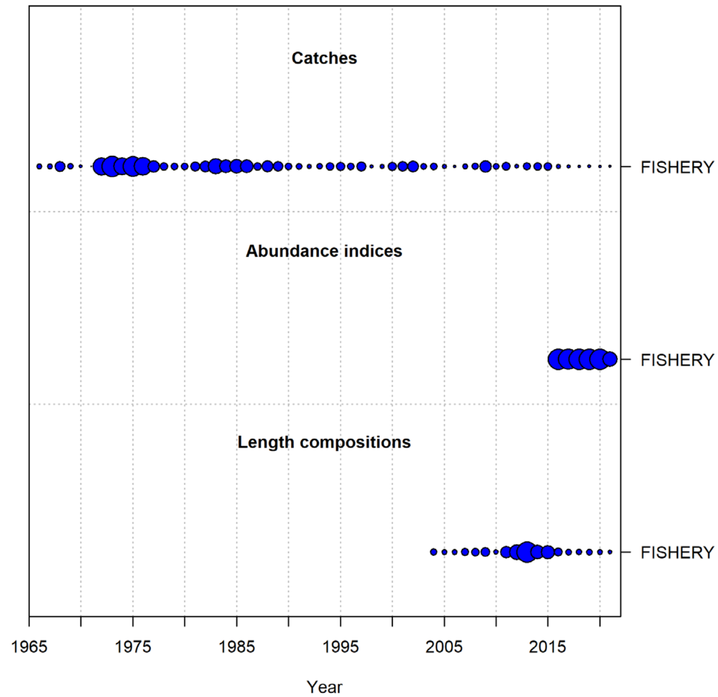


Figure 9-97- Summary of data types used in the SS model. Catches include boat-based and shore-based landings from creel surveys (1986-2021) as well as historical catches from reports (1967-1985). The abundance index is from boat-based creel survey ‘bottomfishing” gear type. Length compositions are from creel surveys (all years) and the biosampling program (2010-2015) filtered for the “bottomfishing” gear.

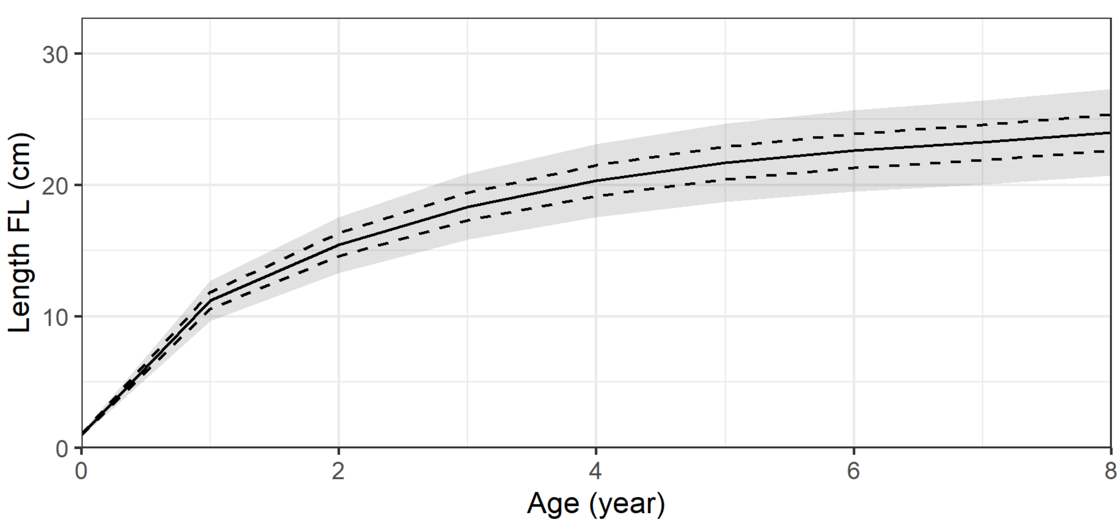


Figure 9-98 – Growth curve following a Von Bertalanffy model with 95% confidence intervals associated with the CV Linf parameter. The central growth platoon (solid line) and the two secondary ones (dashed lines) used in the model are also displayed.

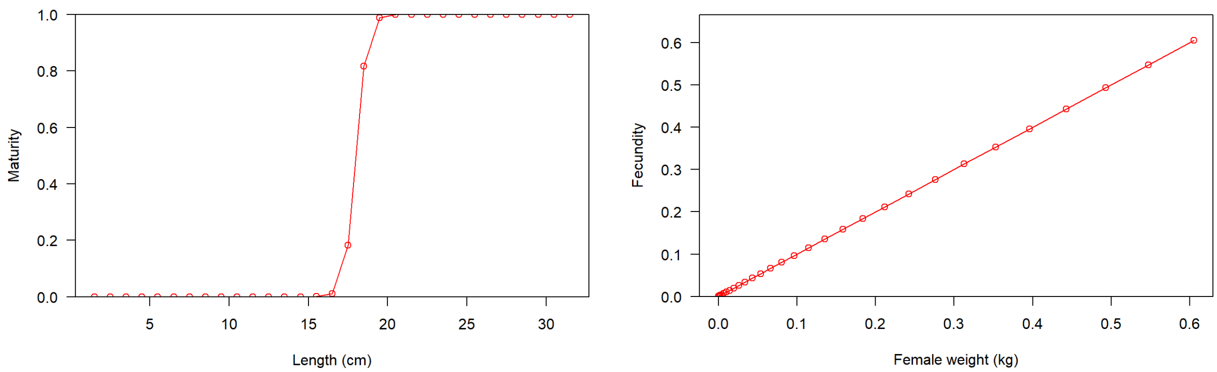


Figure 9-99 – Maturity-at-length (FL; left) and fecundity-at-weight (right) used in the stock assessment model.

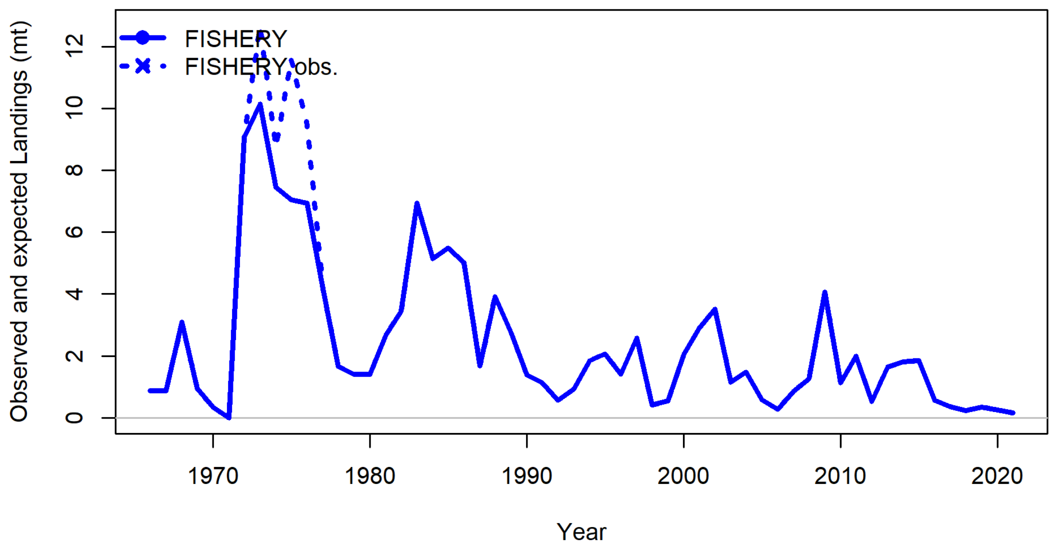


Figure 9-100 – Annual total catch in metric tons (mt). The dashed line represent the observed median catch while the solid line represent the catch as adjusted in the model.

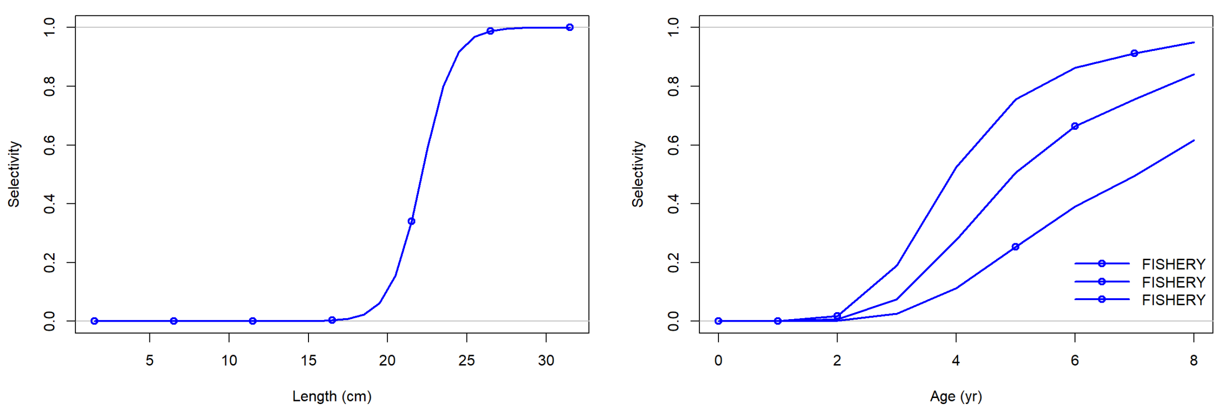


Figure 9-101 – Length-based selectivity estimated by the SS model (left) and the resulting selectivity-at-age for all 3 growth platoons (right).

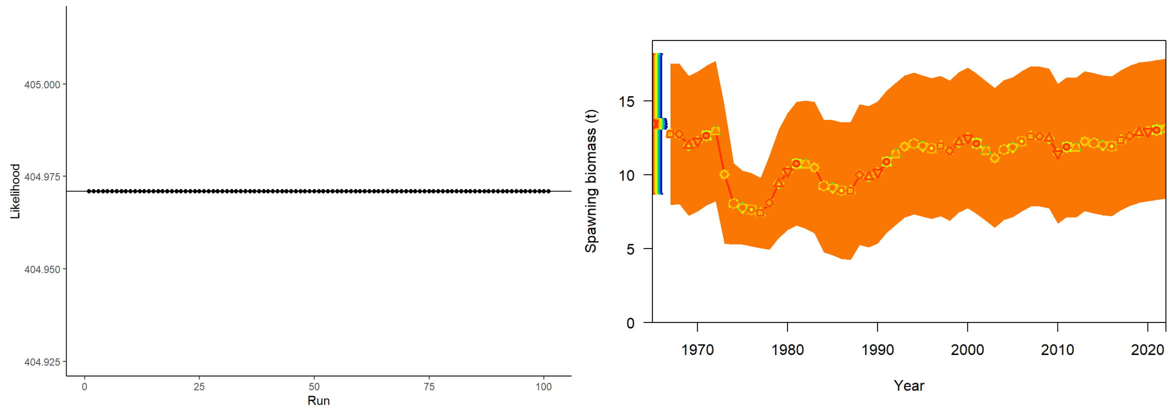


Figure 9-102 - Results of jitter analysis where 100 models were run with randomly varying initial parameter values. Left panel shows the variation in minimum model likelihood value for all 100 model runs. Right panel shows the variation in SSB time series for all 100 model runs.

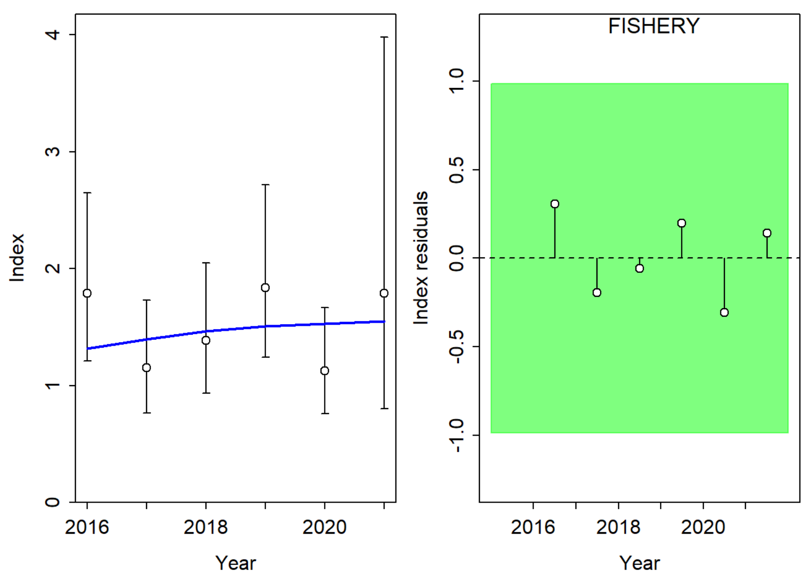


Figure 9-103 – Observed (open dots) vs expected (blue line) CPUE abundance index by year with standard deviations intervals (left). CPUE index residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.22.

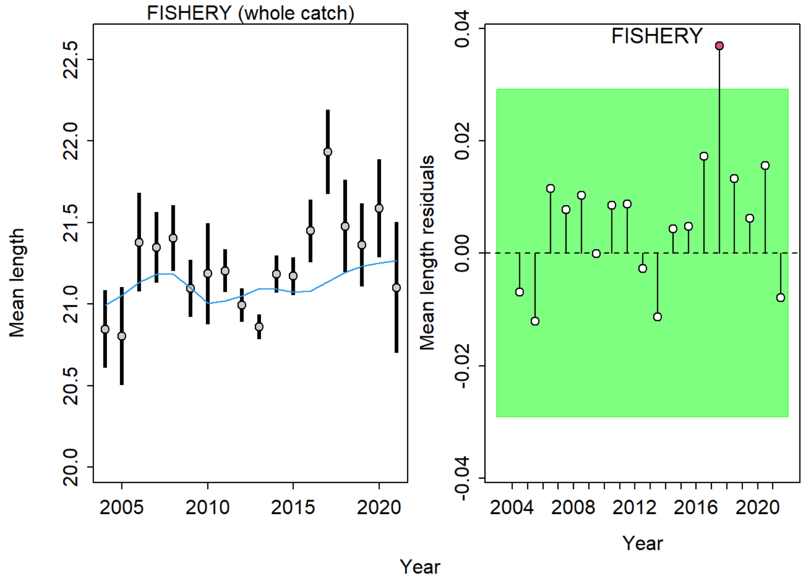


Figure 9-104 – Observed (open dots) vs expected (blue line) mean length by year with standard deviations intervals (left). Mean length residuals by year, with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.01.

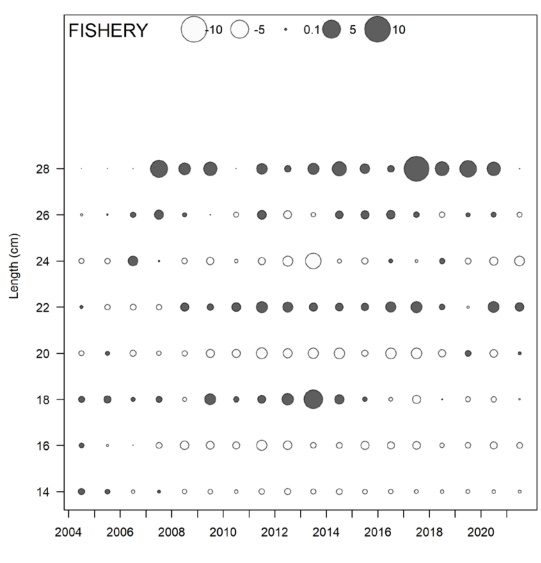


Figure 9-105 – Pearson residual plot of observed vs. expected size frequency data by size bin and year.

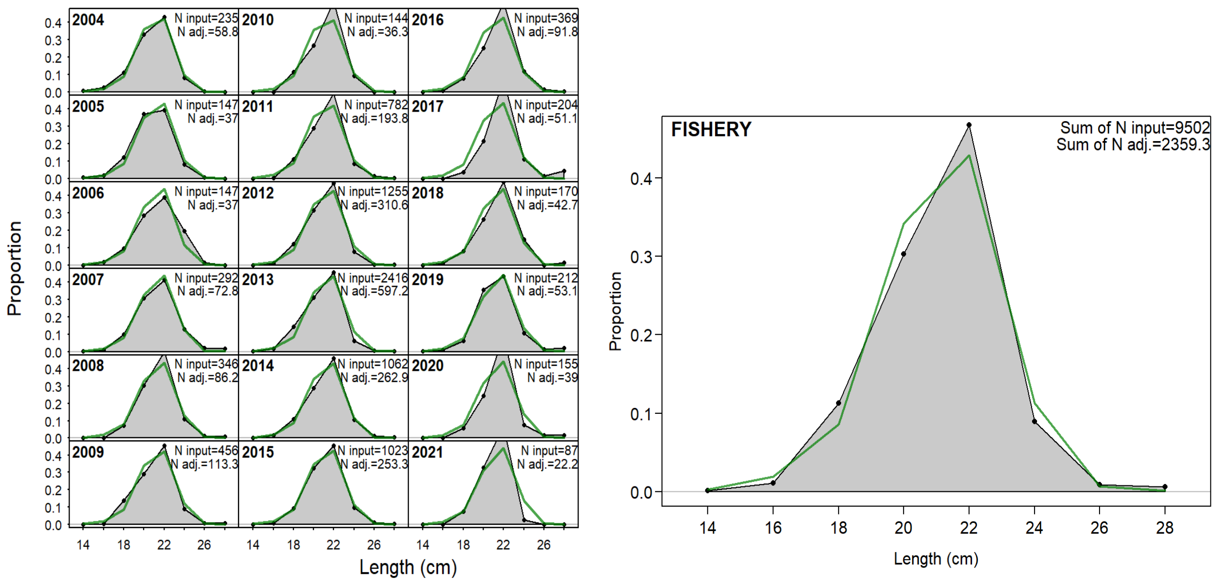


Figure 9-106 – Observed (gray area) vs. expected (green line) abundance-at-length from bottomfishing catch by year (left) and overall (right).

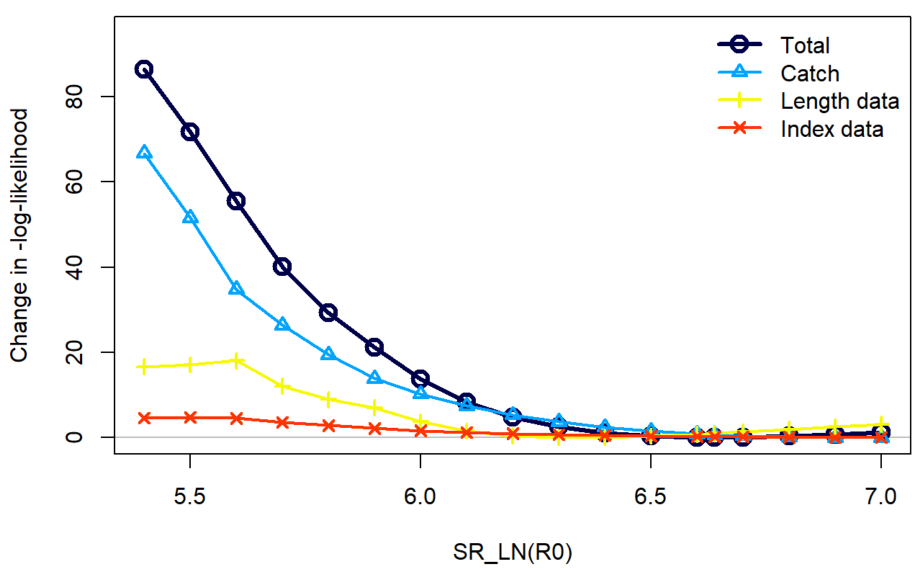


Figure 9-107 – Profiles of the change in negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter (R_0) in log-scale.

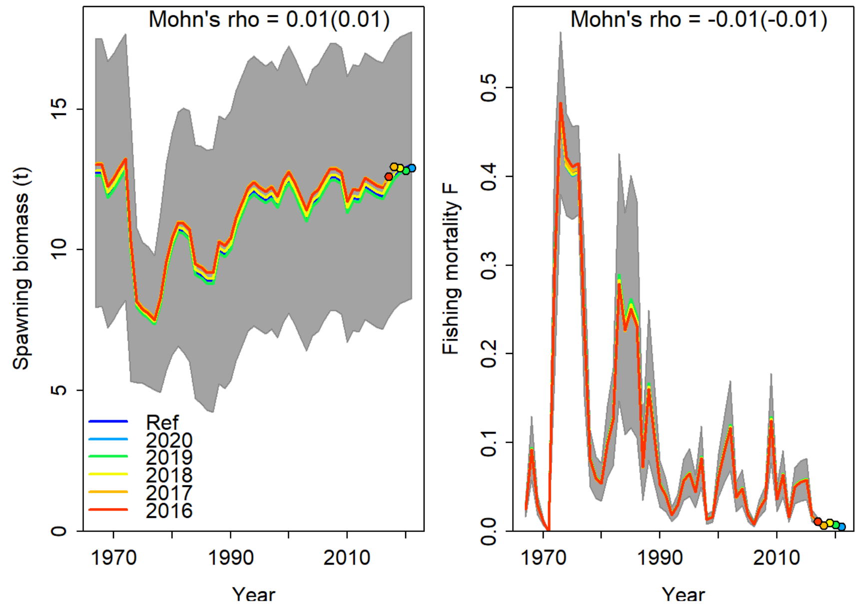


Figure 9-108 – Retrospective analysis of spawning biomass (left) and fishing mortality (right) consisting of 5 reruns of the base case model each fitted with one less year of data from the base case model (blue line).

Table 9-21 – Time series of spawning biomass (SSB, mt), age-0 recruitment (Rec., 1000s of recruits), and instantaneous fishing mortality (F, yr-1) estimated by the SS model. CV is the coefficient of variation.

Year	SSB	CV	Rec.	CV	F	CV	Year	SSB	CV	Rec.	CV	F	CV
1969	11.4	0.25	725.55	0.22	0.025	0.45	1996	11.3	0.25	724.71	0.22	0.043	0.62
1970	11.7	0.24	725.31	0.22	0.011	0.53	1997	11.3	0.24	723.92	0.22	0.080	0.29
1971	12.1	0.23	728.67	0.22	0.000	0.53	1998	11.1	0.25	721.43	0.22	0.012	0.44
1972	12.3	0.23	731.42	0.22	0.335	0.47	1999	11.6	0.24	723.83	0.22	0.019	0.56
1973	9.3	0.30	705.36	0.23	0.343	0.42	2000	11.9	0.24	726.20	0.22	0.062	0.33
1974	8.3	0.29	692.84	0.23	0.319	0.41	2001	11.6	0.24	724.26	0.22	0.089	0.37
1975	8.2	0.26	692.28	0.23	0.348	0.43	2002	10.9	0.25	719.54	0.22	0.113	0.27
1976	8.0	0.26	692.95	0.21	0.349	0.43	2003	10.7	0.26	716.38	0.22	0.040	0.35
1977	7.8	0.28	687.53	0.22	0.186	0.55	2004	11.1	0.25	726.35	0.22	0.043	0.55
1978	8.3	0.28	700.60	0.23	0.067	0.63	2005	11.4	0.24	724.19	0.23	0.014	0.55
1979	9.4	0.26	697.61	0.22	0.062	0.54	2006	11.8	0.24	725.96	0.22	0.007	0.54
1980	10.0	0.25	706.27	0.22	0.045	0.63	2007	12.0	0.23	727.48	0.22	0.022	0.45
1981	10.4	0.26	719.66	0.22	0.074	0.51	2008	12.1	0.23	731.48	0.22	0.035	0.54
1982	10.5	0.25	716.74	0.22	0.125	0.49	2009	11.9	0.23	729.10	0.22	0.123	0.28
1983	10.1	0.27	709.68	0.22	0.302	0.48	2010	10.9	0.25	720.26	0.22	0.037	0.29
1984	8.6	0.29	699.06	0.23	0.253	0.48	2011	11.3	0.24	724.13	0.22	0.055	0.68
1985	8.4	0.29	698.50	0.23	0.229	0.54	2012	11.2	0.25	725.04	0.22	0.013	0.60
1986	8.3	0.30	697.18	0.22	0.199	0.58	2013	11.7	0.24	735.67	0.23	0.052	0.47
1987	8.4	0.30	691.95	0.23	0.060	0.55	2014	11.5	0.25	726.36	0.22	0.048	0.47
1988	9.6	0.28	704.94	0.22	0.152	0.62	2015	11.5	0.25	718.56	0.22	0.056	0.31
1989	9.3	0.29	700.36	0.22	0.115	0.33	2016	11.4	0.24	722.61	0.22	0.018	0.31
1990	9.7	0.29	714.60	0.22	0.052	0.36	2017	11.9	0.24	729.10	0.22	0.011	0.28
1991	10.2	0.26	721.32	0.22	0.042	0.31	2018	12.1	0.24	726.33	0.22	0.007	0.29
1992	10.8	0.26	724.67	0.22	0.018	0.47	2019	12.2	0.22	725.35	0.22	0.010	0.32
1993	11.4	0.24	725.42	0.23	0.028	0.42	2020	12.4	0.22	732.36	0.22	0.008	0.31
1994	11.6	0.24	724.15	0.22	0.057	0.36	2021	12.5	0.23	726.29	0.22	0.004	0.56
1995	11.4	0.25	723.11	0.22	0.064	0.36							

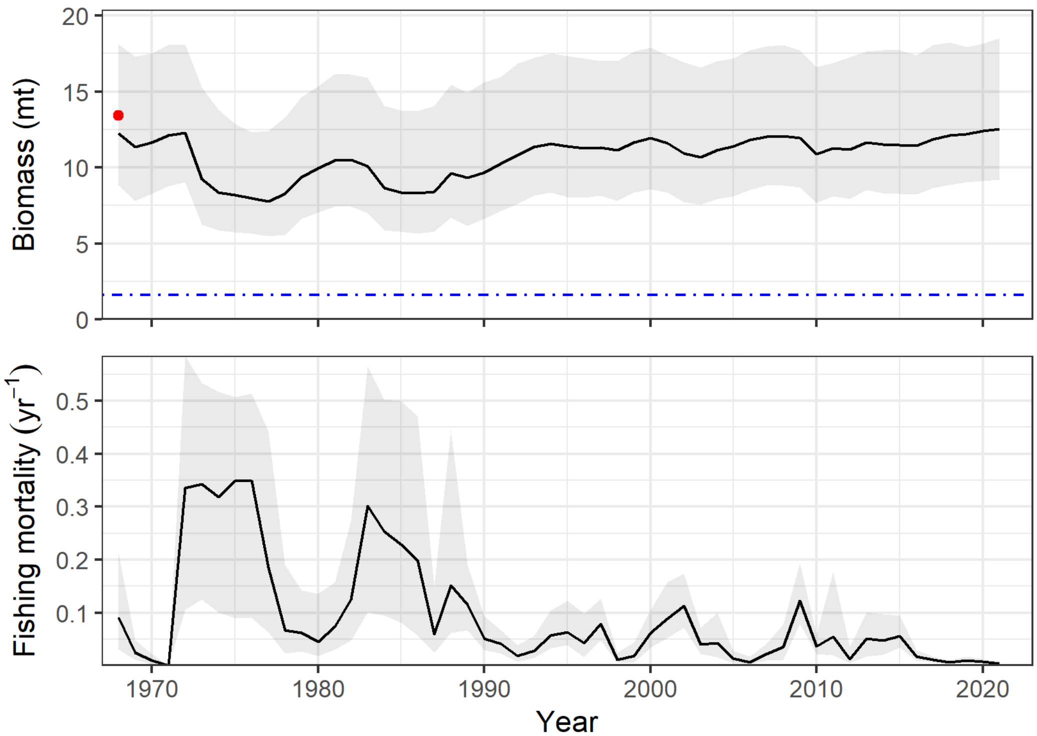


Figure 9-109 – Time series of spawning biomass (solid line) with its 95% confidence interval and SSB_0 estimate (red dot; top panel). The dot-and-dash blue line shows the spawning biomass at the MSST reference point (SSBMSST). Time series of fishing mortality rate with its 95% confidence intervals (bottom panel).

