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Selecting and conditioning operating models for south Pacific albacore

SC20-MI-WP-04 rev1

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REVISIONS:

1. Operating models have been updated with revised natural mortality assumptions in line with the approach of the 2024 stock assessment for south Pacific albacore. Text and figures have been revised accordingly.
2. Figures for natural mortality and maturity at age now show ranges across the grid rather than just the reference case model values.
3. Text updated to reflect the inclusion of only one CPUE scenario in the OM grid.

[1]Oceanic Fisheries Programme, The Pacific Community

Executive Summary

A suite of operating models (OMs) for south Pacific albacore, developed from the 2021 stock assessment model, was provisionally adopted by SC19 as the basis for initial testing of candidate MPs. It was recommended that further work be conducted to continue refining, or revising, the OMs. A revised stock assessment of south Pacific albacore has been conducted this year and the updated suite of OMs, presented here, has adopted many of the updates and improvements to the assessment of the stock.

Table: South Pacific albacore tuna OM uncertainty grid (reference set, 800 model scenarios, including 200 pairs of steepness and natural mortality values, sampled independently from assumed distributions). ‡ denotes those scenarios for which a dedicated fit of MULTIFAN-CL is required.

Axis	**Levels**	**Options**	
		1	**2**
Reference Set			
Process Error			
Recruitment variability	**2**	1973-2020	2000-2020
Observation Error			
Catch and effort c.v.	**1**	20%	
CPUE index c.v.	**1**	30%	
Model Error			
Steepness ‡	**200**	sampled from assumed distbn	
Natural mortality ‡	**200**	sampled from assumed distbn	
Recruitment distbn ‡	**1**	SEAPODYM	
Movement ‡	**1**	SEAPODYM	
Implementation Error			
Effort creep	**2**	0%	1%

The proposed OM grid represents an initial set of scenarios for testing candidate management procedures and can be further modified and enhanced as new information is attained and additional analyses conducted. In particular future work should focus on further developing scenarios for the impacts of climate change and the potential effects of hyperstability in CPUE.

An initial robustness set is also proposed that includes a low recruitment scenario with a more extreme reduction in recruitment than the scenarios considered in the reference set; a higher level of effort creep in longline fisheries; and alternative assumptions for the level of fishing in the WCPFC-CA and EPO.

We invite SC20 to:

- advise whether the sources of uncertainty included in the OM grid are sufficient and if any further scenarios should be considered.
- advise whether the ranges of parameter values adequately reflect our uncertainty in stock

dynamics.

In addition we invite SC20 to note:

- It should not always be necessary to update the suite of operating models each time a new assessment is conducted. Any changes to the OM grid should be considered as part of an agreed monitoring strategy.
- The grid of models outlined in this report form the basis of the evaluations of candidate MPs for south Pacific albacore detailed in WCPFC-SC20/MI-WP-06.

1 Introduction

In 2014 the WCPFC adopted CMM2014-06 (subsequently replaced by CMM2022-03) on the development of a harvest strategy approach for the management of key tuna species of the WCPFC. The measure requires the development and implementation of formal management procedures (MPs) that are designed to achieve defined management objectives. Best practice requires that candidate MPs are tested prior to implementation to ensure that they are likely to achieve desired outcomes. Candidate MPs should be tested against a range of conditions that represent plausible future scenarios of the fish stock and the fishery. This testing is essential in order to identify MPs that are robust to uncertainty in the dynamics of the fishery.

Stock assessments conducted by the Pacific Community (SPC) typically comprise a range of model configurations that present different outcomes for alternative assumptions (uncertainty grid), such as the form of the stock and recruitment relationship (SRR) and the rate of natural mortality (M). Management advice is then based on the range of model outcomes rather than a single model. The stock assessment uncertainty grid is, therefore, a useful starting point for the range of uncertainty that should be considered when testing MPs. However, the assessment uncertainty grid considers only those factors that impact on the historical trajectory of the stock and its current status. When conducting projections of the stock into the future it is often necessary to consider additional factors to ensure that all important sources of uncertainty are adequately captured.

Individual models representing a specific scenario are termed operating models (OMs) and the process of fitting OMs to the available data is termed conditioning (Rademeyer et al., 2007). In this paper we describe the conditioning of operating models for south Pacific albacore, the behaviour and dynamics of the fish population and the fishing fleets that exploit them. This is a particularly important process in the development of the MSE framework and will require ongoing work to periodically re-evaluate the selection of OMs to use in the evaluations. Periodic review of the OMs (as part of a monitoring strategy) will ensure that any new data or updated information can be incorporated into the analyses and provides an opportunity to review the bounds and limits used to define exceptional circumstances.

A suite of operating models (WCPFC-SC19-MI-WP-09), developed from the 2021 stock assessment model, was provisionally adopted by SC19 as the basis for initial testing of candidate MPs. However, given concerns about the estimated stock dynamics for the most recent years, it was recommended that further work be conducted to refine, or revise, the OMs. A revised stock assessment of south Pacific albacore has also been conducted this year and the updated suite of OMs has adopted many of the changes that have been made to update and improve the assessment of the stock. This paper presents the updated suite of OMs for south Pacific albacore tuna.

2 Conditioning the Operating Models

The report of the south Pacific albacore stock assessment (Teears et al., 2024) provides an overview of current knowledge for the biology of south Pacific albacore and describes the southern longline fishery and surface water troll and driftnet fisheries that account for the majority of the catch of albacore in the south Pacific Ocean. We focus here on specific aspects of the biology of south Pacific albacore and associated fisheries that are of particular relevance to the conditioning of operating models.

2.1 Albacore biology

2.1.1 Spatial structure and movement

Albacore occur throughout the south Pacific from the equator to 50°S latitude and from the surface to depths of over 300m. and, within the south Pacific, are considered to comprise a single discrete stock (Murray, 1994). Available tag release and recapture data indicate widescale mixing of adult albacore throughout the south Pacific although very little mixing is assumed to occur betweeen northern and southern hemisphere populations.

Albacore in the southern hemisphere exhibit a seasonal migration between feeding grounds in the sub-tropical convergence zone in the south and spawning grounds in sub-equatorial regions during the austral summer between latitudes 10°S and 25°S (Langley, 2004; Lehodey et al., 2013). The juveniles progressively move south and generally eastwards along the sub-tropical convergence zone (Murray, 1994) and typically first appear in the surface troll fisheries around New Zealand and in the high seas further to the east. Movement rates of south Pacific albacore are, however, subject to considerable uncertainty and the true nature of albacore migration in the south Pacific remains unclear. The assumed spatial structure of the fishery and the movement of fish between regions has been a major source of uncertainty for recent assessments (Castillo Jordan et al., 2021) and OM grids (Scott et al., 2023b).

The revised assessment of south Pacific albacore (Teears et al., 2024) employs a simplified spatial structure where the population is separated into just two regions, with 17 extraction fisheries and 3 index fisheries implemented under a 'fleets-as-areas' approach, where fishery units representing smaller spatial units sit within larger assessment regions (see Figure 1 and Table 1). Movement rates between the two regions were determined from SEAPODYM estimates (Senina et al., 2020) and suggest lower levels of east - west mixing as compared to north - south movement. Under this 2-region configuration the model shows reduced sensitivity to alternative mixing assumptions and consequently movement rates are no longer considered as part of the OM grid.

