SENSITIVITY OF CMP RANKINGS TO CONSERVATION TARGETS FOR ATLANTIC BLUEFIN TUNA

Samuel D. N. Johnson[1,2], Steven P. Rossi[1,2], Sean P. Cox[1,2]

SUMMARY

This paper investigates how the choice of conservation targets influence relative rankings of candidate management procedures (CMPs) for Atlantic Bluefin Tuna (ABT). Three CMPs from different development teams are each tuned to three interpretations of the stated ABT conservation goal to achieve "60% probability of healthy stocks over a 30-year period", where healthy is defined via a Kobe plot where both $F/F_{MSY} \leq 1.0$, and $B/B_{MSY} \geq 1.0$. The probability calculation for this objective differs among interpretations, being calculated as healthy status in (i) 60% of simulation replicates in the 30th year of the projection period; (ii) 60% of simulation replicates and years within the first 30 years of the MSE projection period; or (iii) 60% of simulation replicates in each year within the first 30 years. Tuning each CMP to the desired probability is performed via an iterative grid search over tuning parameter values.

RÉSUMÉ

Le présent document étudie comment le choix des objectifs de conservation influence le classement relatif des procédures de gestion potentielles (CMP) pour le thon rouge de l'Atlantique (ABFT). Trois CMP provenant de différentes équipes de développement sont ajustées sur trois interprétations de l'objectif de conservation déclaré du thon rouge de l'Atlantique, à savoir atteindre une « stocks sains sur une période de 30 ans avec une probabilité de 60% » , où le terme « sain » est défini par un diagramme de Kobe où $F/F_{PME} \leq 1,0$ et $B/B_{PME} \geq 1,0$. Le calcul de la probabilité pour cet objectif diffère selon les interprétations, étant calculé comme l'état sain dans (i) 60 % des répliques de simulation dans la 30e année de la période de projection ; (ii) 60 % des répliques de simulation et des années dans les 30 premières années de la période de projection MSE ; ou (iii) 60 % des répliques de simulation dans chaque année dans les 30 premières années. Le calibrage de chaque CMP à la probabilité souhaitée est effectué au moyen d'une recherche itérative de la matrice dans les valeurs des paramètres de calibrage.

RESUMEN

Este documento investiga como influye la elección de los objetivos de conservación en las clasificaciones relativas de los procedimientos de ordenación candidatos (CMP) para el atún rojo del Atlántico (ABT). Tres CMP de diferentes equipos de desarrollo son calibrados a tres interpretaciones del objetivo de conservación establecido de ABT para lograr «un 60 % de probabilidades de contar con stocks saludables durante un periodo de 30 años», donde saludables se define por medio de un diagrama de Kobe en el que tanto $F/FRMS \leq 1,0$, como $B/BRMS \geq 1,0$. El cálculo de la probabilidad para este objetivo difiere entre las interpretaciones, siendo calculado como saludable en (i) el 60 % de las réplicas de simulación en el año 30 del periodo de proyección, (ii) el 60 % de las réplicas de simulación y años dentro de los primeros 30 años del periodo de proyección de la MSE o (iii) el 60 % de las réplicas de simulación en cada año dentro de los primeros 30 años. La calibración de cada CMP a la probabilidad deseada se realiza mediante una búsqueda iterativa de la matriz en los valores de los parámetros de calibración.

KEYWORDS

Management procedure tuning; sensitivity analysis; conservation targets

[1] Landmark Fisheries Research, 213-2414 Saint Johns St, Port Moody, BC, Canada
[2] School of Resource and Environmental Management, Simon Fraser University, 8888 University Drive, Burnaby, BC, Canada

1. Introduction

Several teams of scientists are developing candidate management procedures (CMPs) for the management strategy evaluation (MSE) of the Atlantic Bluefin Tuna (ABT) multi-stock, trans-boundary fishery. International Commission for the Conservation of Atlantic Tunas (ICCAT) Commissioners will choose, and possibly adopt, one of these CMPs for setting annual ABT total allowable catches (TACs). The ABT MSE process, therefore, aims to rank CMPs according to conservation and yield performance metrics after being tuned to meet a particular target ratios of spawning biomass to B_{MSY} at the end of the first 30 years of the MSE projection period (called Br30).

During development, CMPs are tuned to meet target values of Br30 for each of the West (Gulf of Mexico; GoM) and East (Mediterranean Sea; Med) spawning stocks. Currently, 4 combinations of stock specific Br30 values are used as tuning targets, with CMPs tuned so that the median Br30 values over all 48 operating models are within 0.01 of a given target value. Those four targets bound a range of desirable conservation outcomes while exhibiting spatial harvest trade-offs in the ABT management system.