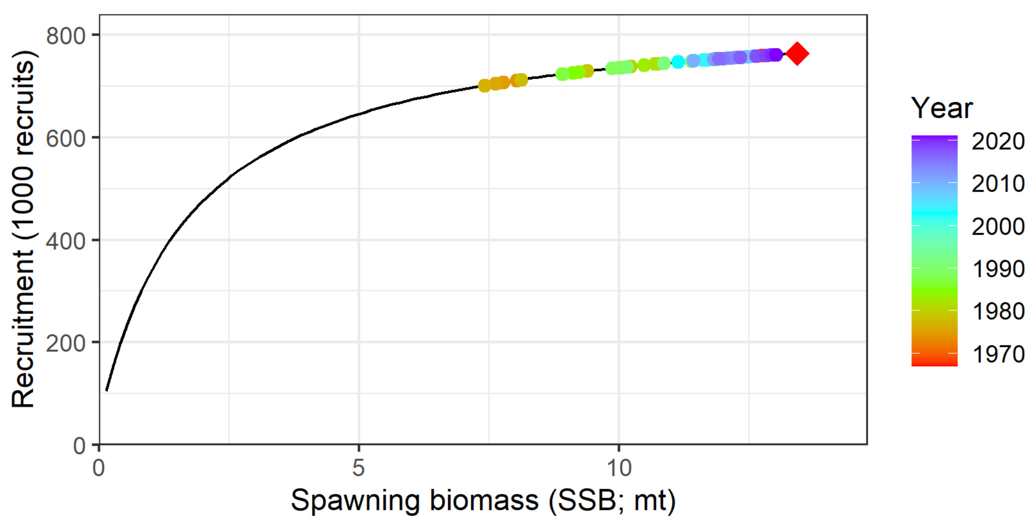


Figure 9-110 – Expected recruitment from the stock-recruitment relationship (black line) and estimated annual recruitment (dots) from SS. Estimated virgin SSB and recruitment is indicated with a red diamond.

Table 9-22 – Estimated biological reference points with 95% confidence interval (SD) derived from the SS base-case model where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield (2021 is the terminal year of the model).

Reference point	Value
F_{MSY} (yr-1)	1.2 (1.156 - 1.246)
F_{2021} (yr-1)	0.004 (0.002 - 0.009)
F_{2021}/F_{MSY}	0.003 (0.001 - 0.008)
SSB_{MSST} (mt)	1.64 (1.17 - 2.47)
SSB_{2021} (mt)	12.52 (9.23 - 18.51)
SSB_{2021}/SSB_{MSST}	7.62 (7.38 - 7.88)
MSY (mt)	8.26 (5.36 - 11.15)
$Catch_{2019-2021}$(mt)	0.26 (0.11 - 0.41)
SPR_{MSY}	0.34 (0.34 - 0.34)
SPR_{2021}	0.99 (0.99 - 0.99)

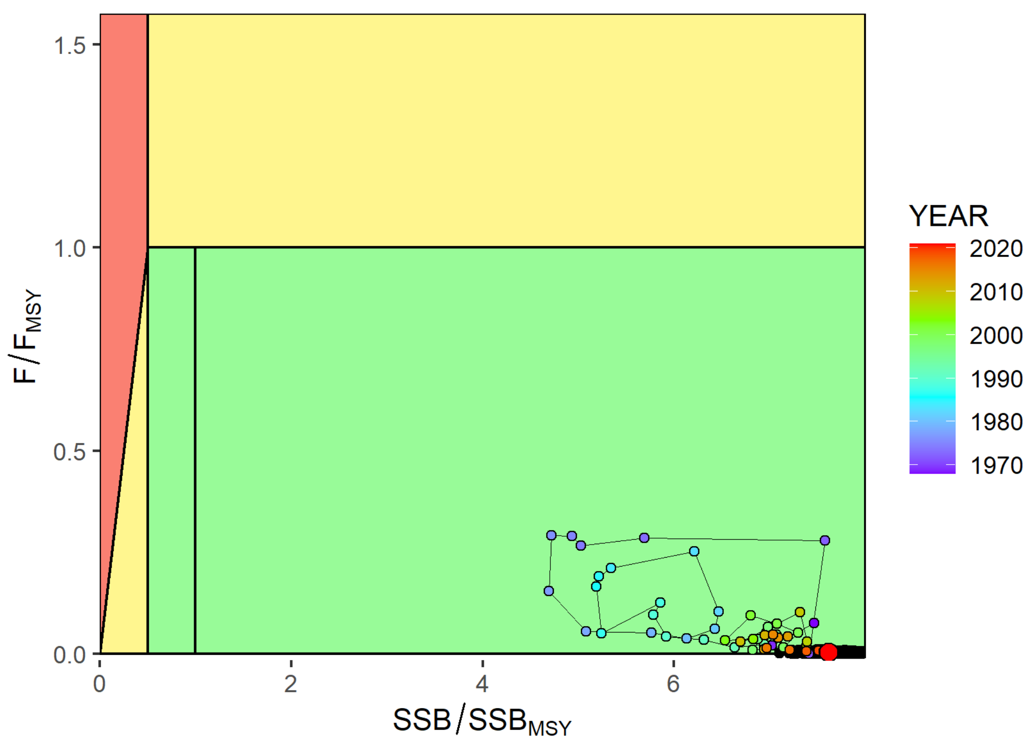


Figure 9-111 – Kobe plot representing the trend in relative fishing mortality and spawning stock biomass between 1969 and 2021 with their associated biological reference areas (red: overfished and overfishing, yellow: overfishing or overfished, green: no overfishing and not overfished). The large red dot indicates median stock status in 2021 and the black dots are one thousand Monte Carlo draws from the stock status distribution to represent the uncertainty around the final year status.

Table 9-23 – Summary table of key model output for all alternative model runs where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield.

Model	F_{2021}	F_{MSY}	F_{2021}/F_{MSY}	SSB_{MSY}	SSB_{MSST}	SSB_{2021}	SSB_{2021}/SSB_{MSY}	SSB_{2021}/SSB_{MSST}	Catch MSY
Base	0.005	1.2	0	3.4	1.7	13	3.8	7.6	8.3
M - 10%	0.006	1	0.01	3	1.5	11.2	3.7	7.5	6.3
M + 10%	0.004	1.44	0	3.8	1.9	15.1	4	7.9	10.8
Steep. - 10%	0.005	0.91	0.01	3.9	1.9	13.1	3.4	6.9	7.3
Steep. + 10%	0.005	1.62	0	2.9	1.5	13	4.5	8.7	9.2
Rec. dev.	0.006	1.2	0	3.3	1.7	10.1	3.1	5.9	8.1
No hist. catch	0.006	1.2	0	2.9	1.5	11	3.8	7.3	7
Alternate LH	0.003	2.58	0	8.7	4.4	33.5	3.9	7.6	20.8

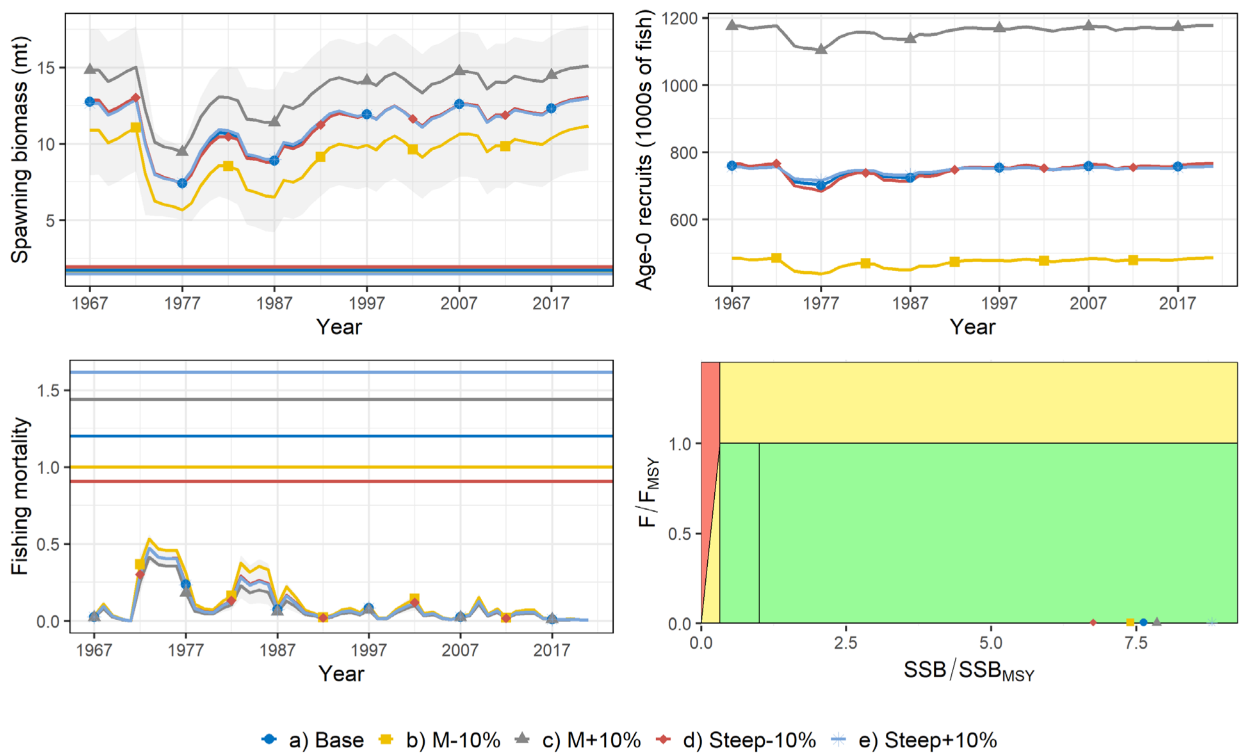


Figure 9-112 – Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) under moderate life-history parameter variation (plus and minus 10% of base parameter values).

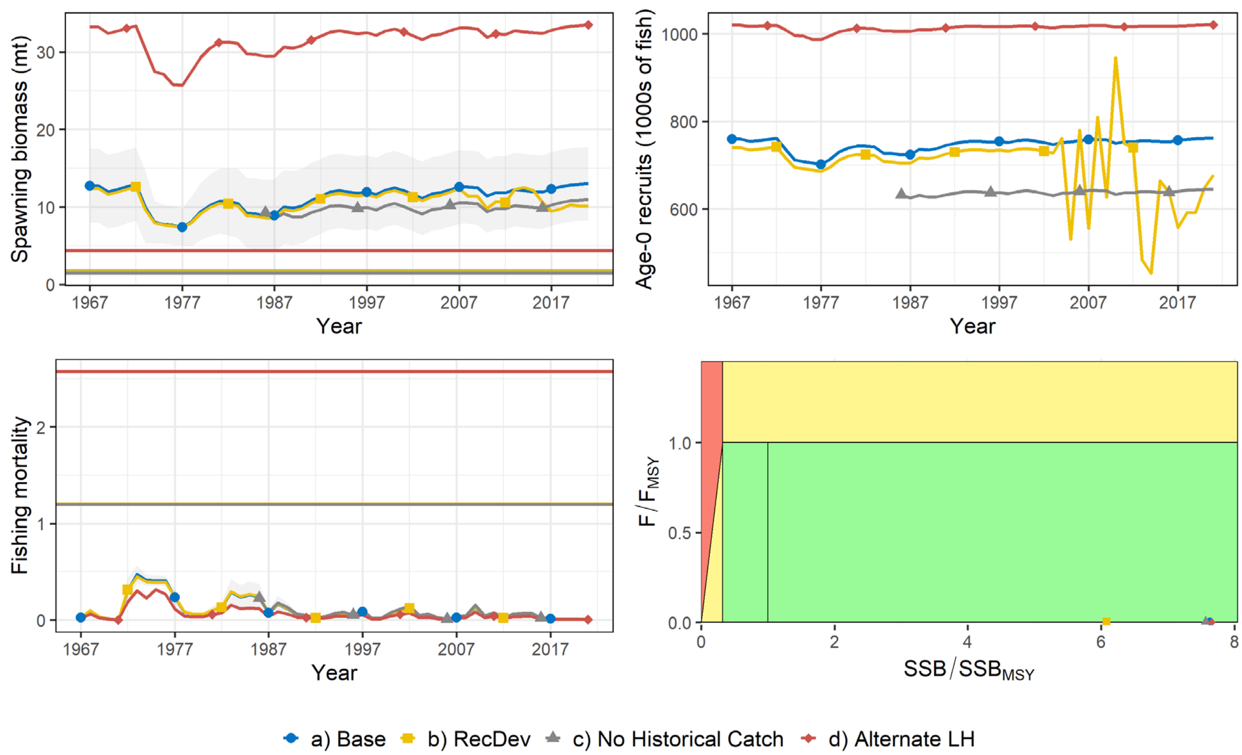


Figure 9-113 - Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) b) with recruitment deviations, c) without historical catch data (model starts in 1986), and d) with an alternate life history parameter source (growth curve from StepwiseLH).

Table 9-24 – Maximum Sustainable Yield (MSY) distribution from median value to 0.1 percentile.

Percentile	*MSY* (mt)
0.50	8.00
0.49	7.96
0.48	7.92
0.47	7.88
0.46	7.85
0.45	7.81
0.44	7.77
0.43	7.73
0.42	7.70
0.41	7.66
0.40	7.62
0.39	7.59
0.38	7.55
0.37	7.51
0.36	7.48
0.35	7.44
0.34	7.40
0.33	7.36
0.32	7.32
0.31	7.28
0.30	7.24
0.29	7.20
0.28	7.16
0.27	7.11
0.26	7.07
0.25	7.03
0.24	6.99
0.23	6.95
0.22	6.90
0.21	6.86
0.20	6.81
0.19	6.76
0.18	6.71
0.17	6.65
0.16	6.60
0.15	6.54
0.14	6.49
0.13	6.43
0.12	6.36
0.11	6.29
0.10	6.22

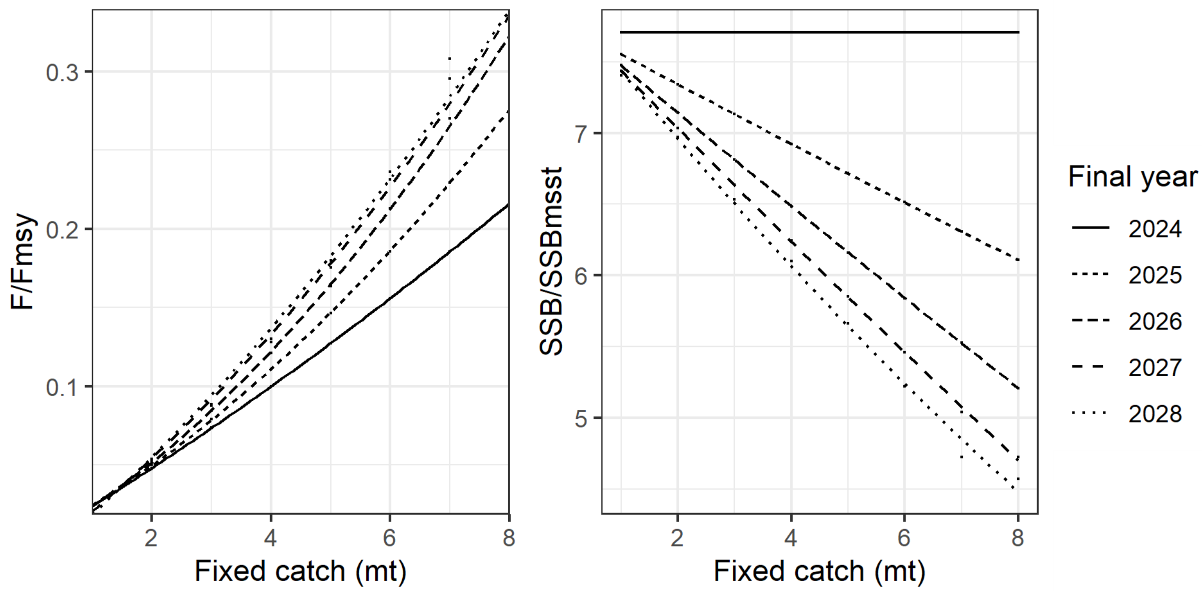


Figure 9-114 – Median stock status for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status is for the final projection year.

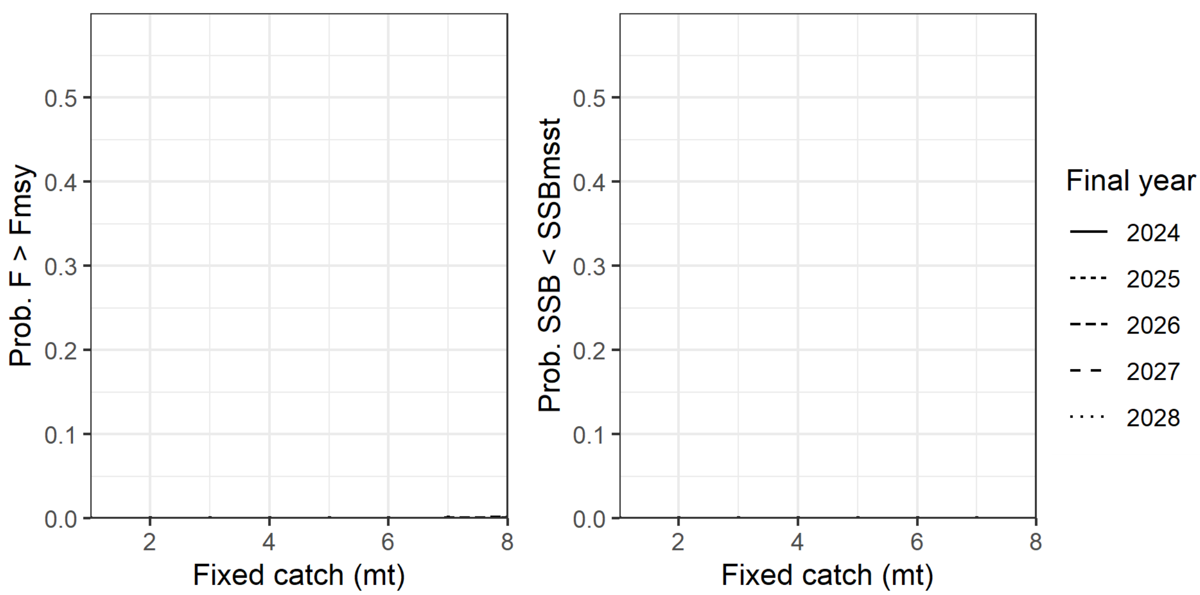
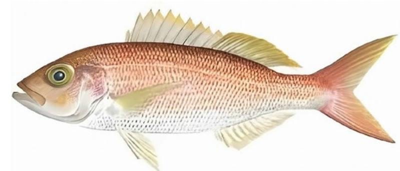


Figure 9-115– Probability of overfishing (left panel) and of stock being overfished (right panel) for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status probabilities are for the final projection year.

9.7 *Pristipomoides flavipinnis*



Palu-sina, *Golden eye jobfish*
Lutjanidae (snappers)

Key model parameters

Parameter	Value	Phase	Source
Natural mortality, M (yr^{-1})	0.19	-2	5.4/A_{max} (Hamel and Cope 2022)
Reference age, A_{min} (yr)	0	-2	-
Maximum age, A_{max} (yr)	28	-2	O'Malley (2019)
Length at A_{min}, L_{Amin} (cm)	1	-2	-
Length at A_{max}, L_{Amax} (cm)	41.2	-2	O'Malley (2019)
Growth rate, K (yr^{-1})	0.47	-2	-
CV of length < L_{Amin}	0.11	-2	-
CV of length > L_{Amin}	0.11	-2	-
Length-weight α	2.1e-5	-2	Kamikawa et al. (2015)
Length-weight β	2.95	-2	-
Length 50% maturity, L_{mat50} (cm)	27.2	-2	StepwiseLH. L_{99}: 47.6 cm (creel+biosampling)
Slope of maturity ogive	-0.98	-2	-
Spawner-recruit steepness (h)	0.75	-2	FishLife 2.0 (Thorson 2019)
Number of platoons	3	-	Fixed
Unfished recruitment (Log R_0)	1.03 (0.23)	1	Estimated
Initial fishing mortality	-	-	Set to zero
Catchability (Log Q)	-1.88 (0.42)	1	Estimated
Extra Q SD	-	1	Set to zero
Length at 50% selectivity (cm)	23.9 (1.4)	2	Estimated
Width to 95% selectivity (cm)	2.1 (2.5)	2	Estimated
Dirichlet parameter (Log theta)	0.97 (0.76)	2	Estimated (note: 1.182, 0.255 normal prior used)

General comments

Data: Catch data are available from 1967 to 2021, CPUE from 2016 to 2021, and size composition observations are available in sufficient numbers from 2011 to 2020 (Figure 9-116). The size data from 2011 to 2012 (combined n=117) and 2018 to 2020 (combined n=66) were combined into two super-periods.

Life history: This species was the only one for which we had an excellent local growth study (O'Malley et al. 2019). This study provided an L_{inf} of 41.2 cm and an A_{max} of 28 years (Figure 9-117). However, no maturity study was found for this species and the StepwiseLH was applied to the 47.6 cm L_{99} value (Figure 9-118). We tested an alternative L_{mat50} from a gray literature source (Brouard and Grandperrin 1985) as an alternate life history model. There is no evidence of sex-specific growth patterns for this species.

Fishery: The re-created historical catch (1967–1985) suggests that few *P. flavipinnis* were caught during the dory project years in the 1970s with a noticeable fishery for this species only starting with the ‘alia program in the early 1980s Figure 9-119). Catch in these early years was around 1 mt per year, while catch afterwards were generally lower (<0.2 mt), except for a few peaks here and there. We first ran a model with an equilibrium catch in the first year (1967) but this resulted in a very low initial F estimate, which suggests that this species was very lightly exploited pre-1967. This is reasonable given the history of the fishery, where deeper areas were hard to access for the local fishermen. We therefore started the model in an unfished state (initial F set to 0). The model estimated length at 50% selectivity at approximately 24 cm and full selectivity at approximately 26 cm (or age 3) with little difference in selectivity-at-age between platoons (Figure 9-120).

Model diagnostics: All estimated parameters converged within the set bounds with the final likelihood gradient of the model being less than 0.0001 and the associated Hessian matrix being positive definite. A jitter analysis of 100 model runs with different random initial starting values also supported that the model converged on a global minimum (Figure 9-121). Further, goodness-of-fit diagnostics indicated that the model fitted the CPUE index well with a successful Runs test but with a large RMSE of 0.4 (Figure 9-122). The mean length model fit passed the Runs test and had a RMSE of 0.04 (Figure 9-123). The yearly and overall size composition data was fitted relatively well, despite the low sample sizes (Figure 9-124 and Figure 9-125). The change in negative log-likelihoods at different fixed log(R_0) values indicated that this parameter's estimate was mainly driven by the length composition data with a clear minimum reached at 1.03 (~2,800 recruits; Figure 9-126). The results of the retrospective analysis, which progressively removed one year of data from 2021 to 2017, showed some pattern for *SSB* and *F* associated with removing 2018 data. This is likely related to anomalous size composition in 2018 (right skew; lower *F* and higher *SSB*) vs the earlier years. However, the Mohn's rho values were around -0.12 and 0.16 for both *SSB* and *F*, respectively (suggested limits are between -0.15 and 0.2; Figure 9-127).

Stock status: *P. flavipinnis* is a rare species with notably low pristine numbers. Population biomass declined from an SSB_0 around 4.4 mt prior to 1967 to about 1.4 mt in the late 1980s following the increased catch associated with the ‘alia program (Figure 9-128 and Table 9-25). Biomass has been increasing consistently since then, reaching values around 3 mt in recent years (the MSST was estimated at 1.0 mt; Figure 9-128). Recruitment stayed close to R_0, varying between 2,300 and 2,700 recruits per year (Figure 9-129). The current stock status (SSB/SSB_{MSST}) is equal to 3.3 (not overfished) with no overfishing occurring. The stock was near the overfished limit for a few years in the late 1980s before rebounding since then. Overfishing occurred for a few years in the 1980s with *F* values around 0.2 (Figure 9-130; Table 9-26) but *F* has been around 0.03 since then (F_{MSY} was estimated at 0.23). Equilibrium catches at F_{MSY} (i.e., the *MSY*) were estimated at 0.6 mt. Catches in recent years have been low, averaging only 0.07 mt (Table 9-26).

Alternate scenarios: We ran 7 alternative models: *M* and steepness plus and minus 10%, no historical catch, with recruitment deviations, and alternate LH source. The alternate specifications did not impact the model results significantly. The alternate LH source, which used Brouard (1985) for L_{mat} did not change the base model results (Table 9-27, Figure 9-131, and Figure 9-132). There was little impact of starting the model in 1986 or adding recruitment deviations. None of the alternative models resulted in overfishing or overfished status in 2021.

Projections: The projection analysis showed the distribution of outcomes in the probability of overfishing and overfished status that would occur in various final years (2024-2028) under various fixed-catch scenarios (Table 9-28; Figure 9-133, and Figure 9-134). The projections indicated some significant probability of overfished status occurring between in 2028 at the upper range of our tested fixed catch values (1.6 mt).

