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Update on IOTC Bigeye Tuna MSE Operating Model Development October 2019

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Acknowledgments

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Contents

1 Summary

IOTC bigeye (BET) Management Strategy Evaluation (MSE) development requests since the 2018 WPTT and WPM were mostly addressed for the IOTC MSE Task Force meeting in Mar 2019 and are documented in a separate information paper (Kolody and Jumppanen 2019a). This paper highlights key changes in the BET reference set OM requested by the IOTC 2019 MSE Task Force meeting and outlines issues to be addressed to progress the bigeye OMs to the next iteration. Issues related to selecting OM ensembles that are relevant to both bigeye and yellowfin are documented in the yellowfin companion paper (Kolody and Jumppanen 2019g). A stand-alone document (attachment 1) summarizes the current state of the bigeye reference set OM as used for MP evaluation in Kolody and Jumppanen (2019c).Key points include:

- The reference set OM is stochastically sampled from 94 Stock Synthesis model specifications, retained from a fractional factorial grid of 144 models with uncertainty in 8 dimensions. Models were rejected based on repeated (usually 5-10) failed attempts to reach numerical convergence from jittered initial parameter values, or a non-trivial Stock Synthesis catch penalty term. We interpret the catch penalty term to mean that the model would require implausible levels of fishing effort to remove some component of the observed catch (in at least one quarter-age-region strata). This could result from unrealistically pessimistic overall dynamics or a problematic space/time distribution of fish (most likely the latter for bigeye).
- The reference set OM is similar to previous iterations and is generally optimistic about current stock status and future stock status at current catch levels. This is consistent with the most recent assessment (Langley 2016), upon which the OM is based. The bigeye reference set OM will need to be compared with the 2019 stock assessment, to ensure that the inferences are still compatible.
- Most of the contrasting OM assumptions appear to have a non-negligible effect, usually in a predictable manner (e.g. lower steepness, M, and increasing CPUE catchability trend tend to be associated with more pessimistic stock status). Tags tend to be associated with more pessimistic outcomes. The least influential assumption appears to be the longline selectivity assumption (logistic or “double-normal”), presumably because the double-normal option tends to estimate only a weak domed shape.
- We have employed and presented a series of model diagnostics that should be able to identify many model interactions and outlier behaviour in a large model grid. However, we recognize that the approach is somewhat qualitative, and there might be other features of interest that are over-looked in these aggregate summary statistics. We continue to welcome suggestions for improving the process of evaluating and selecting models (retention/rejection or non-binary weighting).
- Resources have been identified to support the ongoing technical and scientific requirements for bigeye MSE until at least Dec 2020.

2 Introduction

The Indian Ocean Tuna Commission has committed to using Management Strategy Evaluation (MSE) to meet its obligations for adopting the precautionary approach. IOTC Resolution 12/01 "*On the implementation of the precautionary approach"* identifies the need for fishery reference points and harvest strategies that will help to maintain the stock status at a level that is consistent with the reference points. Resolution 13/10 "*On interim target and limit reference points and a decision framework*" identified interim reference points and elaborated on the need to formulate management measures relative to the reference points, using MSE to evaluate harvest strategies in recognition of the various sources of uncertainty in the system. Resolution 15/10 supersedes 13/10 with a renewed mandate for the Scientific Committee to evaluate the performance of harvest control rules with respect to the species-specific interim target and limit reference points, no later than 10 years following the adoption of the reference points, for consideration of the Commission and their eventual adoption. A species-specific workplan was re-affirmed at the 2017 Commission Meeting, outlining the steps required to adopt simulation-tested Management Procedures for the highest priority species (IOTC 2017). Recognizing the iterative nature of the MSE process, the revised workplan identified 2021 as the earliest possible date for MP implementation. Unlike yellowfin (and skipjack), there have not yet been any initiatives to develop the MSE results into a management resolution.

This paper identifies the most recent OM development requests since the last reports to the IOTC community (IOTC MSE Task Force Mar 2019 and TCMP May 2019), describes subsequent progress and highlights issues of concern for future progress. New MP developments and MP evaluation results are presented in the companion paper (Kolody and Jumppanen 2019c).

This paper assumes that the reader is reasonably familiar with the technical background. More detailed explanations can be found in Kolody and Jumppanen (2016), Jumppanen and Kolody (2018) and various progress reports produced since the last YFT MSE update to the WPTT and WPM (Kolody and Jumppanen 2018 a, b, c, d, e, g).

3 Bigeye MSE Development requests since WPTT/WPM 2019

3.1 Requests from the 2019 IOTC MSE Task Force

Requests for the bigeye MSE development from the 2018 WPTT and WPM meetings were addressed in Kolody and Jumppanen (2019a) and reviewed at the IOTC Task Force meeting March 2019 (WPM 2019). We note that an attempt was made to consider an alternative bigeye growth curve, but it was not possible to reconcile conflicting data, so this request was not pursued further. The MSE Task Force made the following recommendations for the next iteration:

- *The group noted that the BET catches tended to be stable with all tuning levels, and MP adoption might be easier if stricter TAC change constraints were imposed in the early years, so that industry would not have any risk of immediate quota cuts.*

- *It was suggested that the time series plots for the TCMP should be truncated at the 20 year period used for the standard TCMP summary statistics.*

- *The proposed reference [set] OM for the 2019 TCMP comprises 72-144 models with 8 factors in a fractional factorial design:*

    - *3 X steepness: h = 0.7, 0.8, 0.9*
    - *3 X M*
    - *2 X tag weight λ = 0.001, 1.0*
    - *2 X LL CPUE catchability trend 0, 1% per year*
    - *2 X tropical CPUE standardization method: HBF, cluster analysis*
    - *2 X regional scaling factors*
    - *2 X CL assumed sample sizes: ESS=10, 1 iteration of post-fit reweighting*
    - *2 X LL selectivity function: logistic, double normal*

- *It was noted that the double normal selectivity function was not a specific request for BET but was added to be consistent with ALB and SWO (provided that results are plausible).*

- *The group discussed whether the catch penalty should be used as a plausibility criterion for OMs and stock assessments and agreed that further clarification of its implementation was required.*

All these recommended changes were adopted. Subsequent consultation with the Stock Synthesis developers confirms that a non-trivial catch penalty at convergence should be interpreted as a model plausibility problem (Ian Taylor, NOAA, pers. comm.).

3.2 Requests from the 2019 TCMP meeting

The MP results presented to the 2019 TCMP were based on the reference set OM endorsed by the IOTC MSE Task Force in March 2019 (above). The only request from the TCMP (2019) for bigeye represents a reduction of the results to be presented:

*36. The TCMP **SUGGESTED** that the B1 tuning objective could be removed from the next iteration of MP evaluations (unless the 2019 stock assessment substantially changes the perception of the fishery relative to the 2016 assessment and current Operating Model). The justification included:*

• B1 represents a substantially higher risk of exceeding SB reference points than B2 and B3.

• Achieving the B1 tuning requires a substantial increase in average catches in the short term. This does not appear to be desirable for industry at present, because catches have been declining in recent years, despite the perception of healthy stock status.

The 2019 TCMP results included example MPs with quotas fixed at current levels until 2024 as requested by the MSE Task Force. The 2019 TCMP did not express interest in these MPs, so they have not been pursued further.

4 Bigeye Reference Set (*OMrefB19.6*) Summary Diagnostics

Attachment 1 describes the reference set BET OM OMrefB19.6. There are some minor differences from the reference set OM upon which TCMP 2019 results were generated:

- The set of retained models is slightly larger (94 instead of 90 models, due to rerunning of some models with numerical issues and/or file problems resulting from running batch files over the network)
- Where multiple successful convergences were obtained for a single model specification, the set of retained models is based on the run with the lowest objective function value (instead of the first successful convergence).
- Three minor specification errors were corrected:
    - MP data lag decreased from 3 to 2 years
    - Annual recruitment CV slightly reduced
    - A bug in the observed CPUE series to be used by the MP was fixed

These changes have only minor implications for the MP evaluation results presented to the TCMP. The rejection of a large number of models due to convergence problems or a substantial catch likelihood is curious, and probably related to implausible spatial distributions rather than pessimism about the overall stock status. We are not convinced that the plausibility of complicated spatial assessment models are adequately examined in general.

Summary diagnostic plots for the aggregate bigeye ensemble grid are included below, from which we note the following:

- As noted in Attachment 1, the fractional factorial OM reference set grid is fully balanced with respect to each factor, but 37% of the grid was rejected for numerical reasons. As might be expected, the catch penalties were more commonly associated with pessimistic assumptions, resulting in disproportionate rejection of the low M (M06), and to a lesser extent the CPUE assumptions iH and q1). Less obviously, removing the tags (t0001) and higher CL weighting (CLRW) were also disproportionately rejected. Since the filtered OM is not balanced, and not all interactions can be quantified, some inferences about the importance of individual assumptions may be misleading.
- The quality of fit to the CPUE is generally very good (Figure 2 - Figure 5).
- The quality of fit to the size composition data is highly variable among fisheries (Figure 6), and generally not very good. But it is notable that the different model assumptions do not appear to have much of an effect on the quality of fit to the individual fisheries (the baitboat fishery BB1 is the biggest exception).
- Tag likelihoods are summarized in Figure 7 - as would be expected, the tag weighting determines the quality of fit to the tags (and likelihood comparisons between weightings are not meaningful).

- Annualized recruitment deviations were estimated to be lower than the assessment assumptions (Figure 8, independent quarterly CV = 0.6 is approximately an annual CV of 0.42)
- Key stock status indicators are summarized in Figure 9, partitioned by assessment assumption. As would be expected, more pessimistic results tend to be associated with lower steepness, lower M, and a 1% catchability trend increase. The tropical HBF CPUE standardization (as used in the assessment) tends to be more pessimistic than the CPUE series derived from the cluster analysis.
- The functional form of the longline selectivity was the least influential assumption – presumably because the double normal selectivity tends to estimate a function that is only mildly "domed" and resembles the original assessment assumption of a logistic function (Figure 12).
- Figure 10 shows the pairwise relationships among a number of quality-of-fit and stock status indicators, partitioned by model assumptions.
- The biggest concern that we have about OMrefB19.6 is the bimodal distribution of stock status indicators (e.g. Figure 10). This bimodality was not observed in 2018, perhaps because there was an additional, intermediate tag-weighting assumption. However, the smaller mode (associated with high MSY and high B/B(MSY) appears to be the result of several interacting assumptions. No single assumption is consistently associated with the higher mode, however, several assumptions are rarely or never associated with the higher mode – high tag weighting (t10), CPUE catchability trend (q1), HBF standardization (iH), regional scaling assumption iR2, and CLRW CL weighting.
- We note that in other systems (e.g. yellowfin), we have often seen a systematic lack of fit to the stock recruitment relationship (and a trend in recruitment deviations). In this case, the high MSY mode has no recruitment deviation trend, and the trend is negligible for the low MSY mode (e.g. Figure 13 shows the time series with the largest trend, which is negligible).

Parameter bounds issues have been largely resolved through a series of iteratively relaxing bounds (some bounds violations are not considered important, e.g. log-space lower bounds for a parameter that approaches zero, such as selectivity or movement). However, in some cases, overly relaxed bounds can lead to implausible results (possibly related to unstable minimization), which might not be identified without examining every individual model in detail. We do not know the extent to which the priors inherited from the stock assessment are influencing the OM, but they tend to be very diffuse.