2.1.2 Growth and maturity

Daily otolith growth increments indicate a fairly rapid initial growth of south Pacific albacore, reaching 45-50 cm (FL) in their first year (Leroy and Lehodey, 2004). Subsequent growth is slower at around 10 cm per year for ages 2 to 4, declining further thereafter. Growth is similar between the sexes until around 4 to 5 years of age after which males grow slightly larger than females. For both sexes, growth rates can differ with longitude, with length at age slightly greater in the east as compared to the west (Farley et al., 2021). No difference in growth with latitude has been identified.

The growth rate of south Pacific albacore has been a significant source of uncertainty in recent assessments (Figure 2) with estimates of size at age varying markedly between different data sources. Recent studies, however, have yielded improved estimates of growth rates for south Pacific albacore (Farley et al., 2021) and provide more consistent estimates of age at length that correspond more closely to modal peaks of the size composition data, in particular for juvenile and sub-adult fish caught in the New Zealand troll fishery.

Growth is estimated independantly for each OM from a combination of size composition data and conditional length at age data. Estimates of length at age show very little variation between model fits (Figure 2) and contribute little to the overall variability in stock status across the OM grid. Growth appears well estimated within the model, shows good correspondence with length frequency data modes and closely resembles fits obtained from recent studies. For this reason growth is not included in the uncertainty grid.

Maturity at length is invariant across the OM grid. Variability in estimated length at age results in corresponding variability in maturity at age (Figure 3a). 50% maturity (sexes combined) occurs at around age 3 with full maturity at age 6. Maturity for older ages declines slightly representing a reduced reproductive potential as the proportion of females in the population progressively declines for older age classes.

2.1.3 Natural mortality and steepness

Both steepness and natural mortality have previously been considered as key sources of uncertainty to be included in the OM uncertainty grid. Steepness, which refers to the slope of the stock and recruitment curve as it approaches the origin, often has little impact on stock assessment results, but can have substantial impact for MSE analyses when evaluating the performance of management procedures in situations where the stock is reduced to low biomass levels.

Similar to the approach taken for this year's stock assessment of south Pacific albacore, steepness and natural mortality are sampled independently from prior distributions. Values for steepness were drawn from a beta distribution with mean 0.87 and variance 0.004 for the range 0.2 to 1.0. Values for natural mortality were drawn from a lognormal distribution with mean of log(0.36), following the approach of Hamel and Cope (2022), and c.v of 0.2 which was applied to ages 4+ in the model with the Lorenzen function configured accordingly. Two hundred steepness and natural mortality pairs were drawn with marginal distributions closely resembling the assumed underlying distributions (Figure 4).

2.1.4 Recruitment

Future recruitment, both in terms of overall recruitment levels and inter-annual recruitment variability is one of the most influential sources of uncertainty impacting stock status. The 2024 assessment indicates a period of highly variable recruitment early in the time series that may be poorly estimated, followed by progressively increasing recruitment from the late 1970's (Figure 5). Recruitment appears to plateau and potentially dip at the end of the time series. It is unclear whether the period of high recruitment will continue into the future, or if recruitment will decline again to levels observed prior to 2000. Two assumptions for future recruitment are therefore included in the OM grid. One that assumes a lower level of overall recruitment based on long-term mean (1972-2020) recruitment, and a second that assumes a higher level of recent (2000-2020) recruitment.

Predictions of future recruitment in south Pacific albacore derived from SEAPODYM models for four different climate scenarios (Senina et al., 2020) indicate long-term declines in recruitment in the WCPFC-CA and increasing recruitment in the EPO (Figure 6). This scenario is not yet represented in the OMs as the current implementation of MFCL does not allow for temporal changes in future recruitment distributions. The assumed distribution of recruitment remains fixed at 90% and 10% for the WCPFC-CA and EPO respectively. These values are informed by recent SEAPODYM analyses and are consistent with the values assumed for the 2024 stock assessment.

2.2 South Pacific albacore fishery dynamics

Catches of south Pacific albacore are predominantly taken in the southern longline fishery that operates in the sub-tropical waters (10-20°S) of the WCPO. Smaller catches are taken in surface troll fisheries that operate in southern regions, in particular around the coastal waters of New Zealand. Seasonal catches of albacore are also taken in longline fisheries in sub-equatorial regions. Catches of albacore in longline fisheries are typically in the range of 80 to 110 cm. Troll fisheries target smaller fish in the 40 to 80 cm range.

Longline fisheries for south Pacific albacore have operated since at least the 1950's with catches progressively increasing until the early 1980's. Catches increased more rapidly in the following decades with the development of the domestic fisheries of several Pacific Island nations. Catches since 2009 have been around 80,000 tonnes (south Pacific wide) with peak catches in 2017 at around 95,000 tonnes (McKechnie et al., 2024).

2.2.1 Fishery definitions

The spatial structure and fishery definitions of the OMs closely follow that of the 2024 stock assessment with the population divided into two spatial regions representing the WCPFC-CA and EPO, and 17 extraction fisheries implemented in a 'fleets as areas' approach (Table 1 and Figure 1). Ten longline fisheries are defined for the WCPFC-CA and 3 for the EPO. Long-line fisheries operating in the equatorial region (0-10°S) have been defined separately to provide the option for alternative management of these fisheries in a broader mixed fishery context, although for current analyses it is assumed that all fisheries south of the equator will be subject to the south Pacific albacore management procedure.

2.2.2 Catch per unit effort

Three index fisheries are defined. Two for the WCPFC-CA representing the main longline fishery and a recruitment/spawning index, and one for the EPO derived from the catch and effort of longline fisheries in that region. Two options for the WCPFC-CA spawning index were initially considered for inclusion in the OM grid. The first was derived from the southern troll fishery to provide an index of juvenile abundance, the second derived a spawning index from the catches of longline fisheries from the sub-equatorial region. Analyses showed little difference in model outcomes from the two CPUE options and only the first option has been retained. Investigation of alternative CPUE options was limited and only one CPUE scenario is currently included in the OM grid. Work will continue to investigate alternative scenarios that may be considered, under the monitoring strategy, for potential inclusion in future OM grids.

Longline CPUE suggests a slight progressive decline since the 1960's but is generally very flat showing little trend over much of the available time series. This is difficult to reconcile given the marked increase in catches observed in recent decades. The potential for hyperstability in CPUE has been considered previously when testing management procedures for tuna species caught predomininantly in purse seine fisheries. In such cases CPUE may remain high in spite of declining stock abundance through the assumption of a non-linear relationship between abundance and catchability (Harley et al., 2001; Scott et al., 2015). It is unclear, however, whether similar processes may operate in longline fisheries. An alternative explanation of the invariant CPUE is that during periods of reduced catch rates, vessels switch from targetting albacore, choosing either to remain in port, or to target alternative species, switching back to targetting albacore when catch rates improve.

