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OPERATING MODELS FOR THE YELLOWFIN TUNA IN THE WCPO

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Executive summary

The WCPFC harvest strategy workplan schedules the adoption of operating models (OMs) for yellowfin tuna in the WCPO at SC22. OMs form the basis of management procedure (MP) testing by providing a set of plausible, alternative biological and operational dynamics for the stock and fishery. Under the proposed WCPFC mixed fishery harvest strategy approach there is no MP that explicitly considers the stock status of yellowfin. Instead, the fisheries that catch yellowfin are managed through the MPs for WCPO skipjack, bigeye and South Pacific albacore. To ensure the outcomes for yellowfin under the mixed fishery approach are consistent with agreed management objectives, the yellowfin OMs are projected under the fishery conditions specified by the adopted MPs of skipjack and South Pacific albacore and a range of potential MPs of bigeye in the companion report (Scott et al., 2026b).

We present a reference set of 144 OMs for WCPO yellowfin tuna that includes alternative settings for steepness, growth, natural mortality, tag mixing, future recruitment variability and effort creep. We consider scenarios for one-off sensitivity analyses including an alternative maturity ogive and alternative catch histories for the domestic fisheries of Indonesia and Philippines.

The 2023 stock assessment grid resulted in a depletion ($SB/SB_{F=0}$) range of 36.2% to 49.8% in 2021. The OM grid presented here includes an expanded range of uncertainty, in particular for growth and natural mortality and results in a terminal depletion ($SB/SB_{F=0}$) range of 34.8% to 54.3% in 2021. The average depletion ($SB/SB_{F=0}$) across the OM grid is 42.8% in the terminal years (2019-2021) and 43.4% during the reference period (2012–2015), so that the terminal stock status relative to the reference period is 98.3%.

Under an agreed monitoring strategy, scheduled for adoption by WCPFC in 2027, the OMs will be regularly reviewed to ensure they remain appropriate, for example, if new information becomes available.

We invite SC22 to:

- note that the reference set of OMs reflects the most important sources of uncertainty and plausible states of nature for WCPO yellowfin tuna,
- agree the reference set of OMs as the basis for evaluating yellowfin outcomes under the WCPFC mixed fishery harvest strategy framework, and
- provide guidence on additional robustness and senstivity testing,
- note that work will continue in the longer-term to further develop the OMs and this can be managed through an agreed monitoring strategy.

1 Introduction

In 2015, WCPFC12 agreed to a workplan for the adoption of harvest strategies for WCPO skipjack, bigeye, yellowfin and South Pacific albacore tuna (WCPFC, 2025b, attachment 16). An important consideration when developing harvest strategies for these stocks is to account for mixed fishery interactions. In 2019, SC15 agreed to initially consider a multi-species framework for developing mixed fishery harvest strategies. Under this proposed mixed fishery approach, single-stock management procedures (MPs) were to be developed for skipjack, South Pacific albacore and bigeye, with the MPs defining fishing levels in the purse seine and pole and line fisheries as well as 'other' fisheries (skipjack), the southern longline fishery (South Pacific albacore) and the tropical longline fishery (bigeye). An interim skipjack MP was adopted in 2022 (WCPFC, 2022, CMM 2022-01), the South Pacific albacore MP was adopted in 2025 (WCPFC, 2025a, CMM 2022-01) and the the bigeye MP is scheduled for adoption in 2026.

Under the proposed mixed fishery framework, there is no MP that explicitly considers the stock status of yellowfin. Instead, the fisheries that catch yellowfin are primarily managed through the MPs of bigeye, skipjack and South Pacific albacore. However, it is still necessary to evaluate likely outcomes for yellowfin under the MPs for those stocks, and assess the probability of achieving agreed yellowfin management objectives. It will, therefore, be necessary to develop a management strategy evaluation (MSE) framework for yellowfin to perform these evaluations.

Operating models (OMs) form the basis of MP testing by providing a set of plausible, alternative biological and operational dynamics for the stock and fishery. In the case of yellowfin, the tested MPs are the bigeye, skipjack and South Pacific albacore MPs. Uncertainty in biological processes and fishery operations should be sufficiently represented in the set of OMs so that MPs can be tested against these uncertainties. Under the WCPFC harvest strategy workplan, SC22 is scheduled to agree the OMs for yellowfin tuna in the WCPO.

SC21 recommended that the OMs be based on the 2023 stock assessment spatial structure and fishery definitions, with further investigation of spatial structure to be undertaken in the longer-term. A stock assessment of yellowfin tuna in the WCPO is also scheduled for 2026. Work to condition the operating models has, therefore, run concurrently with work to develop the updated stock assessment. As such, it has not been possible for any significant developments to the stock assessment in terms of, for example, spatial structure and fishery groupings to be represented in the OMs. The 2026 stock assessment can be used to identify further areas of potential OM development.

In this paper we develop a grid of OMs for WCPO yellowfin tuna, designed to capture the most important sources of uncertainty. As a starting point, we consider the scenarios identified in recent stock assessments (Magnusson et al., 2023) as well as the recommendations from the review of the 2020 yellowfin stock assessment (Punt et al., 2023). We note that the stock assessment uncertainty grid includes factors that affect the current status and historical trajectory of the stock and investigate a limited set of additional sources of uncertainty associated with both past and future stock dynamics. We consider previous work on retrospective analyses to determine the prediction skill of the proposed operating models. We present recommendations for an OM grid and investigate options for simulating future catch and effort data.

2 Methods

SC21 recommended that the yellowfin OMs be "constructed around the 2023 stock asssessment grid, consistent with the aproach used for the other key tuna species. Additionally, it was recommended that the proposed OM grid be expanded to also take into account similar additional uncertainties as suggested for the bigeye OM grid, as well as recommendations from the past tuna assessment peer reviews" (WCPFC, 2025b).

The 54 model grid from the 2023 assessment contained different settings for the steepness of the stock recruitment relationship, weighting of the size composition data and conditional age-at-length data, and tag mixing period (Figure 4). Growth was not included as an uncertainty axis since it was estimated by the model as suggested in the independent review (Punt et al., 2023). Within the 2023 stock assessment grid, steepness and tag mixing period were most influential on stock status ($SB/SB_{F=0}$) so these uncertainties were retained for the OMs.

Eight areas of uncertainty were identified for further consideration in the bigeye OM grid (Table 1), noting that it may not be possible to address all of them in the short-term. For the yellowfin OMs, we included uncertainty in growth and natural mortality, resulting in 36 combinations of different parameter settings for OM conditioning (see Table 3). For the projection period, two additional axes of uncertainty were included: effort creep and recruitment deviations.

Table 1: List and priorities of uncertainties to be considered in bigeye tuna and yellowfin tuna operating models.

Uncertainty	Priority	Timing
Growth	High	Short (preferably by 2026)
Natural mortality	High	Short (preferably by 2026)
Movement dynamics	High	Short (preferably by 2026)
Hyperstability in CPUE	High	Short (preferably by 2026)
Variability in recruitment	High	Short (preferably by 2026)
Spatial structure	High	Long
Uncertainty in domestic catch level	High	Long
Effect of climate change	High	Long

2.1 Model structure

The proposed OMs retain the same 5-region spatial structure (Figure 3) that was used in the 2023 stock assessment of yellowfin tuna in the WCPO (Magnusson et al., 2023) and have largely retained the associated fishery definitions (Table 2). To facilitate analyses for the proposed mixed fishery design (Scott et al., 2023) for which the tropical longline fishery (TLL) extends from 20°N to 10°S, three additional longline fisheries were defined (Fisheries 33 to 35) to allow separation of the longline fisheries in Regions 1 and 2 at 20°N. Selection patterns for these fisheries were mirrored to their counterparts north of 20° north to remain consistent with the stock assessment estimates.

A further change to the fishery definitions was to separate the handline fisheries of Indonesia and Philippines into two distinct components (fisheries 18 and 36, Table 2). These fisheries have different operational characteristics and target different components of the stock. Separating them allows fishery specific selectivity to be more appropriately determined and also isolates the Indonesian handline fishery for which there is considerable uncertainty in catch and effort statistics.

The yellowfin OMs were conditioned with MultiFan-CL and projected using the in-house framework called *masala*.

2.2 Steepness

Steepness is defined as the ratio of the equilibrium recruitment produced by 20% of the equilibrium unexploited spawning potential to that produced by the equilibrium unexploited spawning potential (Francis, 1992; Harley, 2011). Typically, fisheries data are not very informative on the steepness parameter. Hence, the stock assessment fixed steepness at a moderate value (0.80) and the sensitivity of the model to the value of steepness was explored by setting it to lower (0.65) and higher (0.95) values. Furthermore, the high CV (2.2) of the log-recruitment deviates reduced the impact of the value of steepness.

2.3 Tag mixing

Tag mixing describes the model process in MultiFan-CL whereby fish released with tags are designated a certain number of time periods to mix with the untagged population before they are available to be recaptured by the fishery. In general, the longer the mixing period, the more tags are excluded from the model.

Alternative tag mixing periods were explored in the stock assessment. The yellowfin independent review discussed mixing period assumptions and supported the approach applied to the 2022 skipjack assessment (Punt et al., 2023; Castillo-Jordan et al., 2022) whereby an external individual based model was used to estimate mixing periods but this approach had not been developed for yellowfin yet. An external analysis of tag-recapture patterns was undertaken in lieu of a yellowfin individual based model (Teears et al., 2023). Overall, for tag releases with good numbers of recaptures the qualitative analyses in Teears et al. (2023) supported mixing periods of 1 and 2 quarters which were retained for the OM grid.

2.4 Growth

The independent review recommended growth be estimated within the population model due to bias in external estimations (Punt et al., 2023). Therefore, growth was estimated in the 2023 stock assessment. This required the mean length of the first age class (the L_1 model parameter) to be fixed. This approach led to a very narrow exploration of yellowfin growth throughout the 2023 stock assessment grid.

In the first half of 2026, over 300 age-length samples were added to the yellowfin data from the ageing lab of SPC (Wakefield et al., 2026) and the Fisheries Research Agency (FRA) of Japan (Hasegawa et al., 2026), noting that the samples from Japan were aged by Fish Aging Services (FAS). Two growth models were fitted to these updated data (n=1832) using the R package fishgrowth, with and without the samples from Japan. The samples from Japan were excluded in one of the models due to the different sample location and potential over-representation from the northern region. The extent of spatial differences in yellowfin growth has not yet been determined. Tagging data was not included in the growth models. With the additional yellowfin age-length samples, the resulting curves sat between the 2023 stock assessment model and the model from Farley et al. (2020) (see Figure 1).

In contrast to bigeye, the data supported a narrow range of plausible growth models so the OMs presented in this paper use the parameters from the two most different growth models, the mean growth estimated in the 2023 stock assessment and the growth model estimated by Farley et al. (2020). In order to coerce the model to consider different growth parameters, these parameters were fixed in the OM grid.

2.5 Natural mortality

The assumed level of natural mortality (M) can be a highly influential parameter when modelling population dynamics, but is also very difficult to estimate. The 2023 stock assessment applied a Lorenzen functional form for M-at-age estimation with the asymptotic value of M being estimated. In the proposed OM set, three values of natural mortality were used: 0.173 from the 2023 stock assessment, 0.25 from the 2020 stock assessment, and 0.2 as a plausible middle ground. The corresponding Lorenzen parameter was set to maintain the Lorenzen relationship between natural mortality and growth. As a result, the OMs contain six different natural mortality-at-age relationships as shown in Figure 2.

2.6 Effort creep

A 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 activity over time.

Two effort creep scenarios have been included within the OM grid. In the first, effort creep is assumed not to occur. The second assumes a 2% annual increase in effective effort for purse seine fisheries, similar to the levels assumed when testing the skipjack MP, and a 1% annual increase in effective effort for longline fisheries. Higher levels of effort creep might be considered for robustness testing. These values are informed by recent studies to determine appropriate estimates of effort creep (Hoyle, 2025; Hamer et al., 2024), but are also selected to bound the uncertainty in potential levels of effort creep.

2.7 Recruitment

Variability in future recruitment is one of the most significant sources of uncertainty affecting the future dynamics of the stock. Since it is unclear what overall level of recruitment may occur in the future, two options were considered and included in the OM grid. Recruitment deviation values were sampled from either the long term (1969–2020) or short term (2010–2020) historical values to add environmental and biological uncertainty in the projection period. The recruitment deviations over the long term were more variable and less positive than the short term recruitment deviations (Figure 9).

2.8 Hyperstability

Stock assessments typically assume that catch per unit effort (CPUE) scales in strict proportion with stock abundance. But for schooling species that form aggregations, such as tunas, there is the potential for CPUE to remain high as stock abundance declines. This is known as hyperstability in CPUE (Harley et al., 2001; Gaertner and Dreyfus-Leon, 2004) and, if not properly accounted for, can lead to biased population estimates (Scott et al., 2015). The true extent of hyperstability in CPUE can be very difficult to determine. Instead, management procedures are often tested against a range of hyperstability assumptions to determine if they are robust to it, in the event that it is occurring.