While it is impractical to examine the diagnostics of every OM specification in detail, we did conduct a qualitative inspection of the detailed (r4ss) output plots from the 4 most extreme models in terms of the highest and lowest stock depletion (B/B(MSY)) and productivity (MSY). These "corners" did not appear to have any obvious outlier behaviour indicative of gross model failure (not shown).

Table 1. Operating Model definitions referred to in the text.

Model Name	Definition (assumption abbreviations are defined in Table 2)
OMgridB19.6	The balanced fractional factorial grid defined in attachment 1 (i.e. includes model specifications that were subsequently rejected due to numerical problems).
OMrefB19.6	The reference set OM defined in attachment 1 (OMgridB19.6, filtered for plausibility concerns, and stochastically sampled)
Robustness tests	
OMrobB19.6.iCV3	A robustness scenario with longline CPUE CV of 30% and auto-correlation = 0.5 (annual) in projections (conditioning is unchanged from OMrefB19.6)
OMrobB19.6.10overRep	A robustness scenario with consistent 10% over-catch for all fleets (catch is accurately reported) (conditioning is unchanged from OMrefB19.6)
OMrobB19.6.10overIUU	A robustness scenario with consistent 10% unreported over-catch for all fleets (conditioning is unchanged from OMrefB19.6)
OMrobB19.6.qTrend3	A robustness scenario with a longline CPUE catchability trend of 3% per year in projections (conditioning is unchanged from OMrefB19.6)

Table 2. Model specification abbreviations. Bold indicates BET assessment assumption(s). Some abbreviations may relate to additional explorations that are not reported in the current document.

Abbreviation	Definition
	Stock-recruit function (*h* = steepness)
h70	**Beverton-Holt, *h* = 0.7**
h80	**Beverton-Holt, *h* = 0.8**
h90	**Beverton-Holt, *h* = 0.9**
Rh70	Ricker, *h* = 0.7
Rh80	Ricker, *h* = 0.8
Rh90	Ricker, *h* = 0.9
	Recruitment deviation penalty
sr4	$\sigma_R = 0.4$
sr6	$\boldsymbol{\sigma_R = 0.6}$
sr8	$\sigma_R = 0.8$
	Future recruit failure
r55	3 years of poor recruitment (2019-2022); mean dev = -0.55, consistent with YFT assessment
	Natural mortality multiplier relative to SA-base
M10	**1.0**
M08	0.8
M06	0.6
	Tag recapture data weighting (tag composition and negative binomial)
t00	λ = 0

t0001	λ = 0.0001
t001	λ = 0.01
t01	**λ = 0.1**
t10	**λ = 1.0**
t15	λ = 1.5
	Assumed longline CPUE catchability trend (compounded)
q0	**0% per annum**
q1	1% per annum
q3	3% per annum
q5	5% per annum
	Tropical CPUE standardization method (error assumption for all series)
iH	**Hooks Between Floats (quarterly σ_{CPUE} = 0.2)**
i10H	Hooks Between Floats (quarterly σ_{CPUE} = 0.1)
iC	Cluster analysis (quarterly σ_{CPUE} = 0.2)
i10C	Cluster analysis (quarterly σ_{CPUE} = 0.1)
	Tag mixing period
x3	3 quarters
x4	**4 quarters**
x8	8 quarters
	Longline selectivity (in conditioning)
SS	**Stationary, logistic, shared among areas**
S4	LL selectivity independent among areas
NS	Temporal variability estimated in 10 year blocks
ST	Logistic selectivity trend estimated over time
Sdev	15 years of selectivity deviations estimated

Sspl	Cubic spline function (to admit possibility of dome-shape)
SD	Double-normal selectivity (flexible enough to resemble logistic or dome-shape)
	Size composition input Effective Sample Sizes (ESS)
ESS2	ESS = 2, all fisheries
ESS5	ESS = 5, all fisheries
ESS10	**ESS = 10, all fisheries**
CLRW	ESS = One iteration of re-weighting; the output ESS from a reference case assessment specification (mean over time by fishery, capped at 100)

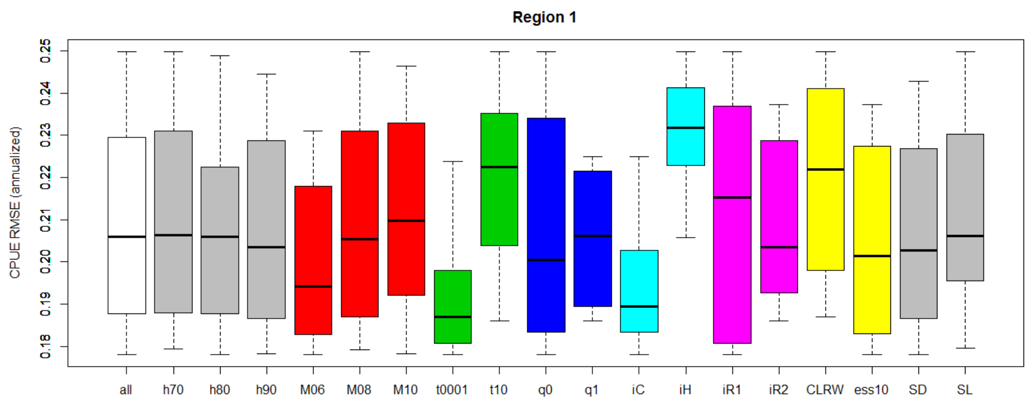


Figure 1. OMrefB19.6 quality of fit (RMSE) for the CPUE series in region 1 (annualized).

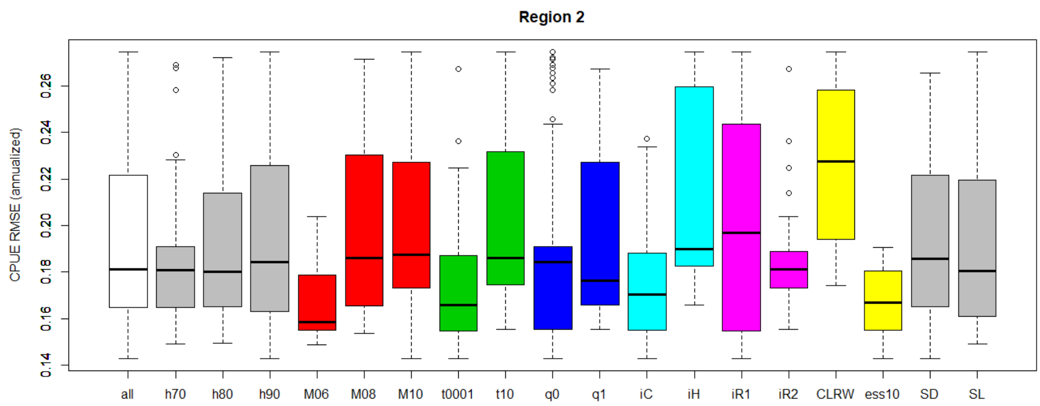


Figure 2. OMrefB19.6 quality of fit (RMSE) for the CPUE series in region 2 (annualized).

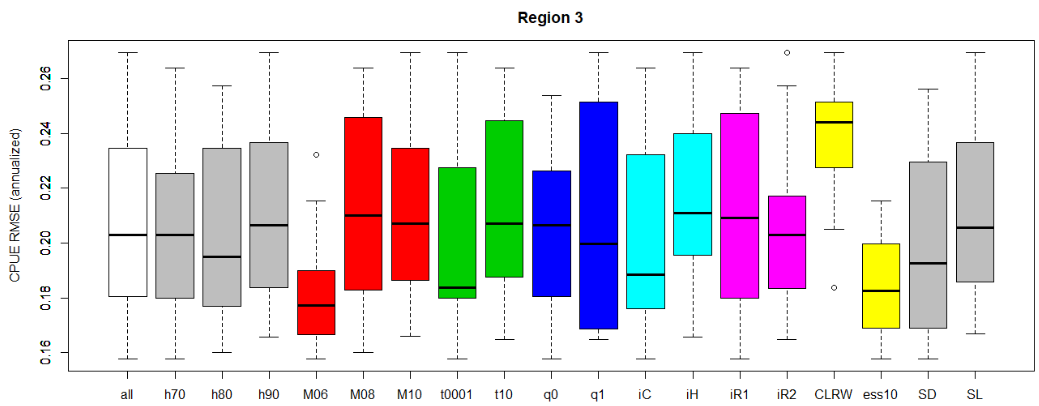


Figure 3. OMrefB19.6 quality of fit (RMSE) for the CPUE series in region 3 (annualized).

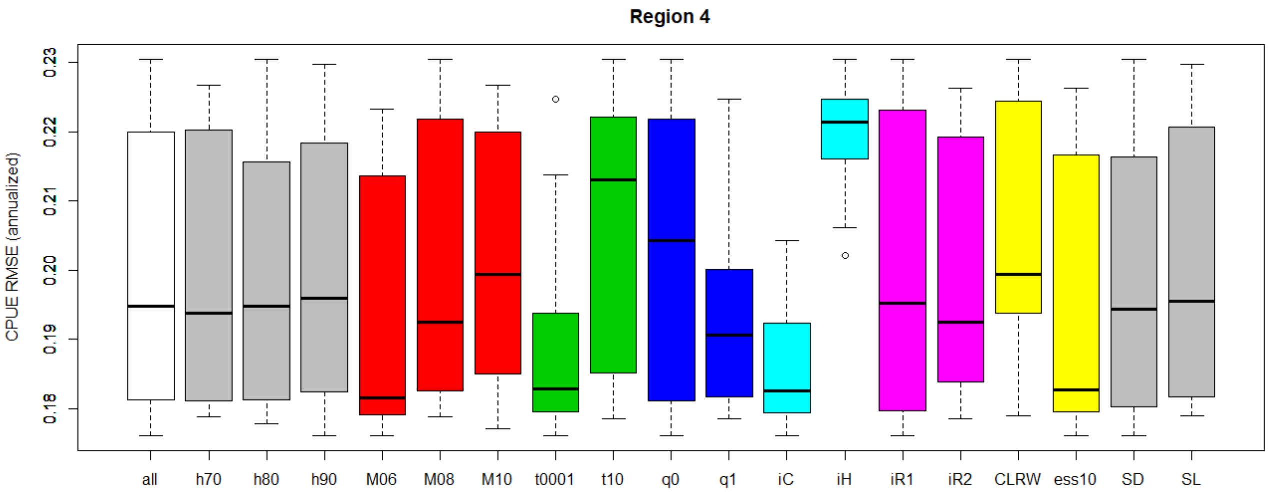


Figure 4. OMrefB19.6 quality of fit (RMSE) for the CPUE series in region 4 (annualized).