A second factor that restricts any consideration of hyperstability in CPUE is that the OMs are now based on a 'catch conditioned' assessment approach. Under this approach the catch data are treated as exact and catchability emerges as an implicit value that has no direct impact on estimates of population abundance. The previous approach for considering hyperstability in CPUE is no longer appropriate and consequently hyperstability is not included in the current OM grid. However, the potential for hyperstability in CPUE, in some form, remains and additional work will be required to explore this issue furher.

2.2.3 Implementation error

Another potential source of implementation error is the occurrence of effort creep in commercial fishing operations. Where effort creep is occurring the efficiency of vessels increases as a result of, for example, technological developments and improvements, such that nominal fishing effort (e.g.days fished) no longer represents a consistent and reliable measure of fishing pressure. The extent to which effort creep is occurring in longline fisheries is unclear, but could be important. Two effort creep scenarios have been included within the OM grid. In the first, effort creep is assumed not to occur, and the second assumes a 1% annual increase in effective effort throughout the projection period. The robustness set includes a third, more severe, level of effort creep. These values have been selected to bound the uncertainty in potential levels of effort creep. Further work will be required to determine more appropriate estimates for longline fisheries.

3 South Pacific albacore OM grid

Although the development of the operating model grid follows the approach taken for the stock assessment quite closely, a number of key changes have been made to ensure that the model structure and design are suitable for simulation testing candidate management procedures. These modifications relate to the preparation of the models to conduct projections and to generate simulated data and comprise: changing the input catch metric from catch in numbers, as used for the stock assessment, to catch in weight, which better reflects a key management metric for the stock; switching the troll fishery input data from a monthly time step to a quarterly time step for the projection period which substantially simplifies the generation of simulated future data; and the explicit estimation of terminal catchability values which are necessary for conducting projections but, as described above, are not formally estimated as part of the stock assessment.

3.1 OM stepwise development

Overall, the changes made to the stock assessment models, described above, had little impact on key model outcomes. Sensitivity tests, conducted on the diagnostic case model, show estimates of stock depletion, recruitment, growth and selectivity remained relatively unchanged following the modifications (Figures 7, 8, 9, 10).

The updated stock assessment employs the 'catch conditioned' model configuration that does not explicitly estimate catchability. Estimates of catchability are required to provide a fishery specific link between catch and effort when conducting effort based projections. An additional step is therefore necessary to estimate fishery specific catchability for each of the operating models. Terminal catchability was estimated from a regression of fishing mortality on fishing effort, allowng for seasonality, using fishery specific catch and effort observations for the most recent 3 years. Observed and predicted values (Figure 11) show that catchability is generally well estimated for all longline fisheries. Catchability was not estimated for troll fisheries and only catch based projections will be conducted for these fisheries.

3.2 OM grid

Models representing the range of scenarios considered for testing candidate management procedures for south Pacific albacore are outlined in Table 2. These scenarios closely resemble current considerations for the 2024 stock assessment uncertainty grid (still under development at the time of writing) as well as considering additional factors that may affect the future dynamics of the stock and the fishery.

We note that some sources of uncertainty previously identified for south Pacific albacore, such as hyper-stability in CPUE and climate change scenarios, are not yet included in the OM grid. These represent important sources of uncertainty and further work will be required to better understand these issues and to develop appropriate scenarios for them. In addition some settings included in the OM grid might be considered preliminary estimates pending further analyses. Scenarios for effort creep have been selected to try to bound their level of uncertainty. We recommend that research continues into these, and other, sources of uncertainty to further develop the OM grid.

Status quo stochastic projections conducted across the OM grid are shown in Figure 13. The projections assume average 2020-22 catch levels into the future, including for the interim period (2023 and 2024). Projections are conducted for the two recruitment scenarios considered above. The results are similar to those provided in WCPFC-SC20/MI-WP-03, but show a slightly greater risk of falling below the LRP. This is because the stock assessment input data are based on catches of albacore in numbers of fish, as compared to the OM grid for which catches are in overall catch weight. Status quo catch based projections for the stock assessment grid assume that the same number of fish will be caught into the future, regardless of their size. Status quo catch projections for the OM grid assume that the same quantity of albacore in tonnes will be caught into the future regardless of numbers. For model runs in which the population declines, fewer large fish will be represented in the catch and a larger number of small fish will need to be caught to achieve the same catch in weight. Consequently, projections based on catch in weight tend to show slightly more pessimistic outcomes.

3.3 Reference set

The OM grid is divided into a reference set and a robustness set (Punt et al., 2014). The reference set is considered to reflect the most plausible scenarios and forms the primary basis for identifying the best performing management strategy. Performance indicators are calculated from the results of evaluations across the reference set (Table 2).

3.4 Robustness set

An initial robustness set is proposed that includes a low recruitment scenario with a more extreme reduction in recruitment than the scenarios considered in the reference set; a higher level of effort creep in longline fisheries; and alternative assumptions for the level of fishing in the WCPFC-CA and EPO.

The robustness set comprises scenarios that are considered less likely, though still plausible, and provides a secondary level of testing when evaluating the performance of candidate management procedures. The main sources of uncertainty included in the reference set of operating models have been developed and parameterised largely on the basis of historical observations. The historical dynamics of the fishery are a useful indication of future status, but there are plausible future scenarios that may deviate from these historical trends. These may include changes to the biology of the stock resulting in, for example, a significant reduction in productivity or changes in the fishery such as a substantial increase in catches in archipelagic waters or in neighbouring regions. With regards to the balance of fishing between the WCPFC-CA and the EPO, scenarios have been selected to test the robustness of the MP to substantial changes in fishery dynamics, rather than on the basis of any expected future changes.

The robustness set comprises a small number of more extreme scenarios and represents a minimal robustness set that can be further considered by the SC (Table 2).

4 Observation error model

A critical function of the grid of operating models is the generation of simulated data used to test the performance of candidate management procedures and in particular the simulation of input data for the estimation method. The estimation method under consideration for the south Pacific albacore MP is based on an age structured production model (ASPM) that requires input data on fishery specific catches and one or more CPUE indices.

Previous analyses have indicated that a c.v. of around 20% to 25% sufficiently resembles the level of observation error for fishery specific estimates of catch and effort (Scott et al., 2023a). Similarly future values of CPUE have been simulated assuming a c.v. of 30% (Figure 14). Under the 30% c.v. assumption for CPUE a number of historical points still fall outside the range of the simulated data, which may suggest that higher levels of variability should be considered. Testing of the estimation method is ongoing and these assumed values represent initial estimates. Additonal, or more extreme values may be considered as part of the OM grid.

5 Conclusions

The proposed OM grid for south Pacific albacore has been revised in line with the updated assessment being conducted this year. Several sources of uncertainty are considered, however, the primary sources of variability in estimates of stock status and population trends are the assumed level of natural mortality and recruitment both in terms of inter-annual variability and overall recruitment levels. Alternative CPUE indices and the assumed level of steepness of the stock and recruitment curve also contribute to uncertainty in stock dynamics along with the assumed level of effort creep in future trajectories.

The proposed OM grid represents an initial set of scenarios for testing candidate management procedures and can be further modifiied and enhanced as new information is attained and additional analyses conducted. In particular future work should focus on further developing scenarios for the impacts of climate change and the potential effects of hyperstability in CPUE.