We note the potential for hyperstability in CPUE for catches of yellowfin tuna in purse seine fisheries but consider it is less likely to occur in longline fishing operations. However, for technical reasons, hyperstability in CPUE is not currently included in the OM grid. The basis of the OMs are catch-conditioned models that do not use fishery specific effort data for extraction fisheries. As such the model provides no fishery specific estimate of catchability to which the biomass dependent exponent of the hyper-stability relationship can be applied. Options for including hyper-stability in the models comprising the OM grid are currently being explored with a view to including it in future iterations of the MSE framework.

2.9 Climate change impacts

The development of climate change scenarios and their incorporation into operating models for WCPO stocks has been identified as an important task, but one that may not be possible to address in the short-term. The design and implementation of current models used in the development of the MSE framework do not fully suport the functionality required to develop and test alternative climate change scenarios. The necessary tools (e.g. *masala*) are under development and are used extensively for evaluating candidate bigeye management procedures (Scott et al., 2026a), but are not yet sufficiently developed to incorporate specific climate change scenarios.

Recent developments in the quantitative modelling of tuna population dynamics using SEAPODYM (Senina et al., 2023, 2026) provide a platform for developing scenarios for alternative spatial structures, movement rates and recruitment distributions under climate change predictions. In addition, studies of the historical variability of key biological processes and fishery characteristics (Gislard and Scutt-Phillips, 2026) can also inform on trends and variability for future scenarios.

2.10 Sensitivity scenarios

Additional testing at this stage focussed on one-off sensitivity analyses to investigate the impact of alternative maturity ogives, catch scenarios and tag mixing periods. Four sensitivity scenarios were run to investigate the model's sensitivity to plausible scenarios not included in the OM set. These sensitivity scenarios may form part of the future robustness testing for the yellowfin evaluations.

Maturity

The first sensitivity investigated the maturity ogive using the updated parameters for yellowfin presented in (2026). The recent analysis found that 50% of yellowfin achieve maturity by 90.76cm, a 14% length-reduction compared to the previous analysis in the WCPO conducted nearly 30 years ago (Itano, 2000). Figure 24 compares the maturity ogive of the sensitivity scenario with the equivalent model from the OM set.

This result may suggest the yellowfin stock is experiencing Fishery Induced Adaptive Changes (FIAC) similar to the observations in the EPO whereby a decrease in length-at-maturity over a 30-year period was attributed to fishing pressure (Schaefer and Fuller, 2022). If this were the case, neither maturity ogive would be appropriate and time-varying maturity would likely be the most plausible implementation. The new histological analysis of gonad tissue in Gislard and Scutt-Phillips (2026) also found significant spatial variation in maturity. At this point in time, the modelling framework cannot implement time-varying nor spatially-varying maturity so these were not considered in the sensitivity scenarios.

Allocation of domestic catch

The second sensitivity looked at the proportion of catch in the domestic fishery of Indonesia allocated to the domestic handline. The catch data from domestic fisheries of Indonesia revealed a significant change in fishery composition in 2024 compared to the historical data. The proportional split of Indonesia catch allocated to the large fish handline and the miscellaneous domestic fishery (drift gillnet, gillnet, small fish handline, troll, and other) changed from an average of 22%/78% from 2010 to 2021 to 54%/46% in 2024. To investigate the possibility that the most recent proportion may have also applied for the historical period, the large fish handline catches were increased and the miscellaneous domestic catches were decreased to match the 54%/46% split and maintain the same total catch of both fisheries (see Figure 25).

Total domestic catch

The third sensitivity increased the total catch from domestic fisheries of Indonesia in region 2 to test the model's sensitivity to region 2 catches if they were historically underestimated or underreported. The catch data from the large fish handline in 2024 showed a dramatic spike compared to the historical levels. For this sensitivity, the historical catches were scaled by 2.75 such that the maximum observed annual catch historically was equal to the 2024 annual catch in the large fish handline fishery. The new catches provided to the model are compared to the original catches in Figure 27.

Tag mixing period

The final sensitivity scenario investigated the tag mixing period. An extended set of sensitivity scenarios were run with 3 quarter tag mixing across all of the natural mortality, growth and steepness options (18 models in total). Allowing the tags to mix for 3 quarters extended beyond the results supported by the qualitative analyses in Teears et al. (2023).

3 Results

Operating models expand on the "best" models typically seen in stock assessments by exploring plausible alternative parameter values and processes. In the case of yellowfin and other tunas in the WCPO, the OMs have been conditioned on mostly the same data as the most recent stock assessment. As described in the sections above, there were some minor changes in the fishery structure and accordingly, data. The objective of the OMs is to explore the range of uncertainty rather than achieve the best model fit. However, the model should still fit the data well.

3.1 Stock status

The 2023 yellowfin stock assessment grid resulted in a depletion range of 36.2% to 49.8% in 2021. With the addition of uncertainty in growth and natural mortality, the set of proposed yellowfin OMs range from a depletion value of 34.8% to 54.3% in 2021 (Figure 5). The absolute spawning biomass was significantly impacted by the assumed value of natural mortality, with the lowest natural mortality ($M = 0.173$) resulting in an initial spawning biomass close to double the models with the highest mortality ($M = 0.25$) (Figure 6). Overall, across the OM grid, the depletion was 42.7% during the terminal years (2019–2021), approximately 98.3% of the average depletion during the reference period (2012–2015).

3.2 Recruitment

The proportional distribution of recruitment was quite consistent throughout the model time period (Figure 7). Region 3 had a very small proportion of annual recruitment throughout the entire timeseries. This result is consistent with the most recent stock assessment (Magnusson et al., 2023, Figures 42–44) and broadly consistent with recent results on a mixed reproductive composition in this region (Gislard and Scutt-Phillips, 2026, Figure 3). Region 2 received 30% to 40% of the recruits consistently through time. A different seasonal pattern was estimated in each region (Figure 8).

3.3 Selectivity

The selectivity of the additional fisheries in the OMs were estimated at plausible values. Notably, selectivities of the handline fisheries of Indonesia and Philippines (HL.ID.2 and HL.PH.2) were fitted separately and this resulted in a higher selectivity for younger fish in the Philippines handline fishery (full selection around 20 quarters compared to 35 quarters in the Indonesian handline fishery). The greatest variation between the estimated selectivities of the OMs was seen in the longline fisheries in Region 1, Region 2 and Region 5. For example, the selectivity for the oldest age for the longline fishery in Region 2 (LL.ALL.2) varied from less than 0.5 to 1. Strongly dome-shaped patterns potentially allow for substantial cryptic biomass in the population.

This range of selection patterns will likely result in highly variable estimates of maximum sustainable yield (MSY) and fishing mortality relative to fishing mortality at MSY (F/FMSY) as seen in the bigeye OMs (Scott et al., 2026c). Methods for calculating MSY under the revised MSE framework are ongoing. Results for MSY based performance indicators for the projection period are not currently available but will be presented for future MP evaluations.

3.4 Movement

The estimated movement between the model regions was very similar to the 2023 stock assessment, with the most significant movement from Region 3 to Region 5 and almost no movement to and from Region 1 (Figure 11). Uncertainty in yellowfin movement rates was suggested for inclusion in the OM grid by SC21 with high priority but noted that this may not be possible in the short-term. We propose that this area of uncertainty be considered in the longer-term alongside issues of stock distribution, spatial structure, and the potential impacts of climate change.

3.5 Diagnostics

Model diagnostics were examined for the 36 OMs that were conditioned on data from the historical period. All OMs were conditioned using MFCL and took approximately 24 hours to run. The fits to CPUE, length and weight composition data (Figure 12, Figure 13 and Figure 14) were consistent across all 36 OMs and closely resembled the fits from the 2023 stock assessment (Magnusson et al., 2023, Figures 22 and 23). Fits to the tagging data were consistent across all the OMs for the Pacific Tuna Tagging Programme (PTTP), Regional Tuna Tagging Programme (RTTP) and Japanese Tagging Programme (JPTP) (Figure 15 – Figure 17). Standardised residuals for tag recapture estimates were also similarly estimated across the OM grid (Figure 18) with a general pattern for initial over-estimation of tag recaptures and subsequent tendency for under-estimation of recaptures at times at liberty greater than three quarters.

Likelihood profiles reveal how key quantities are impacted by different data sources. In the 2023 stock assessment, the likelihood profile of the diagnostic model (most similar to OM4 in the OM set) showed that weight frequency data conflicted with the length frequency data, CPUE data, tag data and age data in the estimation of the spawning stock biomass scale parameter (Magnusson et al., 2023, Figure 12.1). Likelihood profiles are shown for two randomly selected models of the OM grid (Figure 19). The likelihoods were dominated by tag composition data foremost and weight composition data second. Both profiles indicate conflicts within the data which have not been resolved.

Due to time constraints, retrospectives have not been conducted. Retrospectives conducted for the 2023 stock assessment indicated no evidence of strong retrospective bias (Magnusson et al., 2023, Section 12.2). Future investigation of operating models for yellowfin tuna should include consideration of retrospective analyses wherever possible.

3.6 Sensitivity scenarios

The sensitivity scenarios explored in this report indicated relatively little impact on estimates of depletion for the stock as a whole (Figure 22 and Figure 28). The impact on future stock status from projections and fishery specific impacts within the region, remains to be fully explored.

Maturity

The alternative maturity sensitivity scenario, as described in Section 2.10, resulted in a larger absolute spawning biomass (Figure 21) and slightly less depleted stock (Figure 22), consistent with a larger proportion of the stock becoming mature at smaller sizes under the revised maturity schedule. The consequences of a fishery-induced decrease in length-at-50%-maturity are more likely to materialise in MSY results, whereby genetic changes caused by selective harvest may change the mean-weight of harvested fish and total harvest (Schaefer and Fuller, 2022; Conover and Munch, 2002). Methods for calculating MSY under the revised MSE framework are ongoing.

Allocation of domestic catch

The domestic catch allocation sensitivity scenario, as described in Section 2.10, resulted in a larger absolute spawning biomass (Figure 21) and slightly less depleted stock (Figure 22). At a regional scale, Region 2 recovered noticeably between 2007 and 2012, but resulted in the same depletion level in 2021 to the equivalent model from the OM set (Figure 23). All other regions were slightly less depleted for the entire timeseries. The selectivities for fisheries operating in Region 2 showed minor differences when compared to the equivalent model from the OM set (Figure 26).

Total domestic catch

Similar to the other sensitivity scenarios, the total domestic catch sensitivity scenario, as described in Section 2.10, resulted in a larger absolute spawning biomass (Figure 21) and slightly less depleted stock (Figure 22) than the equivalent model from the OM set.

Tag mixing period

Setting the tag mixing period to 3 quarters caused more tag data to be excluded from the model since tags recaptured during the mixing period are discarded by the model. With fewer tags and a more mixed population, the tag attrition residuals (Figure 29) are noticably smaller than the residuals from the OM set (Figure 18).

The relative stock status of the scenarios run with a 3 quarter tag mixing period was generally less depleted than the OM reference set (1 quarter and 2 quarters mixing periods) (Figure 28). Most of the models resulted in a population trajectory already contained within the OM set.

For sensitivity scenarios and robustness testing, the precautionary principle would recommend investigation into factors that result in a more pessimistic stock. In the case of yellowfin, the 3-quarter tag mixing period scenarios do not seem to be an important uncertainty for the OM grid.

3.7 Further work

The proposed OM grid comprises 36 models, based on a combination of model and projection settings. It incorporates many of the most influential sources of uncertainty, most notably in alternative assumptions for growth and natural mortality. Additional sources of uncertainty have been identified that should be considered for future inclusion in the OM grid. These include alternative spatial structures and movement dynamics; recruitment distribution, assumptions on population biology including reproductive potential, and climate change scenarios. Additional sensitivity and robustness scenarios can also be developed. Furthermore, the 2026 stock assessment for yellowfin may inform additional uncertainties to be included in the OM grid.

In some cases further work will be required to develop appropriate scenarios, in particular for climate change and spatial distribution. We note that the OM grid can be modified as new information and modelling approaches become available, and that under an agreed monitoring strategy, the OMs will be regularly reviewed to ensure they remain appropriate.

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Declaration of generative AI and AI-assisted technologies

No AI technologies were used in the preparation of this paper.

4 Appendix

Table 2: Definition of fisheries for the yellowfin tuna operating models.

Number	Fishery	Flag	Region	Selectivity.Group
1	LL.ALL.1a	ALL	1	1
2	LL.ALL.1b	ALL	1	2
3	LL.US.1	US	1	3
4	LL.ALL.4a	ALL	4	4
5	LL.OS.4	OS	4	8
6	LL.OS.2	OS	2	9
7	LL.ALL.2	ALL	2	10
8	LL.ALL.3	ALL	3	11
9	LL.ALL.4b	ALL	4	5
10	LL.AU.5a	AU	5	12
11	LL.ALL.5a	ALL	5	7
12	LL.ALL.5b	ALL	5	6
13	PS.ASS.4a	ASS	4	13
14	PS.UNA.4a	UNA	4	16
15	PS.ASS.4b	ASS	4	14
16	PS.UNA.4b	UNA	4	17
17	MISC.PH.2	PH	2	19
18	HL.PH.2	PH	2	20
19	PS.JP.1	JP	1	21
20	PL.JP.1	JP	1	22
21	PL.ALL.4	ALL	4	23
22	PL.ALL.3	ALL	3	24
23	MISC.ID.2	ID	2	25
24	PS.PHID.2	PH.ID	2	28
25	PS.ASS.3	ALL	3	15
26	PS.UNA.3	ALL	3	18
27	LL.AU.5b	AU	5	12
28	PL.ALL.2	ALL	2	26
29	LL.ALL.5	ALL	5	7
30	PS.ASS.2	ASS	2	13
31	PS.UNA.2	UNA	2	16
32	MISC.VN.2	VN	2	27
33	SLL.ALL.1a	ALL	1	1
34	SLL.ALL.1b	ALL	1	2

Table 2: Definition of fisheries for the yellowfin tuna operating models.