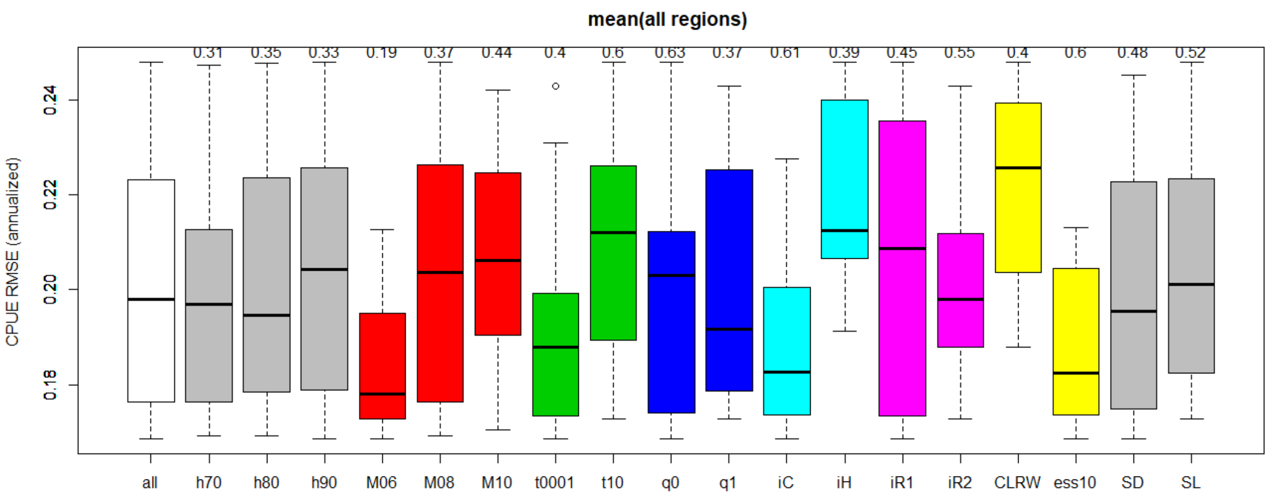
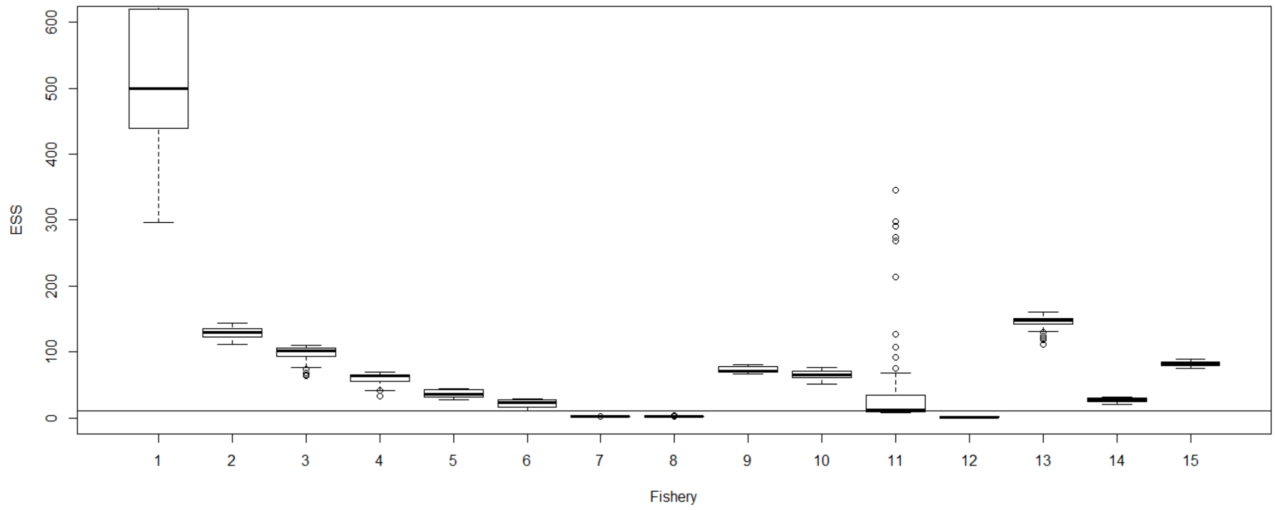


Figure 5. OMrefB19.6 Quality of fit (RMSE) for the mean of all CPUE series (annualized).



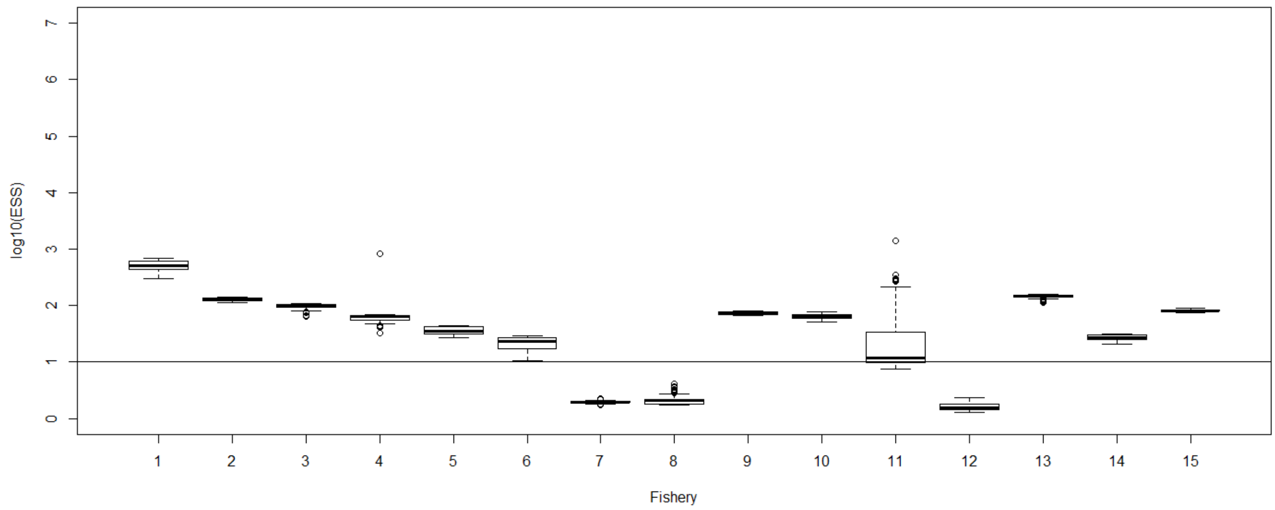


Figure 6. OMrefB19.6 quality of fit (post-fit Effective Sample Size) for the size composition data by fishery (all models combined). The key point is that the different model assumptions do not have much effect on the fit to the size data for the most part.

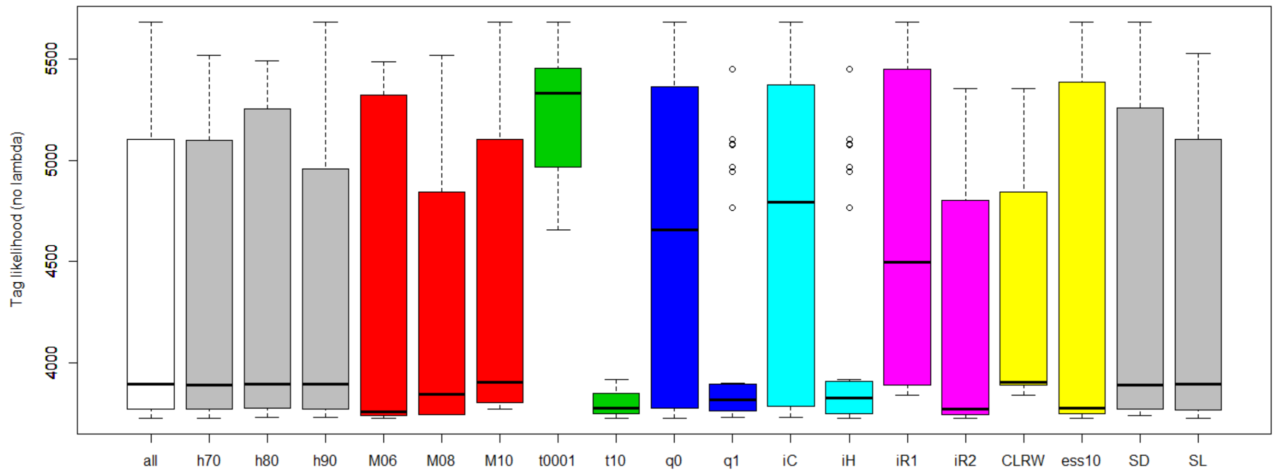


Figure 7. OMref19.6 Tag likelihood summaries marginalized over assumption levels.

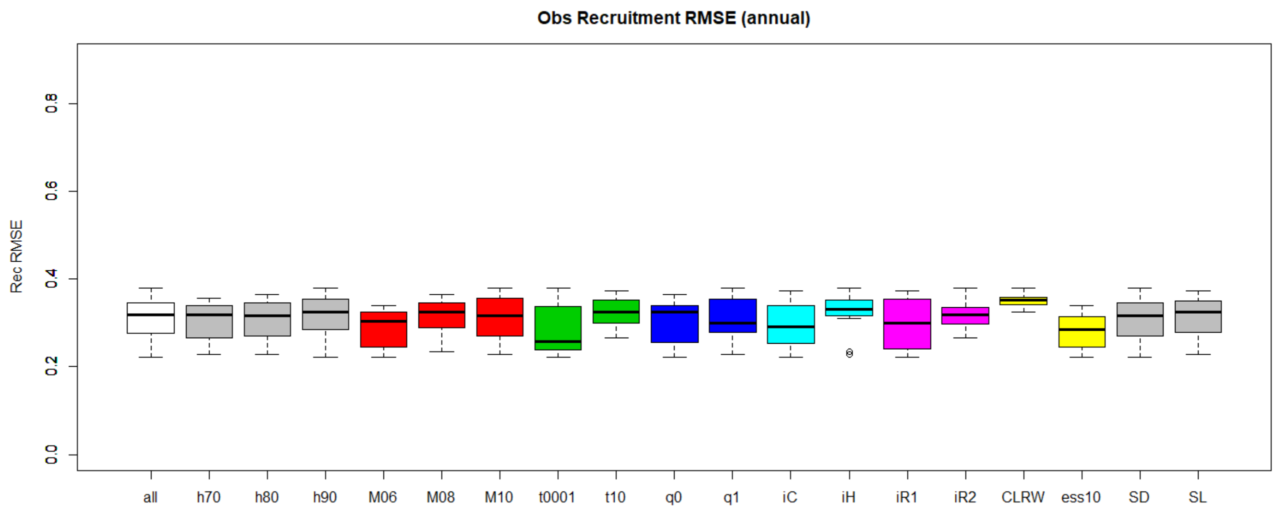


Figure 8. OMrefB19.6 recruitment RMSE (annualized - deviations aggregated across regions and seasons).