A criticism of the current Br30 development tuning targets is that they prescribe stock health at the end of a 30-year projection, but are not specifically concerned with stock health in the intervening period. Focusing on stock status at the end of 30 years may be counter to the ICCAT Commissioners stated objective of having a "60% probability" of healthy stocks over a 30-year period, where healthy is defined as being in the green quadrant of a Kobe plot (ICCAT 2019). In particular, there are three main points where the development tuning target and the ICCAT Commissioners' objective diverge. First, Br30 ≥ 1 implies that biomass is above B_{MSY} (i.e., the stock is not overfished), but does not place any restriction on overfishing ($F/F_{MSY} > 1$) an ABT stock when it is not in an overfished state. Second, targeting a median value over the grid of deterministic operating models implies a 50% target probability, which is lower than the ICCAT Commissioners 60% objective. Finally, the way in which probability is calculated is not defined. Specifically, the word "over" is open to several interpretations, each of which imply different levels of risk tolerance.

In this Standing Committee on Research and Statistics (SCRS) document, we ask whether the relative ranking of three ABT CMPs is sensitive to alternative interpretations of the conservation targets. CMPs are first tuned to three alternative interpretations of the target probability via iterative grid search. The resulting tuned CMPs are then ranked according to other conservation and yield performance metrics.

2. Methods

2.1 Contributed CMPs

Three teams of scientists contributed CMPs for the tuning analysis.

1. The BR CMP (Butterworth and Rademeyer, 2021), developed by Butterworth, Jacobs, Rademeyer and Miyagawa, tuned using α (East) and β (West) parameters, which scale relative harvest rates derived from TACs and average abundance indices. TAC caps are also applied to reduce overfishing in some operating models, with a cap of 45 kt in the East, and 2.35 kt in the West.

2. The LW CMP (Lauretta and Walter, 2020), developed by Matt Lauretta and John Walter of the National Oceanic and Atmospheric Administration, tuned using m_E (East) and m_W (West), which also scale relative harvest rates derived from TACs and the GoM and Med fishery independent spawning stock indices.

3. The AH CMP (Hanke 2020), developed by Alex Hanke of Fisheries and Oceans, Canada, tuned using catchability parameters q_E (East) and q_W (West), which scale relative CPUE indices to biomass, from which TAC is calculated via an approximate $F_{0.1}$ reference fishing mortality rate.

Brief descriptions of each CMP and the parameters used to tune them are given in Table 1. More details of the CMPs can be found in the Standing Committee on Research and Statistics (SCRS) documents cited above, and in the CMP summary table submitted to the SCRS at the April 2021 intersessional meeting (ICCAT 2021, Appendix 5). The code for each CMP used in this analysis is saved in a bitbucket repository, attached to this document as **Appendix A**.

2.2 Alternative conservation targets

Each of the three contributed CMPs is tuned to three alternative conservation targets. Each target interprets the desired probability of ABT stocks being healthy (i.e., biomass is at least B_{MSY}, and fishing mortality is below F_{MSY}) over the first 30 years of the projection in a different way. The alternative targets tested are:

1. Year30: ABT stocks are healthy with 60% probability at the end of the first 30 projection years;
2. All30: ABT stocks are healthy with 60% probability across the first 30 projection years;
3. Each30: ABT stocks are healthy with 60% probability in each of the first 30 projection years.

Probability equations for Year30, All30, and Each30 are given in Table 2. Given that the current operating models being used for CMP development are deterministic (i.e., fixed process errors), the probabilities for Year30 and Each30 must be calculated over the grid of 48 operating models. For All30, the probability is calculated over the 30 years and the grid of 48 operating models. For targets Year30 and All30, CMPs are tuned to exactly 60% probability, while for Each30, CMPs are tuned so that the minimum of probabilities for each of the 30 years is exactly 60%.

2.3 Iterative grid search

All simulations use the CMPs, with versions current as of June 28th, 2021, and the ABT-MSE R package version 7.1.3.

The steps of the grid search are:

1. Define a coarse, 2 dimensional grid of East and West tuning parameters for each contributed CMP, where each combination of parameters defines a realisation of the CMP for the ABT stock,
2. Apply the grid of CMPs to all 48 ABT MSE operating models,
3. Calculate probabilities of stock health according to Year30, All30, and Each30 interpretations for each CMP in the tuning grid,
4. Use a thin-plate spline to interpolate probabilities between grid points and estimate new tuning parameter values associated with 60% probability for each target,
5. If precision of 0.5% is reached, or precision is not improved from previous iteration, then stop. Otherwise, refine the CMP grid in the neighbourhood of parameter values estimated in step 4 and iterate from step 2.