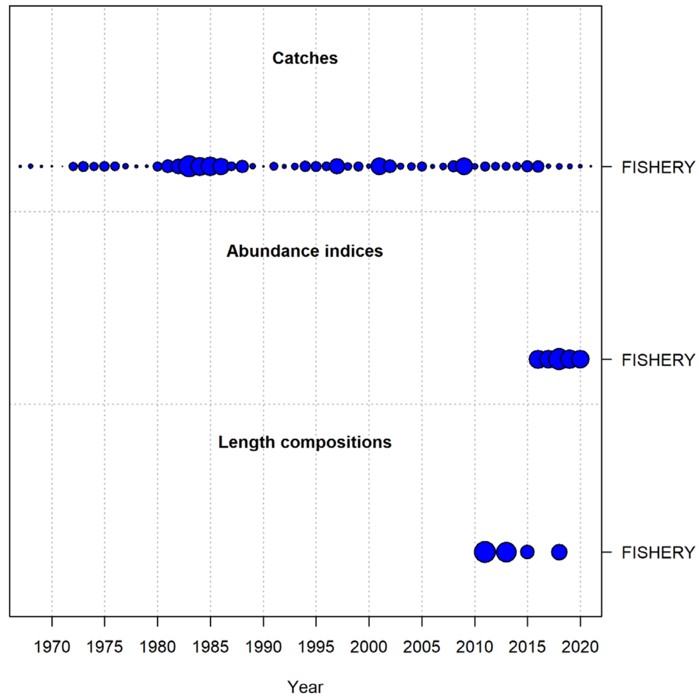


Figure 9-116- Summary of data types used in the SS model. Catches include boat-based and shore-based landings from creel surveys (1986-2021) as well as historical catches from reports (1967-1985). The abundance index is from boat-based creel survey ‘bottomfishing” gear type. Length compositions are from creel surveys (all years) and the biosampling program (2010-2015) filtered for the “bottomfishing” gear.

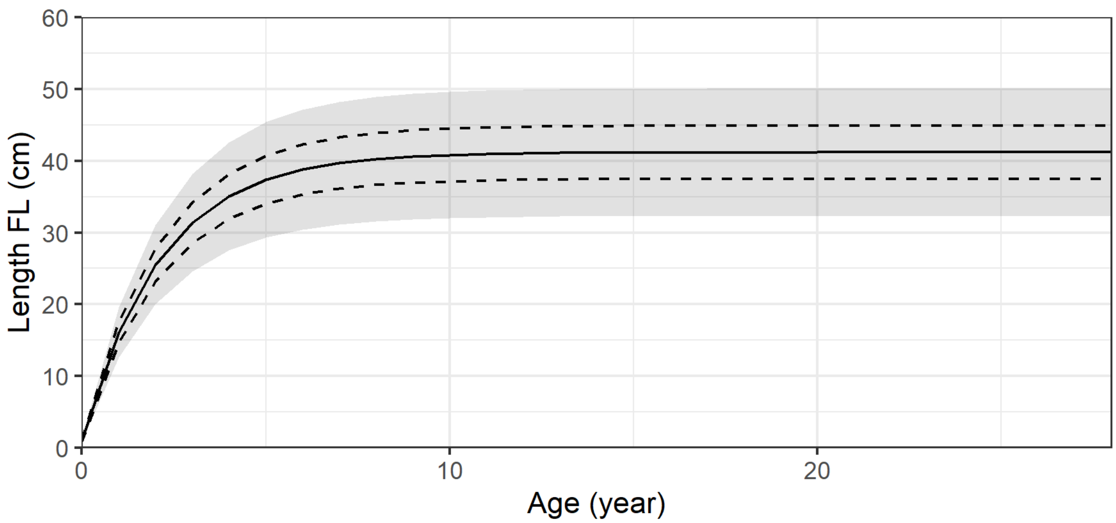


Figure 9-117 – Growth curve following a Von Bertalanffy model with 95% confidence intervals associated with the CV Linf parameter. The central growth platoon (solid line) and the two secondary ones (dashed lines) used in the model are also displayed.

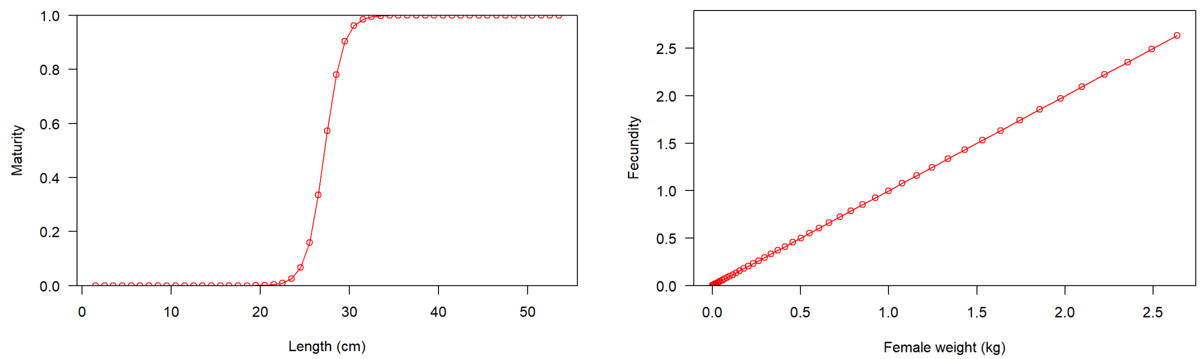


Figure 9-118 – Maturity-at-length (FL; left) and fecundity-at-weight (right) used in the stock assessment model.

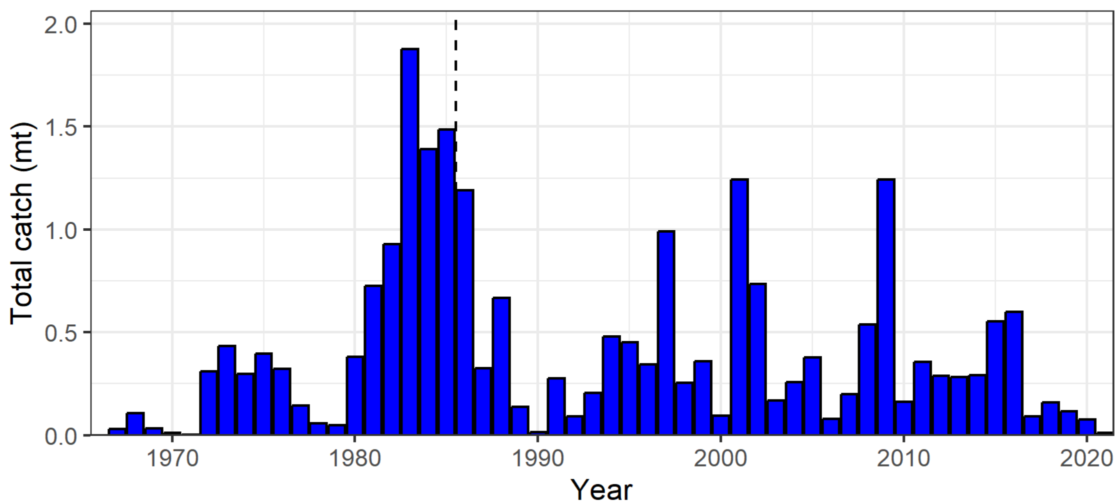


Figure 9-119 – Annual total catch in metric tons (mt). The vertical dashed line indicates the start of the creel survey program (1986) with older data coming from historical catch reports.

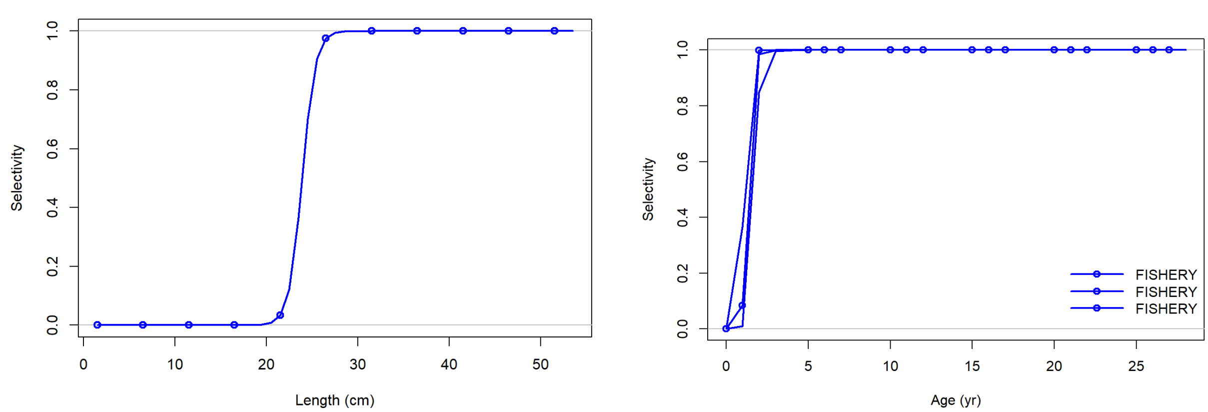


Figure 9-120 – Length-based selectivity estimated by the SS model (left) and the resulting selectivity-at-age for all 3 growth platoons (right).

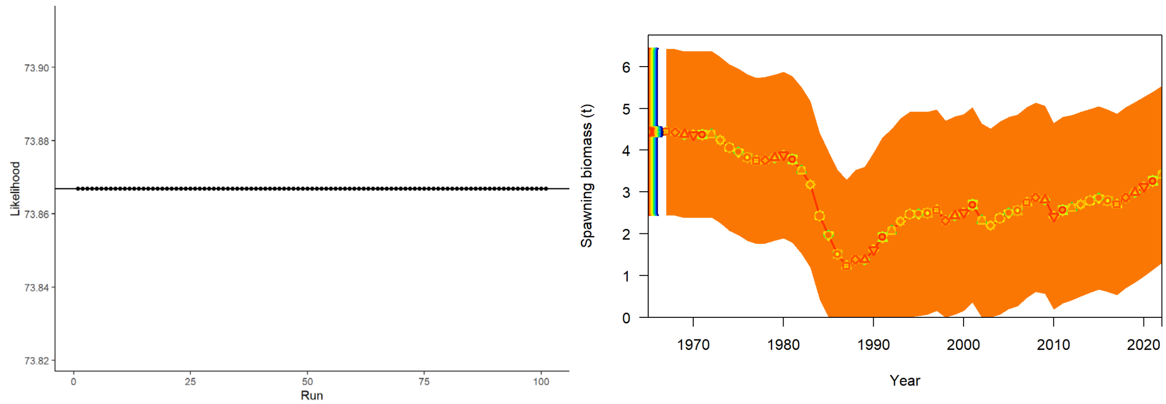


Figure 9-121 - Results of jitter analysis where 100 models were run with randomly varying initial parameter values. Left panel shows the variation in minimum model likelihood value for all 100 model runs. Right panel shows the variation in SSB time series for all 100 model runs.

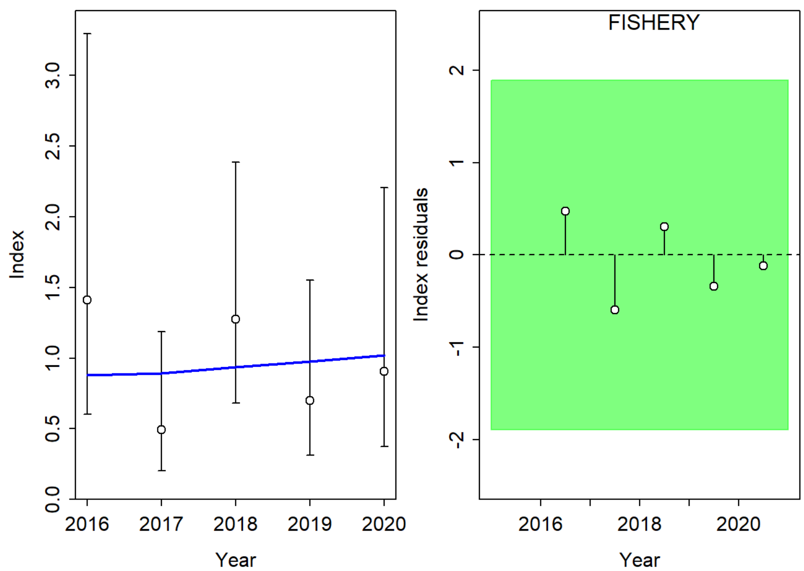


Figure 9-122 – Observed (open dots) vs expected (blue line) CPUE abundance index by year with standard deviations intervals (left). CPUE index residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.40.

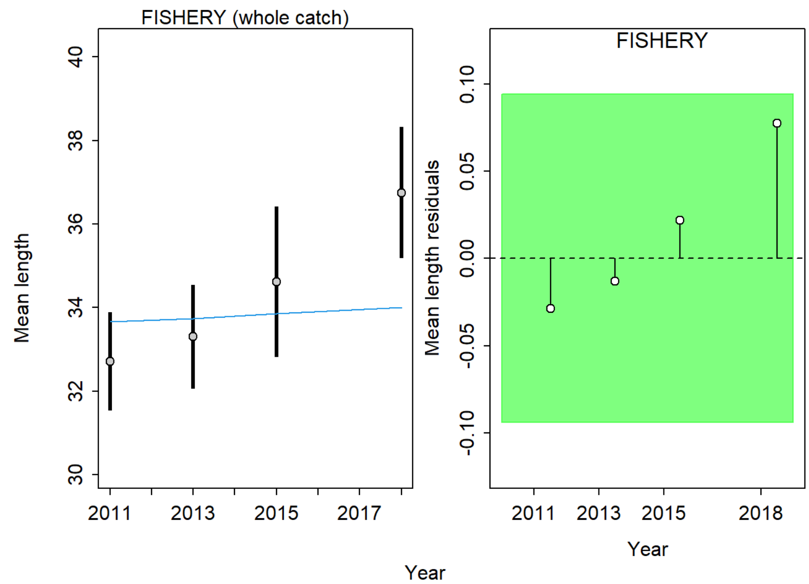


Figure 9-123 – Observed (open dots) vs expected (blue line) mean length by year with standard deviations intervals (left). Mean length residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.04.

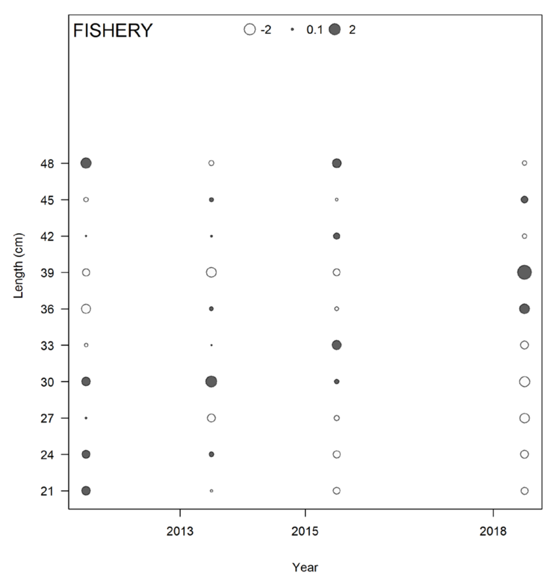


Figure 9-124 – Pearson residual plot of observed vs. expected size frequency data by size bin and year.

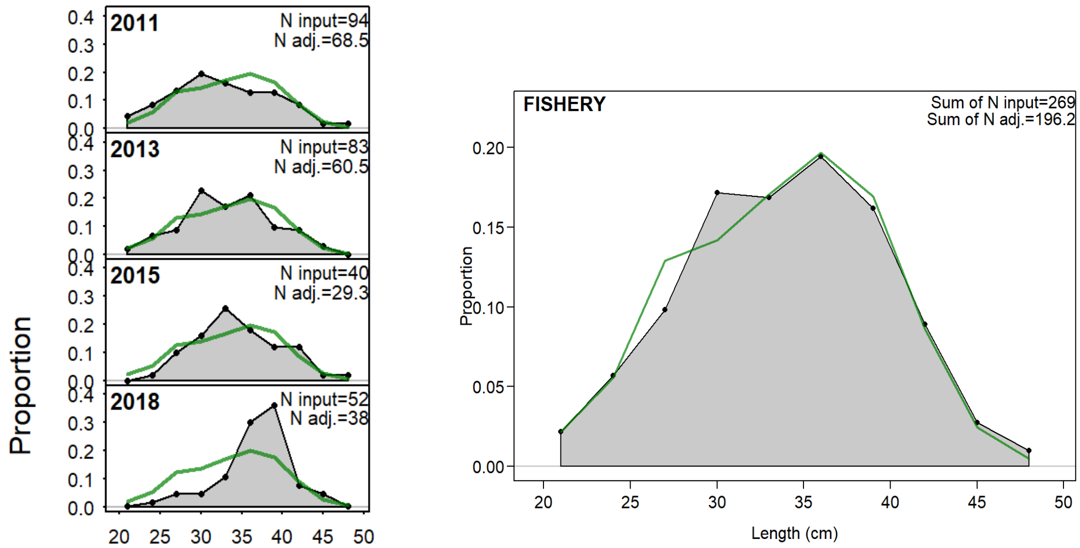


Figure 9-125 – Observed (gray area) vs. expected (green line) abundance-at-length from bottomfishing catch by year (left) and overall (right).

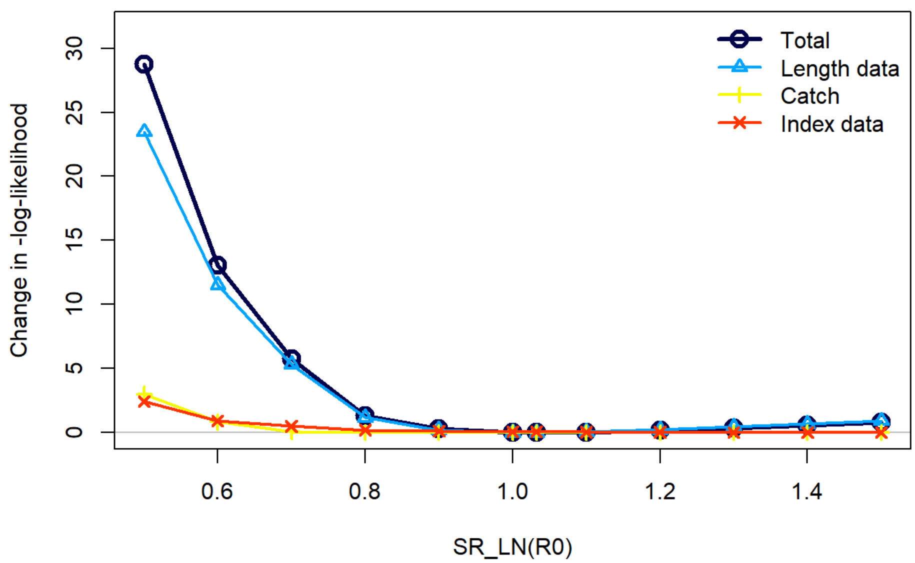


Figure 9-126 – Profiles of the change in negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter (R_0) in log-scale.

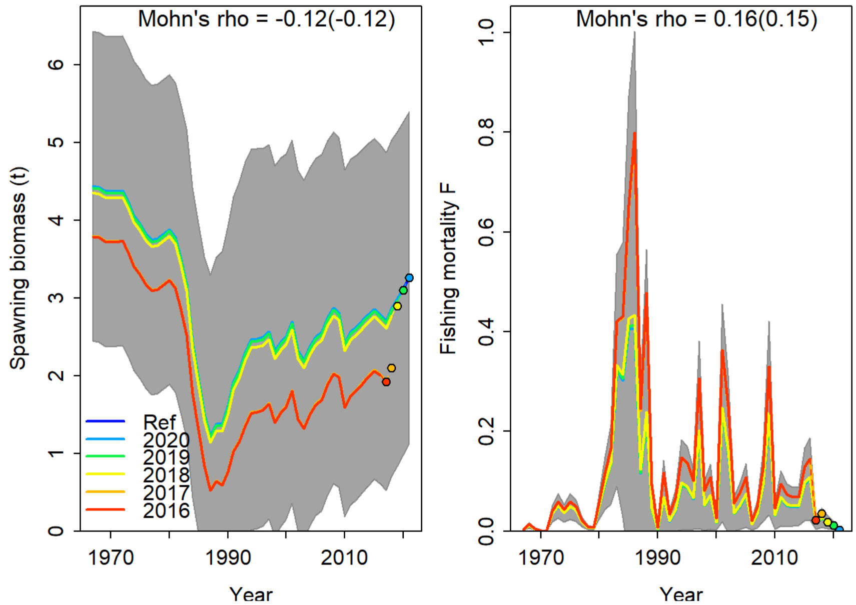


Figure 9-127 – Retrospective analysis of spawning biomass (left) and fishing mortality (right) consisting of 5 reruns of the base case model each fitted with one less year of data from the base case model (blue line).

Table 9-25 – Time series of spawning biomass (SSB, mt), age-0 recruitment (Rec., 1000s of recruits), and instantaneous fishing mortality (F, yr-1) estimated by the Stock Synthesis model. CV is the coefficient of variation.

Year	SSB	CV	Rec.	CV	F	CV	Year	SSB	CV	Rec.	CV	F	CV
1969	4.3	0.26	2.73	0.25	0.003	0.59	1996	2.4	0.54	2.57	0.30	0.052	0.80
1970	4.2	0.26	2.75	0.26	0.001	0.67	1997	2.5	0.52	2.59	0.29	0.153	0.88
1971	4.2	0.26	2.73	0.26	0.000	0.49	1998	2.1	0.57	2.54	0.30	0.036	1.18
1972	4.3	0.26	2.73	0.26	0.031	0.50	1999	2.3	0.54	2.55	0.30	0.061	0.82
1973	4.1	0.27	2.74	0.26	0.042	0.62	2000	2.3	0.54	2.55	0.30	0.015	0.61
1974	4.0	0.27	2.73	0.26	0.027	0.46	2001	2.5	0.50	2.58	0.29	0.195	0.77
1975	3.9	0.30	2.72	0.26	0.038	0.63	2002	2.1	0.58	2.52	0.30	0.117	0.74
1976	3.8	0.29	2.71	0.27	0.038	0.48	2003	1.9	0.60	2.50	0.30	0.024	0.95
1977	3.6	0.30	2.72	0.25	0.013	0.60	2004	2.2	0.55	2.53	0.29	0.040	0.74
1978	3.7	0.31	2.71	0.26	0.006	0.55	2005	2.3	0.51	2.59	0.28	0.065	0.75
1979	3.7	0.30	2.74	0.27	0.006	0.44	2006	2.3	0.48	2.57	0.30	0.012	0.81
1980	3.8	0.29	2.68	0.26	0.032	0.51	2007	2.6	0.48	2.59	0.28	0.025	0.83
1981	3.7	0.29	2.68	0.26	0.081	0.63	2008	2.6	0.45	2.61	0.28	0.085	0.66
1982	3.4	0.33	2.71	0.26	0.100	0.68	2009	2.5	0.46	2.61	0.28	0.201	0.50
1983	3.1	0.35	2.64	0.26	0.222	0.73	2010	2.2	0.50	2.55	0.29	0.026	0.64
1984	2.5	0.46	2.56	0.27	0.171	0.90	2011	2.3	0.48	2.57	0.28	0.048	0.69
1985	2.1	0.55	2.51	0.30	0.224	0.82	2012	2.4	0.45	2.58	0.28	0.036	0.65
1986	1.8	0.65	2.46	0.33	0.215	1.45	2013	2.5	0.44	2.61	0.27	0.034	0.72
1987	1.4	0.81	2.36	0.37	0.075	3.07	2014	2.6	0.42	2.65	0.28	0.042	0.64
1988	1.5	0.77	2.36	0.37	0.124	1.81	2015	2.7	0.42	2.63	0.27	0.069	0.65
1989	1.5	0.79	2.36	0.38	0.027	2.16	2016	2.7	0.42	2.59	0.27	0.094	0.52
1990	1.7	0.70	2.41	0.35	0.003	2.15	2017	2.6	0.42	2.60	0.27	0.014	0.61
1991	2.1	0.67	2.55	0.32	0.043	1.17	2018	2.8	0.41	2.63	0.27	0.024	0.46
1992	2.1	0.61	2.57	0.31	0.016	0.71	2019	2.9	0.40	2.63	0.27	0.015	0.56
1993	2.3	0.59	2.59	0.30	0.031	0.76	2020	3.0	0.37	2.63	0.28	0.009	0.67
1994	2.5	0.50	2.59	0.30	0.075	1.38	2021	3.2	0.34	2.67	0.26	0.001	0.51
1995	2.5	0.52	2.58	0.30	0.060	1.10							

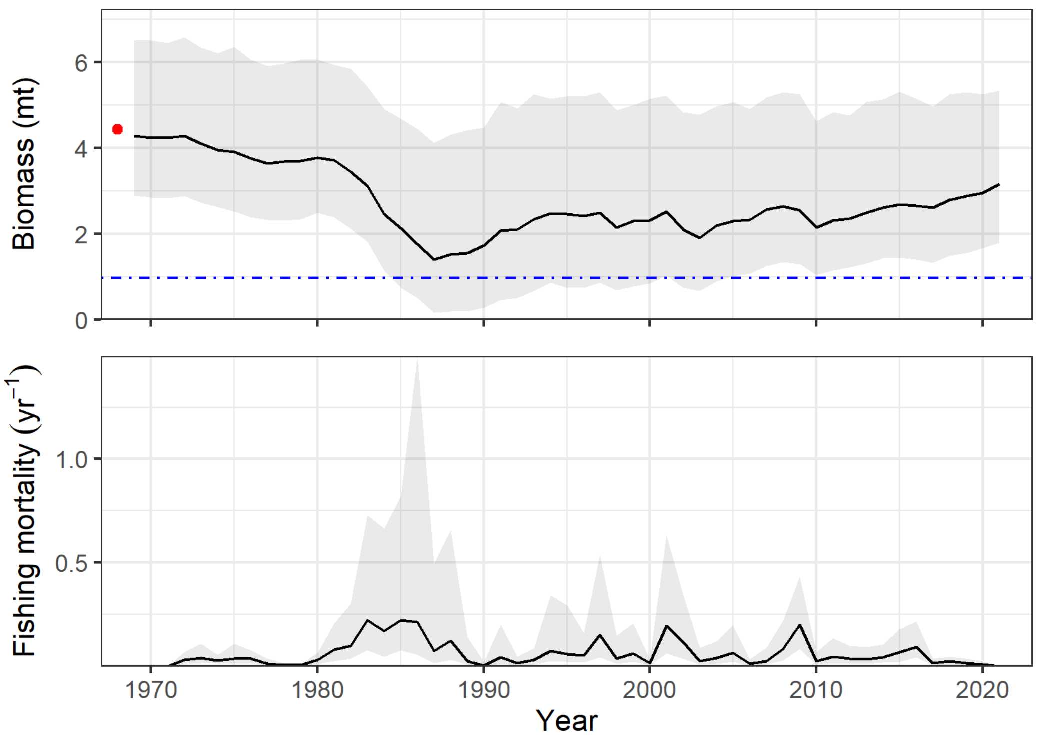


Figure 9-128 – Time series of spawning biomass (solid line) with its 95% confidence interval and SSB_0 estimate (red dot; top panel). The dot-and-dash blue line shows the spawning biomass at the MSST reference point (SSBMSST). Time series of fishing mortality rate with its 95% confidence intervals (bottom panel).