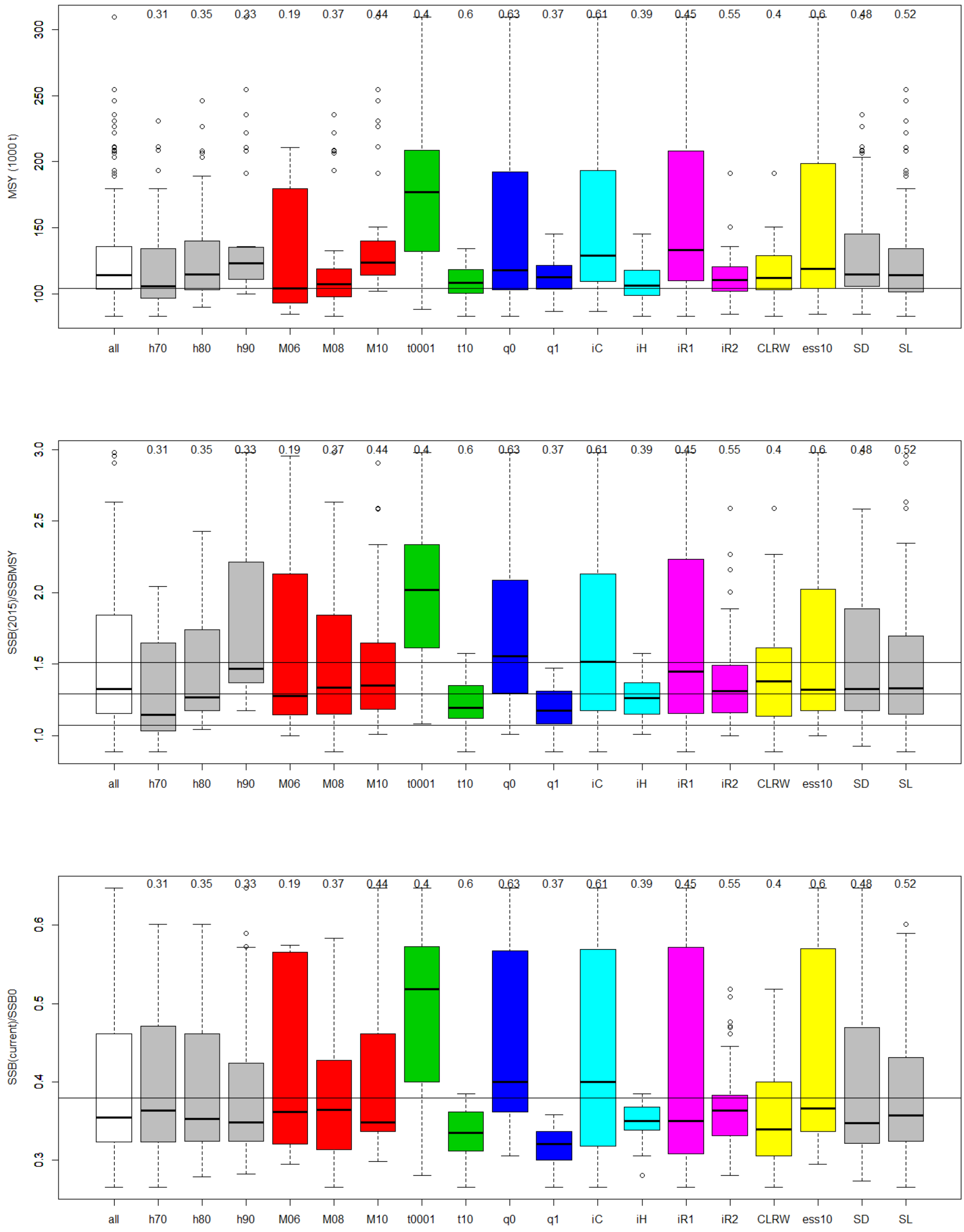
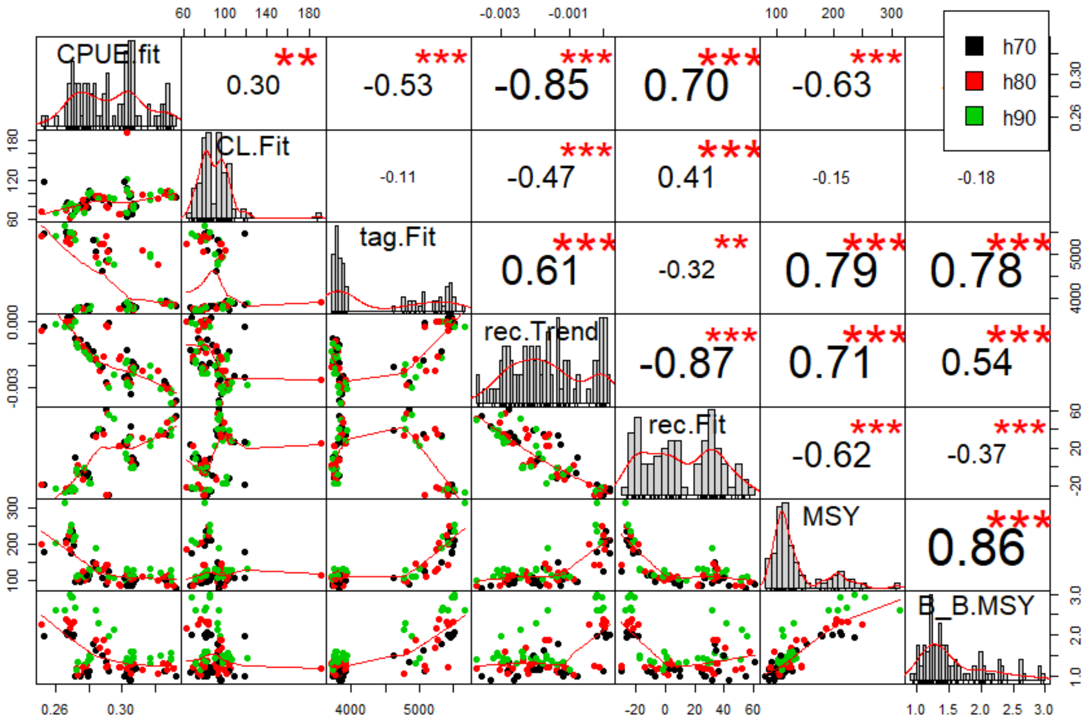


Figure 9. OMrefB19.6 key stock status inferences marginalized over model assumptions.



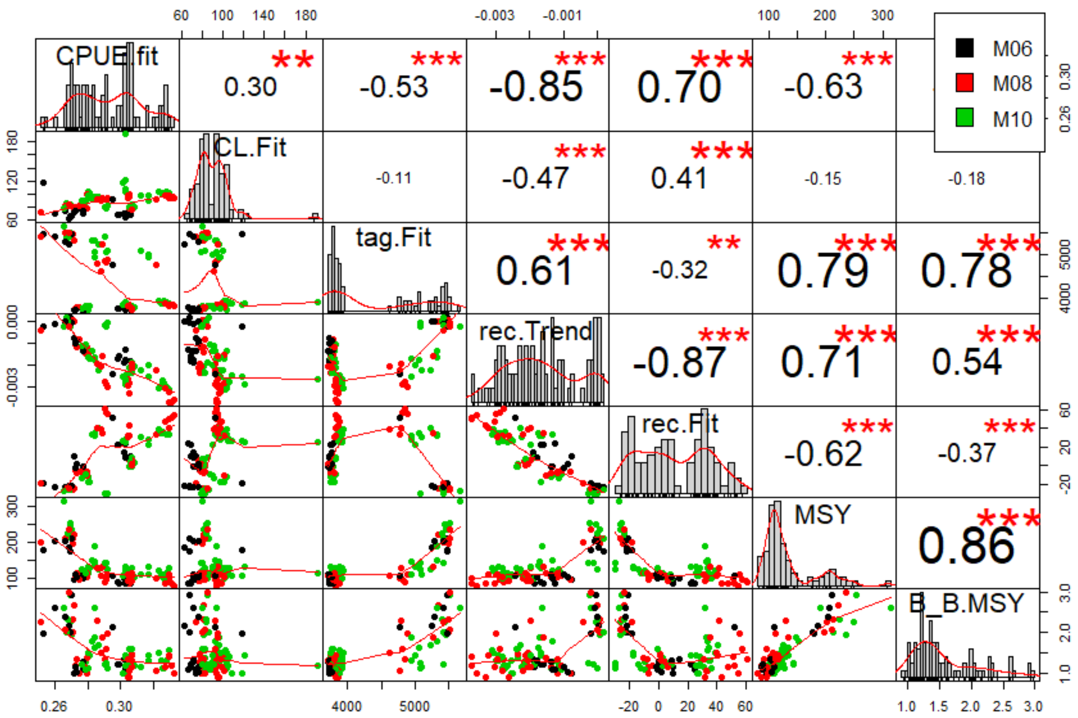
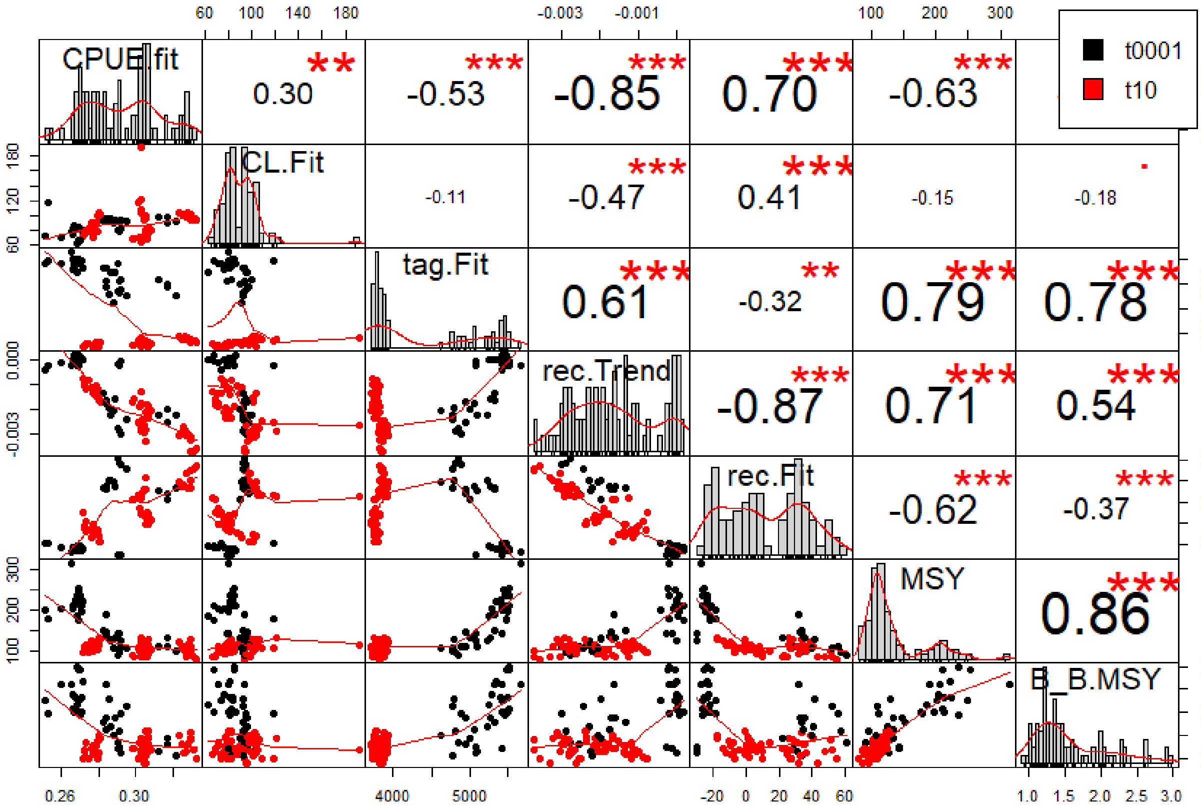
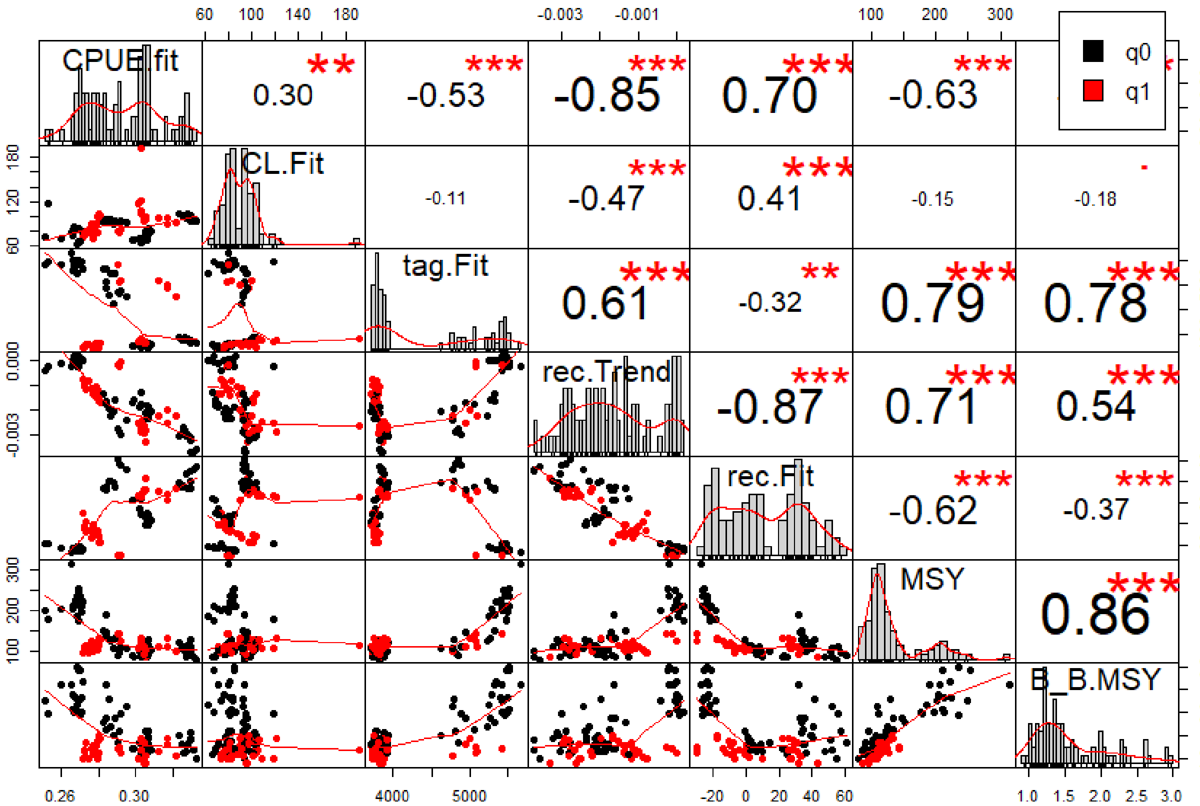