We invite SC20 to:

- advise whether the sources of uncertainty included in the OM grid are sufficient and if any further scenarios should be considered.
- advise whether the ranges of parameter values adequately reflect uncertainty in stock dynamics.

In addition we invite SC20 to note:

- It should not always be necessary to update the suite of operating models each time a new assessment is conducted. Any changes to the OM grid should be considered as part of an agreed monitoring strategy.
- The grid of models outlined in this report form the basis of the evaluations of candidate MPs for south Pacific albacore detailed in WCPFC-SC20/MI-WP-06.

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A Tables

Table 1: South Pacific albacore fishery definitions.

Gear	number	Code	Flag	Region
Longline	1	LL-DWFN	ALL	1a
Longline	2	LL-DWFN	ALL	1b
Longline	3	LL-DWFN	ALL	1c
Longline	4	LL-DWFN	ALL	1d
Longline	5	LL-PICT	ALL	1ab
Longline	6	LL-PICT	ALL	1cd
Longline	7	LL-AZ	AU/NZ	1abcd
Longline	8	LL-DWFN	ALL	1ef
Longline	9	LL-PICT	ALL	1ef
Longline	10	LL-AZ	AU/NZ	1ef
Troll	11	TR-ALL	ALL	1e
Troll	12	TR-ALL	ALL	1f
Drift net	13	DN-ALL	ALL	1ef
Longline	14	LL-EPO	ALL	2a
Longline	15	LL-EPO	ALL	2b
Longline	16	LL-EPO	ALL	2c
Troll	17	TR-EPO	ALL	2abc
Longline	18	LL-INDEX	ALL	1abcd
Troll	19	TR-INDEX	ALL	1ef
Longline	20	LL-INDEX	ALL	2abc

Table 2: South Pacific albacore tuna OM uncertainty grid (reference set, 800 model scenarios, including 200 pairs of steepness and natural mortality values, sampled independently from prior distributions). ‡ denotes those scenarios for which a dedicated fit of MULTIFAN-CL is required. A minimal robustness set is also proposed.

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Natural mortality ‡	**200**	sampled from prior distbn	
Recruitment distbn ‡	**1**	SEAPODYM	
Movement ‡	**1**	SEAPODYM	
Implementation Error			
Effort creep	**2**	0%	1%
Robustness Set			
Low recruitment	1		
Effort creep	1	2%	
Increased EPO catches	2	50% increase	100% increase

B Figures

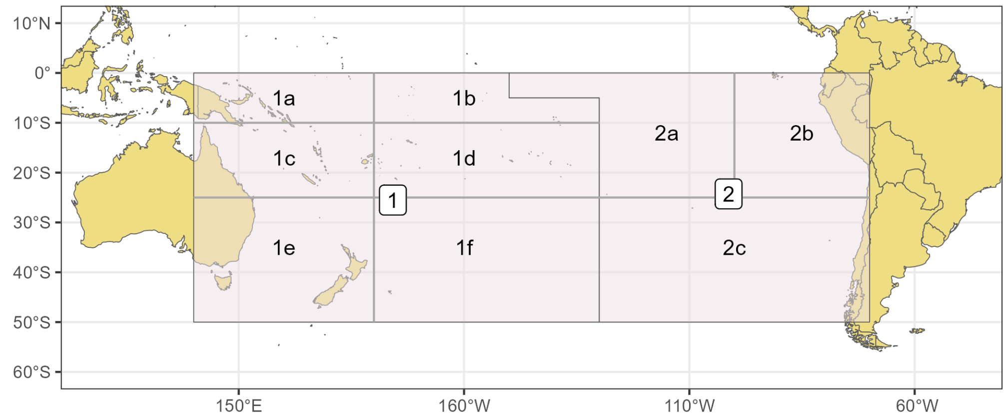
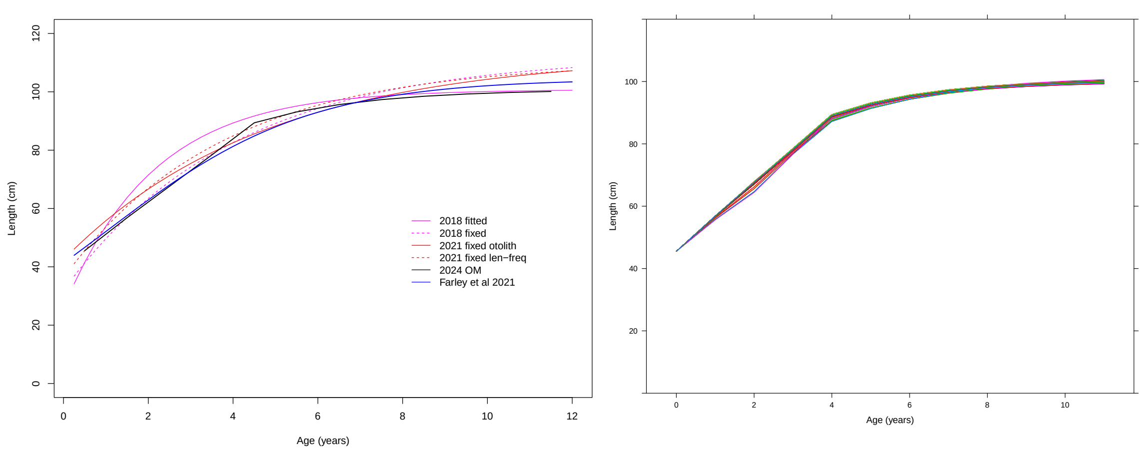


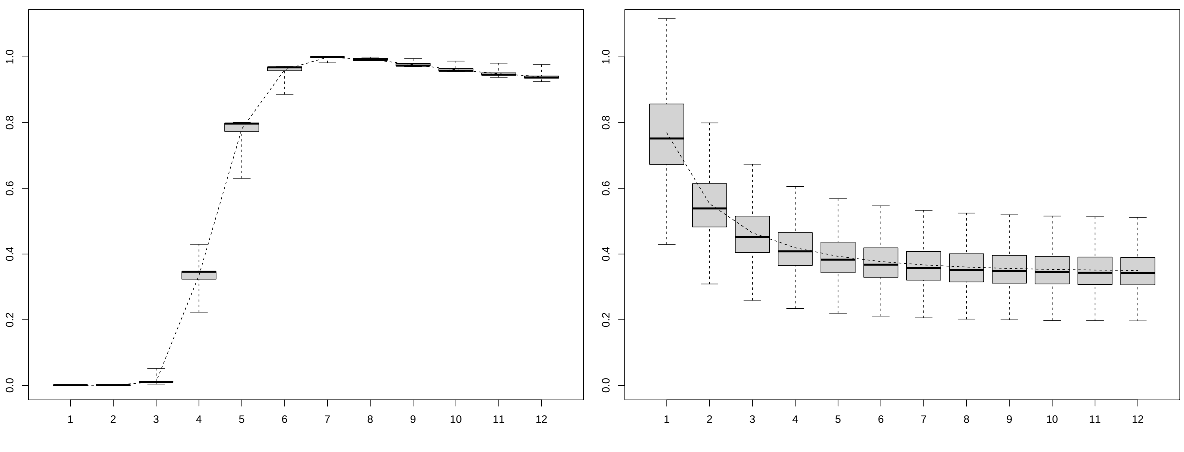
Figure 1: Spatial structure of the 2024 south Pacific albacore OM grid. The population is modelled over 2 regions with assumed mixing. Fisheries are defined for smaller sub-regions and implemented as a fisheries-as-areas approach.