Number	Fishery	Flag	Region	Selectivity.Group
35	SLL.US.1	US	1	3
36	HL.ID.2	ID	2	29
37	Index.1	ALL	1	30
38	Index.2	ALL	2	30
39	Index.3	ALL	3	30
40	Index.4	ALL	4	30
41	Index.5	ALL	5	30

Table 3: Parameter settings for yellowfin OMs. Effort creep and recruitment uncertainty expand the total number of OMs to 144.

OM	Lmin	Lmax	k	M	h	tmix
1	19.8	141.96	0.13	0.17	0.65	1
2	19.8	141.96	0.13	0.17	0.65	2
3	19.8	141.96	0.13	0.17	0.80	1
4	19.8	141.96	0.13	0.17	0.80	2
5	19.8	141.96	0.13	0.17	0.95	1
6	19.8	141.96	0.13	0.17	0.95	2
7	19.8	141.96	0.13	0.20	0.65	1
8	19.8	141.96	0.13	0.20	0.65	2
9	19.8	141.96	0.13	0.20	0.80	1
10	19.8	141.96	0.13	0.20	0.80	2
11	19.8	141.96	0.13	0.20	0.95	1
12	19.8	141.96	0.13	0.20	0.95	2
13	19.8	141.96	0.13	0.25	0.65	1
14	19.8	141.96	0.13	0.25	0.65	2
15	19.8	141.96	0.13	0.25	0.80	1
16	19.8	141.96	0.13	0.25	0.80	2
17	19.8	141.96	0.13	0.25	0.95	1
18	19.8	141.96	0.13	0.25	0.95	2
19	19.3	148.50	0.11	0.17	0.65	1
20	19.3	148.50	0.11	0.17	0.65	2
21	19.3	148.50	0.11	0.17	0.80	1
22	19.3	148.50	0.11	0.17	0.80	2
23	19.3	148.50	0.11	0.17	0.95	1
24	19.3	148.50	0.11	0.17	0.95	2

Table 3: Parameter settings for yellowfin OMs. Effort creep and recruitment uncertainty expand the total number of OMs to 144.

OM	Lmin	Lmax	k	M	h	tmix
25	19.3	148.50	0.11	0.20	0.65	1
26	19.3	148.50	0.11	0.20	0.65	2
27	19.3	148.50	0.11	0.20	0.80	1
28	19.3	148.50	0.11	0.20	0.80	2
29	19.3	148.50	0.11	0.20	0.95	1
30	19.3	148.50	0.11	0.20	0.95	2
31	19.3	148.50	0.11	0.25	0.65	1
32	19.3	148.50	0.11	0.25	0.65	2
33	19.3	148.50	0.11	0.25	0.80	1
34	19.3	148.50	0.11	0.25	0.80	2
35	19.3	148.50	0.11	0.25	0.95	1
36	19.3	148.50	0.11	0.25	0.95	2

Table 4: Axes of uncertainty in the yellowfin operating models

Type	Axis	Levels	Options
Model error	Steepness	3	0.65, 0.8, and 0.95
	Tag mixing period	2	1 quarter and 2 quarters
	Growth	2	
	Natural mortality	3	0.17, 0.2 and 0.25
Process error	Recruitment period	2	long term and short term
Implementation error	Effort creep	2	off and on (2% PS, 1% LL)

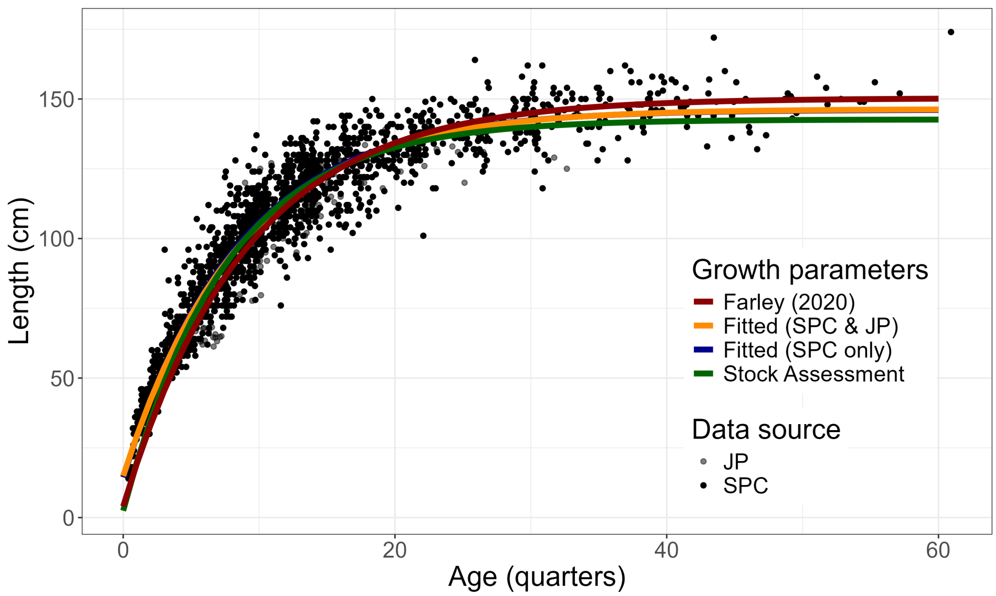

Figure 1: Alternative growth models for yellowfin tuna determined from a range of sources

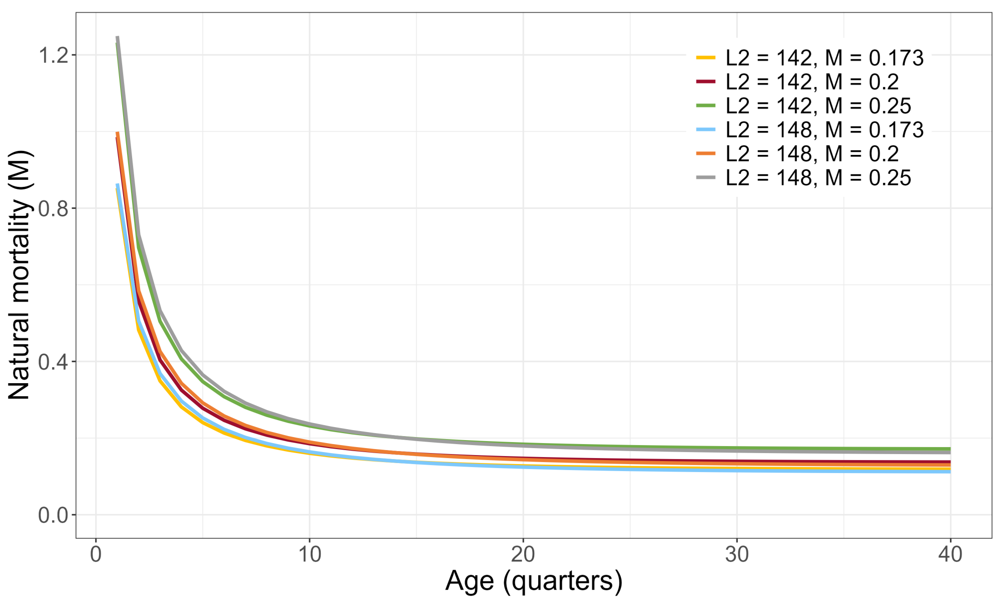

Figure 2: Natural mortality-at-age resulting from six combinations of growth and natural mortality. L2 is the mean length of the oldest age class and M is the mean natural mortality across length classes.

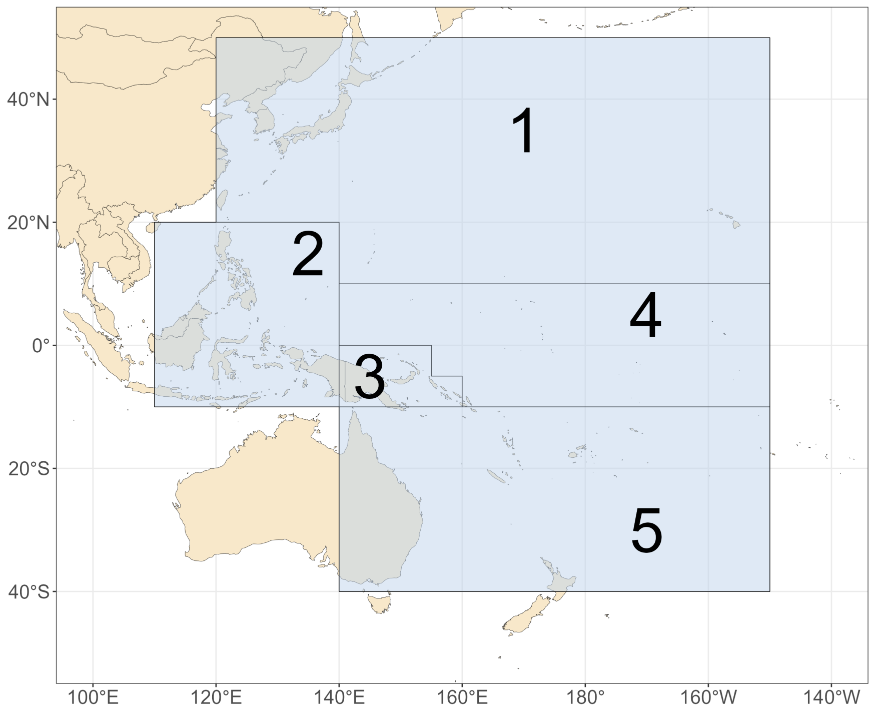

Figure 3: The geographical area and the boundaries of the model regions for the 5 region structure of the yellowfin tuna operating models.

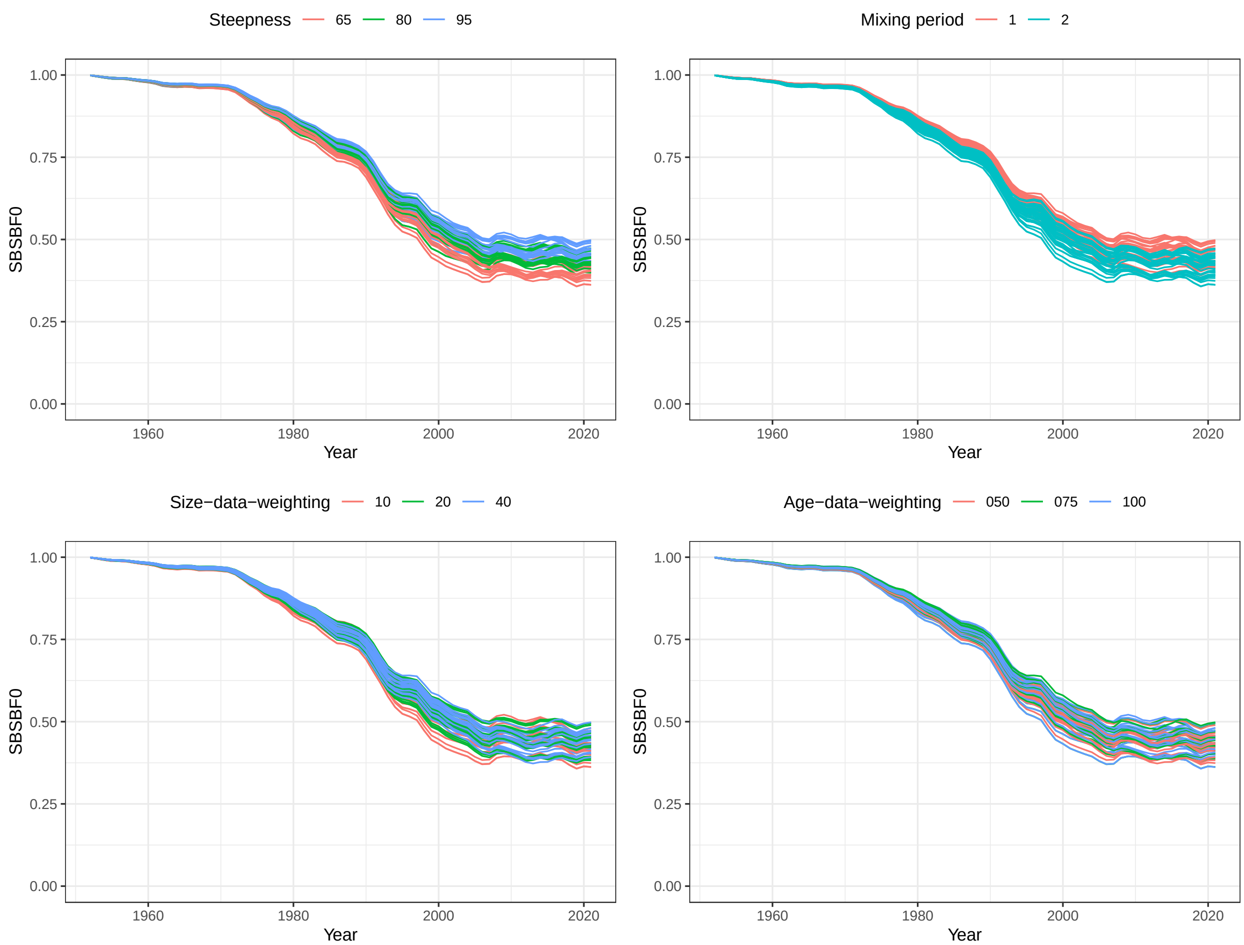

Figure 4: Impact of uncertainties from the 2023 stock assessment grid on depletion ($SB/SB_{F=0}$).