Figure 10. Operating Model OMrefB19.6 relationships among various quality of fit and stock status summary indices, partitioned by assumptions indicated in legend.





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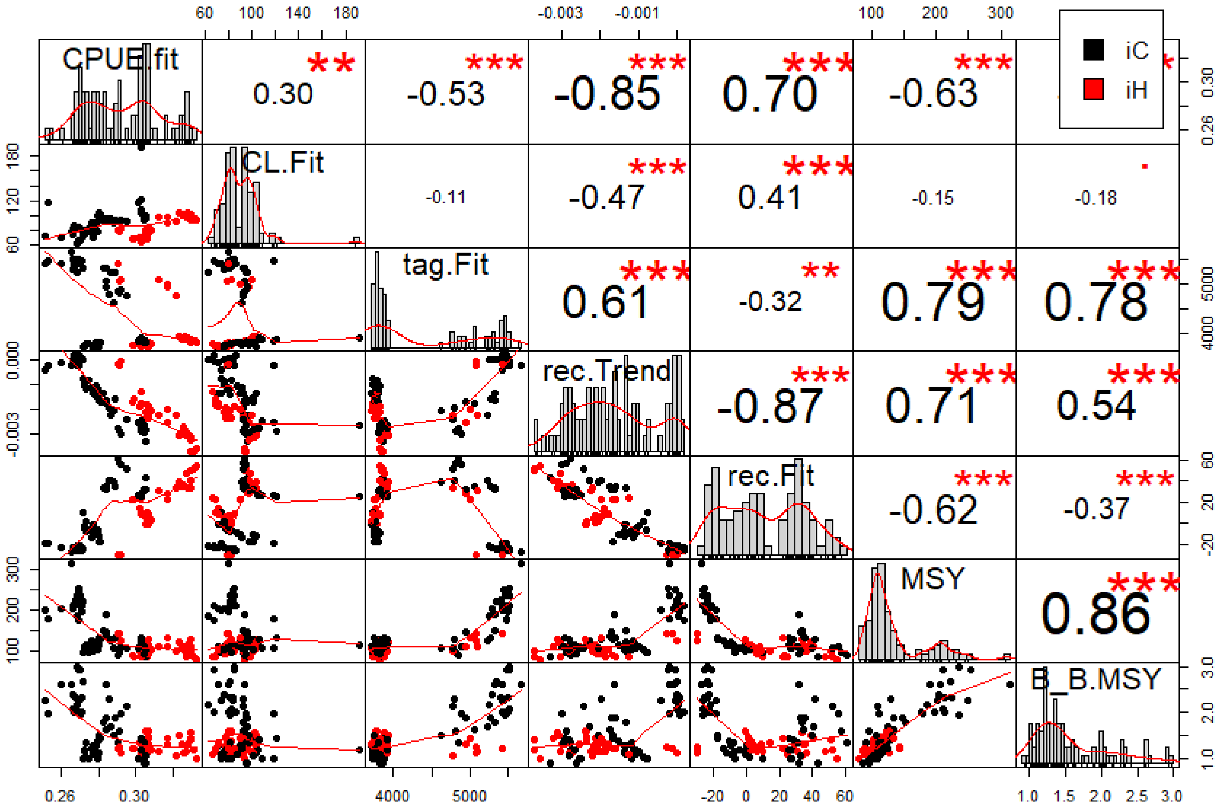

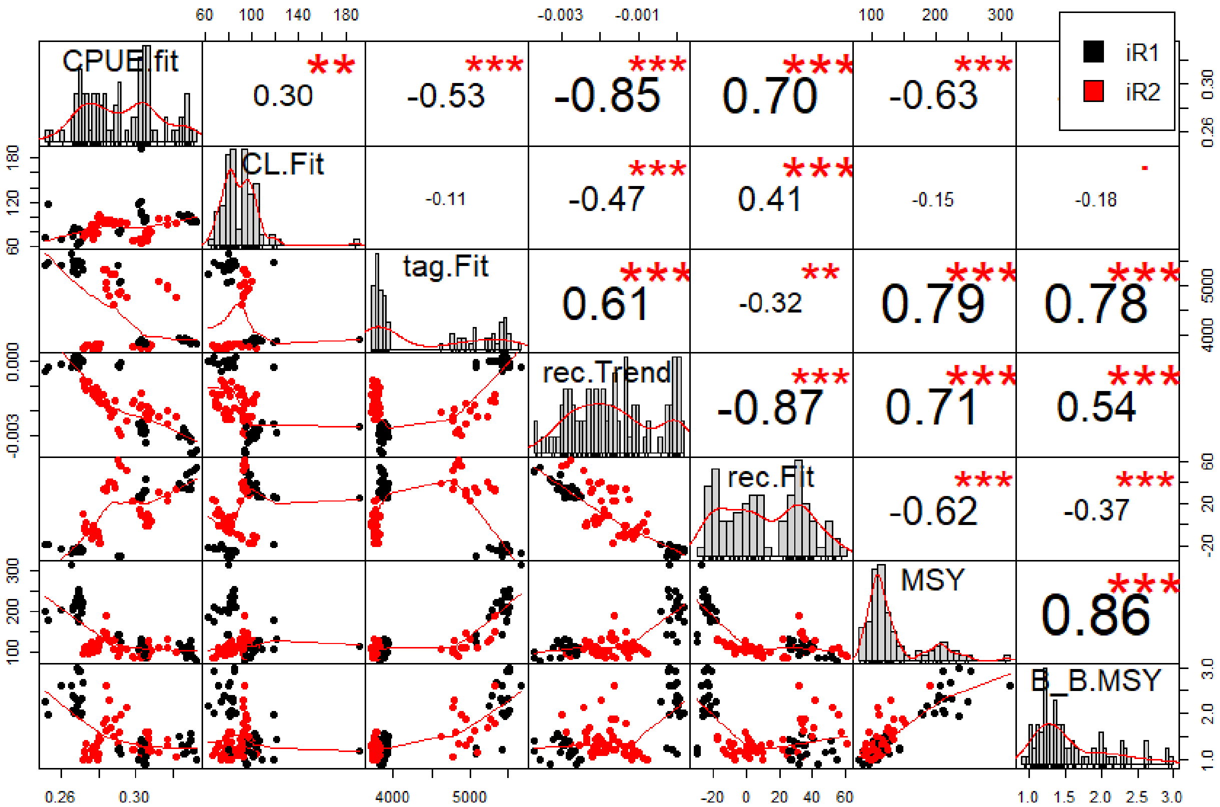

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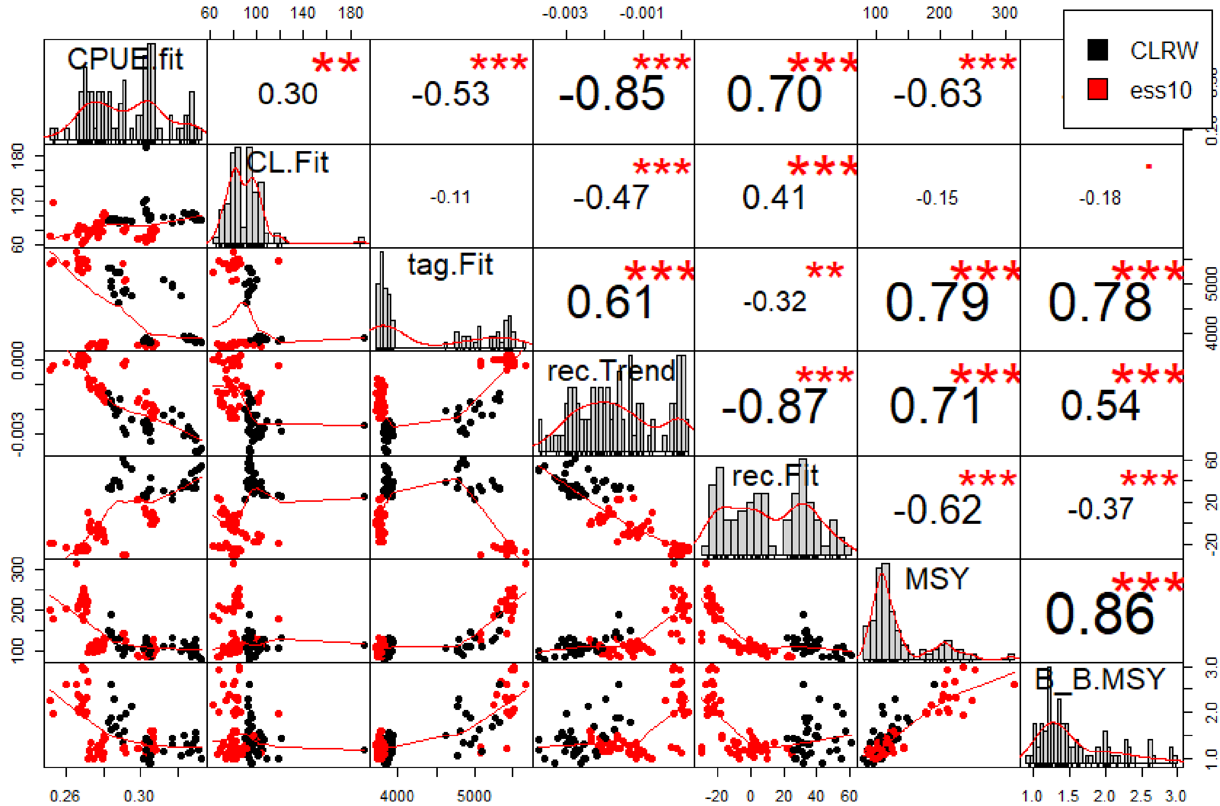