(a)

(b)

Figure 2: Length at age estimates for south Pacific albacore for recent stock assessments (a) and fitted length at age across the grid of 200 (model error) operating models (b).



(a) (b)

Figure 3: Reproductive potential at age (a) and natural mortality at age across the grid of 200 (model error) operating models (b).

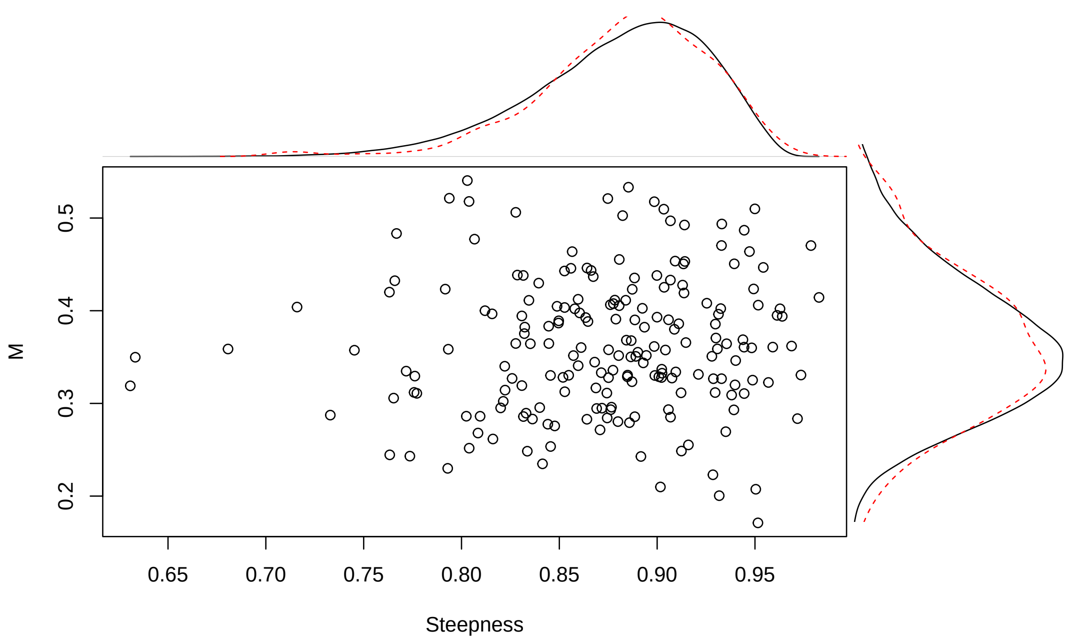


Figure 4: Natural mortality and steepness pairs across the grid of operating models. Density plots show the assumed (black) and marginal (red) distributions of steepness and M.

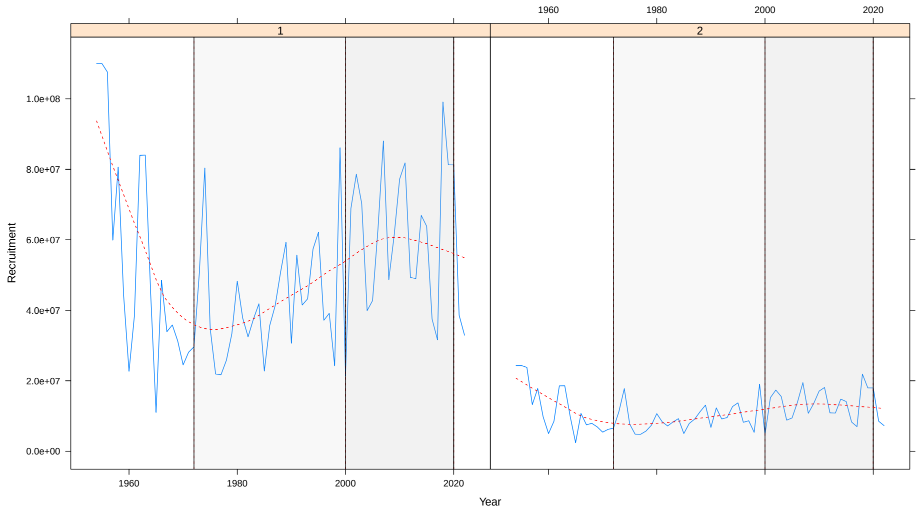


Figure 5: Recruitment time series for the WCPFC-CA (region 1) and the EPO (region 2) from the diagnostic model. Shaded periods represent the time period for re-sampling recuitment deviates representing a long-term time series (1972-2020) for which recrutiment has been both below and above average, and a short-term time series (2000-2020) for which recruitment has been mostly above average. Red dotted line shows a loess smoother with span 0.4

Figure 6: Seapodym estimates of future recruitment for the WCPFC-CA (region 1) and the EPO (region 2) under four different climate models.

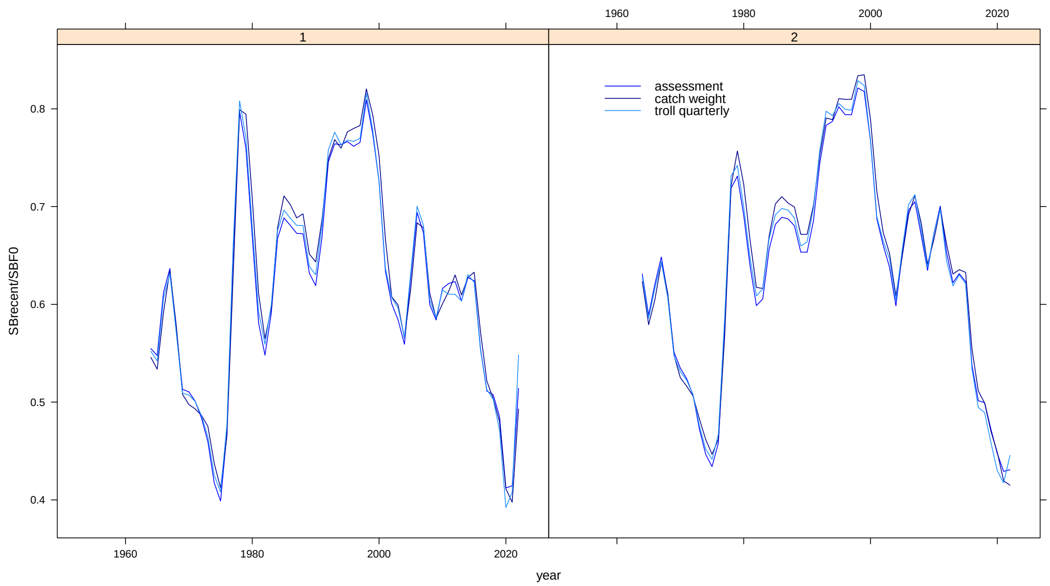


Figure 7: Stepwise changes in estimates of stock depletion from preparation of the operating models. Depletion estimates are shown for the WCPFC-CA (region 1) and the EPO (region 2).