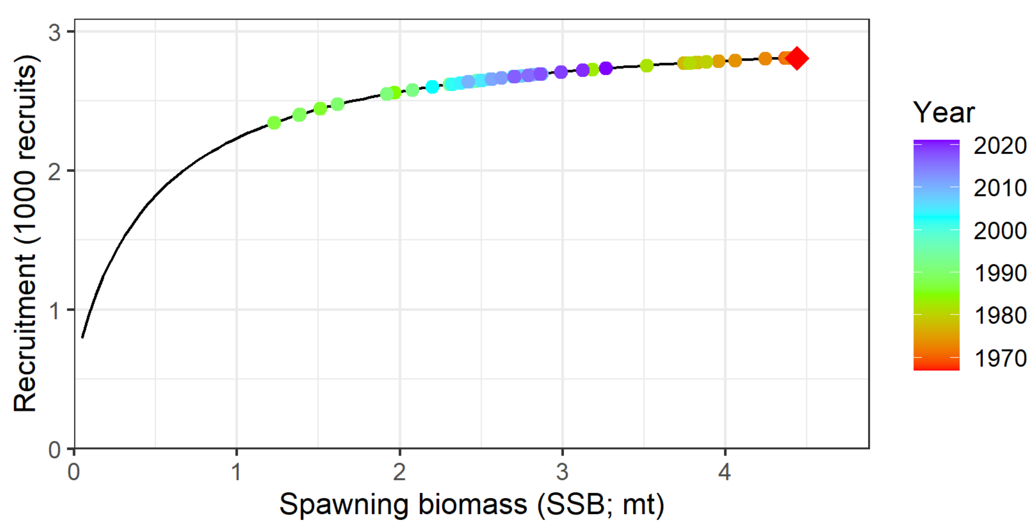


Figure 9-129 – Expected recruitment from the stock-recruitment relationship (black line) and estimated annual recruitment (dots) from SS. Estimated virgin SSB and recruitment is indicated with a red diamond.

Table 9-26 – Estimated biological reference points with 95% confidence interval (SD) derived from the SS base-case model where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield (2021 is the terminal year of the model).

Reference point	Value
F_{MSY} (yr$_{-1}$)	0.231 (0.208 - 0.257)
F_{2021} (yr$_{-1}$)	0.001 (0.001 - 0.003)
F_{2021}/F_{MSY}	0.006 (0.003 - 0.012)
SSB_{MSST} (mt)	0.96 (0.43 - 2.11)
SSB_{2021} (mt)	3.17 (1.8 - 5.35)
SSB_{2021}/SSB_{MSST}	3.28 (2.73 - 3.92)
MSY (mt)	0.62 (0.35 - 0.89)
Catch$_{2019\text{-}2021}$(mt)	0.07 (0.02 - 0.12)
SPR_{MSY}	0.34 (0.34 - 0.34)
SPR_{2021}	0.99 (0.98 - 1)

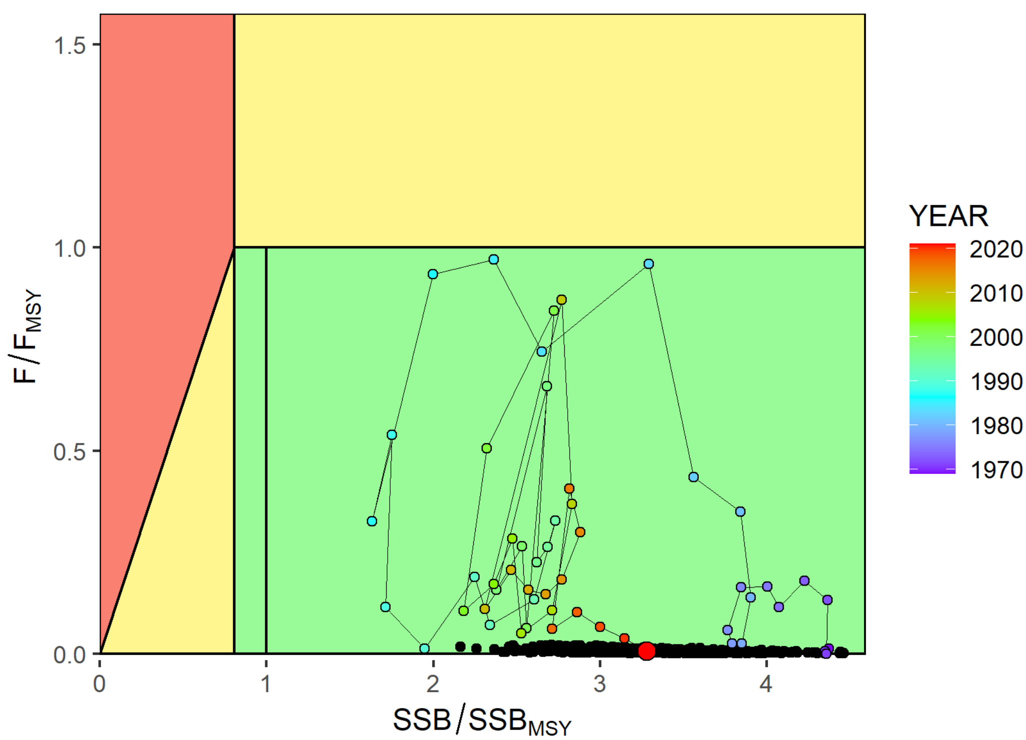


Figure 9-130 – Kobe plot representing the trend in relative fishing mortality and spawning stock biomass between 1969 and 2021 with their associated biological reference areas (red: overfished and overfishing, yellow: overfishing or overfished, green: no overfishing and not overfished). The large red dot indicates median stock status in 2021 and the black dots are one thousand Monte Carlo draws from the stock status distribution to represent the uncertainty around the final year status.

Table 9-27 – Summary table of key model output for all alternative model runs where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield.

Model	F_{2021}	F_{MSY}	F_{2021}/F_{MSY}	SSB_{MSY}	SSB_{MSST}	SSB_{2021}	SSB_{2021}/SSB_{MSY}	SSB_{2021}/SSB_{MSST}	Catch MSY
Base	0.002	0.23	0.01	1.2	1	3.3	2.8	3.3	0.6
M - 10%	0.002	0.21	0.01	1.2	1	2.7	2.3	2.7	0.5
M + 10%	0.001	0.25	0	1.4	1.1	4	2.9	3.6	0.8
Steep. - 10%	0.002	0.19	0.01	1.4	1.1	3.3	2.4	3	0.6
Steep. + 10%	0.002	0.27	0.01	1.1	0.9	3.2	2.9	3.6	0.7
Rec. dev.	0.002	0.23	0.01	1.2	0.9	2.5	2.1	2.8	0.6
No hist. catch	0.001	0.23	0	1.4	1.1	3.7	2.6	3.4	0.7
Alternate LH	0.002	0.2	0.01	1.1	0.8	2.8	2.5	3.5	0.6

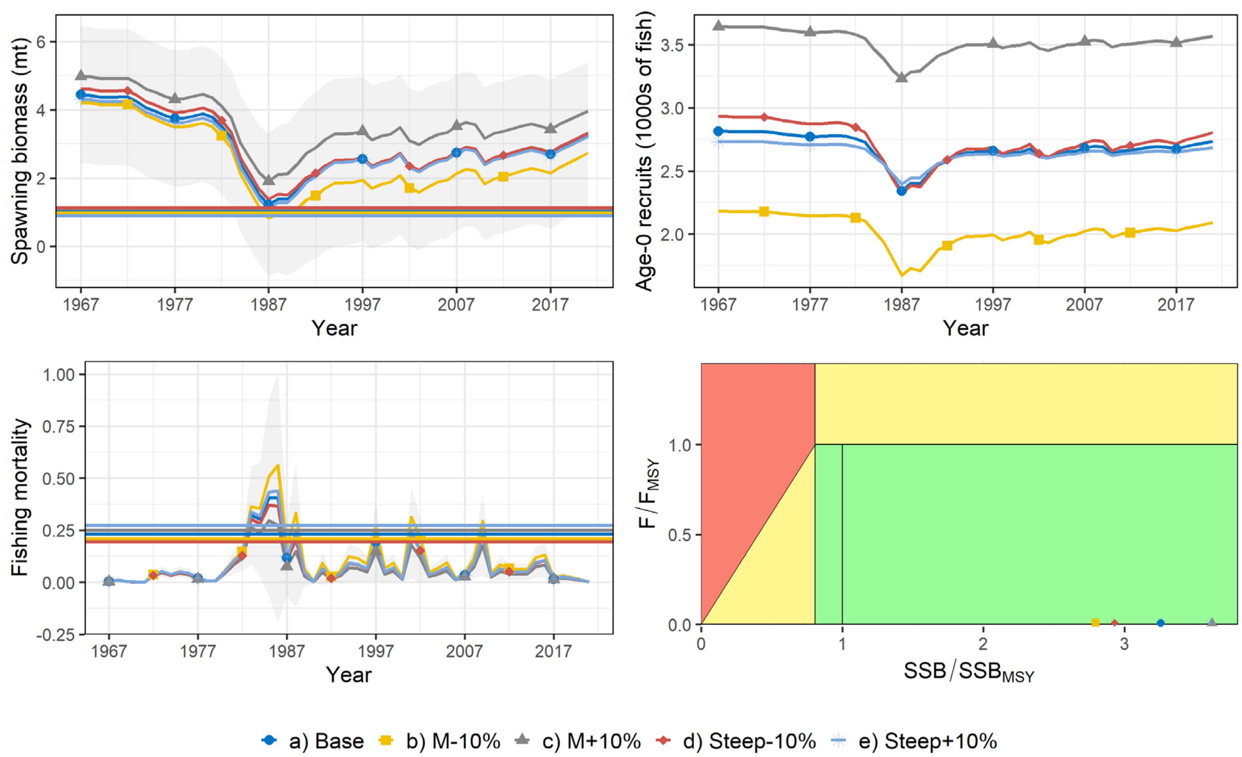


Figure 9-131 – Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) under moderate life-history parameter variation (plus and minus 10% of base parameter values).

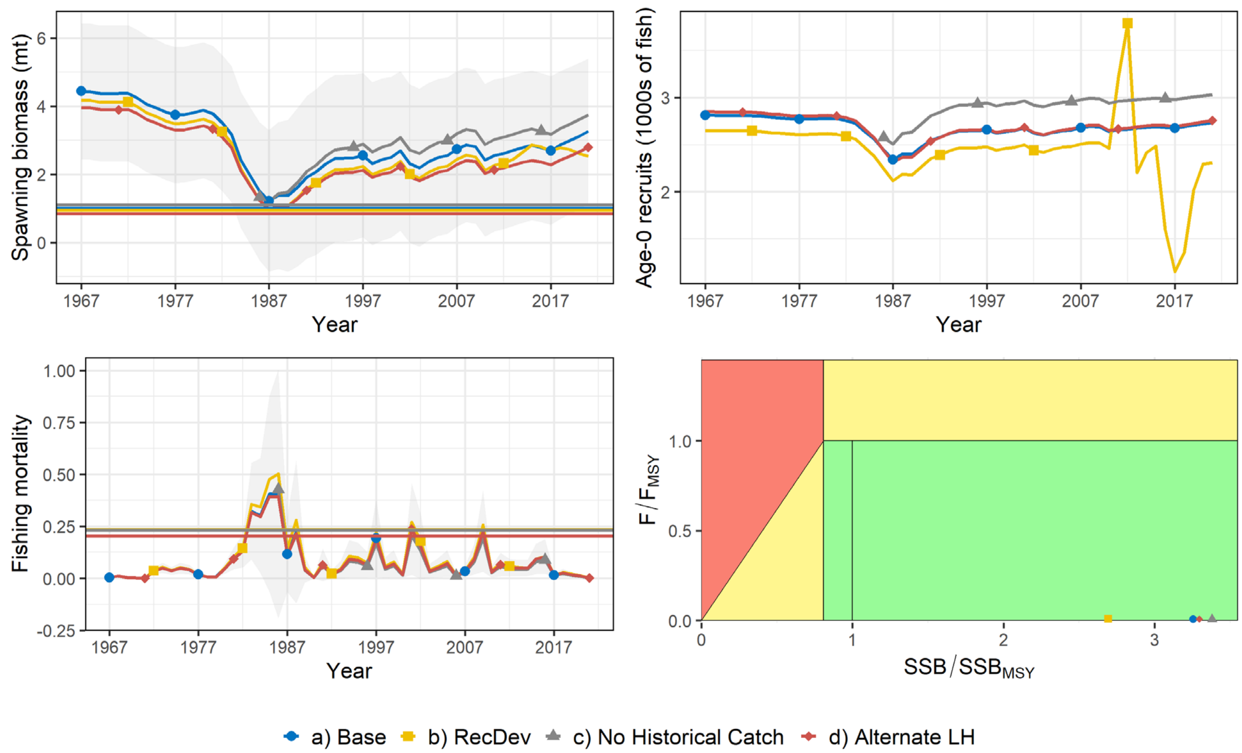


Figure 9-132 - Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) b) with recruitment deviations, c) without historical catch data (model starts in 1986), and d) with an alternate life history parameter source (L_{mat} from Brouard 1985).

Table 9-28 - The annual fixed catch values (metric tons) applied from 2024 to a final projection year resulting in a given probability of overfishing ($F/F_{MSY}>1$) in that final year. Catches for years prior to the start of the new catch guidance (2022 and 2023) were fixed at the mean of the last 3 years of catch data (2019 to 2021).

Probability of	Fixed catch (mt) from 2024 to:				
$F > F_{MSY}$	2024	2025	2026	2027	2028
0.50	1.67	1.43	1.29	1.19	1.12
0.49	1.66	1.42	1.28	1.18	1.11
0.48	1.65	1.41	1.27	1.17	1.10
0.47	1.63	1.40	1.27	1.17	1.09
0.46	1.62	1.39	1.26	1.16	1.08
0.45	1.61	1.38	1.25	1.15	1.07
0.44	1.60	1.37	1.24	1.14	1.07
0.43	1.59	1.36	1.23	1.14	1.06
0.42	1.58	1.35	1.22	1.13	1.05
0.41	1.57	1.34	1.21	1.12	1.04
0.40	1.56	1.33	1.21	1.11	1.03
0.39	1.55	1.32	1.20	1.10	1.03
0.38	1.53	1.31	1.19	1.10	1.02
0.37	1.52	1.30	1.18	1.09	1.01
0.36	1.51	1.29	1.17	1.08	1.00
0.35	1.50	1.28	1.16	1.07	1.00
0.34	1.49	1.27	1.15	1.06	0.99
0.33	1.48	1.26	1.14	1.06	0.98
0.32	1.46	1.25	1.13	1.05	0.97
0.31	1.45	1.24	1.12	1.04	0.97
0.30	1.44	1.23	1.11	1.03	0.96
0.29	1.43	1.22	1.10	1.02	0.95
0.28	1.41	1.21	1.09	1.02	0.95
0.27	1.40	1.21	1.08	1.01	0.94
0.26	1.39	1.20	1.07	1.00	0.93
0.25	1.37	1.19	1.06	0.99	0.93
0.24	1.36	1.18	1.05	0.98	0.92
0.23	1.35	1.17	1.04	0.97	0.91
0.22	1.33	1.16	1.03	0.97	0.91
0.21	1.32	1.15	1.02	0.96	0.90
0.20	1.31	1.14	1.01	0.95	0.89
0.19	1.29	1.13	1.00	0.94	0.89
0.18	1.28	1.12	0.99	0.93	0.88
0.17	1.27	1.11	0.98	0.92	0.88
0.16	1.25	1.10	0.97	0.91	0.87
0.15	1.24	1.09	0.96	0.91	0.86
0.14	1.22	1.08	0.95	0.90	0.86
0.13	1.21	1.07	0.94	0.89	0.85
0.12	1.19	1.06	0.92	0.88	0.85
0.11	1.18	1.06	0.91	0.87	0.84
0.10	1.16	1.05	0.90	0.86	0.84

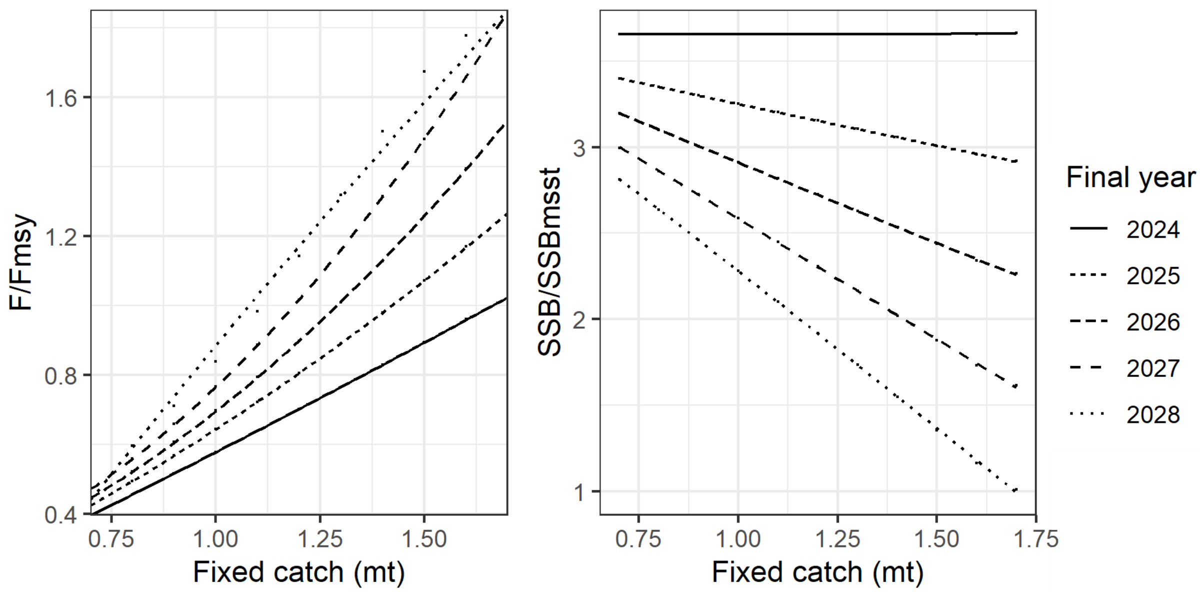


Figure 9-133 – Median stock status for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status is for the final projection year.

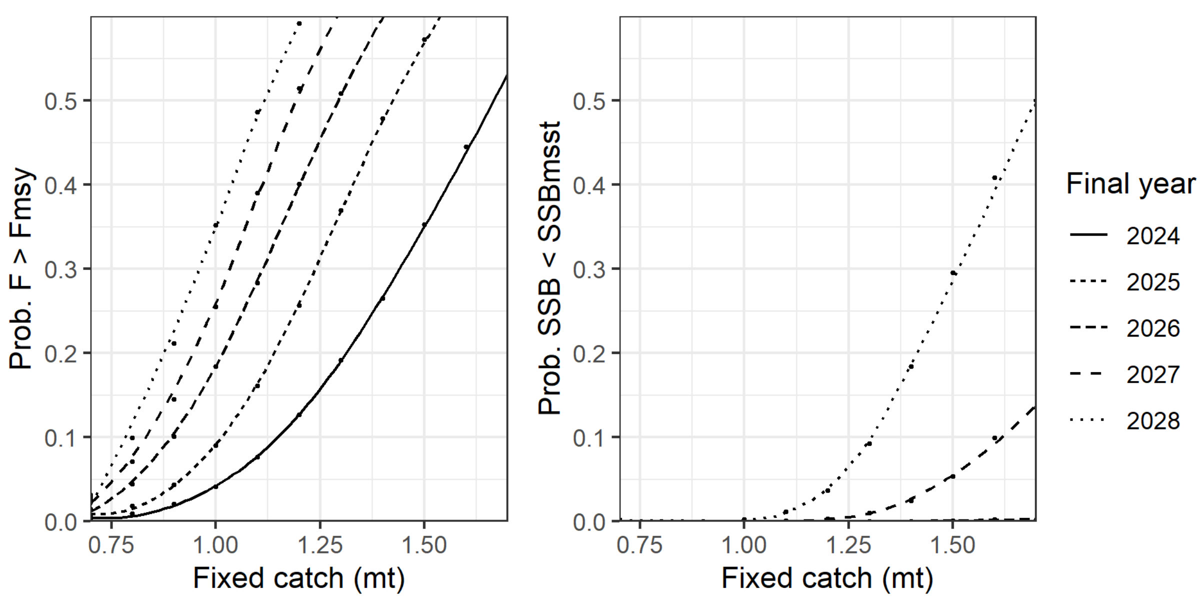


Figure 9-134– Probability of overfishing (left panel) and of stock being overfished (right panel) for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status probabilities are for the final projection year.

9.8 *Pristipomoides zonatus*

Palu-ula, *Oblique-banded snapper*
Lutjanidae (snappers)

Key model parameters

Parameter	Value	Phase	Source
Natural mortality, M (yr^{-1})	0.18	-2	5.4/A_{max} (Hamel and Cope 2022)
Reference age, A_{min} (yr)	0	-2	-
Maximum age, A_{max} (yr)	30	-2	Schemmel (2021)
Length at A_{min}, L_{Amin} (cm)	14.9 – 13.8	-2	Female - Male
Length at A_{max}, L_{Amax} (cm)	35.3 – 38.3	-2	Schemmel (2021), female - Male
Growth rate, K (yr^{-1})	0.27 – 0.29	-2	-
CV of length < L_{Amin}	0.08	-2	-
CV of length > L_{Amin}	0.08	-2	-
Length-weight α	1.80e-5	-2	Kamikawa et al. (2015)
Length-weight β	3.04	-2	-
Length 50% maturity, L_{mat50} (cm)	23.6	-2	Schemmel (2021)
Slope of maturity ogive	-0.87	-2	-
Spawner-recruit steepness (h)	0.73	-2	FishLife 2.0 (Thorson 2019)
Number of platoons	3	-	Fixed
Unfished recruitment (Log R_0)	0.83 (0.03)	1	Estimated
Initial fishing mortality	-	-	Set to zero
Catchability (Log Q)	-2.11 (0.17)	1	Estimated
Extra Q SD	-	1	Set to zero
Length at 50% selectivity (cm)	22.2 (0.65)	2	Estimated
Width to 95% selectivity (cm)	4.1 (0.9)	2	Estimated
Dirichlet parameter (Log theta)	1.60 (0.72)	2	Estimated (note: 1.182, 0.255 normal prior used)

General comments

Data: Catch data are available from 1967 to 2021, CPUE from 2016 to 2021, and size composition observations are available in sufficient numbers from 2016 to 2020 (Figure 9-135). The size data were aggregated into four super-periods: from 2009-2011 (combined n=46), 2012-2014 (combined n=77), 2015-2016 (combined n=79), and 2018-2020 (combined n=43).

Life history: We found two recent growth studies with large sample sizes: Schemmel et al. (2021) in Guam and Andrews and Scofield (2021) in Hawaii. The growth curves were relatively close (L_{inf} 36.9 cm vs 42.5 cm) but Schemmel (2021) provided sex-specific curves, which appears necessary for this species. We tested the Andrews (2021) curve as an alternate model run. Schemmel (2021) also provided length-at-maturity information. The resulting growth and maturity curves are presented in Figure 9-136 and Figure 9-137.

Fishery: The re-created historical catch (1967–1985) suggests that few *P. zonatus*, like other deep snappers, were caught during the dory project years in the 1970s with a noticeable fishery for this species only starting with the ‘alia program in the early 1980s (Figure 9-138). Catches during the ‘alia program were high at about 1 to 1.5 mt before decreasing to less than 0.5 mt since then. We first ran a model with an equilibrium catch in the first year (1967), but this resulted in a very low initial F estimate, which suggests that this species was very lightly exploited pre-1967. Therefore, we started the model in an unfished state (initial F set to 0). The model estimated length at 50% selectivity at approximately 22 cm and full selectivity at approximately 26 cm (or age 4) with little differences in selectivity-at-age between platoons (Figure 9-139).

Model diagnostics: All estimated parameters converged within the set bounds with the final likelihood gradient of the model being less than 0.0001 and the associated Hessian matrix being positive definite. A jitter analysis of 100 model runs with different random initial starting values also supported that the model converged on a global minimum (Figure 9-140). Further, goodness-of-fit diagnostics indicated that the model fitted the CPUE index moderately well with a successful Runs test but with a large RMSE of 0.7 (Figure 9-141). The large RMSE was due to the CPUE index ignoring a decline followed by an increase in observed CPUE between 2016 and 2020. The mean length model fit passed the Runs test and had a RMSE of 0.04 (Figure 9-142). The yearly and overall size composition data was fitted relatively well with no clear residual pattern (Figure 9-143 and Figure 9-144). The change in negative log-likelihoods at different fixed log(R_0) values indicated that this parameter's estimate was mainly driven by the length composition data with a clear minimum reached at 0.8 (~2,300 recruits; Figure 9-145). The results of the retrospective analysis, which progressively removed one year of data from 2021 to 2017, showed no significant pattern for SSB or F with Mohn's rho values around 0 for both (suggested limits are between -0.15 and 0.2; Figure 9-146).

Stock status: Population biomass declined from an SSB_0 around 2.8 mt prior to 1967 to a very low SSB close to 0.1 mt in the late 1980s, following the increased catch associated with the ‘alia program (Figure 9-147 and Table 9-29). Biomass has been increasing consistently since then, reaching values around 2 mt in recent years (the MSST was estimated at 0.6 mt; Figure 9-147). Recruitment declined dramatically in the 1980s following these large declines in biomass, from 2,200 recruits to less than 1,000, before rebounding with the *SSB* (Figure 9-148). The current stock status (SSB/SSB_{MSST}) is equal to 3.3 (not overfished) with no overfishing occurring. The stock was overfished in the late 1980s all the way to the early 2000s, but has since recovered. Overfishing occurred starting in 1983 until 1998 (Figure 9-149; Table 9-30) with fishing mortality hitting maximum values in the 80s, before staying mostly below 0.05 after 2001 (F_{MSY} was estimated at 0.19). Equilibrium catches at F_{MSY} (i.e., the *MSY*) were estimated at 0.4 mt. Catches in recent years have been low, averaging only 0.04 mt (Table 9-30).