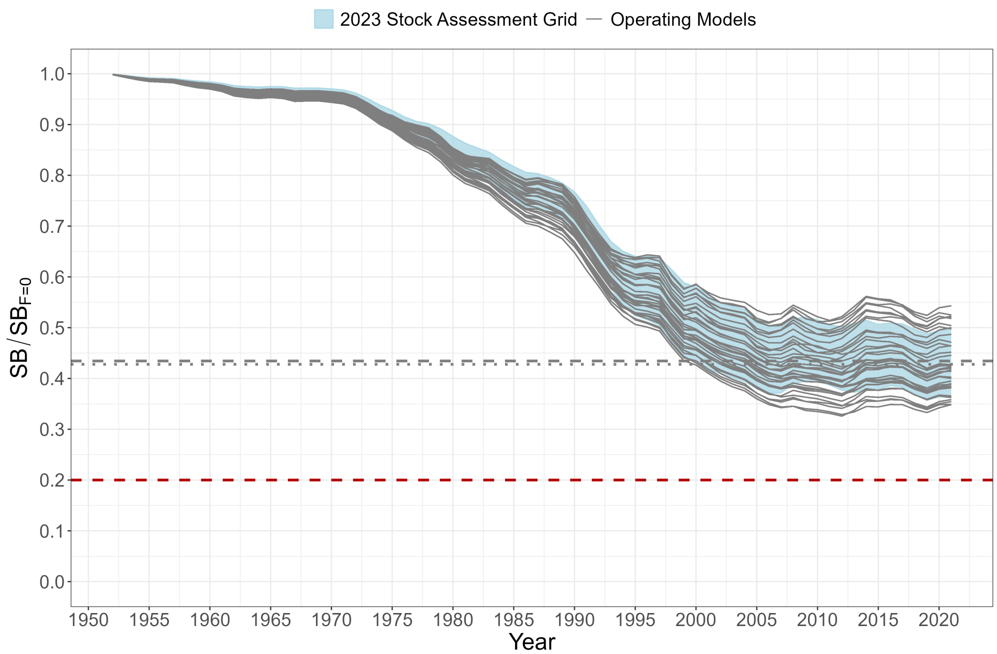

Figure 5: Relative depletion (SB/SB_{F0}) of the 36 OMs (grey lines) compared to the 2023 stock assessment grid (blue shaded). Horizontal dashed lines show the LRP (red) and the average of 2012 to 2015 depletion for the OM grid (dashed) and the average of 2019 to 2021 depletion for the OM grid (dotted).

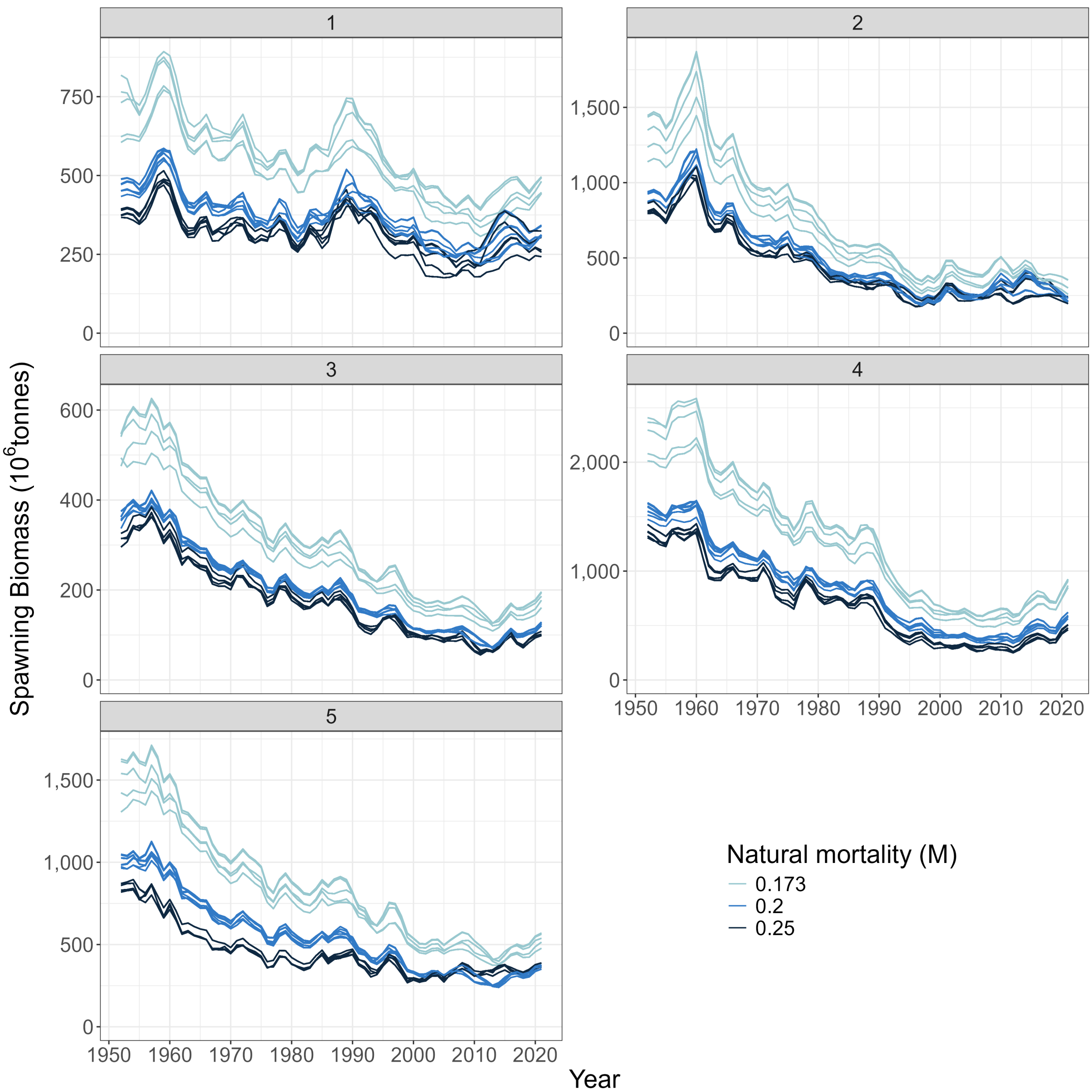

Figure 6: Absolute spawning biomass by area for the 36 OMs coloured by natural mortality (M).

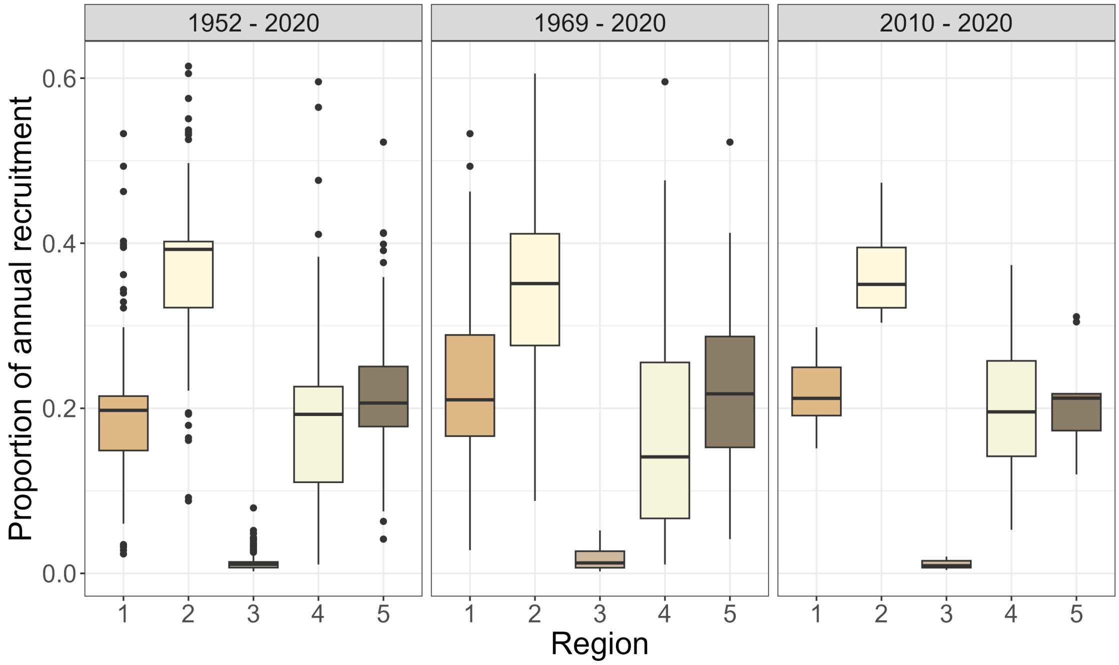

Figure 7: Proportion of annual recruitment in each region for three time periods: 1952-2020, 1969-2020 and 2010-2020.

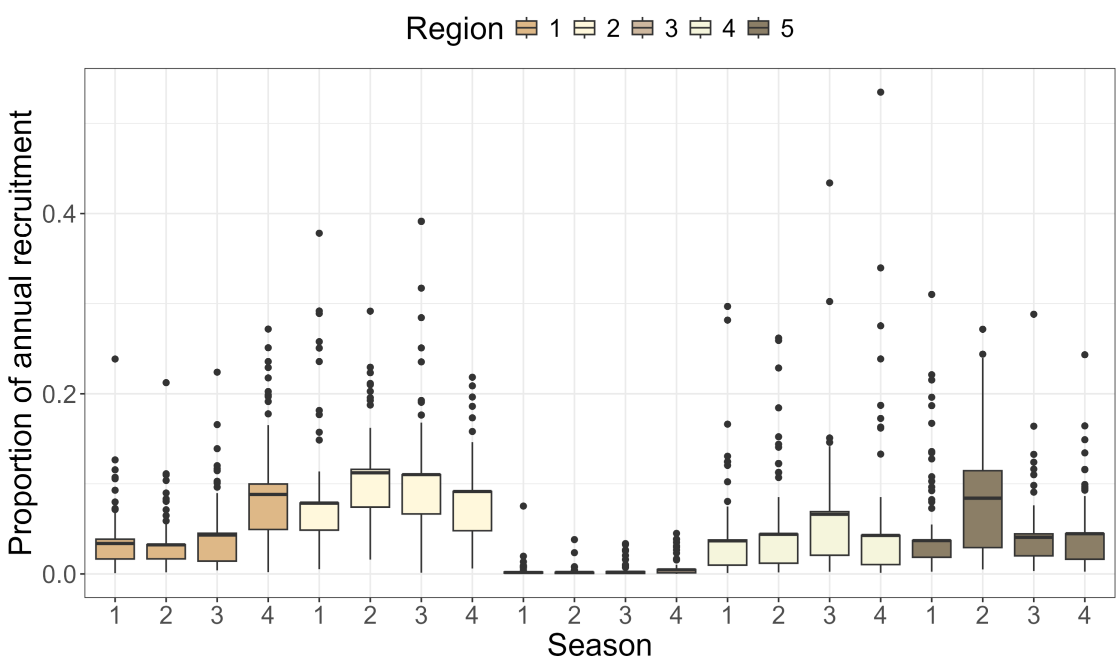

Figure 8: Proportion of annual recruitment in each region in each season.

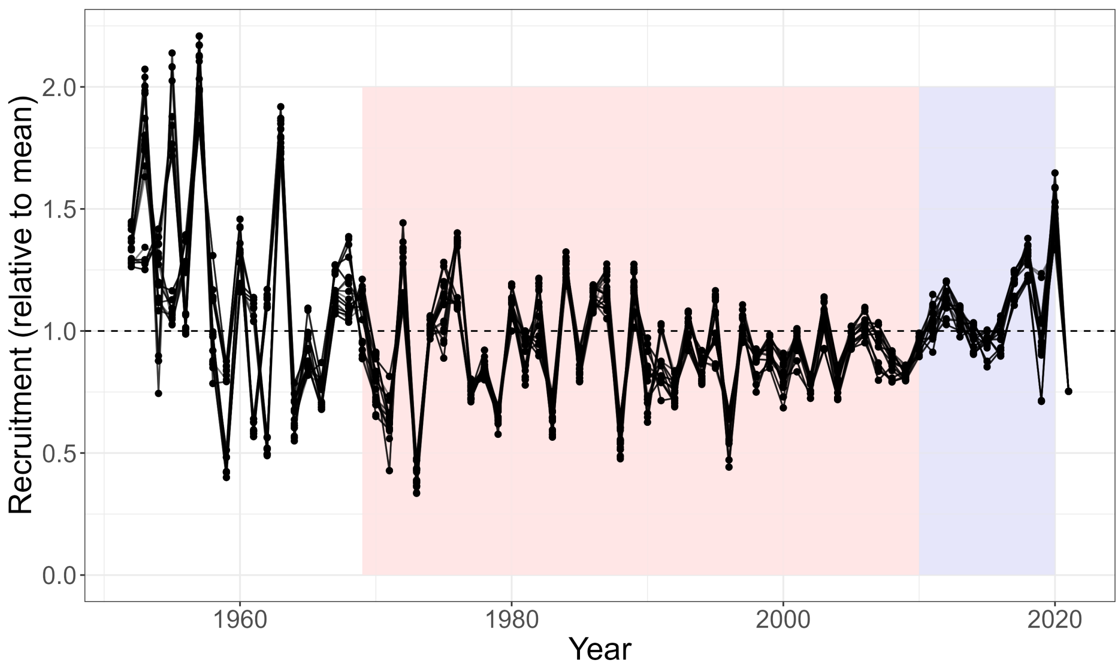

Figure 9: Recruitment relative to the mean recruitment for 36 OMs. Shaded regions show the sampling period for the long term (1969–2020) and short term (2010–2020) recruitment used for the projections.