For the first iteration, one coarse grid per CMP is sufficient, but on successive iterations with refined grids, a separate grid for each target may be required (Tables 3 - 5). If multiple grid points are associated with the target value of 60%, then the grid points associated with lower catch quotas are taken as the optimal values.

Operating model spawning biomass and fishing mortality simulation envelopes are shown for the CMPs under the final tuning parameters values. To avoid scaling differences between OMs, biomass is plotted as $Br = B/B_{MSY}$ and fishing mortality as $Fr = F/F_{MSY}$ for each spawning stock.

2.4 Rankings and sensitivity

Once tuned to each of the three targets, the three CMPs were ranked by conservation and yield performance. Conservation performance was measured by the ratio of ABT spawning stock biomass relative to B_{MSY} at the end of the first 30 years (Br30), the average ratio of biomass to B_{MSY} over years 10 – 30 (AvgBr), and lowest depletion (LD). Yield performance was measured as the average catch over the first 30 projection years (AvC30). Rankings according to the median of all metrics, and the 5th percentile of Br30, are compared between tuning targets.

3. Results

3.1 CMP Tuning Results

3.1.1 BR CMP

The initial coarse grid shows that Each30 and Year30 have similar probability surfaces over the tuning parameters, while All30 requires much higher catch limits to meet the 60% target (**Figure 1**). Estimates of the optimal parameters are almost identical for Each30 ($\alpha = 3.88$, $\beta = 1.01$) and Year30 ($\alpha = 3.88$, $\beta = 0.99$), while the optimal parameters meeting a 60% probability for All30 were not included in the initial grid.

The inability to meet the 60% target for All30 was partly due to the catch caps. Catch caps limit the fishing mortality when stocks are healthy, creating (desirable) limits on the probability of overfishing or being overfished. To help meet the 60% target for All30, a wider grid centred around higher α parameter values with relaxed catch caps (50kt in the East, no cap in the West) is defined as the first refinement for the All30 target (Table 3), based on the parameters needed to meet Br30 = 1 for both stocks (Pers. Comm, Rademeyer 2021). The second refinement is actually an expansion of the grid, relaxing the cap to 55kt in the East, meeting the required precision.

3.1.2 LW CMP

The response surfaces are shown in **Figure 2** for Year30, All30, and Each30 targets for the East and West stocks over the initial coarse grid for the LW CMP.

In the initial grid search, the optimised relative harvest rate multipliers that meet the 60% target are highest for All30, which measured the probability of stocks being healthy within the first 30 projection years ($m_E = 8.95$, $m_W = 9.14$). For Year30, which measures the probability of a healthy stock in year 30 only, the optimal values were lower ($m_E = 7.34$, $m_W = 8.42$), and the lowest values were for Each30 ($m_E = 7.21$, $m_W = 8.03$), which measured the minimum probability of a stock being healthy in each of the first 30 projection years.

After one refinement, the LW CMP meets Year30 with acceptable precision (**Table 4**), but a second refinement is needed for All30 and Each30, as 60% is not within the first grid refinement for either of those targets. Multiple grid points in the second refinement are associated with each tuning target, so the lowest multiplier values (i.e., lower harvest rates) that meet the 60% target are selected as the final tuned parameter values.

3.1.3 AH CMP

The response surfaces showing each alternative conservation metric interpretation for East and West stocks over the first refined grid for the AH CMP are shown in **Figure 3.**

The initial grid search showed that the range of q values used was very wide, with all of the variation concentrated in a low range of q values for both east and west areas. As before, the lowest optimal q values (implying higher catch limits) were for All30 ($q_E = 0.278$, $q_W = 0.223$), which targets a 60% probability of healthy stocks over the first 30 years. As with the LW CMP, Year30 and Each30 were associated with lower catch limits. Unlike the LW CMP, the q values appear very close for Year30 ($q_E = 0.349$, $q_W = 0.258$) and Each30 ($q_E = 0.254$, $q_W = 0.263$); however, that closeness is relative and may disappear with a more refined grid, given the relatively small range of response variation in the initial grid.

The first refined grid has step sizes at 25% of the original tuning grid, and the same grid axes are used for all three targets given that the first estimates of the optimal parameter values are very close (**Table 4**). Optimal tuning parameter estimates for the first refinement are very close to the estimates from the original grid (**Figure 3**). The second refinement is specific to each tuning target, using a step size of 0.01, and centred around the estimated optimal values. Unlike the AH CMP, no grid points produced values of Metric 1 – 3 that were within 0.5% of the 60% target for both East and West stocks, so the optimal q_E and q_W values estimated from the thin plate spline were taken as the final tuned parameters (**Table 5**).