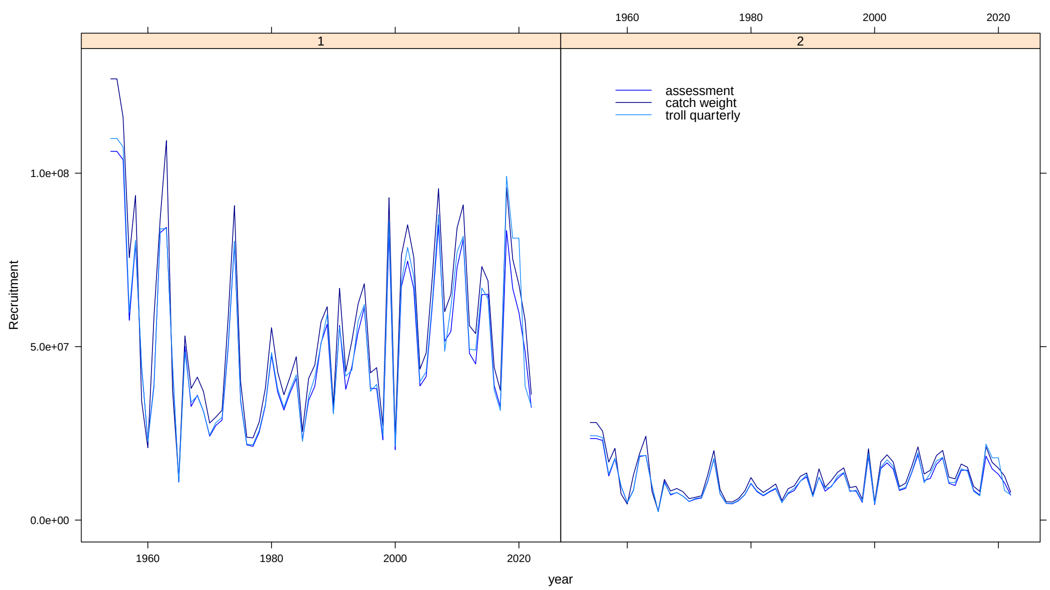


Figure 8: Stepwise changes in estimates of recruitment from preparation of the operating models. Recruitment estimates are shown for the WCPFC-CA (region 1) and the EPO (region 2).

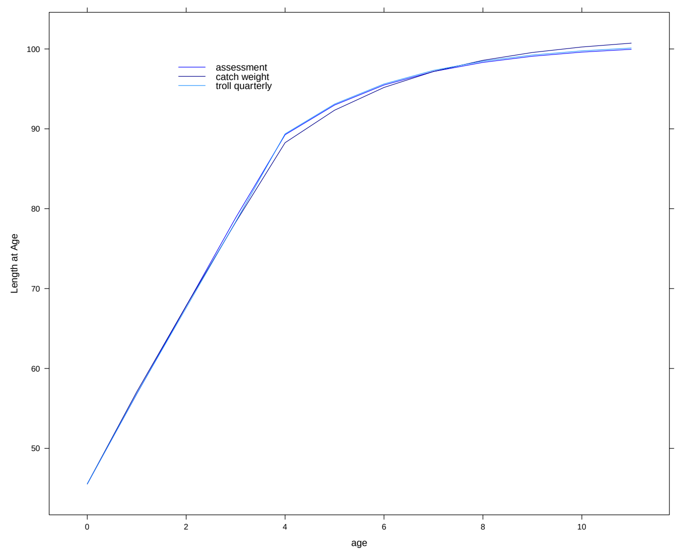


Figure 9: Stepwise changes in estimates of length at age from preparation of the operating models (note that the troll quarterly line is obscured by the line showing the assessment estimates).

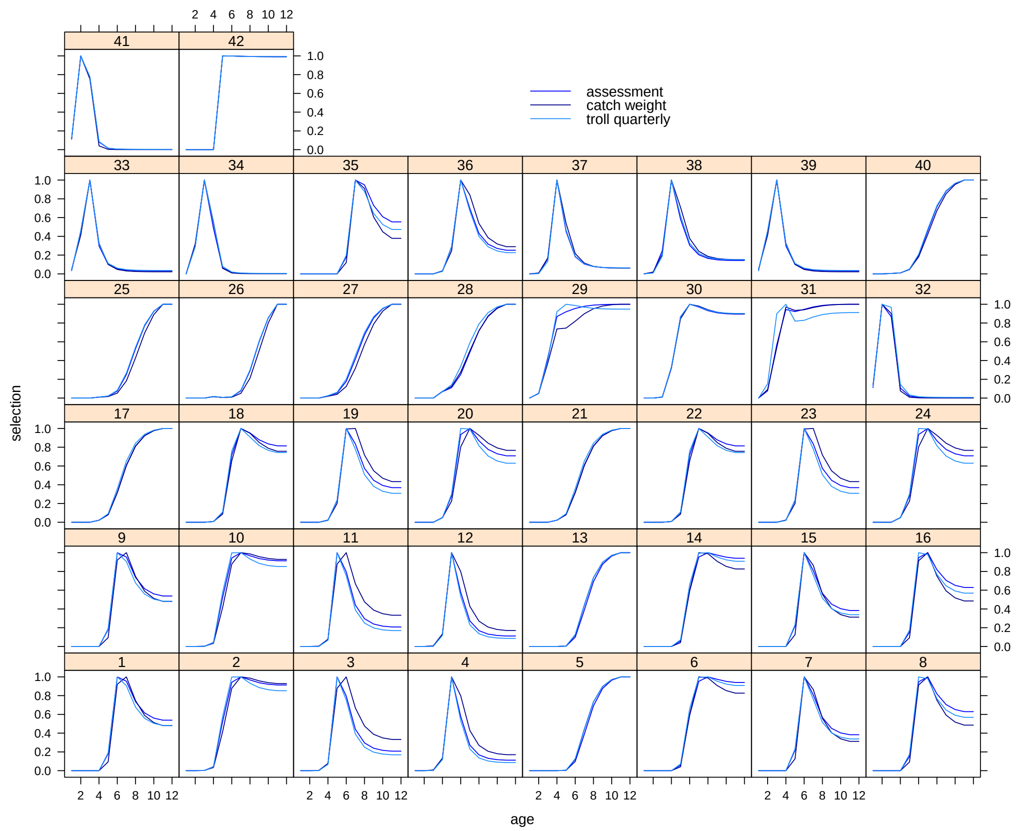


Figure 10: Stepwise changes in estimates of fishery specific selection from preparation of the operating models.