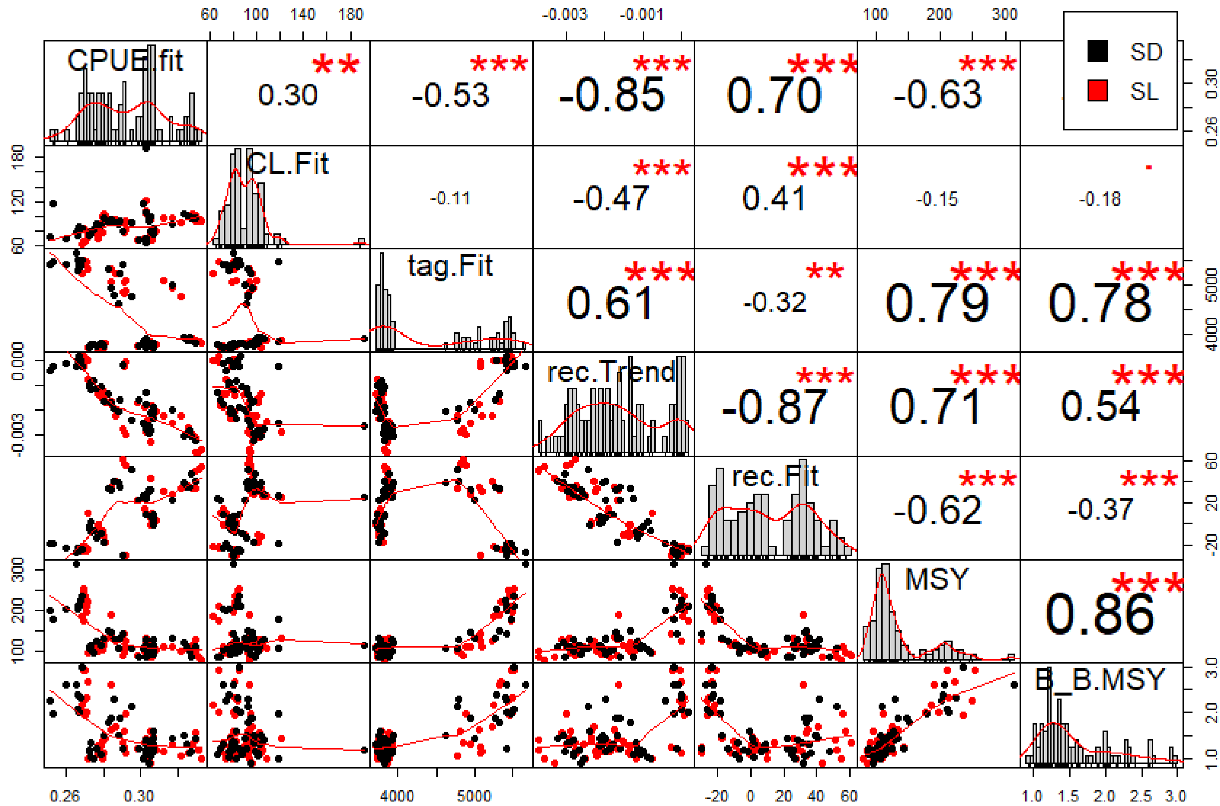

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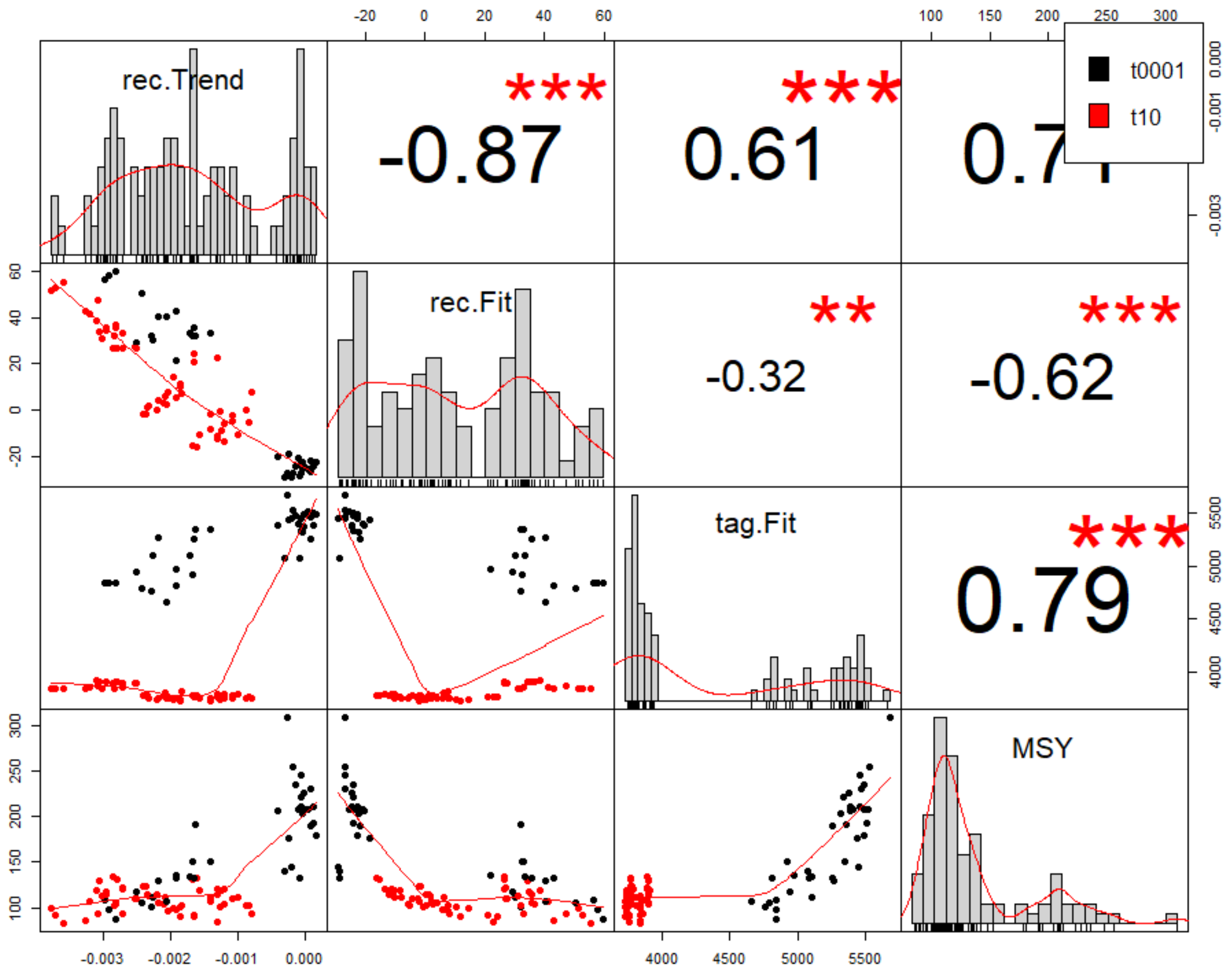


Figure 11. Relationship among various quality-of-fit indicators and MSY, indicating that the high MSY values are associated with the smallest recruitment deviation trends.

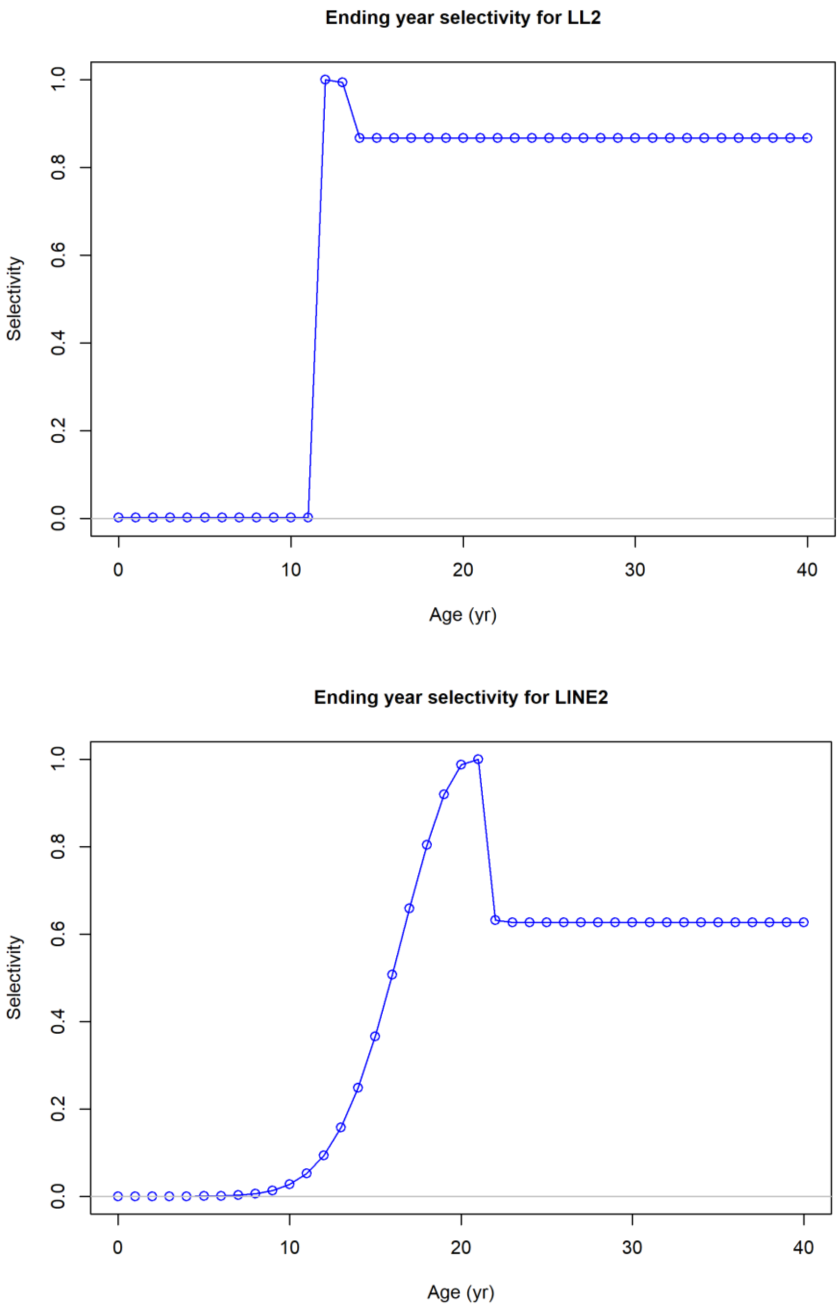
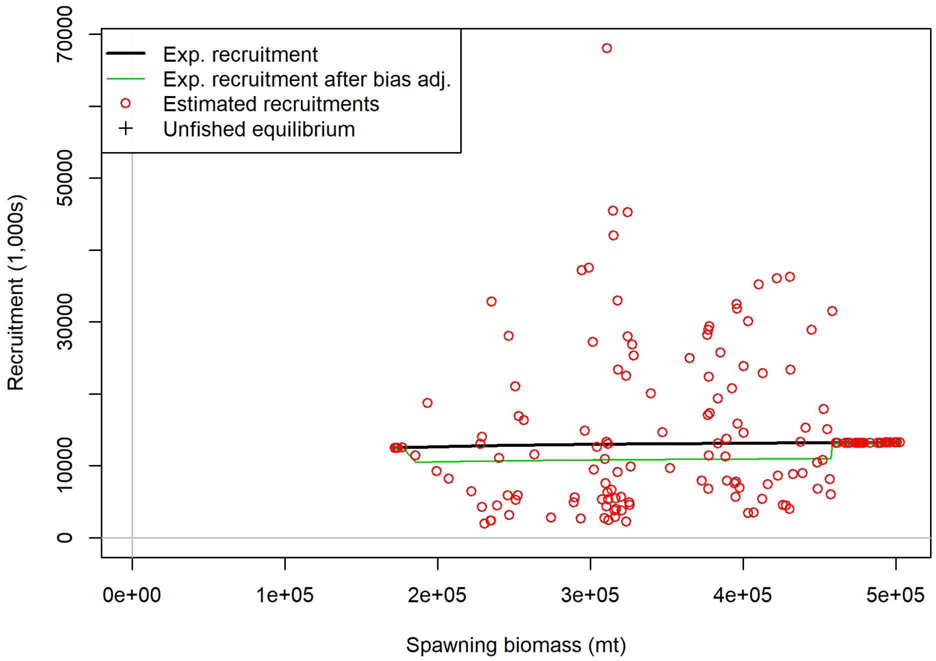