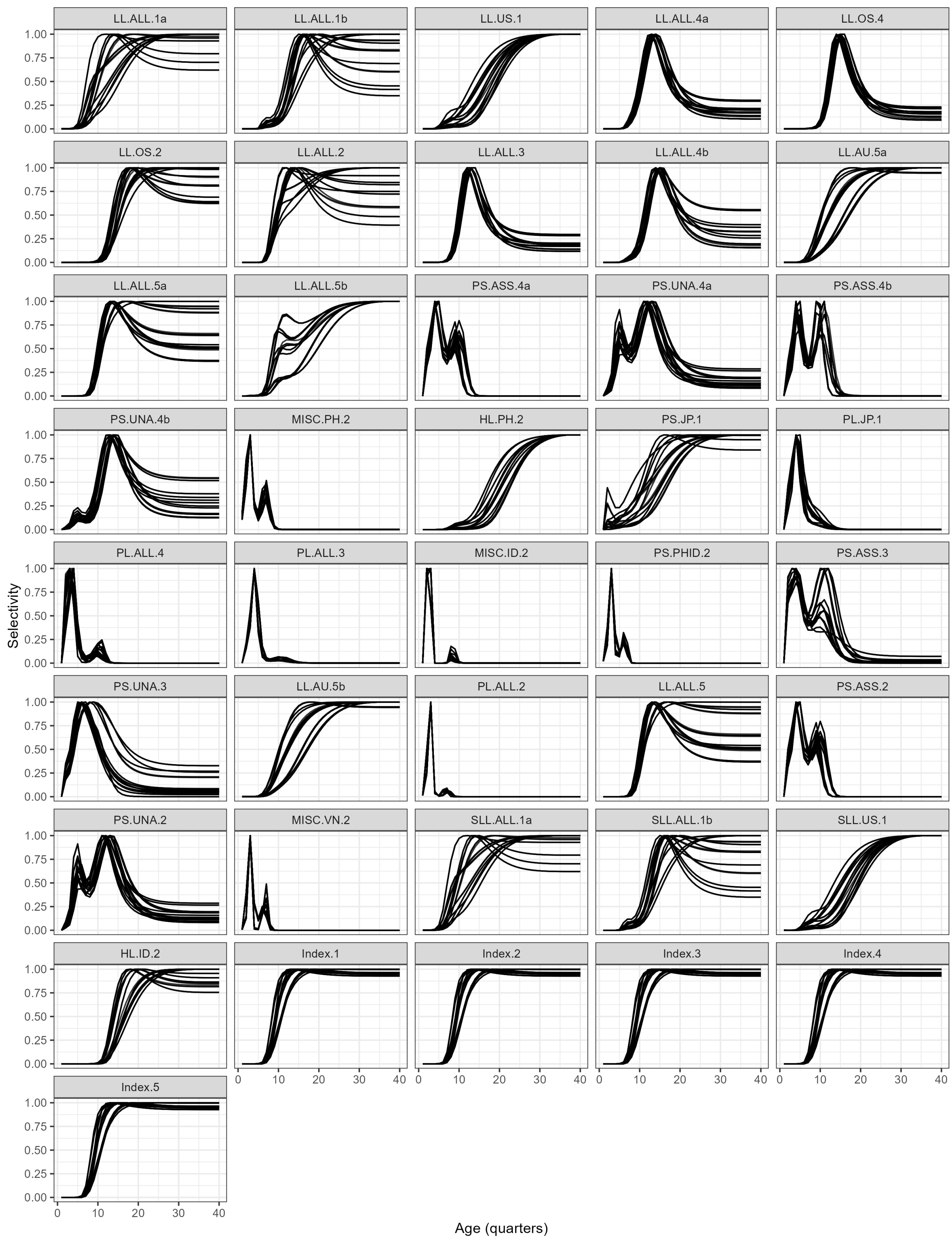

Figure 10: Estimated selectivities of 36 OMs from MFCL.

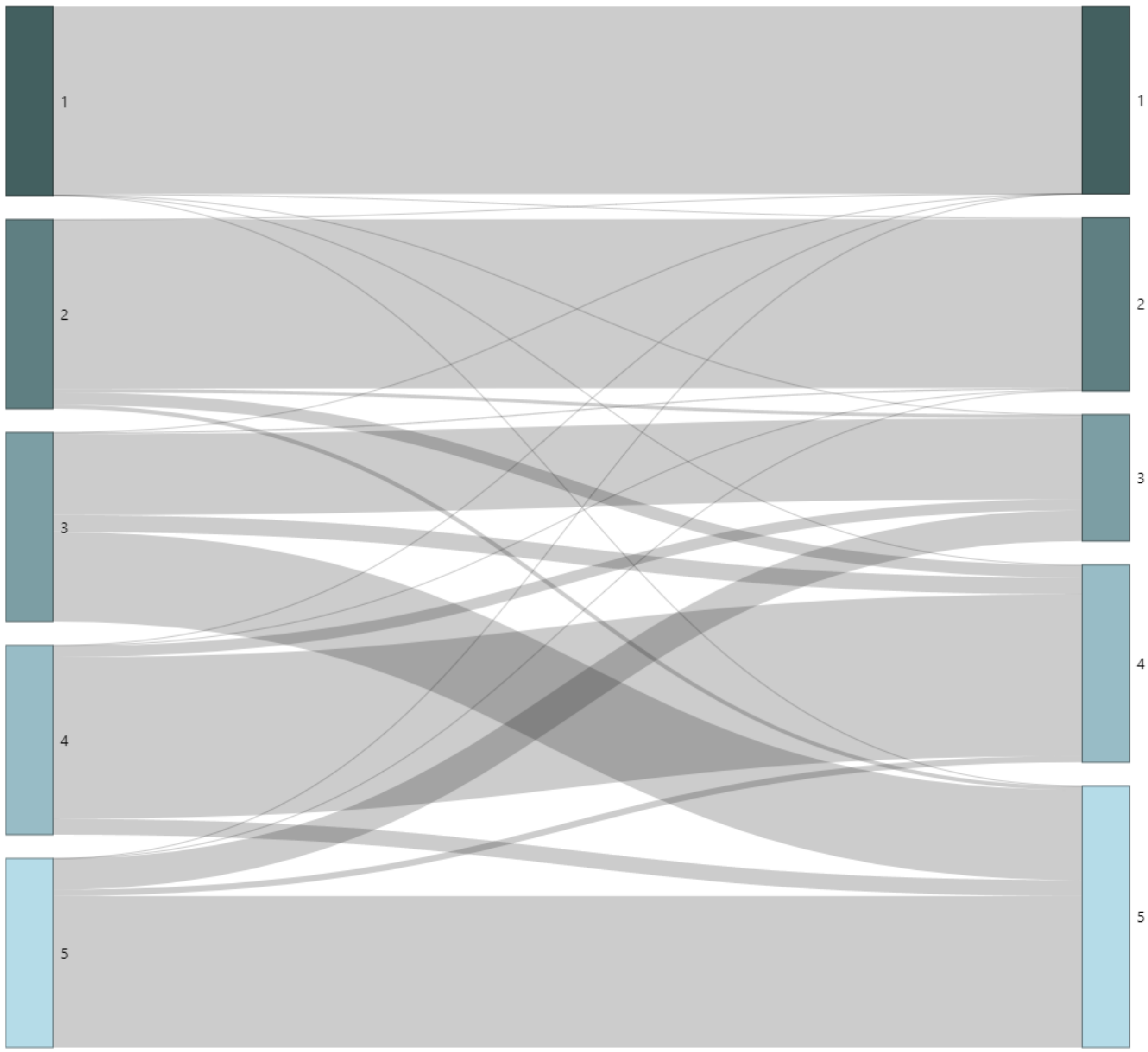

Figure 11: Estimated movement (all ages and seasons) from one OM estimated by MFCL during OM-conditioning. Estimated movement is shown FROM the model regions on the left TO the model regions on the right.

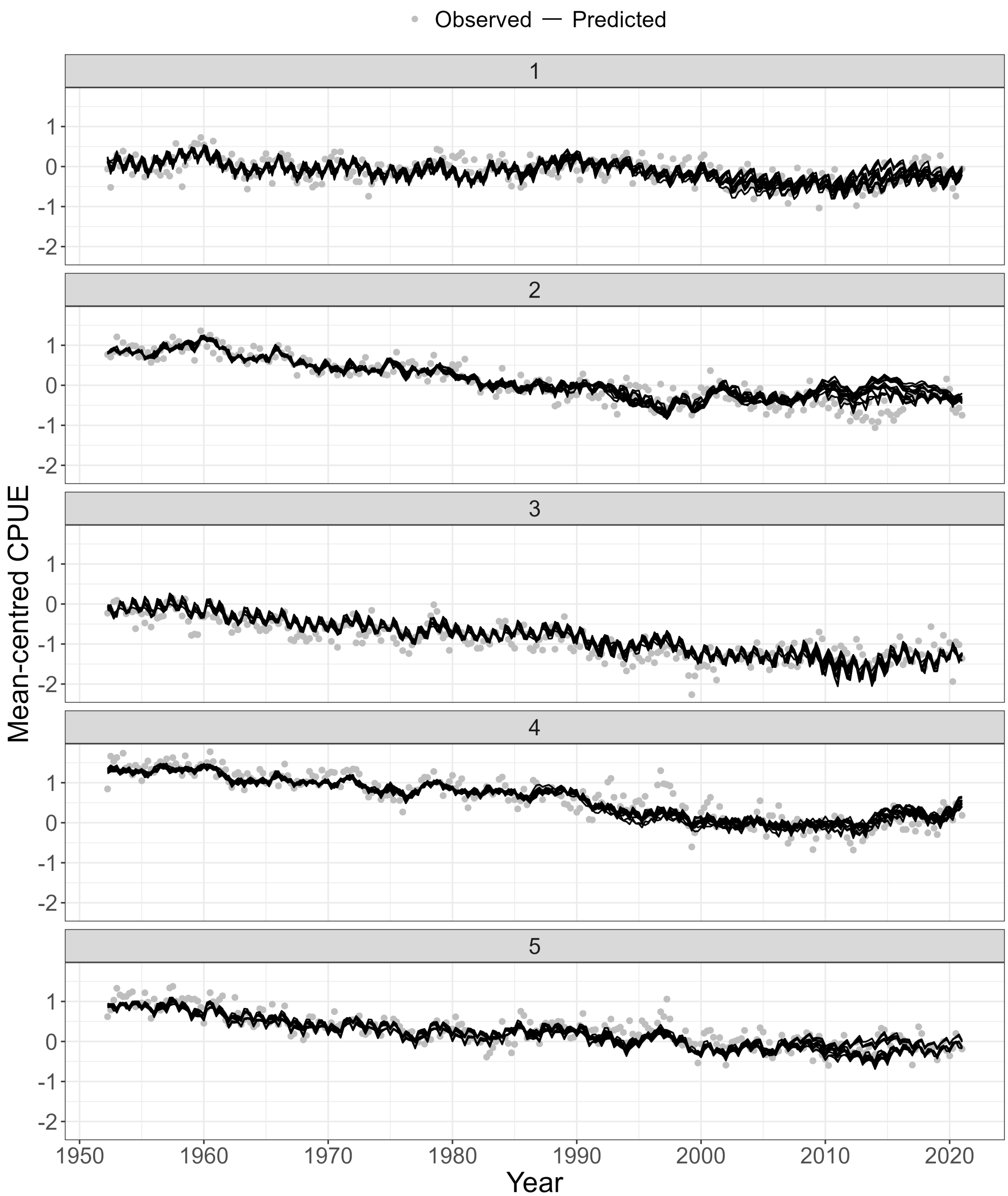

Figure 12: CPUE fit for the longline index fleets in each region of all yellowfin OMs

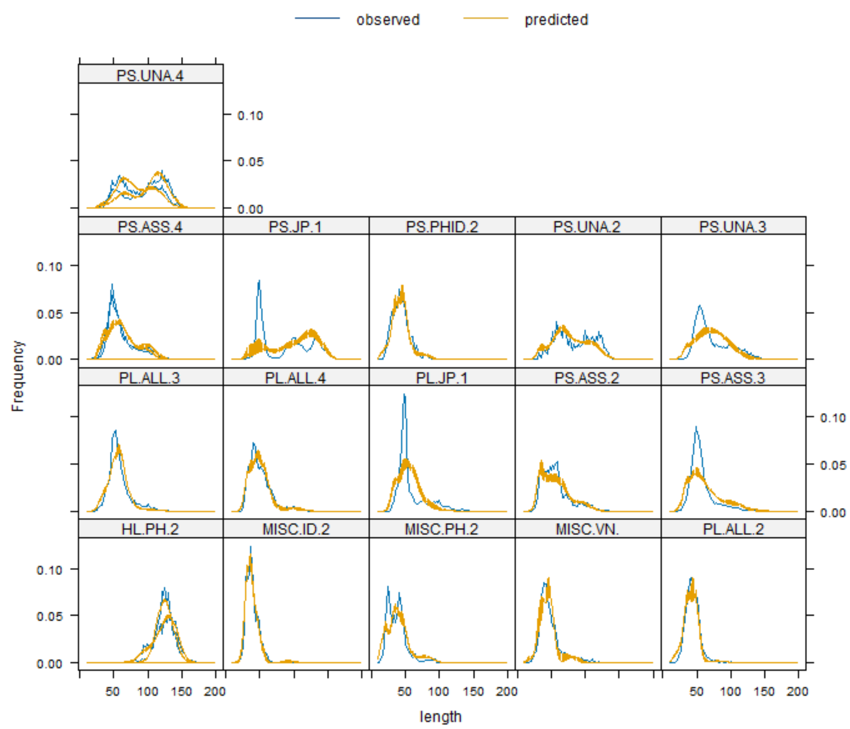

Figure 13: MFCL fit to length composition data across all yellowfin OMs.