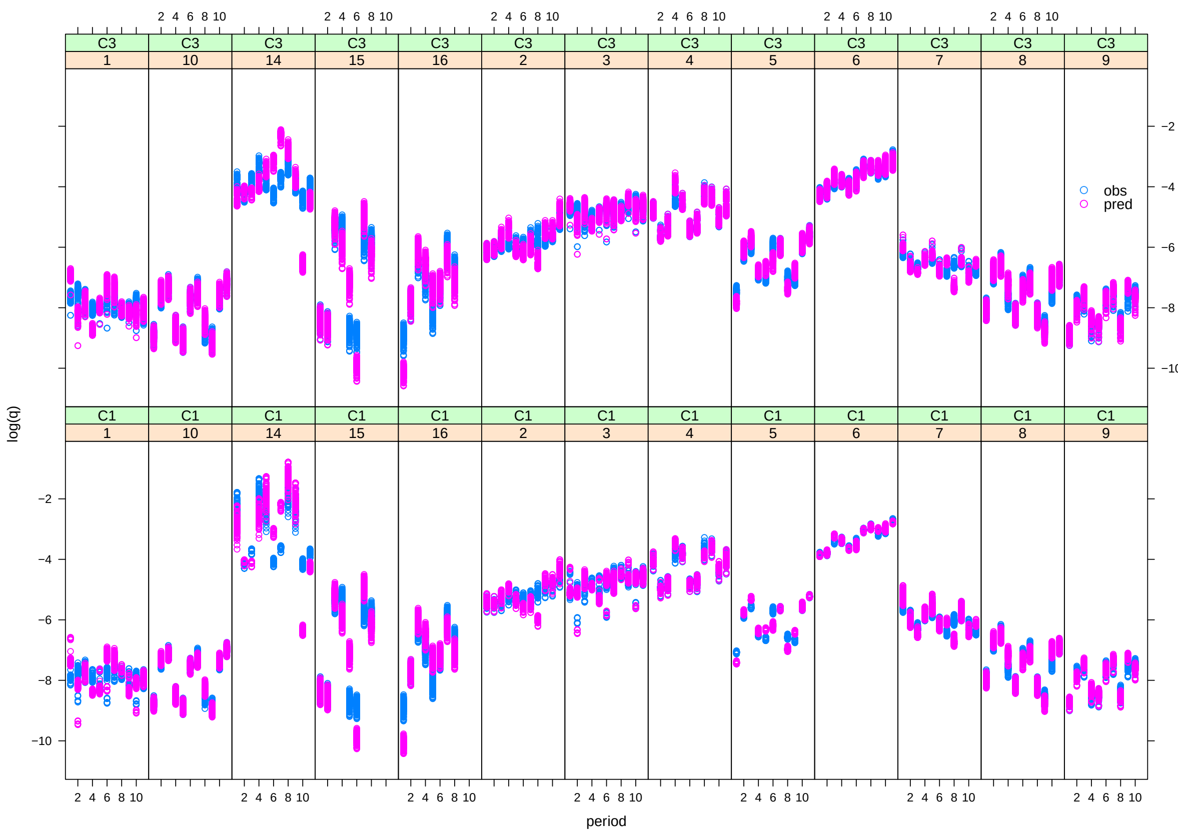


Figure 11: Estimates of log(catchability) for longline extraction fisheries, from fishery specific fishing mortality and fishing effort regressions, allowing for seasonality, across the grid of operating models.

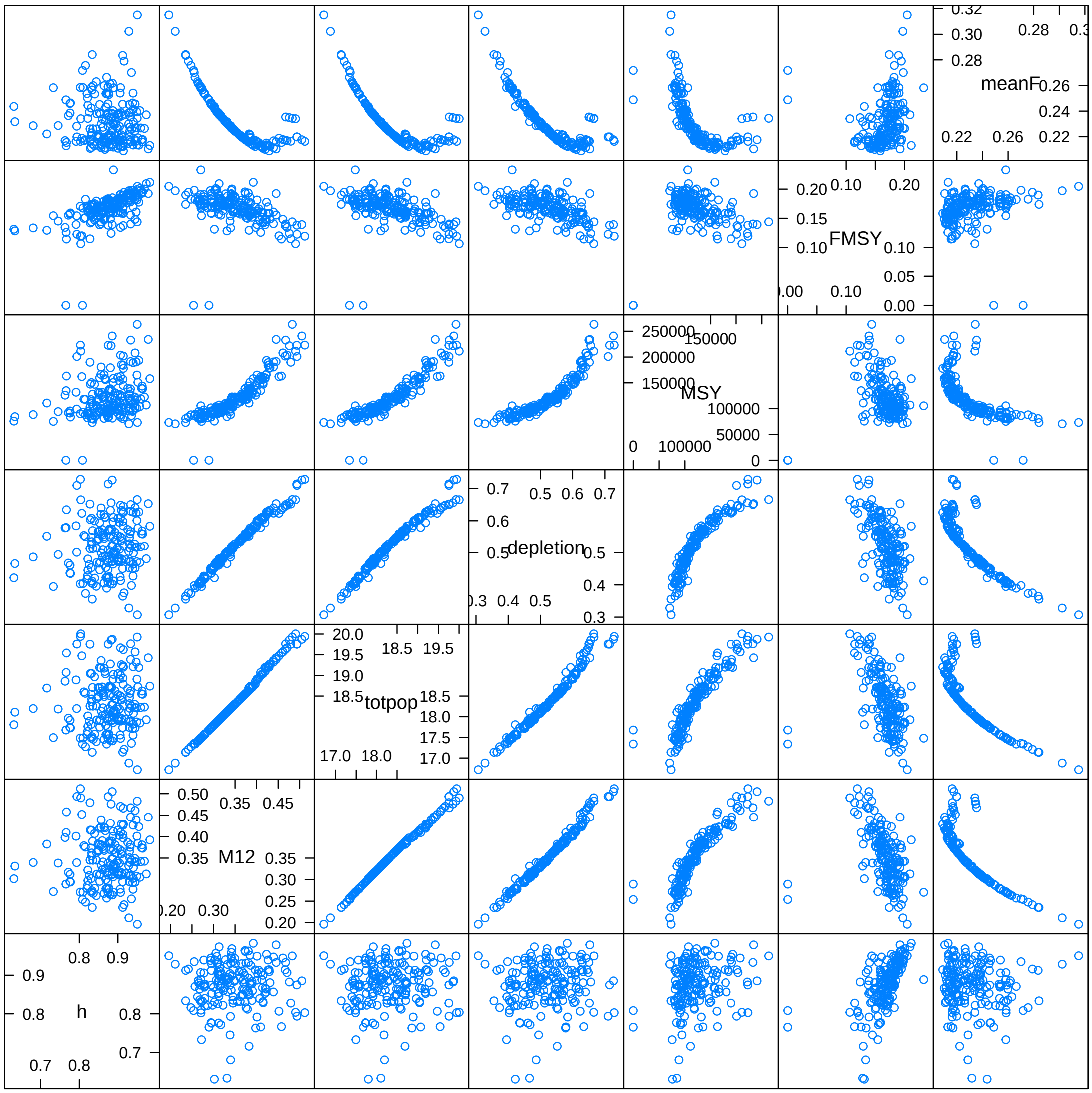
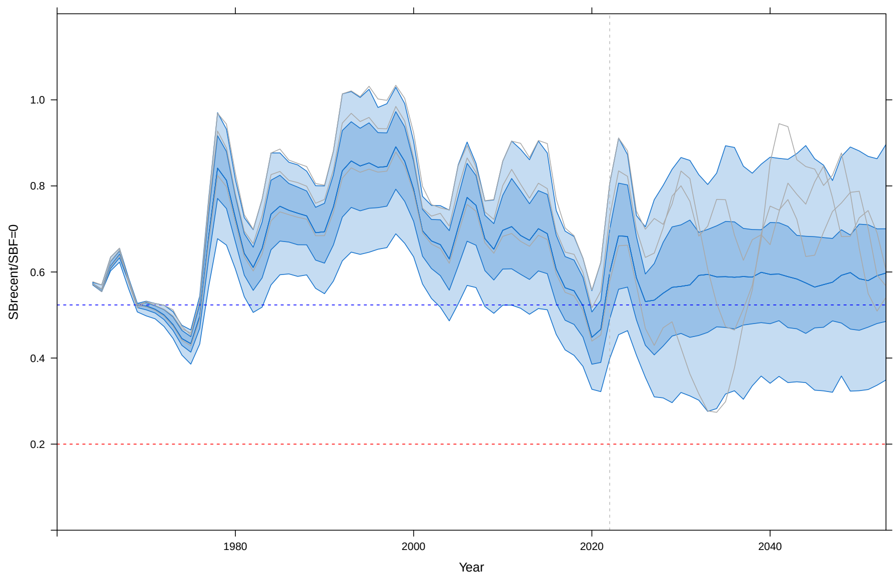
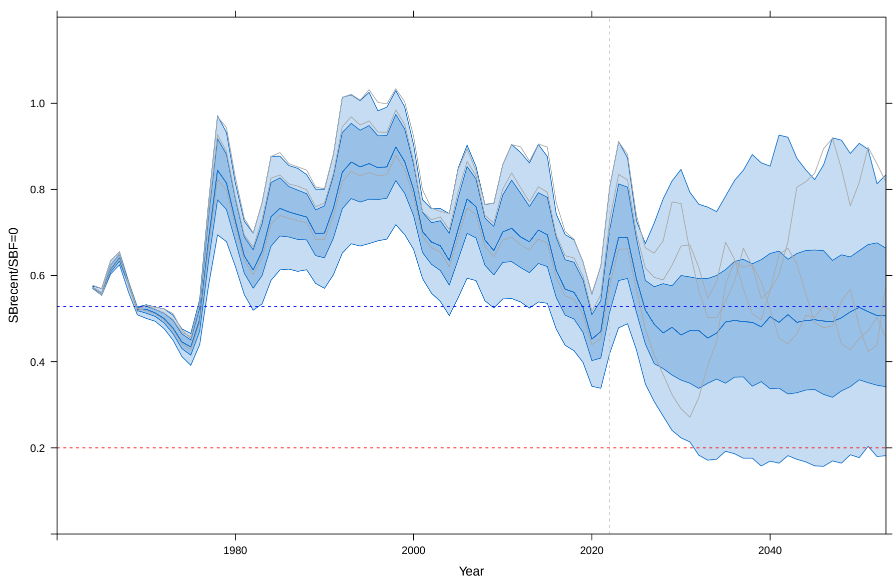