Figure 12. “Double-normal” selectivity estimates from two models with contrasting M (h70_M06_t0001_q0_iC_iR1_ess10_SD, h70_M10_t0001_q0_iC_iR1_ess10_SD).



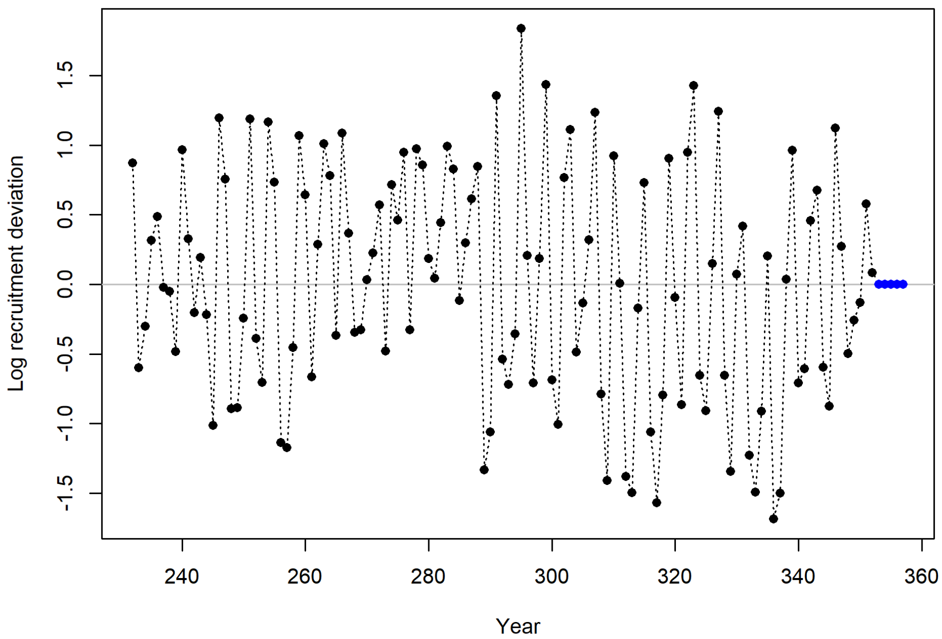


Figure 13. Stock recruitment relationship and recruitment deviations from Model `h90_M08_t10_q0_iH_iR1_CLRW_SL`, with the largest (negative) recruitment deviation trend from the OMrefB19.6 ensemble.

4.1 Reference set OMref19.6 projection dynamics

When projected forward with simple constant catch management, the basic projection dynamics of OMrefB19.6 appear to be consistent with general perceptions of current stock status (Figure 14). In the absence of fishing, SSB rapidly rebuilds to ~2030, and continues to increase slowly beyond that. Current catches are estimated to be near replacement levels, with ~90% of scenarios sustaining biomass above SSB(MSY). The median biomass is estimated to increase substantially in the first two years of projections with current catches.

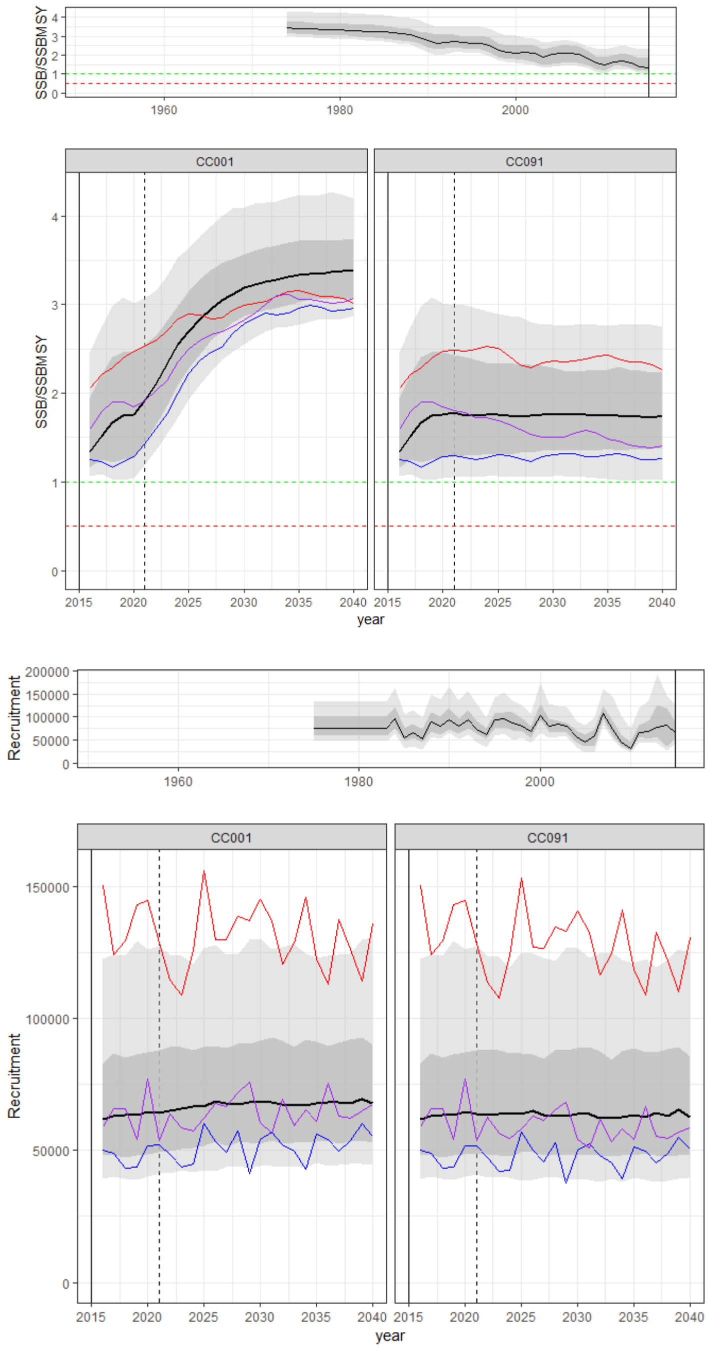


Figure 14. OMrefB19.6 spawning biomass (top) and recruitment (bottom) dynamics assuming zero future fishing (left) or constant current catch at 91 Kt (right). Ribbons indicate 25-50th and 10-90th percentiles, thick black line is the median and 3 coloured lines are random individual trajectories.

5 BET Robustness Operating Models

Four robustness scenarios were explored in this iteration (all of which assume the OMref19.6 reference set conditioning):

- *OMrobB19.6.ICV30* - What happens if the (annualized aggregate) longline CPUE observation error CV is increased to 30% (auto-correlation 0.5) in projections?

- *OMrobB19.6.10overRep* - What happens if there is a consistent 10% future over-catch (accurately reported), equally distributed among fleets?

- *OMrobB19.6.10overIUU* – What happens if there is a 10% future over-catch (unreported), equally distributed among fleets ?

- *OMrobB19.6.qTrend3* - What happens if the longline CPUE catchability trend is 3% per year going forward (but remains as in the reference scenario for conditioning)?

No model diagnostics are supplied for these robustness test OMs because they all use the reference set conditioning. MP evaluation results are provided in Kolody and Jumppanen (2019c)

Three additional robustness scenarios were suggested by the WPTT/WPM 2018 (related to spatial structure, stock structure and non-stationary biology). These scenarios have not been addressed because they would require substantial code modifications, additional data manipulation and analyses and/or some important arbitrary decisions. These proposals relate to real uncertainties that may be worth revisiting at some point, however, we (in consultation with the MSE task force) considered them to be low priorities within the scope of the current MSE project. These scenarios need to be defined more clearly, and this should probably follow careful debate within the broader IOTC scientific community.

6 Discussion

Key summary points of the current bigeye OMs for WPTT/WPM consideration:

1. The current OM assumptions are summarized in attachment 1. The bigeye assessment and OM share some of the concerns expressed for yellowfin (e.g. reliance on commercial CPUE data and tag mixing assumptions that may not be valid). However, the reliability of recent bigeye assessments has not been questioned to the same degree as yellowfin assessments, presumably because i) the stock assessment model is not prone to numerical problems, ii) the stock status is not perceived to require disruptive management action, and iii) the historical bigeye catch data may be better than yellowfin because the artisanal catch represents a much smaller proportion of the total. This is probably sufficient grounds for prioritizing bigeye lower than yellowfin at this time, but it is worth considering the extent to which our level of uncertainty in bigeye might be under-stated in the IOTC scientific community.
2. The bigeye reference set OM will need to be compared with the 2019 stock assessment, to ensure that the inferences are compatible. i.e. The OM should encompass a greater degree of uncertainty than the assessment to ensure that MPs are robust, and the central tendency of the assessment should not be in the tails of the OM.
3. In most cases, the reference set OM tends to be influenced by the alternative model assumptions in a predictable manner. We continue to welcome suggestions for revising the OMs – by either adding important uncertainty dimensions or changing some existing assumptions if new arguments justify increasing or decreasing the uncertainty represented. The longline selectivity dimension is probably the lowest priority for retention. We consider the bimodal distribution of stock status inferences to be undesirable and expect that it could be resolved by adding intermediate levels to one or more factors. However, we would first want to consider any new insights gained through point 2 above.
4. We have employed a series of model diagnostics that should be able to identify many model interactions and outlier behaviours in a large model grid. We recognize that the approach is somewhat qualitative, and there might be other features of interest that are over-looked in these aggregate summary statistics. We continue to welcome suggestions for improving the process of model selection (retention/rejection or non-binary weighting). However we note that diagnostics need to be applicable to a large ensemble or else the whole approach to OM development would need to be revised.
5. Additional assumptions that are thought to be plausible and challenging for management should be discussed for inclusion in either the OM reference set or robustness tests. These scenarios should be considered carefully – i.e. a Management Procedure cannot be expected to handle every possible adverse outcome. “Exceptional circumstances” meta-rules are intended to interrupt MP implementation when extreme unexpected events occur (this might include multiple moderately disruptive events occurring simultaneously).