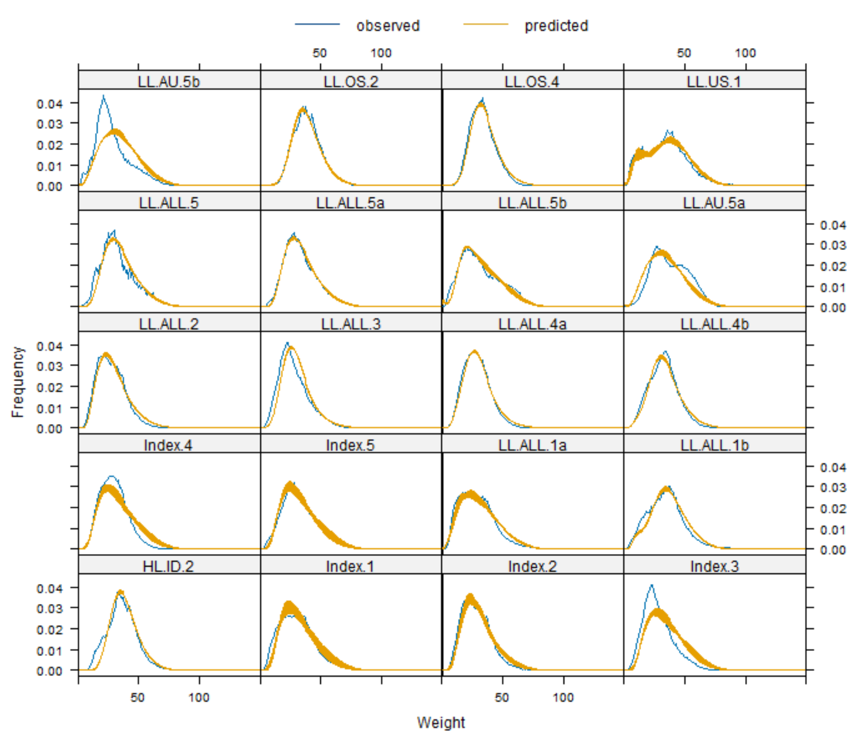

Figure 14: MFCL fit to weight composition data across all yellowfin OMs.

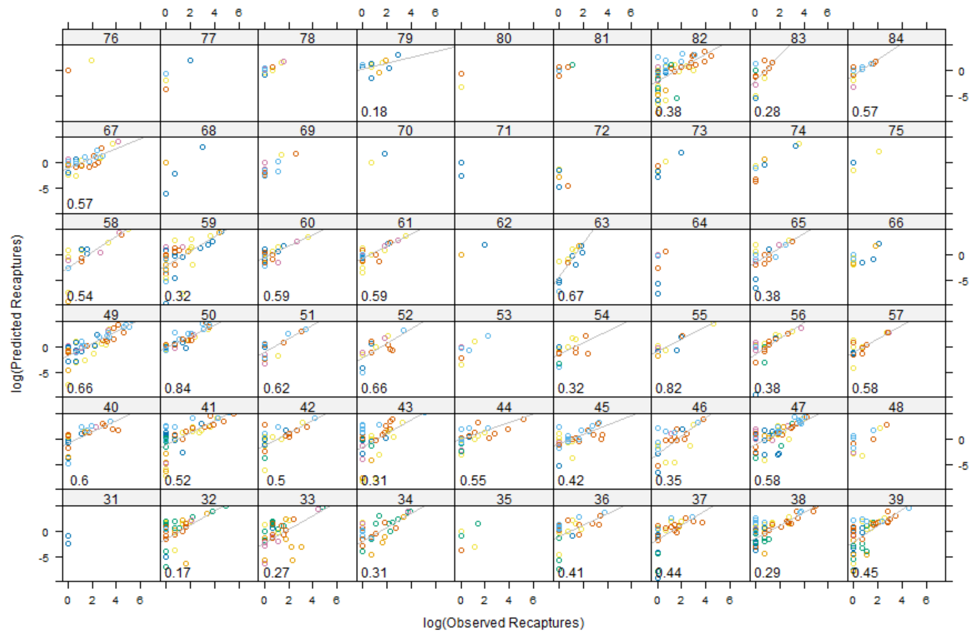

Figure 15: Predicted vs observed tag recaptures from the Pacific Tuna Tagging Programme (PTTP).

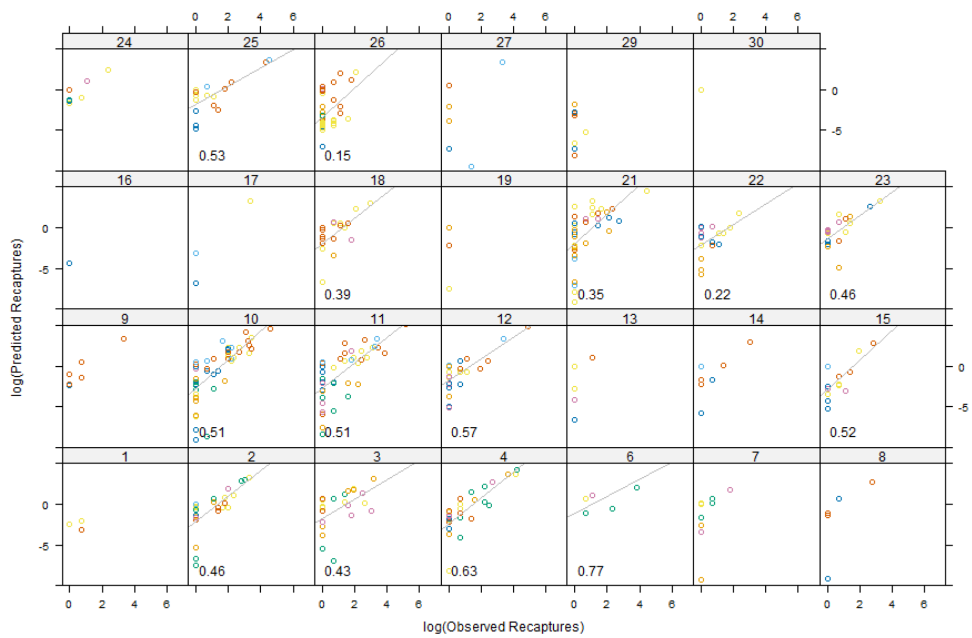

Figure 16: Predicted vs observed tag recaptures from the Regional Tuna Tagging Programme (RTTP).

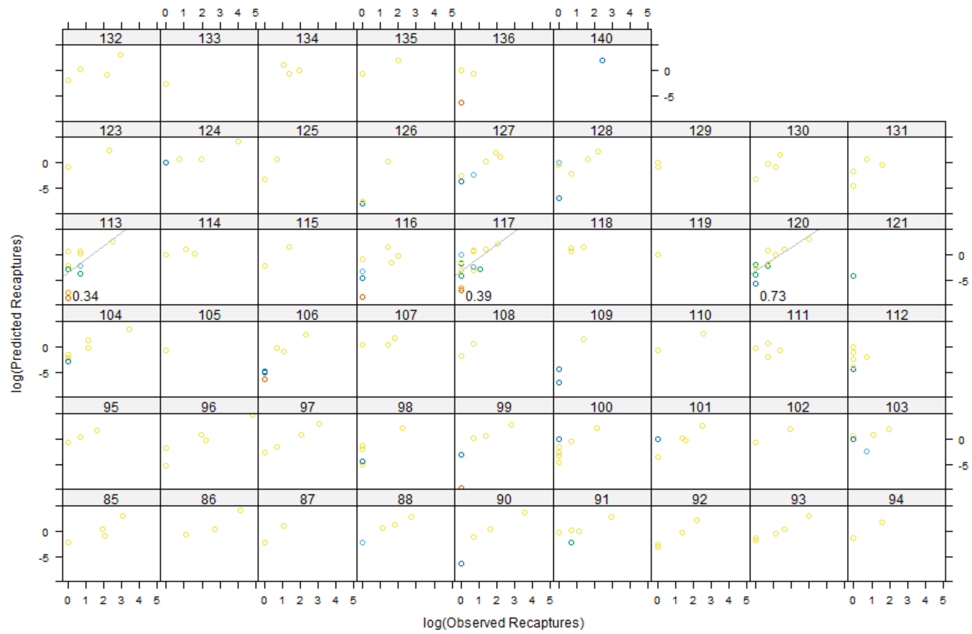

Figure 17: Predicted vs observed tag recaptures from the Japanese Tagging Programme (JPTP).

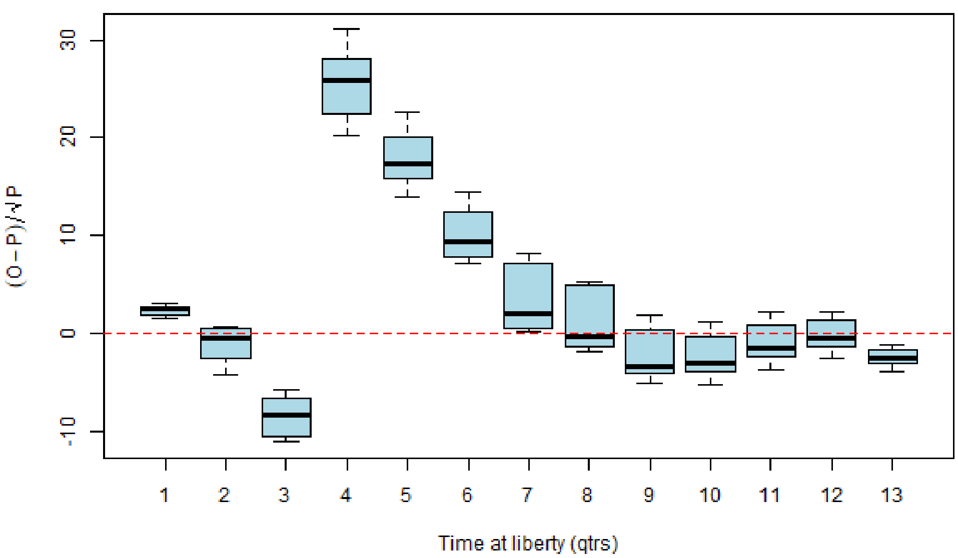

Figure 18: Standardised residuals for tag recapture estimates with time at liberty across the OM set (36 models).

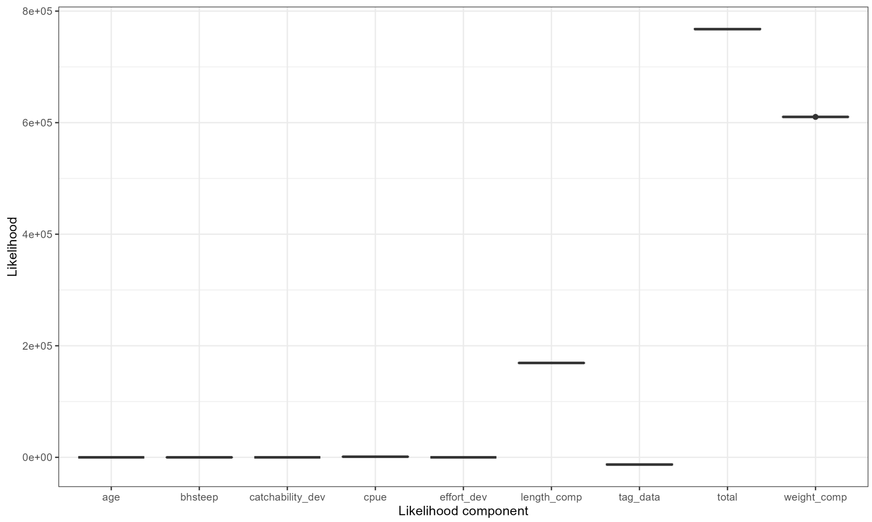

Figure 19: Boxplot of likelihood contributions across the 36 OMs.