Alternate scenarios: We ran 7 alternative models: *M* and steepness plus and minus 10%, no historical catch, with recruitment deviations, and alternate LH source. The alternate specification with the largest impact was using the StepwiseLH as a growth parameter source (Table 9-31, Figure 9-150, and Figure 9-151). The lower L_{inf} parameter resulted in lower *F*s values and higher SSB. There was little impact of starting the model in 1986 or adding recruitment deviations. None of the alternative models resulted in overfishing or overfished status in 2021.

Projections: The projection analysis showed the distribution of outcomes in the probability of overfishing and overfished status that would occur in various final years (2024-2028) under various fixed-catch scenarios (Table 9-32; Figure 9-152, and Figure 9-153). The projections indicated low probability of overfished status occurring between 2024 and 2028 for the range of fixed catch explored (< 1 mt per year).

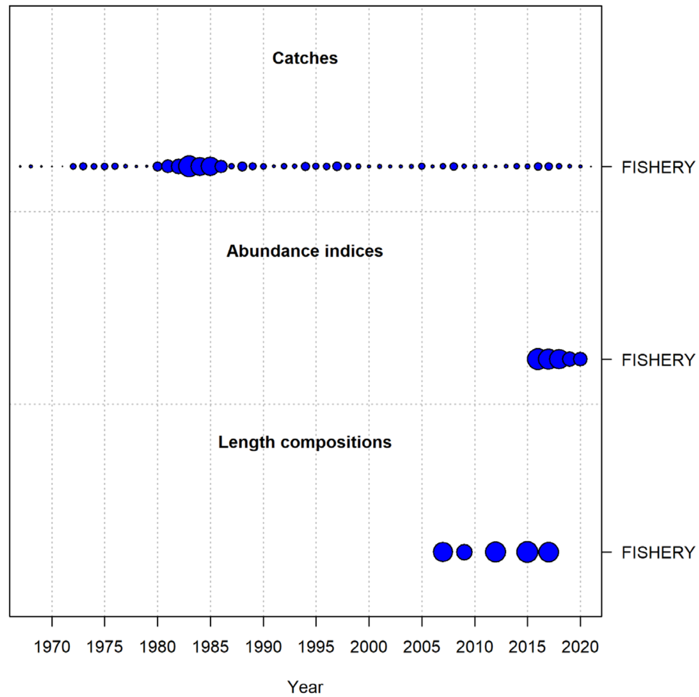


Figure 9-135- Summary of data types used in the SS model. Catches include boat-based and shore-based landings from creel surveys (1986-2021) as well as historical catches from reports (1967-1985). The abundance index is from boat-based creel survey 'bottomfishing" gear type. Length compositions are from creel surveys (all years) and the biosampling program (2010-2015) filtered for the "bottomfishing" gear.

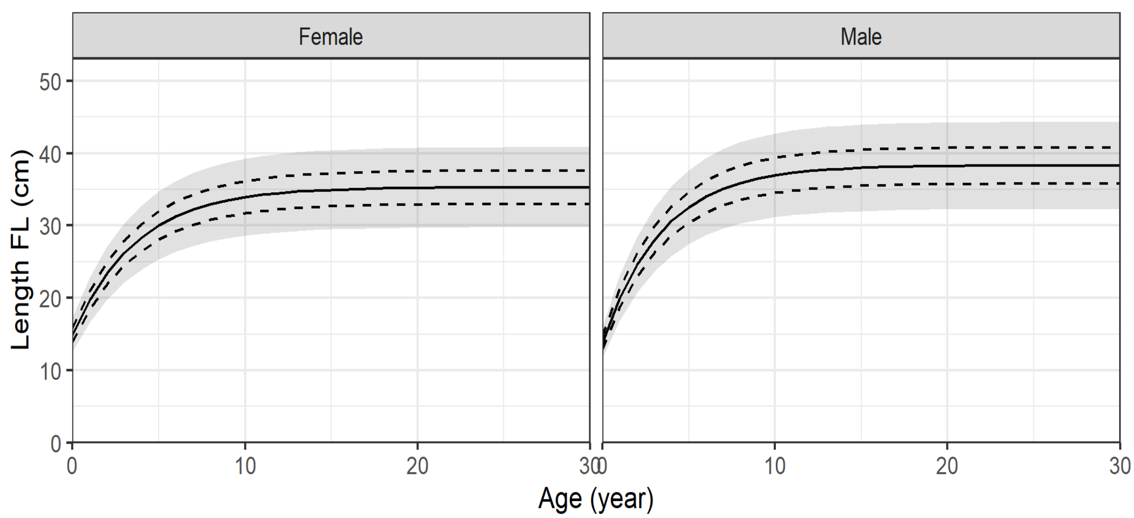


Figure 9-136 – Growth curve following a Von Bertalanffy model with 95% confidence intervals associated with the CV Linf parameter. The central growth platoon (solid line) and the two secondary ones (dashed lines) used in the model are also displayed.

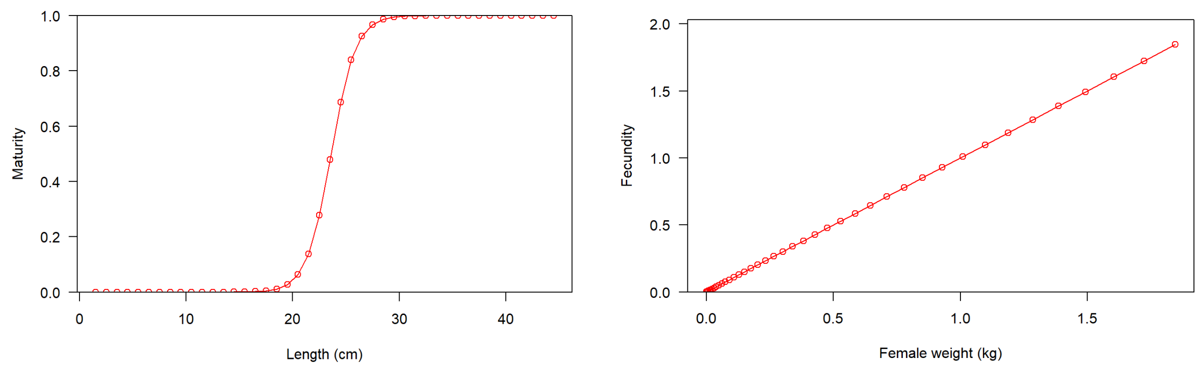


Figure 9-137 – Maturity-at-length (FL; left) and fecundity-at-weight (right) used in the stock assessment model.

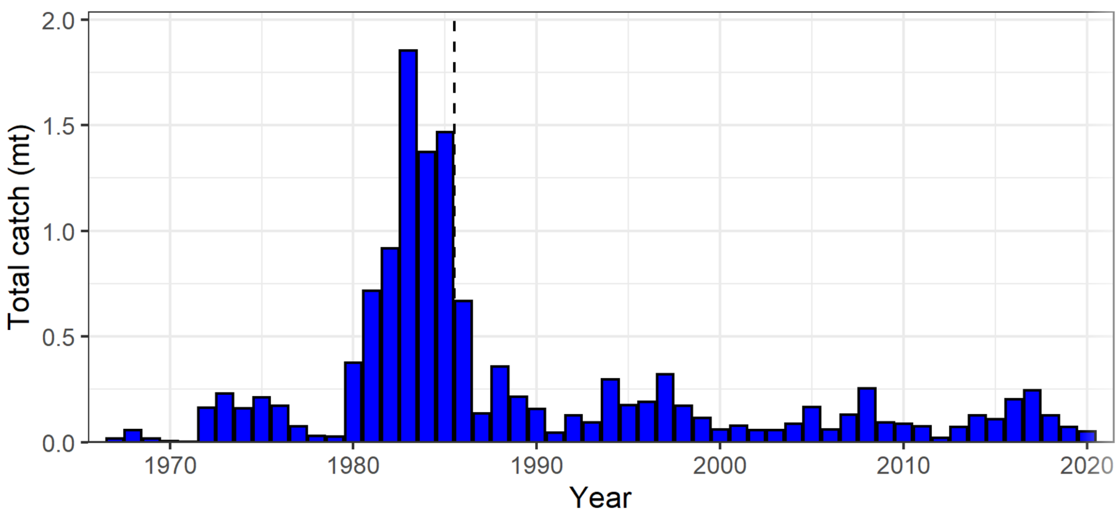


Figure 9-138 – Annual total catch in metric tons (mt). The vertical dashed line indicates the start of the creel survey program (1986) with older data coming from historical catch reports.

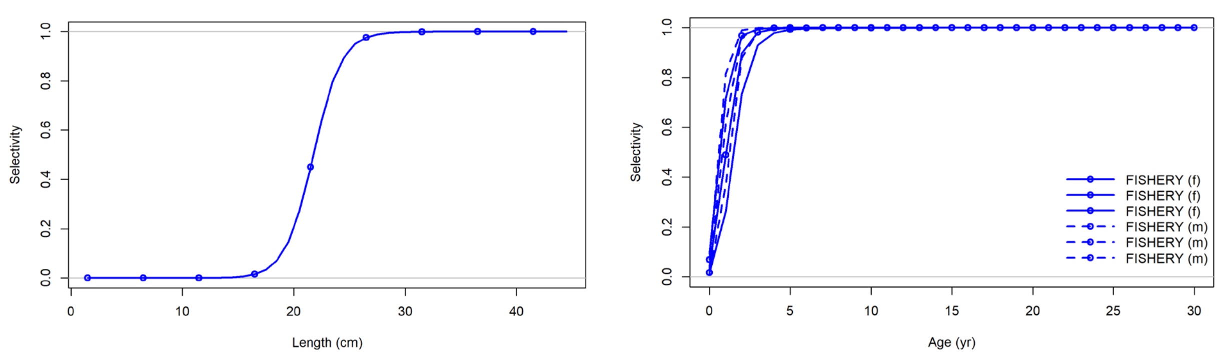


Figure 9-139 – Length-based selectivity estimated by the SS model (left) and the resulting selectivity-at-age for all 3 growth platoons (right).

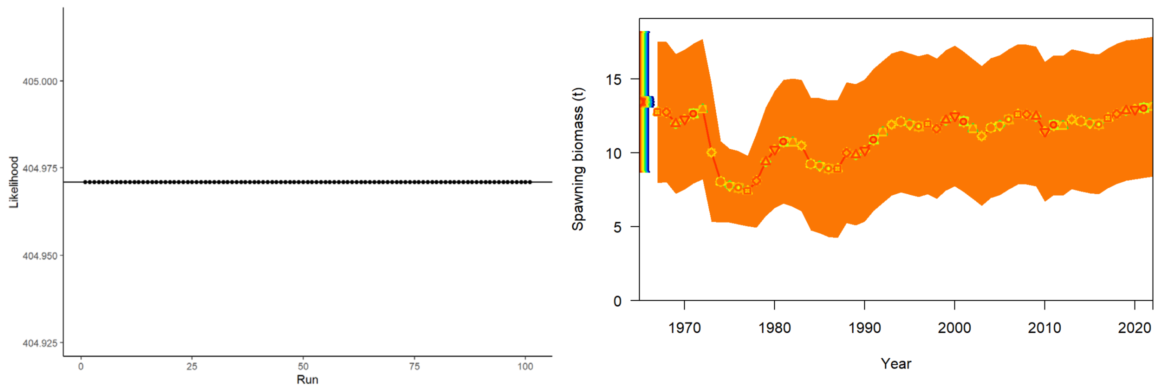


Figure 9-140 - Results of jitter analysis where 100 models were run with randomly varying initial parameter values. Left panel shows the variation in minimum model likelihood value for all 100 model runs. Right panel shows the variation in SSB time series for all 100 model runs.

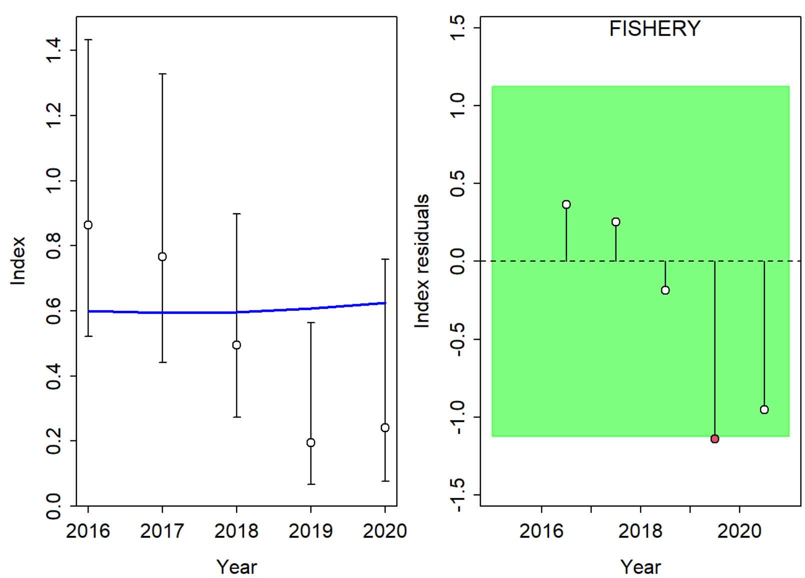


Figure 9-141 – Observed (open dots) vs expected (blue line) CPUE abundance index by year with standard deviations intervals (left). CPUE index residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.7.

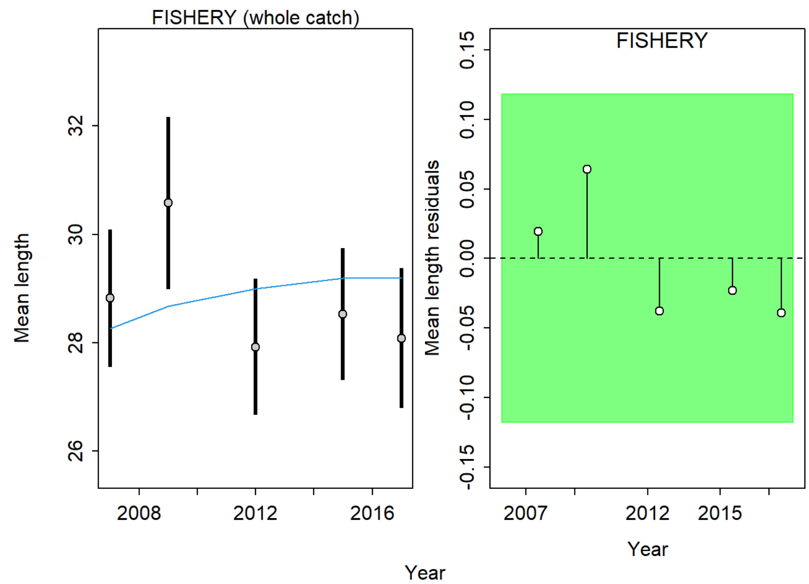


Figure 9-142 – Observed (open dots) vs expected (blue line) mean length by year with standard deviations intervals (left). Mean length residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.04.

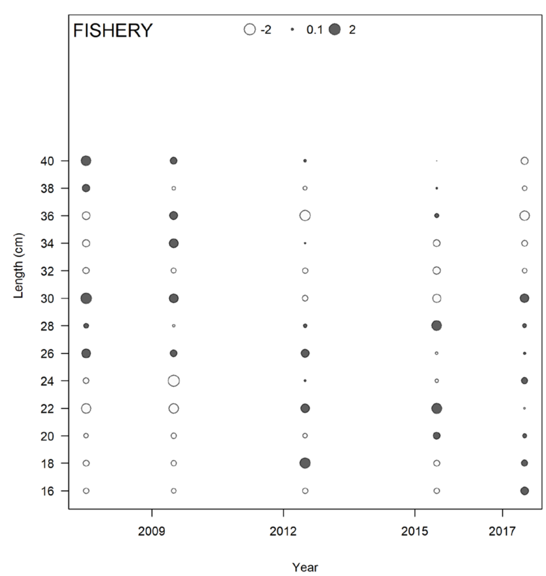


Figure 9-143 – Pearson residual plot of observed vs. expected size frequency data by size bin and year.

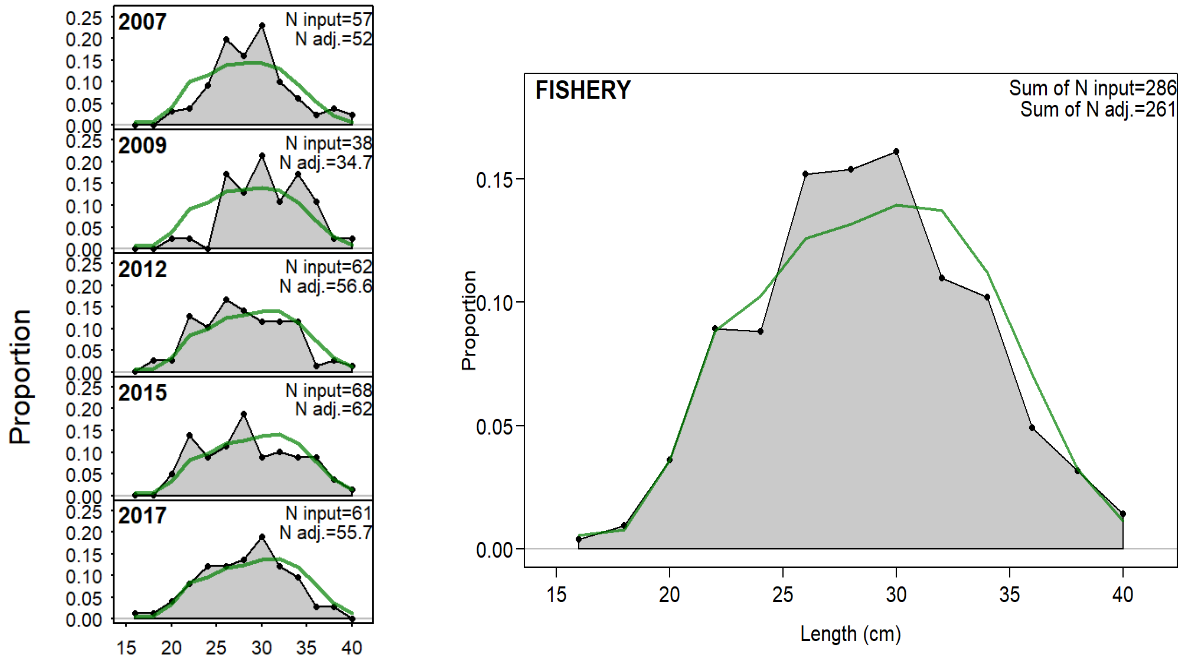


Figure 9-144 – Observed (gray area) vs. expected (green line) abundance-at-length from bottomfishing catch by year (left) and overall (right).

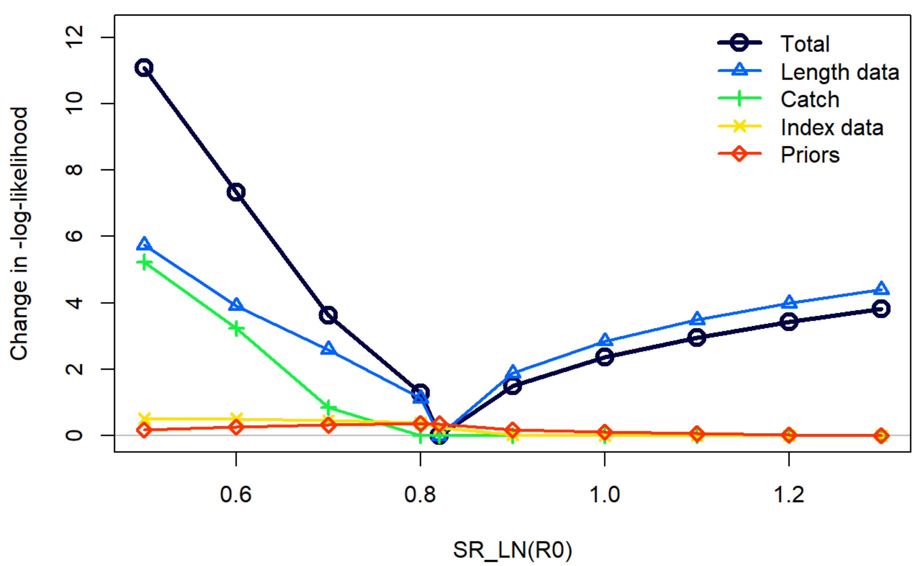


Figure 9-145 – Profiles of the change in negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter (*R_0*) in log-scale.

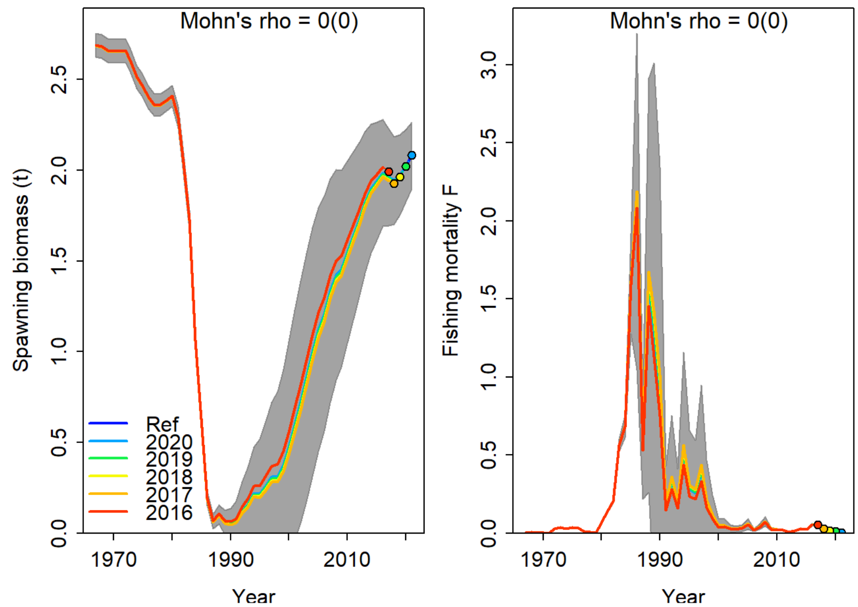


Figure 9-146 – Retrospective analysis of spawning biomass (left) and fishing mortality (right) consisting of 5 reruns of the base case model each fitted with one less year of data from the base case model (blue line).

Table 9-29 – Time series of spawning biomass (SSB, mt), age-0 recruitment (Rec., 1000s of recruits), and instantaneous fishing mortality (F, yr-1) estimated by the SS model. CV is the coefficient of variation.

Year	SSB	CV	Rec.	CV	F	CV	Year	SSB	CV	Rec.	CV	F	CV
1969	2.6	0.14	2.20	0.14	0.003	0.47	1996	0.3	0.67	1.40	0.23	0.183	1.00
1970	2.6	0.14	2.20	0.14	0.001	0.56	1997	0.3	0.66	1.47	0.23	0.302	0.83
1971	2.6	0.14	2.20	0.14	0.000	0.48	1998	0.3	0.71	1.48	0.25	0.124	1.09
1972	2.6	0.14	2.20	0.14	0.025	0.82	1999	0.4	0.67	1.55	0.24	0.080	0.89
1973	2.5	0.16	2.19	0.14	0.032	0.54	2000	0.4	0.61	1.64	0.21	0.038	0.70
1974	2.4	0.16	2.19	0.14	0.025	0.67	2001	0.6	0.53	1.73	0.19	0.038	0.68
1975	2.4	0.17	2.18	0.14	0.043	0.68	2002	0.7	0.46	1.80	0.17	0.022	0.70
1976	2.3	0.17	2.17	0.14	0.028	0.40	2003	0.8	0.41	1.87	0.16	0.023	0.64
1977	2.2	0.17	2.17	0.14	0.013	0.41	2004	1.0	0.36	1.92	0.16	0.026	0.64
1978	2.2	0.17	2.17	0.14	0.005	0.55	2005	1.1	0.32	1.97	0.15	0.049	0.53
1979	2.3	0.17	2.17	0.14	0.004	0.48	2006	1.2	0.29	2.00	0.15	0.015	0.70
1980	2.3	0.16	2.17	0.14	0.067	0.62	2007	1.3	0.27	2.03	0.15	0.032	0.73
1981	2.2	0.17	2.16	0.14	0.123	0.43	2008	1.4	0.26	2.05	0.15	0.060	0.54
1982	1.9	0.18	2.14	0.14	0.230	0.44	2009	1.4	0.25	2.06	0.15	0.027	0.37
1983	1.6	0.20	2.08	0.14	0.533	0.49	2010	1.5	0.23	2.07	0.15	0.022	0.30
1984	1.0	0.32	1.91	0.16	0.688	0.71	2011	1.6	0.22	2.09	0.15	0.015	0.62
1985	0.5	0.52	1.62	0.18	1.691	0.50	2012	1.7	0.21	2.10	0.15	0.006	0.68
1986	0.2	0.85	1.15	0.24	1.895	0.42	2013	1.8	0.20	2.12	0.14	0.013	0.57
1987	0.1	0.72	0.89	0.15	0.464	0.72	2014	1.8	0.19	2.13	0.15	0.024	0.47
1988	0.1	0.59	1.00	0.15	1.167	0.66	2015	1.9	0.19	2.13	0.14	0.020	0.84
1989	0.1	0.79	0.90	0.19	0.825	0.90	2016	1.9	0.18	2.13	0.14	0.055	0.24
1990	0.1	0.91	0.89	0.23	0.398	1.34	2017	1.9	0.18	2.13	0.14	0.052	0.30
1991	0.1	0.98	0.98	0.26	0.110	1.42	2018	1.9	0.19	2.13	0.14	0.028	0.27
1992	0.1	0.73	1.15	0.23	0.181	0.91	2019	1.9	0.18	2.13	0.14	0.014	0.35
1993	0.2	0.70	1.25	0.22	0.114	0.89	2020	1.9	0.18	2.14	0.14	0.009	0.41
1994	0.2	0.56	1.37	0.21	0.398	0.77	2021	2.0	0.17	2.15	0.14	0.001	0.42
1995	0.2	0.68	1.34	0.24	0.193	0.93							

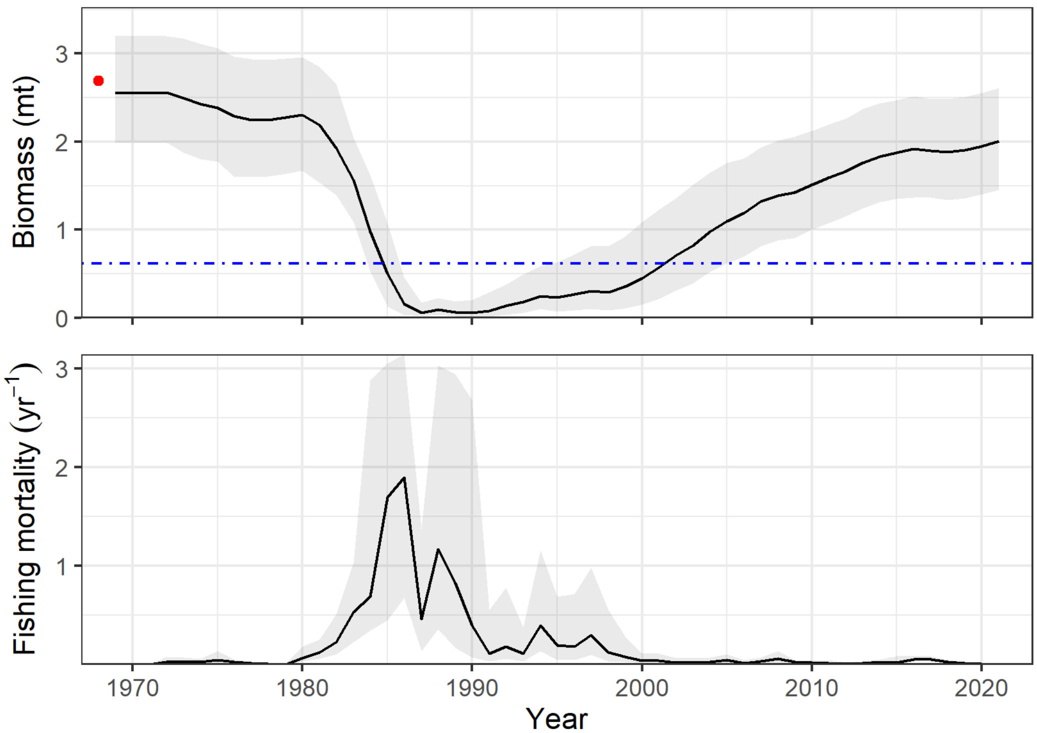


Figure 9-147 – Time series of spawning biomass (solid line) with its 95% confidence interval and SSB_0 estimate (red dot; top panel). The dot-and-dash blue line shows the spawning biomass at the MSST reference point (SSBMSST). Time series of fishing mortality rate with its 95% confidence intervals (bottom panel).