Resources have been identified to support the technical and scientific requirements for bigeye MSE until at least Dec 2020.

7 References

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8 Attachment 1. Current (Sep 2019) State of the IOTC Bigeye reference set Operating Model for MP evaluations

State of the IOTC Bigeye Operating Models for Management Procedure evaluation Sep 2019

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Introduction

This document provides a brief description of the most recent state of the bigeye tuna Operating Models (OMs) used for Management Procedure (MP) evaluation, including the reference set *OMrefB19.6,* and various robustness tests. The documentation for the latest version of the MSE software, technical documentation, and series of project reports is publicly available from github https://github.com/pjumppanen/niMSE-IO-BET-YFT/. The iterative and sometimes circuitous decision process undertaken by the IOTC technical working groups and analysts to reach the current state of the OM are not described here. These may be found in various IOTC working papers, information papers and meeting reports, along with various model results and diagnostics that were used to guide the OM development process.

OMrefB19.6 was proposed by the MSE task force in March 2019, and provided the basis for the MP evaluations presented to the TCMP in May 2019. A couple of minor specification errors were subsequently identified and corrected (with negligible implications for the MP evaluation results). The definition and role of the robustness tests is continuously evolving and not described here.

Conditioning Software

This version of the OM is an ensemble of models conditioned using the *Stock Synthesis* assessment software version SS3.24z.exe (e.g. Methot and Wetzel 2013).

Projection Software

The projection software is available from https://github.com/pjumppanen/niMSE-IO-BET-YFT/. The population dynamics equations conform to fairly standard assumptions, and are fully documented in the technical reference (also on github).

Reference Set OM

The various models in the OM ensemble are derived from the reference case stock assessment defined from the 2016 assessment (Langley 2016), except that the temperate seasonal CPUE series were aggregated into a single series (each weighted by their respective series means). Key structural assumptions include:

- 4 regions (Figure 1) with age-dependent movement
- Quarterly dynamics (implemented with calendar quarters as SS model-years)
- 15 fisheries (Table 1)
- Beverton-Holt recruitment dynamics
- Parameter estimation objective function includes
    - Standardized longline CPUE. Region 1A and 1B share one series and R2 has one series. In the assessment, R3 was split into 4 seasonal series with

independent catchability – in the OM these series were aggregated into one series with each season independently re-normalized.
    - Size composition data
    - Tags (excluded in some OM scenarios)
    - Recruitment penalties on deviations from stock recruit relationship and mean spatial distribution
    - Diffuse priors on all estimated parameters
- Estimated parameters:
    - Fishery selectivity (stationary, various functional forms, parameters shared among some fleets)
    - Longline catchability - regional scaling factors are used to scale relative density to relative abundance among regions, such that 1A, 1B, 2 share catchability and catchabilities are estimated independently for the 4 seasonal fisheries in region 3
    - Virgin recruitment
    - Recruitment deviations from the Beverton-Holt stock-recruit relationship, recruitment spatial partitioning among tropical regions (1 and 2). There are no spatial deviations over time.
    - Juvenile and adult movement rates
    - Initial fishing mortality

OM Reference Set Grid

- Model structural and parameter uncertainty is introduced to the OM through the alternative assumptions listed in Table 2.
- Only the point estimates for parameters and states from each model specification (maximum posterior density) are retained for the OM.
- A fractional-factorial experimental design was used to evaluate a subset of 144 models, which would allow the estimation of all main effects in the context of a GLM (the full factorial grid with all interactions would require 576 models).
- In recognition that the IOTC bigeye assessment model parameter estimates can be sensitive to initial starting conditions, minimization was repeated from randomly jittered starting conditions until either (i) successful minimization was achieved 3 times (maximum gradient of the objective function with respect to the estimated parameters <0.01) or (ii) 10 attempts at minimization were completed.

OM Reference Set *OMrefB19.6*

- Within an individual model configuration, the version with the lowest objective function value (from the jittered minimizations) were retained (initially). The best fit models were subsequently rejected from the reference grid if:
    - Minimization unsuccessful (max. grad. >0.01)
    - SS3 Catch Penalty >1E-5 (i.e. model struggles to remove the observed catch, which is assumed to be related to the pessimistic retrospective patterns)
- All retained models were subject to a qualitative comparison of simple diagnostics to identify outlier behaviour or polymodal stock status inferences (no obvious problems were noted). The four most extreme models (highest and lowest depletion and productivity) were visually examined in more detail, without obvious evidence for blatant model failure.
- The OM reference set grid is fully balanced with respect to each factor, while the retained grid has 94 of the original models, with the factor level distribution shown in Table 4. Rejected models were notably associated with option M06 (and to a lesser extent iH and q1).
- Each SS model is assigned a plausibility weighting. To date, models have only been assigned a weighting of 0 or 1, such that all retained models are uniformly weighted. *OMrefB19.6* consists of 500 models randomly sampled (with replacement) from the grid of retained models.
- Key projection assumptions are summarized in Table 4.

References

Langley, A. 2016. Stock assessment of bigeye tuna in the Indian Ocean for 2016 — model development and evaluation. IOTC-2016-WPTT18-20.

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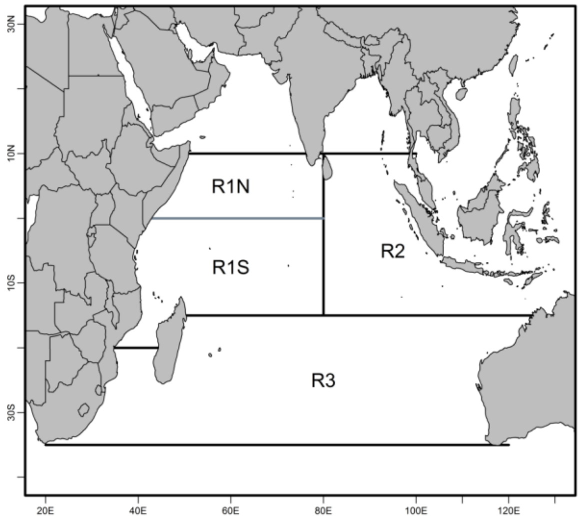

Figure 1. Spatial structure for the bigeye tuna OM (figure from Langley 2016).

Table 1. Fishery definitions in the BET 2016 assessment (ordered as in the model control files, not the stock assessment report).

Fishery	Definition
FL2	Fresh Tuna Longline Region 2
LL1	Longline R1S
LL2	Longline R2
LL3	Longline R3
PSFS1	Purse Seine Free-school R1S
PSFS2	Purse Seine Free-school R2
OT1	Other R1 (include gillnet, trolling and other minor artisanal gears)
OT2	Other R2 (include gillnet, trolling and other minor artisanal gears)
PSLS1	Purse Seine Log set R1S
PSLS2	Purse Seine Log set R2
BB1	Bait Boat R1S
LINE2	Includes small scale fisheries using handlines, small longlines and the gillnet/longline combination fishery of Sri Lanka.
LL4	Longline R1N
PSFS4	Purse Seine Free-school R1N
PSLS4	Purse Seine Log set R1N

Table 2. Assumptions in OMrefB19.6 Stock Synthesis conditioning. Bold indicates the reference case assumption from the Langley (2016) assessment.

Abbreviation	Definition
	Stock-recruit function (h = steepness)
h70	Beverton-Holt, h = 0.7
h80	**Beverton-Holt, h = 0.8**
h90	Beverton-Holt, h = 0.9
	Natural mortality multiplier relative to reference case M vector
M10	**1.0**
M08	0.8
M06	0.6
	Tag recapture data weighting (tag composition and negative binomial)
t0001	λ = 0.001
t10	**λ = 1.0**
	Assumed longline CPUE catchability trend (compounded)
q0	**0% per annum**
q1	1% per annum
	Tropical longline CPUE standardization method
iH	**Hooks Between Floats**
iC	Cluster analysis
	Longline fishery selectivity
SL	**Stationary, logistic, shared among areas**
SD	Stationary, double-normal (potentially dome-shaped), shared among areas
	Size composition input Effective Sample Sizes (ESS)
ESS10	**ESS = 10, all fisheries**
CLRW	ESS = One iteration of re-weighting from reference case model, capped at 100.

Table 3. Frequencies of reference set grid assumptions retained after convergence and plausibility criteria are applied. If all models were retained, each assumption would be equally represented (i.e. either 0.33 or 0.5, depending on the number of assumption levels). Assumption abbreviations are defined in Table 2.

Model Assumption (proportion represented in OMrefB19.6)		
h70 0.30	h80 0.37	h90 0.33
M06 0.20	M08 0.37	M10 0.43
t0001 0.41	t10 0.59	
iC 0.62	iH 0.38	
iR1 0.47	iR2 0.53	
q0 0.63	q1 0.37	
CLRW 0.41	ESS10 0.59	
SD 0.49	SL 0.51	

Table 4. OM Projection assumptions in the bigeye reference set and robustness sets. Reference set values not listed are identical to the model-specific conditioning assumptions/estimates. Robustness case values are identical to the reference set except as noted.

OM	Projection assumption	Value
OMrefB19.6	Reference set OM	
	Initial population error CV (a = age in quarters)	0.6exp(-0.1a)
	Recruitment deviation penalty Recruitment deviation lag(1) auto-correlation quarterly (annual equivalents)	σ_R = 0.6 (0.42)* ρ_R = 0.5 (0.21)*
	CPUE observation error CPUE observation error lag(1) auto-correlation (annual)	σ_R = 0.2 ρ_R = 0.5
	Multinomial Catch-at-length sample size (all fisheries)	100
	Selectivity stationary for all fisheries	
	Quota Implementation error	CV = 0
	First MP quota year	2021
	Assumed catches 2016, 2017-2020	87, 91 Kt
	MP data lag (i.e. data from 2018 informs 2021 quota)	2 years**
	Quota allocation (average observed over)	2014-2015
	Number of stochastic realizations	500
OMrobB19.6.iCV3	elevated CPUE error in projections (conditioning as OMrefB19.6)	σ_R = 0.3 ρ_R = 0.5
OMrobB19.6.10overRep	10% overcatch for all fleets (catch is accurately reported) (conditioning as OMrefB19.6)	
OMrobB19.6.10overIUU	10% unreported overcatch for all fleets (conditioning as OMrefB19.6)	
OMrobB19.6.qTrend3	CPUE catchability trend of 3% per year in projections (conditioning as OMrefB19.6)	

* Due to a change in parameterization between quarterly and annual units, results presented to TCMP 2019 erroneously overstated the intended recruitment projection CV with (annualized) σ_R = 0.6, ρ_R = 0.5.

**Results presented to TCMP 2019 erroneously had a 3 year data lag.