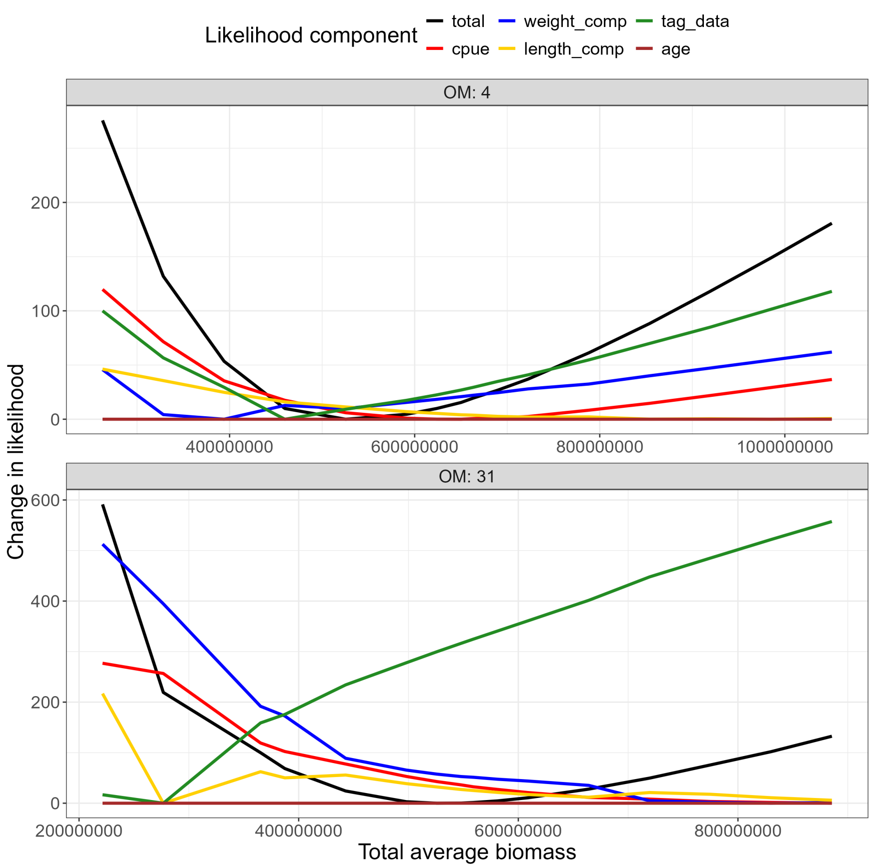

Figure 20: Likelihood profiles of OM4 and OM31.

4.1 Sensitivity Scenarios

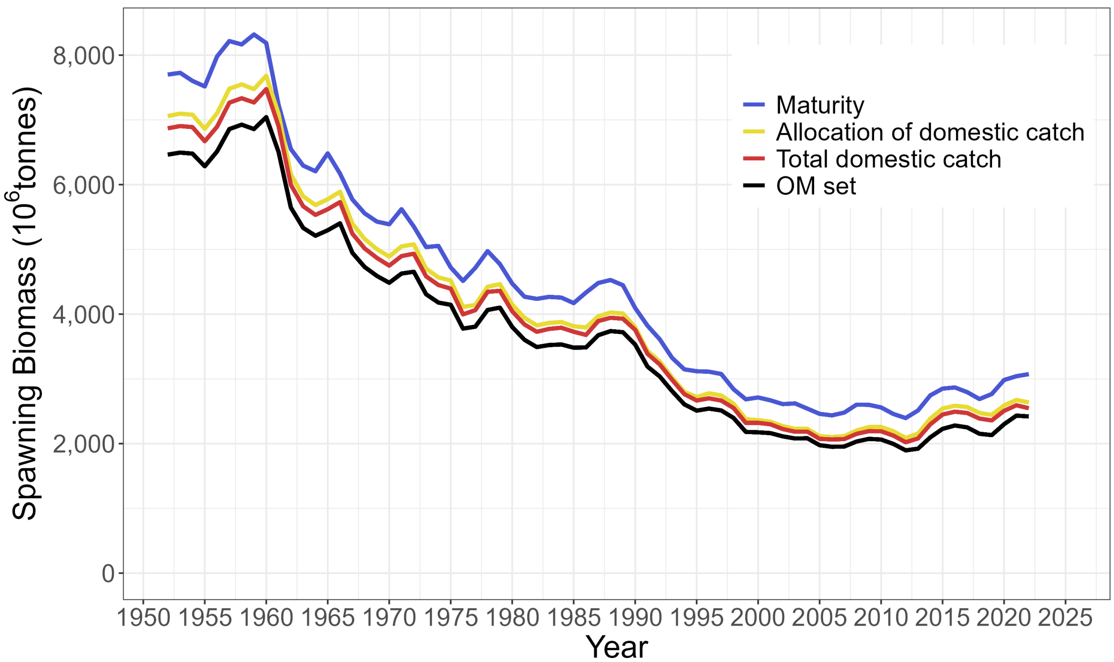

Figure 21: Spawning biomass from sensitivity models compared to the equivalent model from the OM set.

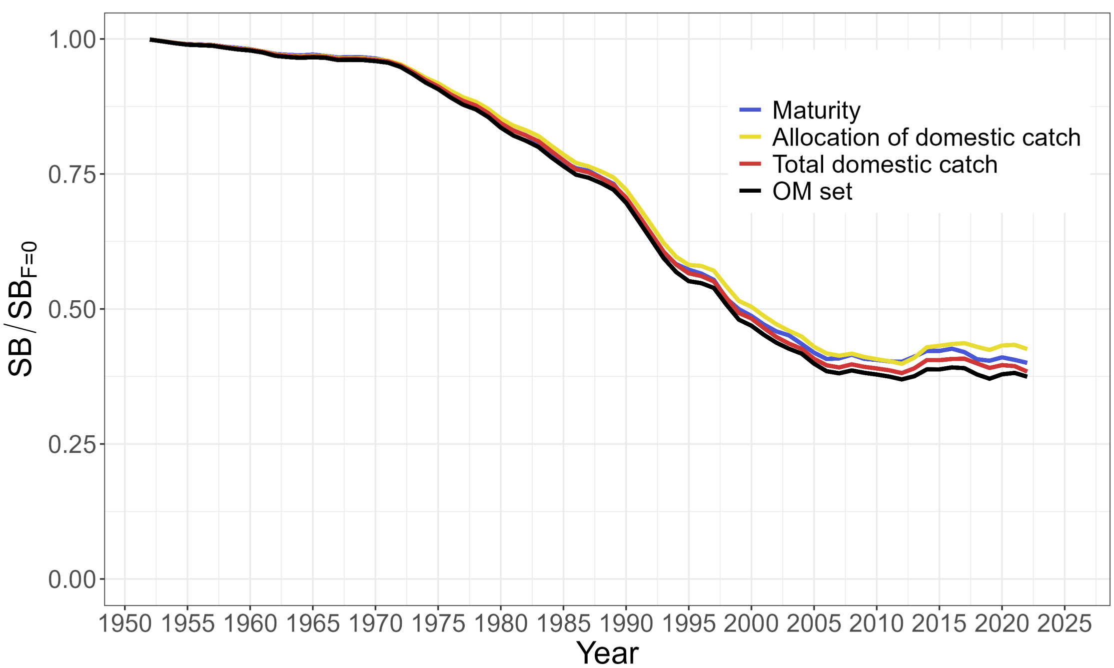

Figure 22: Biomass depletion from sensitivity models compared to the equivalent model from the OM set.

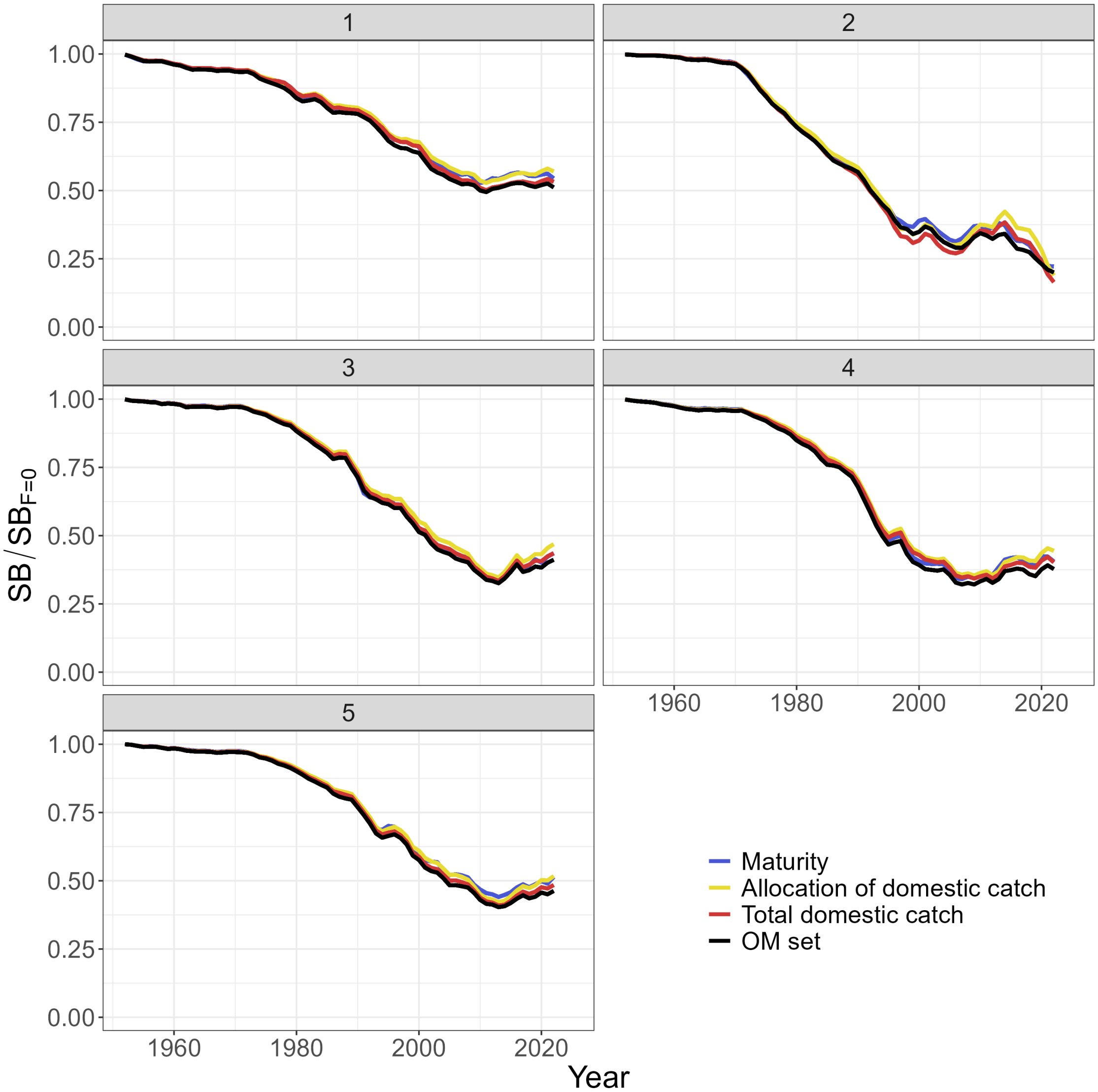

Figure 23: Biomass depletion by area from sensitivity models compared to the equivalent model from the OM set.

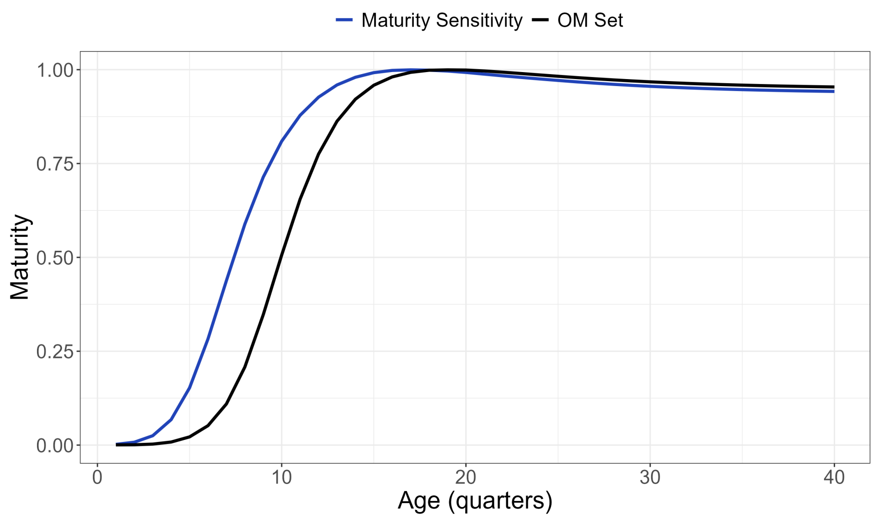

Figure 24: Maturity ogive in sensitivity scenario compared to the equivalent model from the OM set.