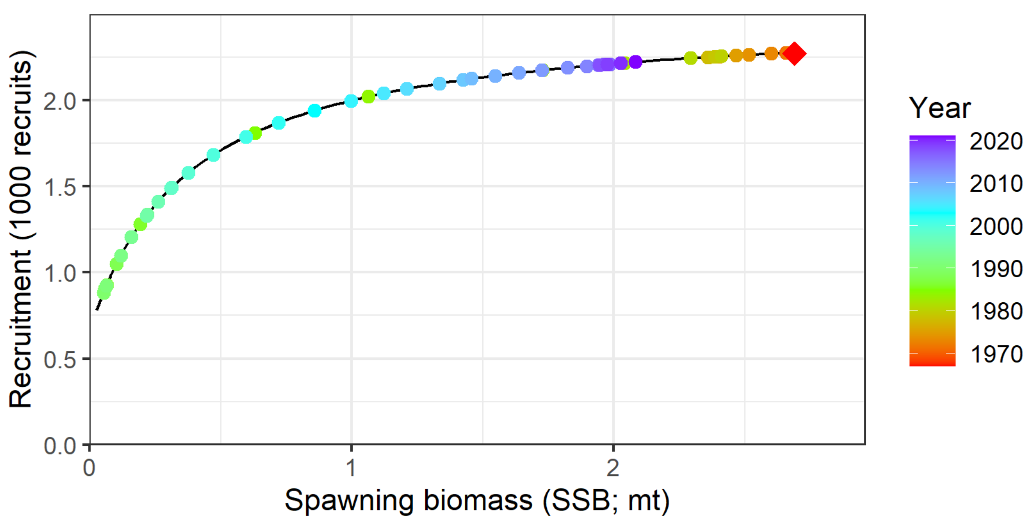


Figure 9-148 – Expected recruitment from the stock-recruitment relationship (black line) and estimated annual recruitment (dots) from SS. Estimated virgin SSB and recruitment is indicated with a red diamond.

Table 9-30 – Estimated biological reference points with 95% confidence interval (SD) derived from the SS base-case model where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield (2021 is the terminal year of the model).

Reference point	Value
F_{MSY} (yr-1)	0.192 (0.177 - 0.209)
F_{2021} (yr-1)	0.001 (0.001 - 0.003)
F_{2021}/F_{MSY}	0.007 (0.004 - 0.013)
SSB_{MSST} (mt)	0.61 (0.29 - 1.29)
SSB_{2021} (mt)	2.01 (1.45 - 2.61)
SSB_{2021}/SSB_{MSST}	3.28 (2.97 - 3.53)
MSY (mt)	0.37 (0.36 - 0.37)
$\text{Catch}_{2019\text{-}2021}$(mt)	0.04 (0.01 - 0.07)
SPR_{MSY}	0.36 (0.35 - 0.36)
SPR_{2021}	0.99 (0.99 - 0.99)

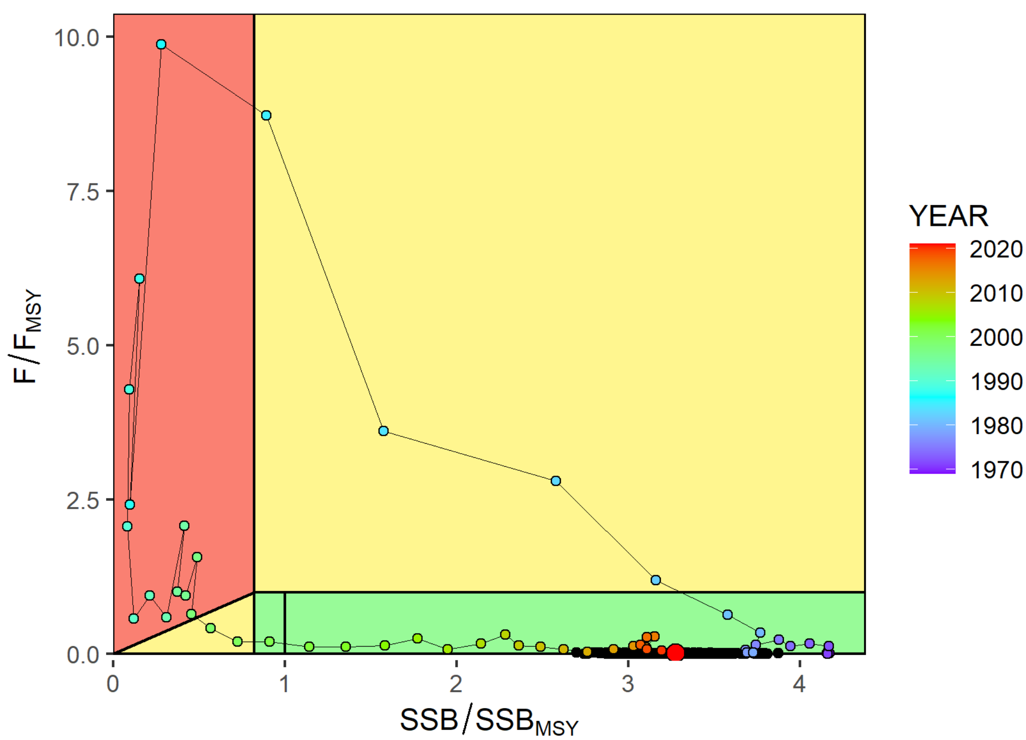


Figure 9-149 – Kobe plot representing the trend in relative fishing mortality and spawning stock biomass between 1969 and 2021 with their associated biological reference areas (red: overfished and overfishing, yellow: overfishing or overfished, green: no overfishing and not overfished). The large red dot indicates median stock status in 2021 and the black dots are one thousand Monte Carlo draws from the stock status distribution to represent the uncertainty around the final year status.

Table 9-31 – Summary table of key model output for all alternative model runs where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield.

Model	F_{2021}	F_{MSY}	F_{2021}/F_{MSY}	SSB_{MSY}	SSB_{MSST}	SSB_{2021}	SSB_{2021}/SSB_{MSY}	SSB_{2021}/SSB_{MSST}	Catch MSY
Base	0.001	0.19	0.01	0.8	0.6	2.1	2.6	3.5	0.4
M - 10%	0.001	0.18	0.01	0.9	0.7	2.3	2.6	3.3	0.4
M + 10%	0.001	0.21	0	0.7	0.6	1.9	2.7	3.2	0.4
Steep. - 10%	0.001	0.16	0.01	0.9	0.7	2.1	2.3	3	0.3
Steep. + 10%	0.001	0.22	0	0.7	0.6	2.1	3	3.5	0.4
Rec. dev.	0.001	0.2	0	0.8	0.6	1.8	2.2	3	0.4
No hist. catch	0.002	0.19	0.01	0.6	0.5	1.5	2.5	3	0.3
Alternate LH	0.001	0.19	0.01	0.9	0.7	2.3	2.6	3.3	0.4

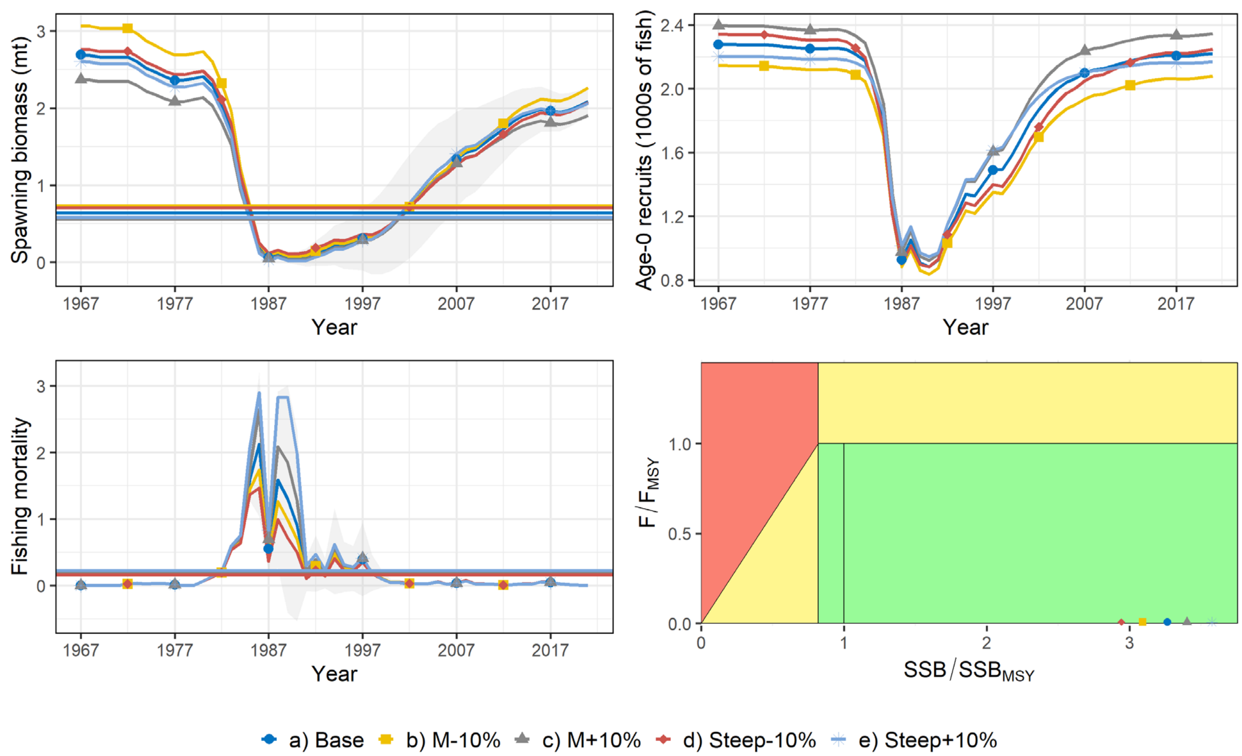


Figure 9-150 – Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) under moderate life-history parameter variation (plus and minus 10% of base parameter values).

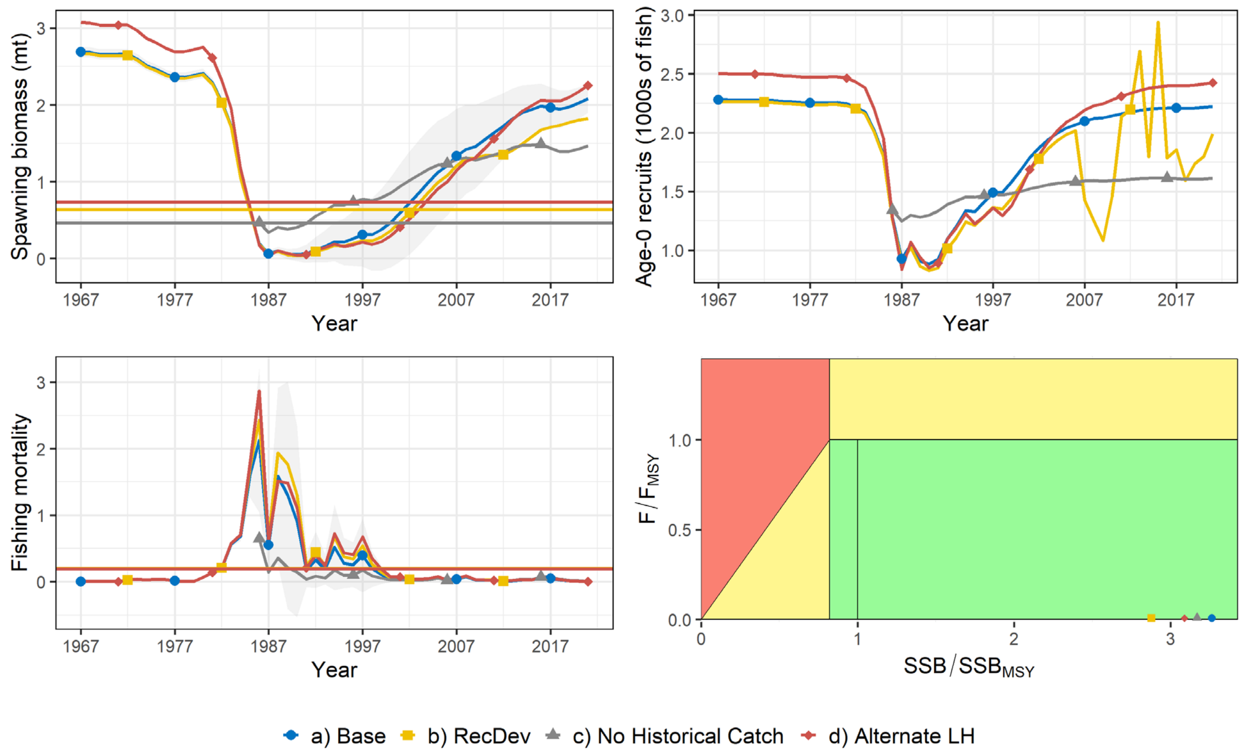


Figure 9-151 - Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) b) with recruitment deviations, c) without historical catch data (model starts in 1986), and d) with an alternate life history parameter source (growth curve from StepwiseLH).

Table 9-32 - The annual fixed catch values (metric tons) applied from 2024 to a final projection year resulting in a given probability of overfishing ($F/F_{MSY}>1$) in that final year. Catches for years prior to the start of the new catch guidance (2022 and 2023) were fixed at the mean of the last 3 years of catch data (2019 to 2021).

Probability of	Fixed catch (mt) from 2024 to:				
$F > F_{MSY}$	2024	2025	2026	2027	2028
0.50	0.92	0.81	0.73	0.67	0.64
0.49	0.92	0.80	0.73	0.67	0.63
0.48	0.92	0.80	0.73	0.67	0.63
0.47	0.91	0.80	0.73	0.67	0.63
0.46	0.91	0.80	0.72	0.66	0.63
0.45	0.91	0.79	0.72	0.66	0.62
0.44	0.90	0.79	0.72	0.66	0.62
0.43	0.90	0.79	0.72	0.66	0.62
0.42	0.90	0.79	0.71	0.65	0.62
0.41	0.89	0.78	0.71	0.65	0.61
0.40	0.89	0.78	0.71	0.65	0.61
0.39	0.88	0.78	0.70	0.65	0.61
0.38	0.88	0.77	0.70	0.64	0.60
0.37	0.88	0.77	0.70	0.64	0.60
0.36	0.87	0.77	0.69	0.64	0.60
0.35	0.87	0.76	0.69	0.63	0.59
0.34	0.86	0.76	0.69	0.63	0.59
0.33	0.86	0.76	0.68	0.63	0.59
0.32	0.85	0.75	0.68	0.63	0.58
0.31	0.85	0.75	0.67	0.62	0.58
0.30	0.84	0.74	0.67	0.62	0.58
0.29	0.84	0.74	0.67	0.61	0.57
0.28	0.83	0.73	0.66	0.61	0.57
0.27	0.83	0.73	0.66	0.61	0.57
0.26	0.82	0.72	0.65	0.60	0.56
0.25	0.82	0.72	0.65	0.60	0.56
0.24	0.81	0.71	0.64	0.59	0.56
0.23	0.80	0.71	0.64	0.59	0.55
0.22	0.80	0.70	0.64	0.59	0.55
0.21	0.79	0.70	0.63	0.58	0.54
0.20	0.79	0.69	0.63	0.58	0.54
0.19	0.78	0.69	0.62	0.57	0.54
0.18	0.77	0.68	0.62	0.57	0.53
0.17	0.77	0.68	0.61	0.56	0.53
0.16	0.76	0.67	0.61	0.56	0.52
0.15	0.76	0.66	0.60	0.55	0.52
0.14	0.75	0.66	0.59	0.55	0.51
0.13	0.74	0.65	0.59	0.54	0.51
0.12	0.74	0.64	0.58	0.54	0.50
0.11	0.73	0.64	0.58	0.53	0.50
0.10	0.72	0.63	0.57	0.53	0.49

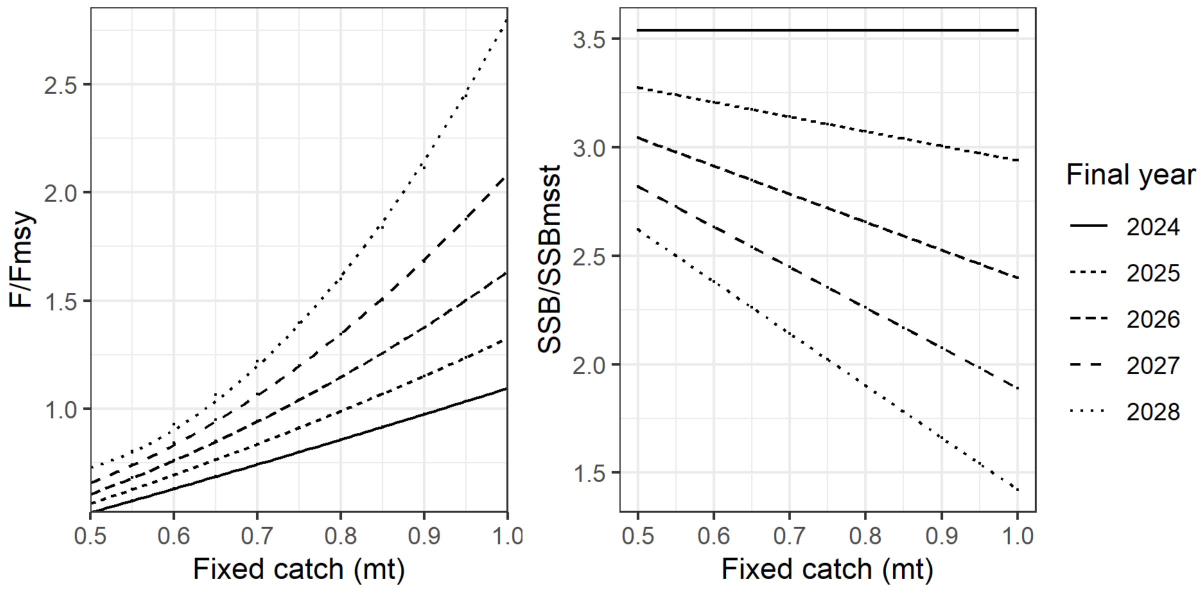


Figure 9-152 – Median stock status for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status is for the final projection year.

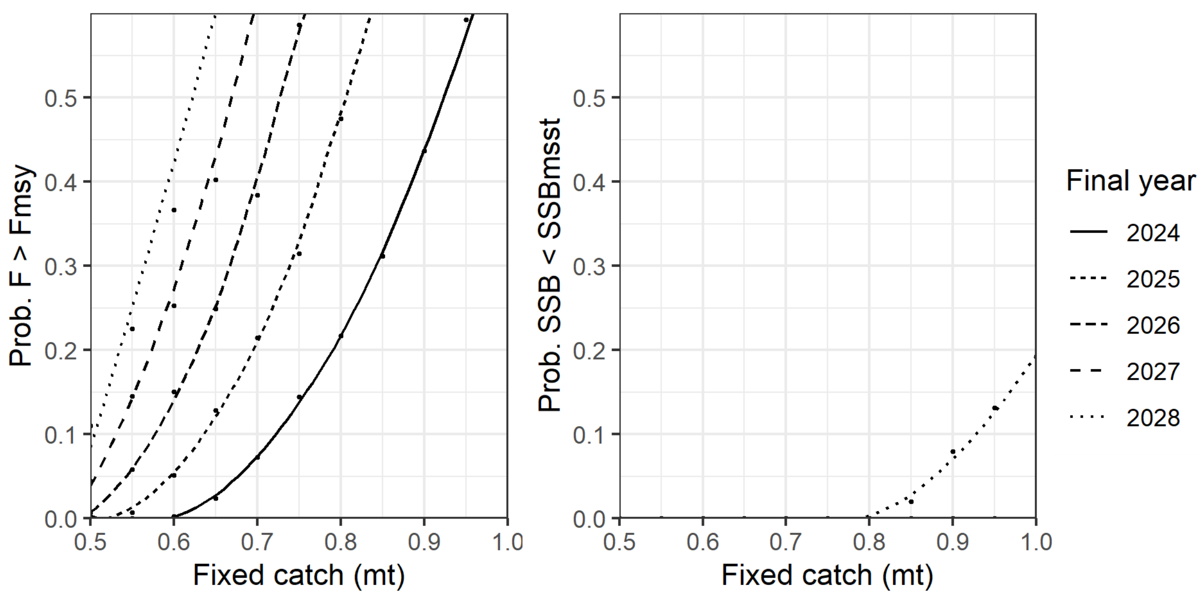


Figure 9-153– Probability of overfishing (left panel) and of stock being overfished (right panel) for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status probabilities are for the final projection year.

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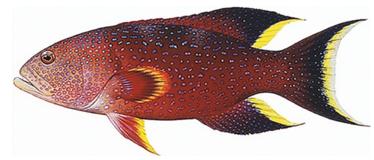
9.9 *Variola louti*



Velo, *Yellow-edged lyretail grouper*
Serranidae (groupers)

Key model parameters

Parameter	Value	Phase	Source
Natural mortality, M (yr^{-1})	0.36	-2	5.4/A_{max} (Hamel and Cope 2022)
Reference age, A_{min} (yr)	1	-2	-
Maximum age, A_{max} (yr)	15	-2	Grandcourt (2005) and Schemmel (2023)
Length at A_{min}, L_{Amin} (cm)	15.2	-2	StepwiseLH. L_{99}: 49.4 cm (creel+biosampling)
Length at A_{max}, L_{Amax} (cm)	46.1	-2	-
Growth rate, K (yr^{-1})	0.25	-2	-
CV of length < L_{Amin}	0.12	-2	-
CV of length > L_{Amin}	0.12	-2	-
Length-weight α	1.30e-5	-2	Kamikawa et al. (2015)
Length-weight β	3.09	-2	-
Length 50% maturity, L_{mat50} (cm)	26	-2	Schemmel (2023)
Slope of maturity ogive	-0.74	-2	-
Hermaph. inflection age (yr)	5.9	-2	Schemmel (2023)
Spawner-recruit steepness (h)	0.77	-2	FishLife 2.0 (Thorson 2019)
Number of platoons	3	-	Fixed
Unfished recruitment (Log R_0)	1.52 (0.22)	1	Estimated
Initial fishing mortality	-	-	Set to zero
Catchability (Log Q)	-3.23 (0.41)	1	Estimated
Extra Q SD	-	1	Set to zero
Length at 50% selectivity (cm)	23.0 (0.8)	2	Estimated
Width to 95% selectivity (cm)	3.8 (1.1)	2	Estimated
Dirichlet parameter (Log theta)	0.70 (0.56)	2	Estimated (note: 1.182, 0.255 normal prior used)

General comments

Data: Catch data are available from 1967 to 2021, CPUE from 2016 to 2021, and size composition observations are available in sufficient numbers from 2011 to 2017 (Figure 9-154). No super-periods were used. The size data after 2016 were too sparse to be combined into a super-period.

Life history: We found multiple growth studies but two had large sample sizes and A_{max} values: Grandcourt (2005) in the Seychelles and Schemmel (2023) in Guam. Both had similar A_{max} estimates (15 years and 14 years) but Schemmel (2023) had a lower L_{inf} which appears more appropriate for Samoa (43.8 cm vs. 51 cm). Schemmel (2023) provided a maturity curve and showed that this species is a protogynous hermaphrodite with a sex-change inflection age around 5.9 years (this information was added to our model; Figure 9-159). The StepwiseLH approach generated a very similar curve to Schemmel (2023) with an L_{inf} of 46.1 cm, which resulted in a tighter fit to the length data and lower variability around SSB. We selected this curve for our base model and ran an alternate model with Schemmel (2023). The resulting growth and maturity curves are presented in Figure 9-155 and Figure 9-156. We also tested an alternate model with no hermaphroditism.

Fishery: The re-created historical catch (1967–1985) suggests that few *V. louti*, like other deep species, were caught during the dory project years in the 1970s (< 0.2 mt) with a noticeable fishery for this species only starting with the ‘alia program in the early 1980s with catches around 0.6 to 1.0 mt (Figure 9-157). Catches afterwards have been highly variable between 0.2 and 0.7 mt. We first ran a model with an equilibrium catch in the first year (1967) but this resulted in a very low initial F estimate, which suggests that this species was very lightly exploited pre-1967. Therefore, we started the model in an unfished state (initial F set to 0). The model estimated length at 50% selectivity at approximately 23 cm and full selectivity at approximately 27 cm (or age 3) with some small differences in selectivity-at-age between platoons (Figure 9-158).