Figure 12: Scatter plot matrix for key factors and model estimates of the albacore OM grid, showing the influence of steepness (h) and natural mortality (M12) on model estimates of depletion (SBrecent/SBF0), MSY and F/FMSY as well as the total population scaling parameter (totpop).

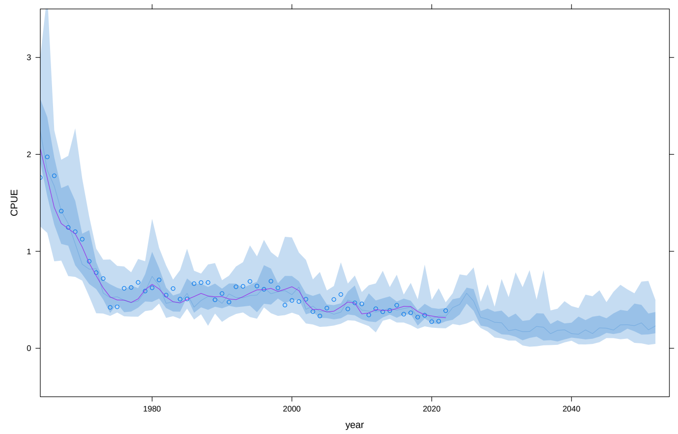


(a) Short-term recruitment (2000-2020).

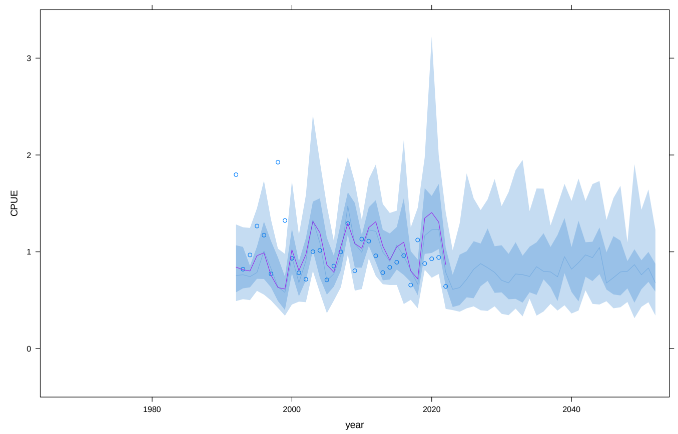


(b) Long-term recruitment (1973-2020).

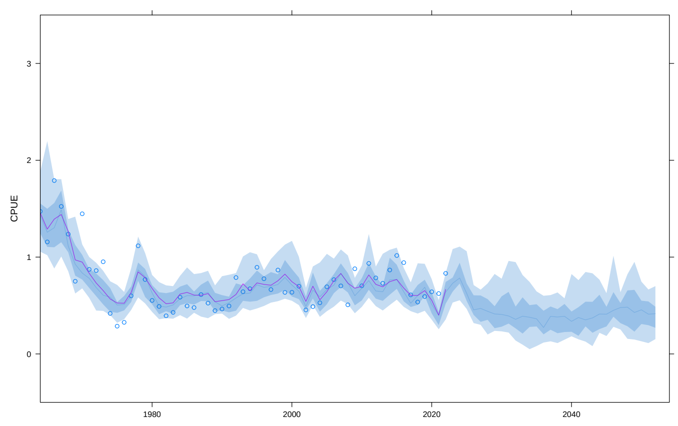
Figure 13: Status quo stochastic projections across the OM grid under long- and short-term recruitment conditions. Horizontal lines show the LRP (red) and the basis of the current iTRP (96 % of average 2017-19 depletion, blue dashed lines). Ribbons show 60th and 95th percentiles of SB.recent/SBF0. Three randomly selected projection runs are also shown (grey lines).



(a) WCPFC-CA longline index.



(b) Troll fishery recruitment index.



(c) EPO longline index.

Figure 14: Observed (points), fitted (lines), and simulated (shaded) CPUE for the diagnostic case model for the 3 index fisheries. Historical (1952:2022) and future (2023:2054) CPUE simulated assuming a 30% cv. Shading shows the 60th and 95th percentile range.