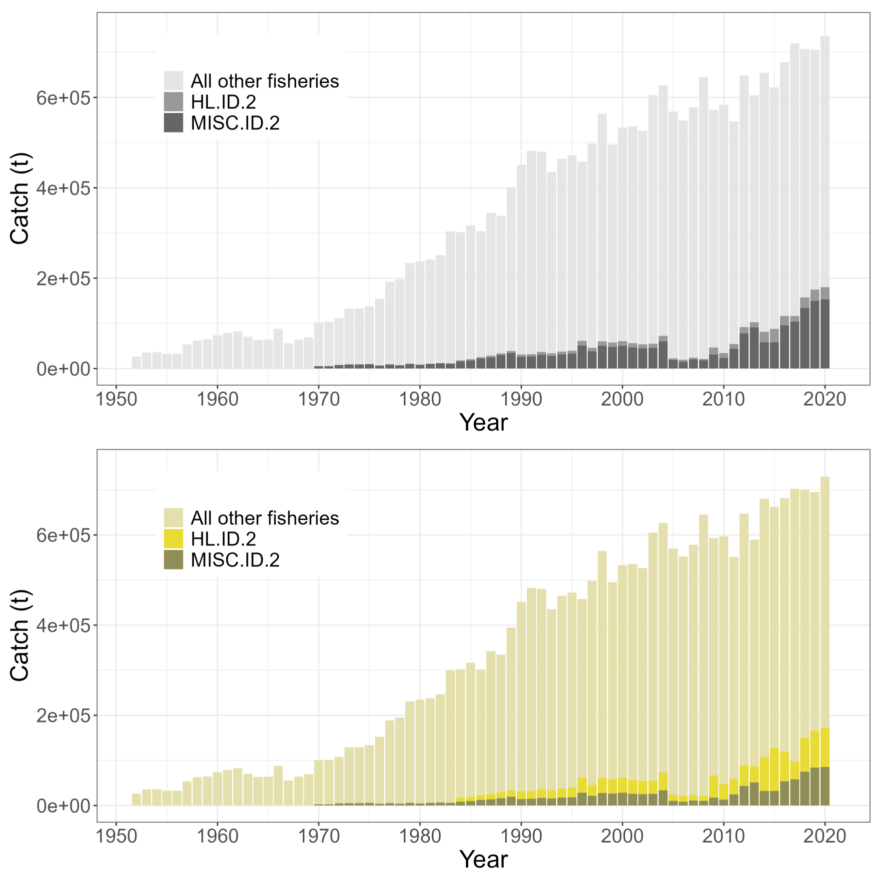

Figure 25: Allocation of catch between the domestic fisheries of Indonesia in region 2 for the OM set model (top panel) and the sensitivity model (bottom panel).

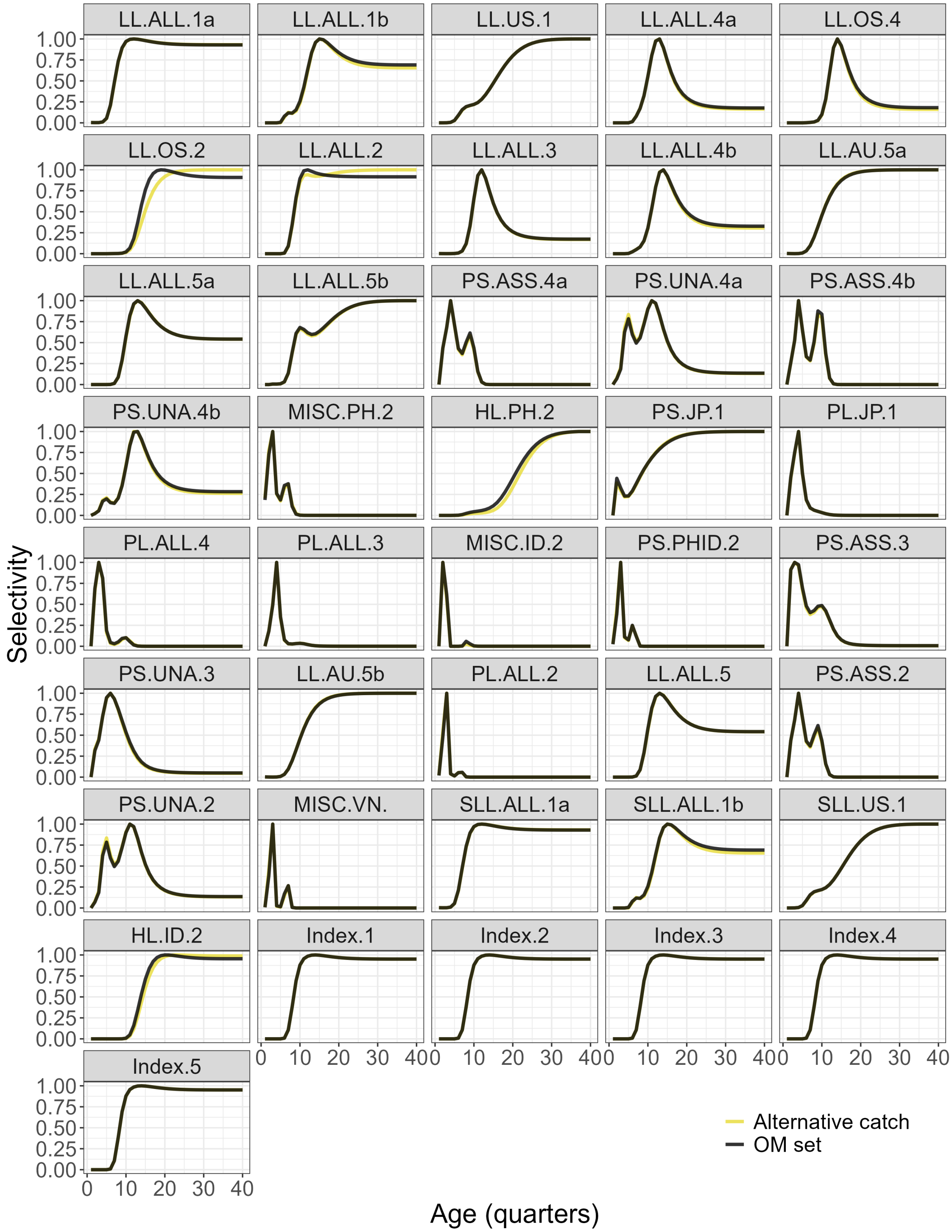

Figure 26: Fishery selectivity from domestic catch allocation sensitivity model compared to the equivalent model from the OM set.

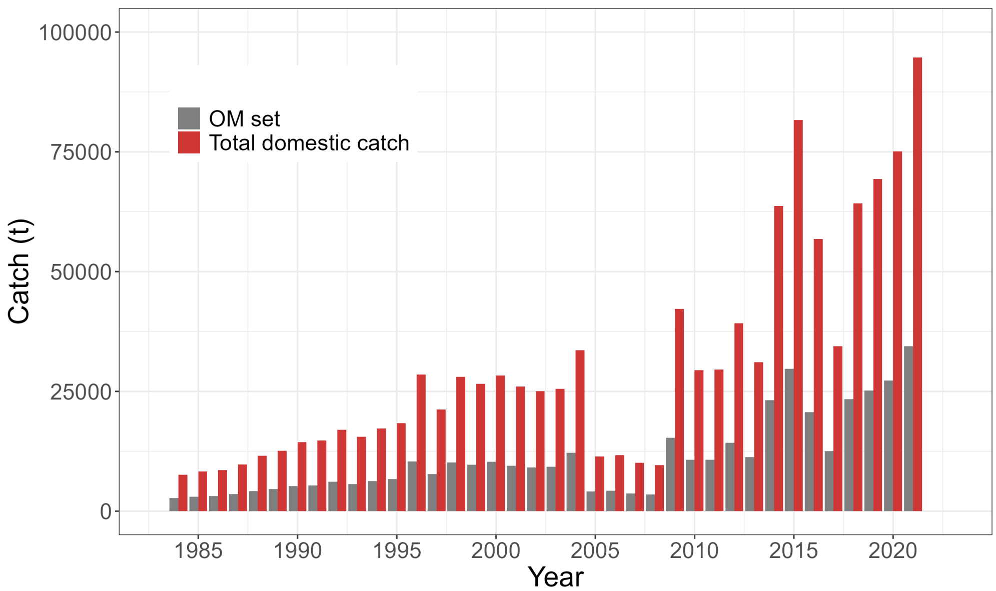

Figure 27: Total catch of the domestic handline fishery of Indonesia in region 2 for the OM set model and the sensitivity model.

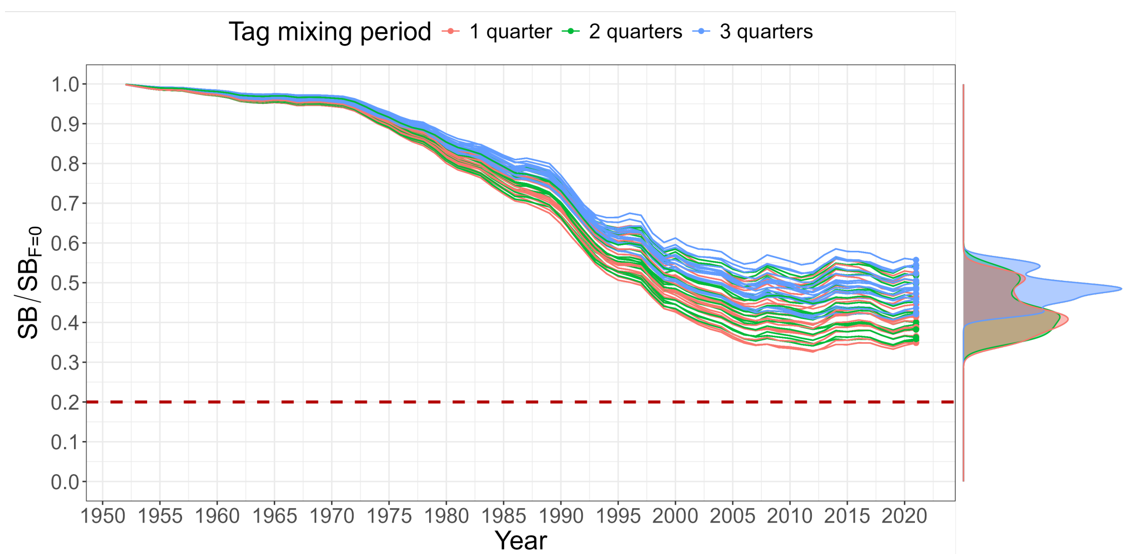

Figure 28: Relative depletion ($SB/SB_{F=0}$) of the 18 additional models run with a 3 quarter tag mixing period compared to the OM set with a 1 quarter and 2 quarter tag mixing period.

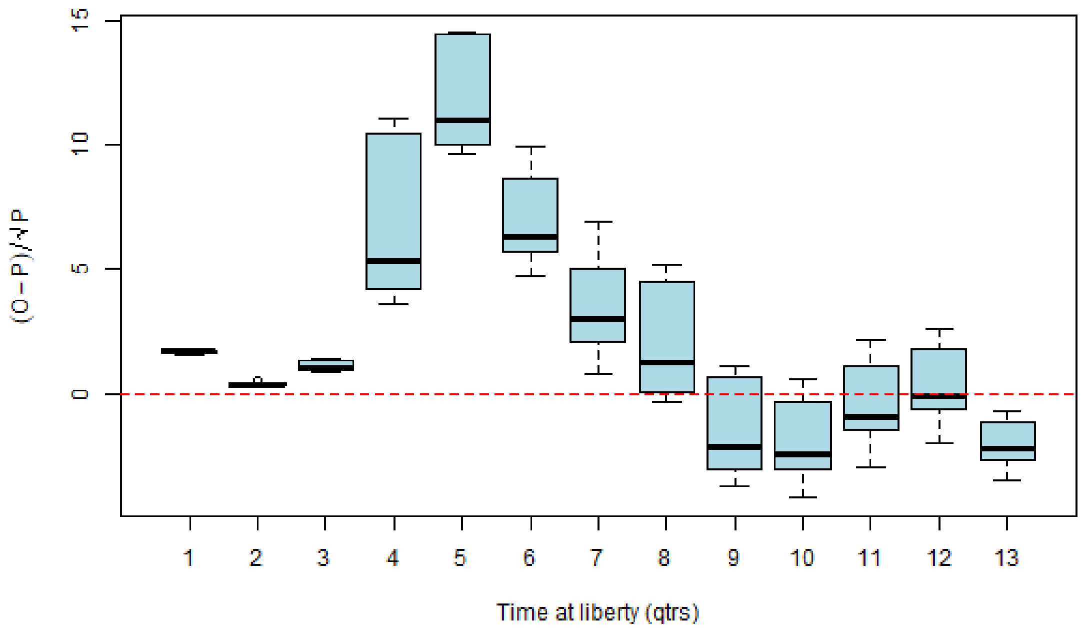

Figure 29: Standardised residuals for tag recapture estimates with time at liberty across the tag mixing period sensitivity scenarios (18 models).

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