Model diagnostics: All estimated parameters converged within the set bounds with the final likelihood gradient of the model being less than 0.0001 and the associated Hessian matrix being positive definite. A jitter analysis of 100 model runs with different random initial starting values also supported that the model converged on a global minimum (Figure 9-160). Further, goodness-of-fit diagnostics indicated that the model fitted the CPUE index moderately well with a successful Runs test but with a large RMSE of 0.67 (Figure 9-161). The mean length model fit passed the Runs test and had a RMSE of 0.08 (Figure 9-162). The yearly and overall size composition data was fitted relatively well with some large residuals in 2011, which had an oddly shaped size structure with a strong left skew that did not carry to 2012 (Figure 9-163 and Figure 9-164). The change in negative log-likelihoods at different fixed log(R_0) values indicated that this parameter's estimate was mainly driven by the length composition data with a clear minimum reached at 1.5 (~4,500 recruits; Figure 9-165). The results of the retrospective analysis, which progressively removed one year of data from 2021 to 2017, showed no significant pattern for SSB or F, with Mohn's rho values around 0.02 for both (suggested limits are between -0.15 and 0.2; Figure 9-166).

Stock status: Population biomass declined from an SSB_0 around 2.3 mt prior to 1967 to about 0.7 mt in the late 1980s following the increased catch associated with the ʻalia program (Figure 9-167 and Table 9-33). Biomass has been increasing consistently since then, reaching values around 2.0 mt in recent years (the MSST was estimated at 0.5 mt; Figure 9-167). Recruitment stayed close to R_0, varying between 3,900 and 4,700 recruits per year (Figure 9-168). The current stock status (SSB/SSB_{MSST}) is equal to 4.1 (not overfished) with no overfishing occurring. The stock was close to overfished in 1987 (SSB of 0.7 mt). Overfishing occurred only in 1985 (Figure 9-169; Table 9-34), with fishing mortality hitting a maximum value of 0.47 (F_{MSY} was estimated at 0.43). Equilibrium catches at F_{MSY} (i.e., the *MSY*) were estimated at 0.5 mt. Catches in recent years have been low, averaging only 0.1 mt (Table 9-34).

Alternate scenarios: We ran 7 alternative models: *M* and steepness plus and minus 10%, no historical catch, with recruitment deviations, and alternate LH source. The alternate LH source, which used Schemmel (2023) for growth, increased the *SSB* (lower L_{inf}, lower *F*, increased population scale) (Table 9-35, Figure 9-170, and Figure 9-171). There was little impact of starting the model in 1986 or adding recruitment deviations. None of the alternative models resulted in overfishing or overfished status in 2021.

Projections: The projection analysis showed the distribution of outcomes in the probability of overfishing and overfished status that would occur in various final years (2024-2028) under various fixed-catch scenarios (Table 9-36; Figure 9-172, and Figure 9-173). The projections indicated some probability of overfished status occurring by 2028 for the upper range of the explored fixed catch (> 1 mt per year).

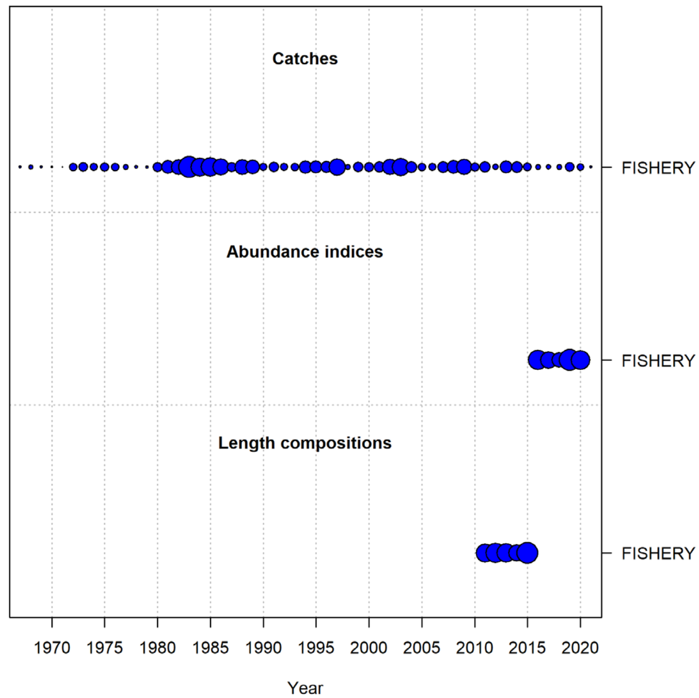


Figure 9-154- Summary of data types used in the SS model. Catches include boat-based and shore-based landings from creel surveys (1986-2021) as well as historical catches from reports (1967-1985). The abundance index is from boat-based creel survey 'bottomfishing" gear type. Length compositions are from creel surveys (all years) and the biosampling program (2010-2015) filtered for the "bottomfishing" gear.

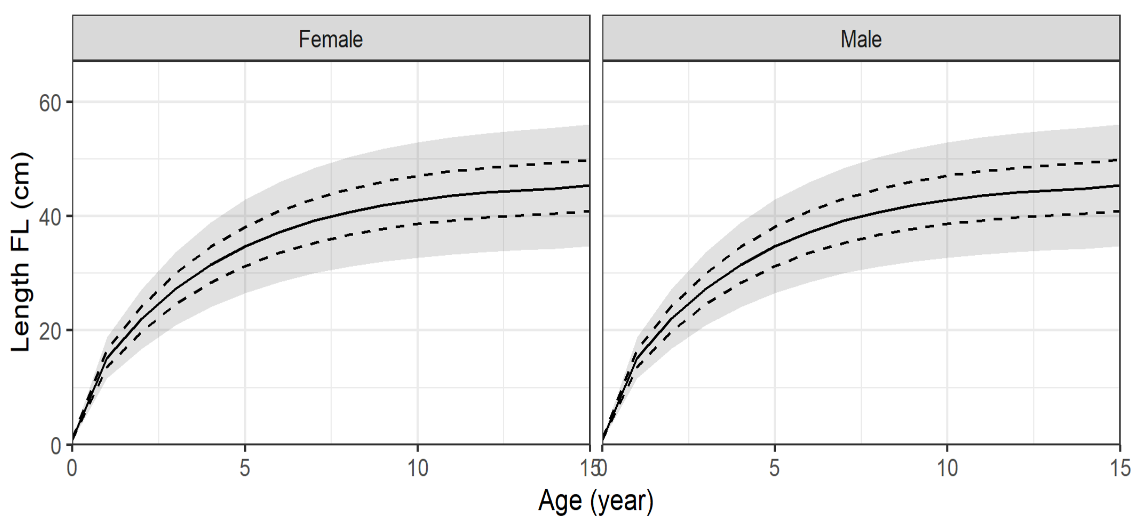


Figure 9-155 – Growth curve following a Von Bertalanffy model with 95% confidence intervals associated with the CV Linf parameter. The central growth platoon (solid line) and the two secondary ones (dashed lines) used in the model are also displayed.

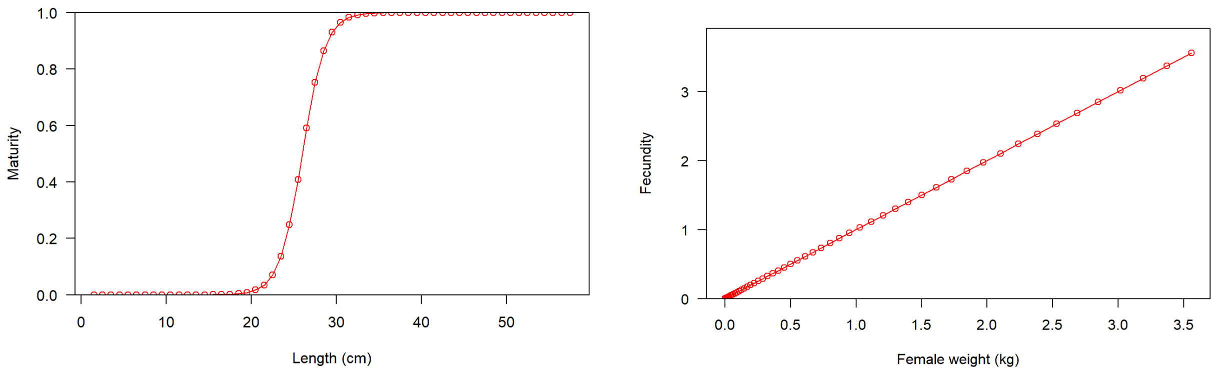


Figure 9-156 – Maturity-at-length (FL; left) and fecundity-at-weight (right) used in the stock assessment model.

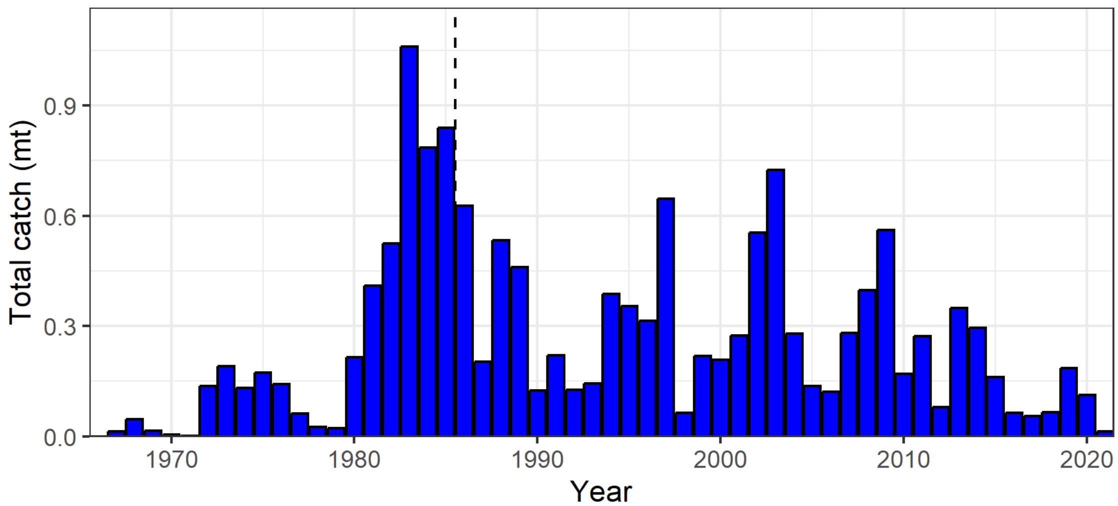


Figure 9-157 – Annual total catch in metric tons (mt). The vertical dashed line indicates the start of the creel survey program (1986) with older data coming from historical catch reports.

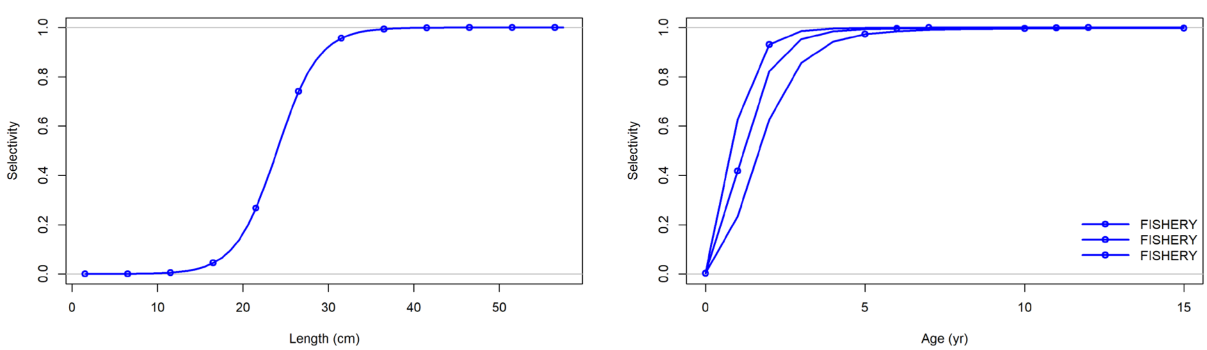


Figure 9-158 – Length-based selectivity estimated by the SS model (left) and the resulting selectivity-at-age for all 3 growth platoons (right).

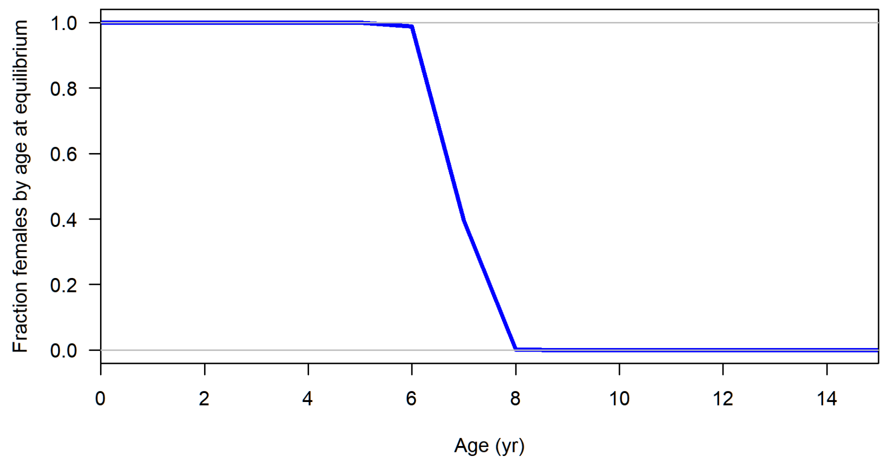


Figure 9-159 - Proportion of females transitioned to males by age (protogynous hermaphrodite).

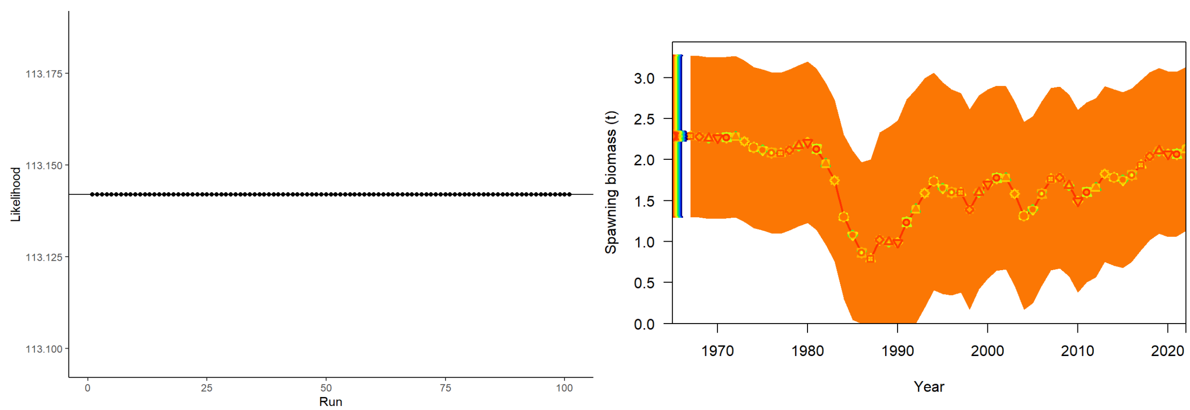


Figure 9-160 - Results of jitter analysis where 100 models were run with randomly varying initial parameter values. Left panel shows the variation in minimum model likelihood value for all 100 model runs. Right panel shows the variation in SSB time series for all 100 model runs.

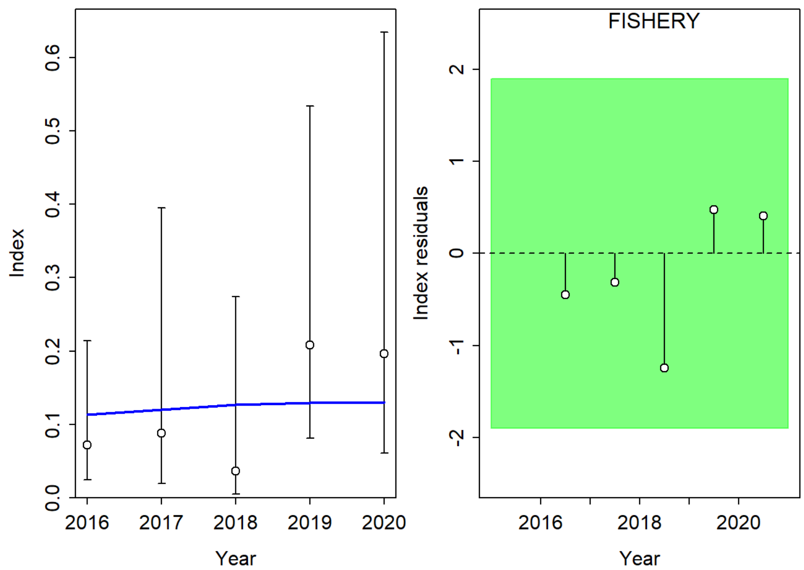


Figure 9-161 – Observed (open dots) vs expected (blue line) CPUE abundance index by year with standard deviations intervals (left). CPUE index residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.67.

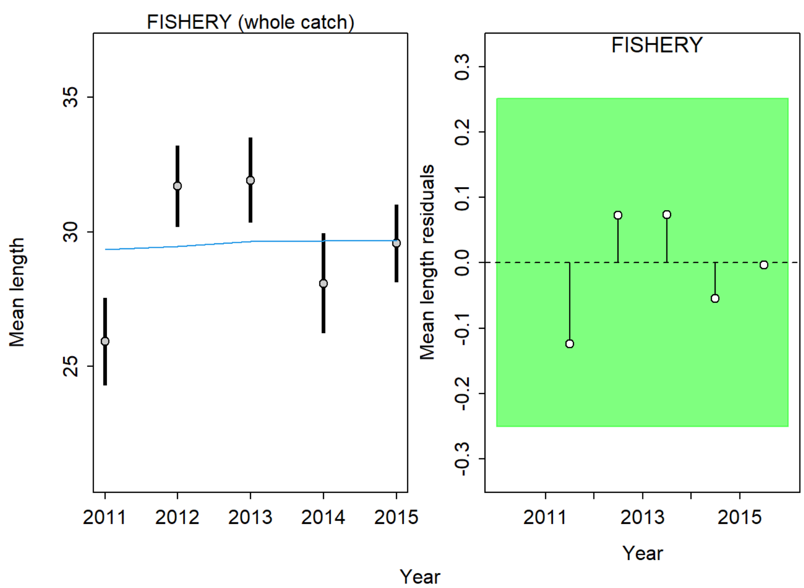


Figure 9-162 – Observed (open dots) vs expected (blue line) mean length by year with standard deviations intervals (left). Mean length residuals by year with the background color indicating the result of the Runs test (right panel; green=pass, red=fail). The width of this colored area represents three residual standard deviations (points falling outside this area are colored in red). The root mean square error (RMSE) is 0.08.

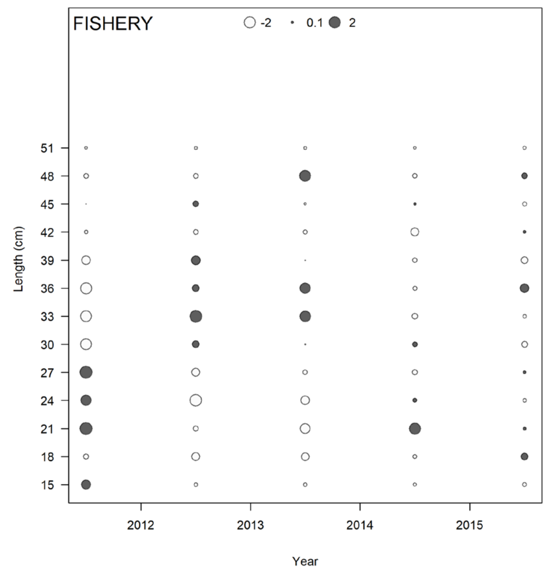
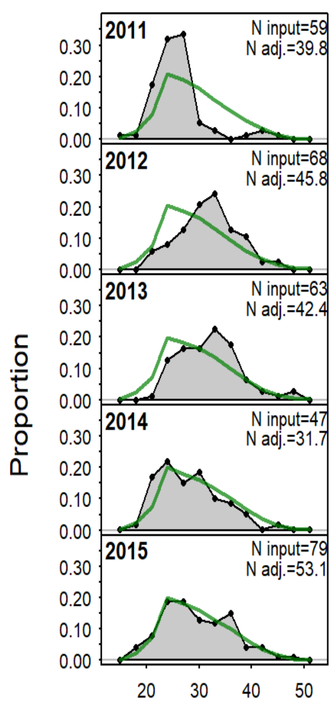


Figure 9-163 – Pearson residual plot of observed vs. expected size frequency data by size bin and year.



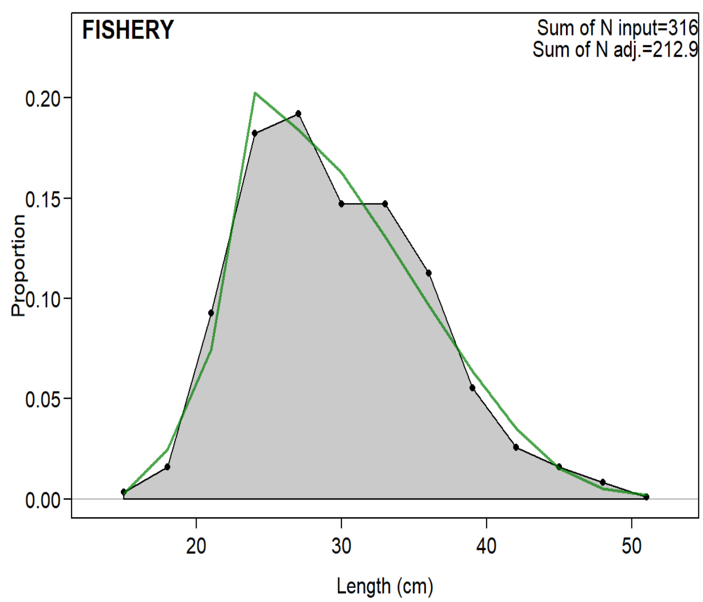


Figure 9-164 – Observed (gray area) vs. expected (green line) abundance-at-length from bottomfishing catch by year (left) and overall (right).

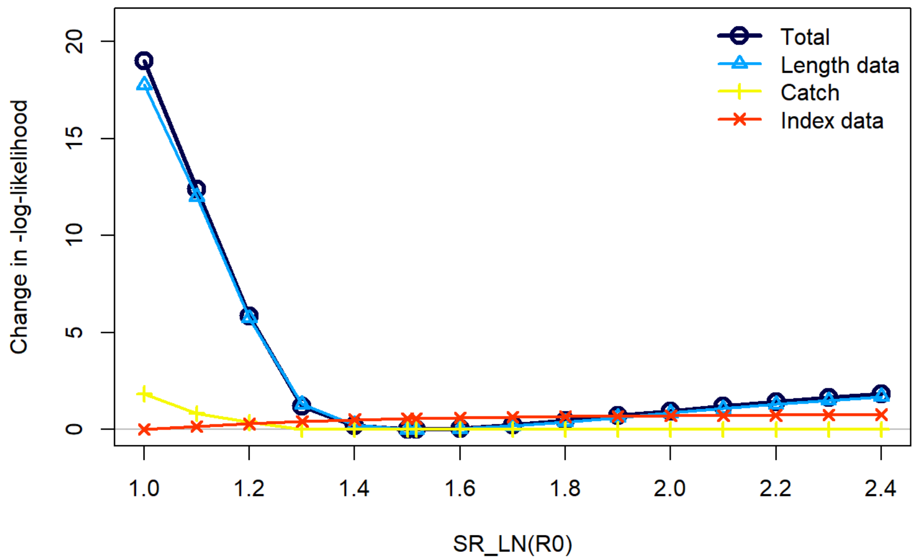


Figure 9-165 – Profiles of the change in negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter (R_0) in log-scale.

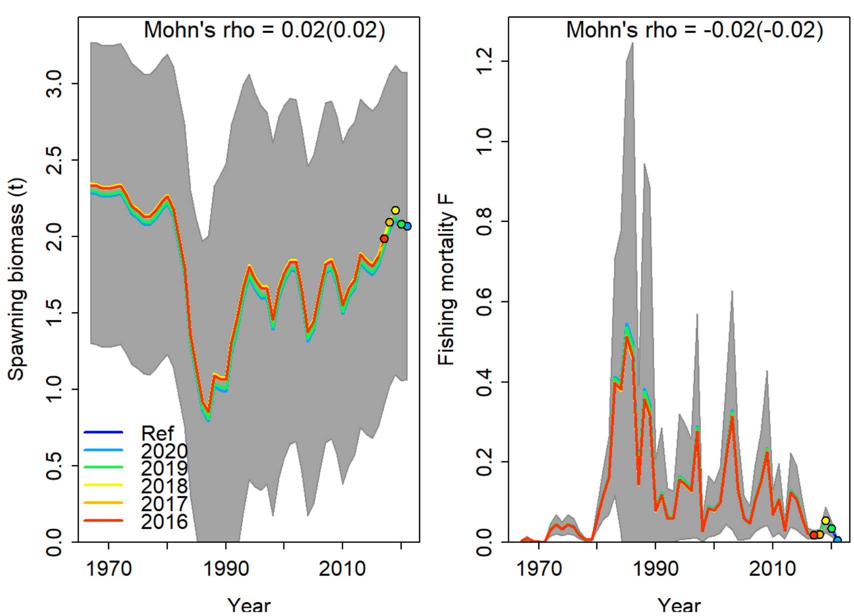


Figure 9-166 – Retrospective analysis of spawning biomass (left) and fishing mortality (right) consisting of 5 reruns of the base case model each fitted with one less year of data from the base case model (blue line).

Table 9-33 – Time series of spawning biomass (SSB, mt), age-0 recruitment (Rec., 1000s of recruits), and instantaneous fishing mortality (F, yr-1) estimated by the SS model. CV is the coefficient of variation.

Year	SSB	CV	Rec.	CV	F	CV	Year	SSB	CV	Rec.	CV	F	CV
1969	2.3	0.25	4.70	0.24	0.002	0.56	1996	1.4	0.47	4.44	0.26	0.110	0.74
1970	2.3	0.25	4.71	0.24	0.001	0.58	1997	1.4	0.43	4.50	0.26	0.218	0.70
1971	2.3	0.24	4.69	0.25	0.000	0.50	1998	1.3	0.45	4.47	0.26	0.022	0.72
1972	2.4	0.24	4.70	0.24	0.029	0.61	1999	1.6	0.38	4.54	0.26	0.070	0.67
1973	2.3	0.25	4.70	0.25	0.035	0.49	2000	1.7	0.36	4.57	0.26	0.064	0.76
1974	2.2	0.26	4.70	0.25	0.027	0.51	2001	1.8	0.34	4.59	0.25	0.080	0.59
1975	2.2	0.27	4.68	0.25	0.030	0.71	2002	1.8	0.32	4.61	0.25	0.199	0.85
1976	2.2	0.26	4.69	0.25	0.029	0.56	2003	1.6	0.41	4.55	0.26	0.277	0.66
1977	2.2	0.27	4.69	0.24	0.013	0.63	2004	1.4	0.48	4.47	0.27	0.107	1.03
1978	2.2	0.27	4.69	0.24	0.005	0.54	2005	1.4	0.46	4.53	0.26	0.049	0.68
1979	2.2	0.26	4.74	0.25	0.005	0.51	2006	1.6	0.38	4.56	0.26	0.038	0.78
1980	2.3	0.25	4.65	0.25	0.048	0.55	2007	1.9	0.35	4.60	0.25	0.083	0.66
1981	2.2	0.26	4.64	0.24	0.076	0.61	2008	1.8	0.34	4.61	0.25	0.126	0.69
1982	2.0	0.29	4.68	0.25	0.122	0.54	2009	1.7	0.36	4.60	0.25	0.212	0.47
1983	1.9	0.30	4.62	0.25	0.386	0.60	2010	1.5	0.40	4.54	0.26	0.056	0.56
1984	1.3	0.44	4.39	0.26	0.308	1.14	2011	1.6	0.37	4.57	0.26	0.082	0.56
1985	1.0	0.62	4.17	0.28	0.472	1.05	2012	1.7	0.34	4.59	0.25	0.023	0.55
1986	0.7	0.83	3.83	0.33	0.346	1.18	2013	1.9	0.31	4.64	0.24	0.092	0.63
1987	0.7	0.88	3.87	0.32	0.117	1.83	2014	1.9	0.32	4.69	0.25	0.084	0.80
1988	0.9	0.74	4.11	0.30	0.325	1.27	2015	1.8	0.34	4.62	0.25	0.047	0.69
1989	0.8	0.85	3.93	0.33	0.336	1.44	2016	1.9	0.34	4.58	0.25	0.017	0.46
1990	0.7	0.95	3.72	0.36	0.091	1.32	2017	2.0	0.30	4.64	0.25	0.016	0.45
1991	0.9	0.81	4.12	0.29	0.127	1.16	2018	2.1	0.29	4.68	0.24	0.018	0.37
1992	1.1	0.70	4.27	0.28	0.072	0.95	2019	2.2	0.27	4.66	0.24	0.056	0.37
1993	1.3	0.61	4.39	0.27	0.054	1.22	2020	2.1	0.27	4.64	0.25	0.031	0.37
1994	1.5	0.49	4.45	0.27	0.164	0.76	2021	2.1	0.27	4.68	0.24	0.003	0.59
1995	1.4	0.49	4.42	0.26	0.136	0.85							

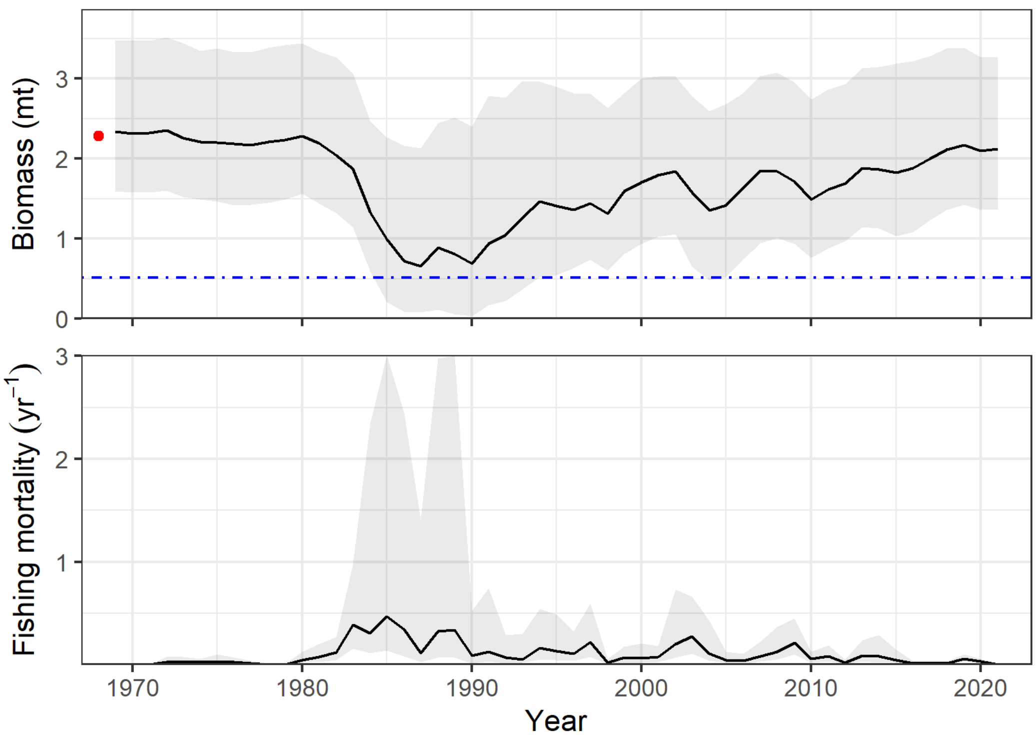


Figure 9-167 – Time series of spawning biomass (solid line) with its 95% confidence interval and SSB_0 estimate (red dot; top panel). The dot-and-dash blue line shows the spawning biomass at the MSST reference point (SSBMSST). Time series of fishing mortality rate with its 95% confidence intervals (bottom panel).

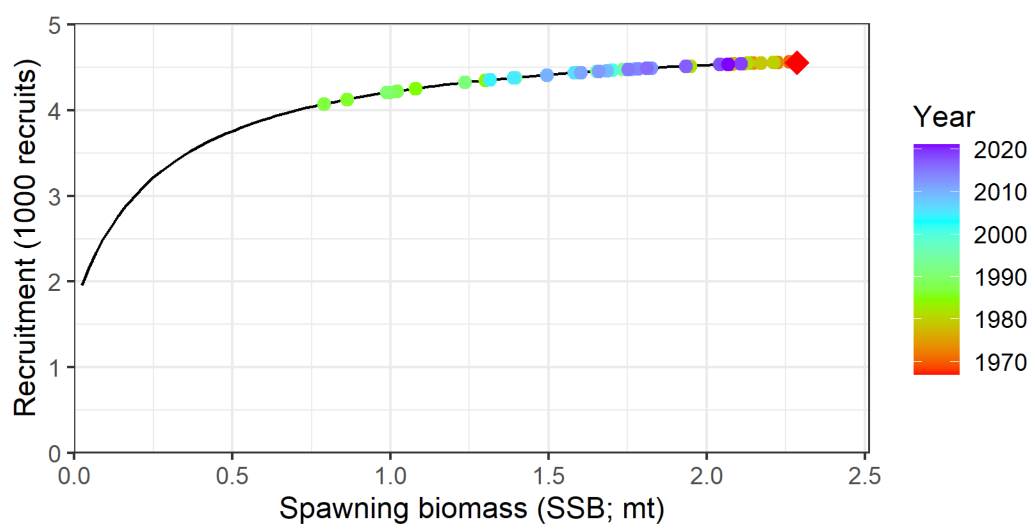


Figure 9-168 – Expected recruitment from the stock-recruitment relationship (black line) and estimated annual recruitment (dots) from SS. Estimated virgin SSB and recruitment is indicated with a red diamond.

Table 9-34 – Estimated biological reference points with 95% confidence interval (SD) derived from the SS base-case model where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield (2021 is the terminal year of the model).

Reference point	Value
F_{MSY} (yr-1)	0.428 (0.368 - 0.505)
F_{2021} (yr-1)	0.003 (0.001 - 0.008)
F_{2021}/F_{MSY}	0.007 (0.003 - 0.016)
SSB_{MSST} (mt)	0.51 (0.26 - 0.96)
SSB_{2021} (mt)	2.13 (1.37 - 3.26)
SSB_{2021}/SSB_{MSST}	4.14 (3.54 - 4.76)
MSY (mt)	0.46 (0.27 - 0.65)
$Catch_{2019-2021}$(mt)	0.1 (0.04 - 0.17)
SPR_{MSY}	0.39 (0.39 - 0.4)
SPR_{2021}	0.99 (0.98 - 0.99)

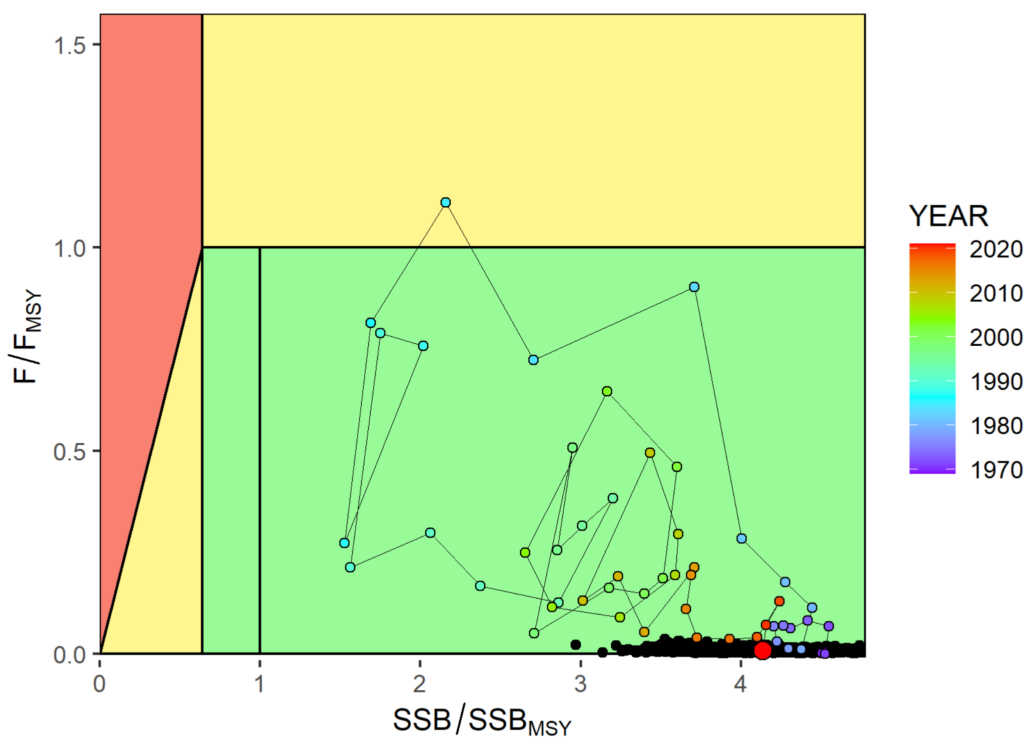


Figure 9-169 – Kobe plot representing the trend in relative fishing mortality and spawning stock biomass between 1969 and 2021 with their associated biological reference areas (red: overfished and overfishing, yellow: overfishing or overfished, green: no overfishing and not overfished). The large red dot indicates median stock status in 2021 and the black dots are one thousand Monte Carlo draws from the stock status distribution to represent the uncertainty around the final year status.

Table 9-35 – Summary table of key model output for all alternative model runs where F is the instantaneous annual fishing mortality rate, SPR is spawning potential ratio, SSB is spawning stock biomass, MSST is minimum stock size threshold, and MSY is maximum sustainable yield.

Model	F_{2021}	F_{MSY}	F_{2021}/F_{MSY}	SSB_{MSY}	SSB_{MSST}	SSB_{2021}	SSB_{2021}/SSB_{MSY}	SSB_{2021}/SSB_{MSST}	Catch MSY
Base	0.004	0.43	0.01	0.8	0.5	2.1	2.6	4.2	0.5
M - 10%	0.005	0.4	0.01	0.7	0.5	1.8	2.6	3.6	0.4
M + 10%	0.003	0.47	0.01	0.9	0.6	2.5	2.8	4.2	0.6
Steep. - 10%	0.004	0.37	0.01	0.9	0.5	2.1	2.3	4.2	0.4
Steep. + 10%	0.004	0.49	0.01	0.7	0.5	2.1	3	4.2	0.5
Rec. dev.	0.005	0.43	0.01	0.7	0.5	1.9	2.7	3.8	0.4
No hist. catch	0.004	0.43	0.01	0.8	0.5	2.2	2.8	4.4	0.5
Alternate LH	0.003	0.45	0.01	1.1	0.7	3.2	2.9	4.6	0.7

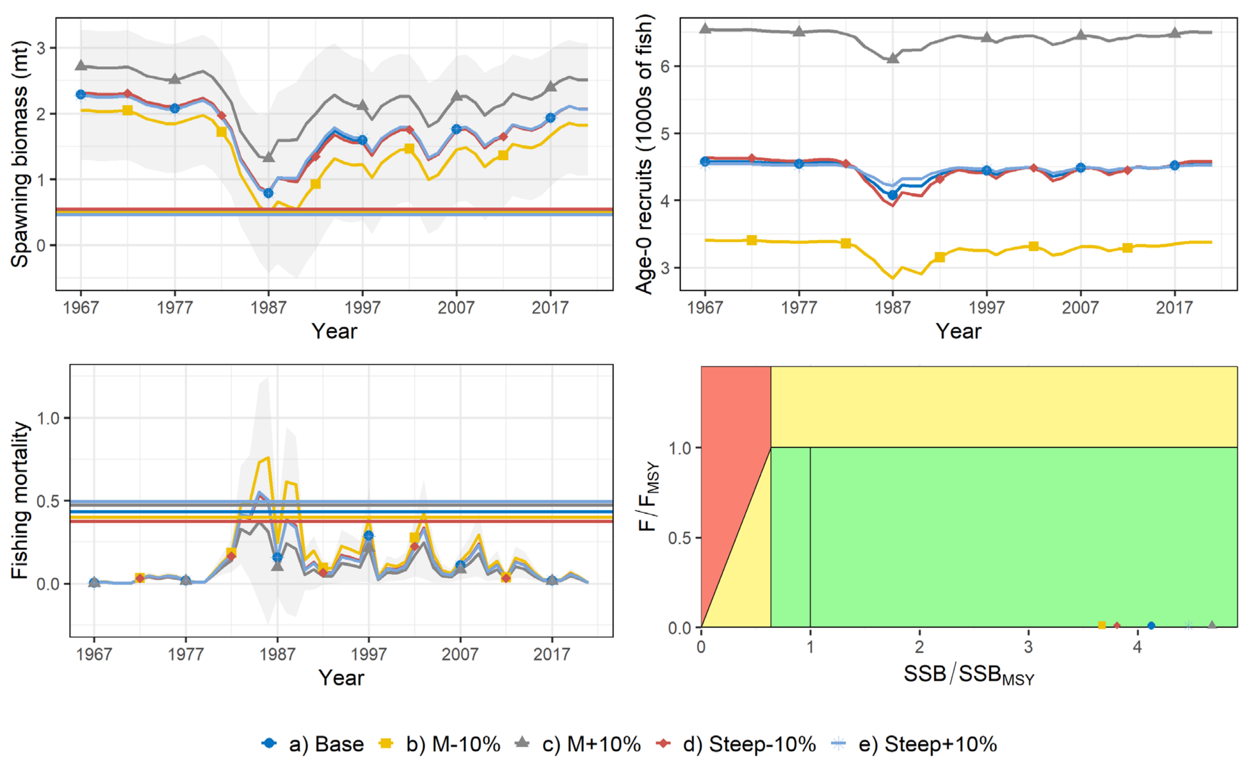


Figure 9-170 – Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) under moderate life-history parameter variation (plus and minus 10% of base parameter values).

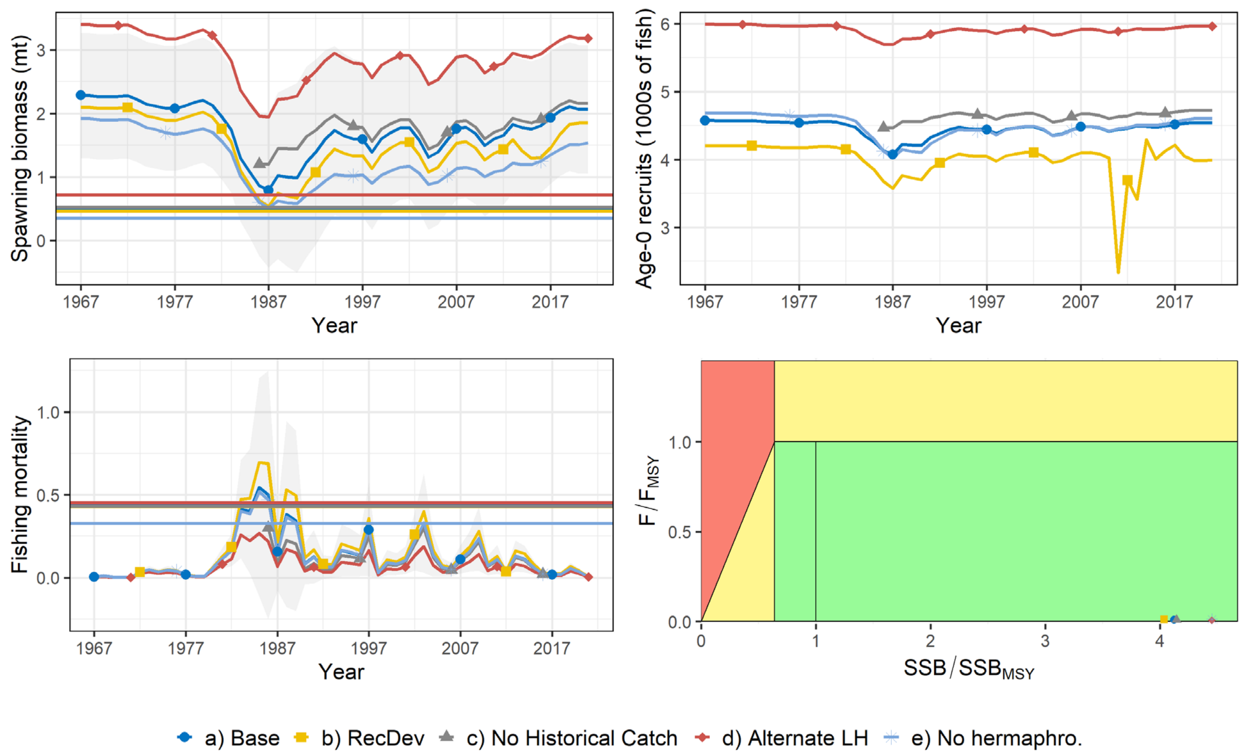


Figure 9-171 - Alternative model runs showing differences in spawning biomass, recruitment, fishing mortality, and a Kobe plot of the final year stock status (in order from left to right) b) with recruitment deviations, c) without historical catch data (model starts in 1986), and d) with an alternate life history parameter source (growth curve from Schemmel 2023).

Table 9-36 - The annual fixed catch values (metric tons) applied from 2024 to a final projection year resulting in a given probability of overfishing (F/F_{MSY}>1) in that final year. Catches for years prior to the start of the new catch guidance (2022 and 2023) were fixed at the mean of the last 3 years of catch data (2019 to 2021).

Probability of	Fixed catch (mt) from 2024 to:				
$F > F_{MSY}$	2024	2025	2026	2027	2028
0.50	0.50	1.40	1.10	0.95	0.85
0.49	0.49	1.39	1.09	0.94	0.85
0.48	0.48	1.39	1.09	0.94	0.84
0.47	0.47	1.38	1.08	0.93	0.84
0.46	0.46	1.37	1.07	0.92	0.83
0.45	0.45	1.36	1.07	0.92	0.83
0.44	0.44	1.35	1.06	0.91	0.82
0.43	0.43	1.34	1.05	0.91	0.81
0.42	0.42	1.33	1.05	0.90	0.81
0.41	0.41	1.32	1.04	0.89	0.80
0.40	0.40	1.31	1.03	0.89	0.80
0.39	0.39	1.30	1.03	0.88	0.79
0.38	0.38	1.29	1.02	0.87	0.78
0.37	0.37	1.28	1.01	0.86	0.78
0.36	0.36	1.27	1.00	0.86	0.77
0.35	0.35	1.26	1.00	0.85	0.77
0.34	0.34	1.25	0.99	0.84	0.76
0.33	0.33	1.24	0.98	0.84	0.76
0.32	0.32	1.23	0.97	0.83	0.75
0.31	0.31	1.22	0.97	0.82	0.74
0.30	0.30	1.21	0.96	0.82	0.74
0.29	0.29	1.20	0.95	0.81	0.73
0.28	0.28	1.19	0.94	0.80	0.73
0.27	0.27	1.18	0.93	0.80	0.72
0.26	0.26	1.17	0.93	0.79	0.71
0.25	0.25	1.16	0.92	0.78	0.71
0.24	0.24	1.15	0.91	0.78	0.70
0.23	0.23	1.14	0.90	0.77	0.70
0.22	0.22	1.12	0.89	0.76	0.69
0.21	0.21	1.11	0.88	0.75	0.69
0.20	0.20	1.10	0.88	0.75	0.68
0.19	0.19	1.09	0.87	0.74	0.67
0.18	0.18	1.08	0.86	0.73	0.67
0.17	0.17	1.07	0.85	0.73	0.66
0.16	0.16	1.06	0.84	0.72	0.66
0.15	0.15	1.05	0.83	0.71	0.65
0.14	0.14	1.04	0.82	0.70	0.65
0.13	0.13	1.02	0.81	0.70	0.64
0.12	0.12	1.01	0.80	0.69	0.63
0.11	0.11	1.00	0.80	0.68	0.63
0.10	0.10	0.99	0.79	0.68	0.62

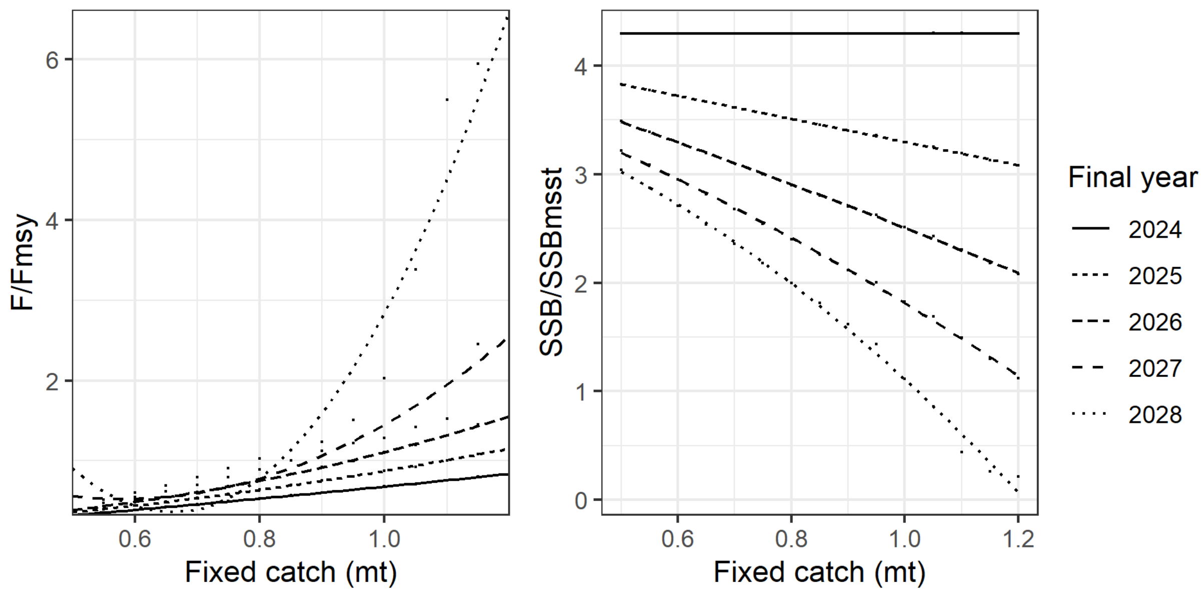


Figure 9-172 – Median stock status for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status is for the final projection year.

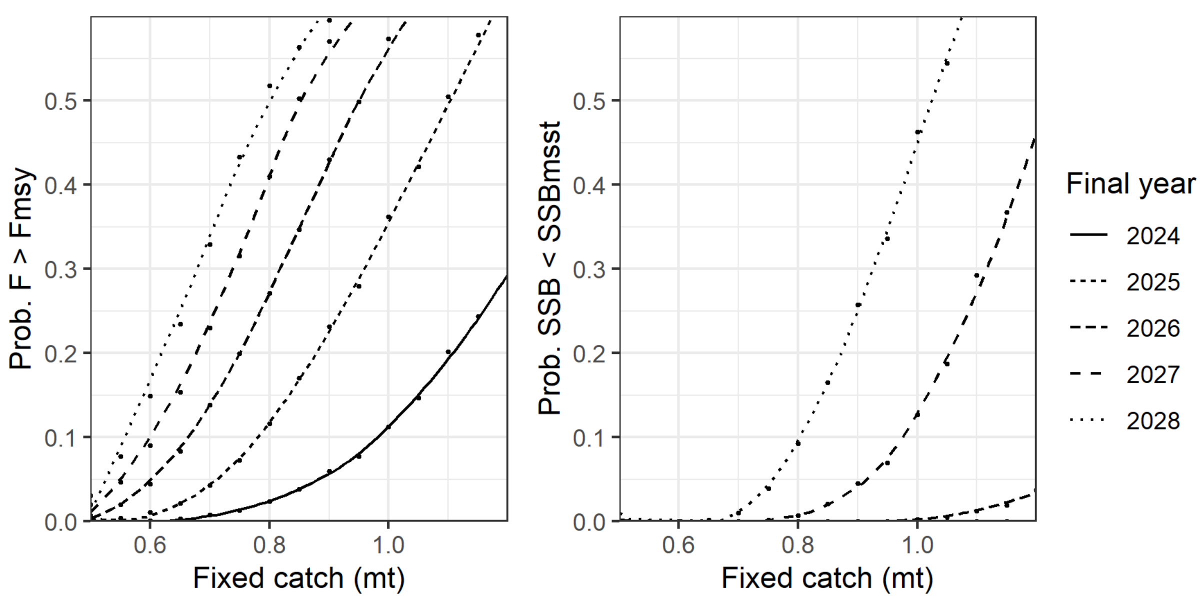


Figure 9-173– Probability of overfishing (left panel) and of stock being overfished (right panel) for a range of catch values (metric tons) fixed for a given range of years starting in 2024. The stock status probabilities are for the final projection year.