3.2 Performance and dynamics of tuned CMPs

Rankings of CMPs differ by performance metrics and are sensitive to the tuning target (**Table 6**). For example, when tuned to the Year30 target, the median Br30 values show that the LW CMP is ranked highest for East stock, and the BR CMP is ranked highest for the West. The ranking changes for the West stock under the All30 tuning, as the LW CMP median Br30 value increases by a small amount to 1.14, while the BR CMP drops to third with a median Br30 of 0.91. The LD metric (lowest depletion) was most sensitive to the tuning target, where performance outcomes and CMP rankings for the All30 tuning target were different from the Year30 and Each30 tuning target.

The Each30 and Year30 targets lead to similar conservation performance for each CMP for the East stock. CMP outcomes for AvgBr, median Br30, 5th percentile Br30, and LD for the East stock were similar under Each30 and Year30 tuning targets, and changed slightly for the West stock. This similarity is evident in the East stock biomass ratio simulation envelopes, which are qualitatively identical for both targets (**Figures 4-6**). The West stock biomass ratio envelopes are also qualitatively identical, despite dissimilar median Br30 and AvgBr values between Each30 and Year30 tuning target.

Performance metrics values for several stocks and tuning targets are very close (e.g., East and West Br30 under the Year30 target, West AvgBr under All30), so any ranking derived from those values will likely be sensitive to the introduction of process errors in stochastic operating models.

4. Discussion

In this SCRS paper, the sensitivity of CMP rankings to alternative interpretations of ICCAT commissioners' stated conservation objectives is tested. Rankings of CMP conservation and yield performance, as measured by Br30, AvgBr, and AvC30, were somewhat insensitive to the choice of tuning target for the East stock. For the West stock, CMP rankings for Br30 and AvC30 differed between the All30 and other two tuning target. Difference in Br30 and AvC30 values across CMPs were greatest for the least conservative All30 tuning target, and were smallest for the most conservative Each30 tuning target.

For all CMPs, the tuning target that produced the highest fishing mortality rates was All30, where stocks had to be healthy in 60% of the first 30 projection years. Higher "tuned" fishing mortality rates in both areas makes sense for this interpretation given that a CMP can maintain healthy stocks in the first 60% of projection years, after which any overfishing or overfished state will not affect the performance. In contrast, while the Year30 target to be healthy in the last year does not prescribe dynamics in the intervening time, it is more likely that a stock will be kept in good health for the first 30 years if it must be healthy with a higher probability at the end of the 30 years. Of course, this behaviour likely depends strongly on the context of these ABT stocks, which are both recovering quickly over the last few years of the historical period in all operating models.

Uncertainty and sensitivity of the CMP performance to alternative metrics is likely under-represented in this analysis, given the deterministic operating models. While deterministic ABT operating models use non-equilibrium recruitment, the recruitment process errors are fixed. This means that the tuning process may be tantamount to "fitting" the CMPs to a fixed future, biasing the results. On the other hand, the variability from the range of operating model hypotheses themselves may overwhelm the uncertainty provided by process errors. This analysis should be repeated on stochastic operating models to determine the extent to which the deterministic recruitment under-represents variation in CMP performance.

Using fishing mortality ratios to derive the three alternative targets may be redundant with biomass ratios, as within an operating model each biomass ratio is associated with a fixed fishing mortality rate at equilibrium (e.g., B_{MSY} and F_{MSY}). Therefore, targeting a biomass ratio with a specified probability (e.g., 60%) will tend to produce fishing mortality rates that meet the associated equilibrium fishing mortality ratio, when integrating over multiple replicates in stochastic operating models. Further, in transient states (i.e., not at equilibrium, early in the projection period), placing a restriction on the fishing mortality will exclude CMPs that overfish more than 40% of the time but avoid an overfished state 60% of the time, which may occur under the right combination of stochastic process errors, observation errors, and initial stock health (e.g., by only overfishing when the stock is healthy).

Tuning performance to a high precision is difficult for the alternative conservation metrics used here. The three alternative conservation metrics are probabilities calculated from pass/fail (logical) indicators, so the precision is limited by the number of data points where a pass or fail are recorded. For example, for the Year30 target (probability of a healthy stock in year 30), there are 48 operating models used to calculate the probability, so the probability estimates are always some multiple of 1/48, or around 0.021, similarly for the Each30 target (minimum probability of stocks being healthy over all years). The resulting discrete metrics create response surfaces that are less smooth than for continuous metrics, such as the Br30 metric used for development tuning.

References

Butterworth, D. and Rademeyer, R. 2021. Further refinements of the BR CMP. SCRS/2021/018

Hanke, A. 2020. A description of 4 candidate management procedures for bluefin tuna. SCRS/2020/144

ICCAT 2019. Report of the intersessional meeting of Panel 2. Madrid, Spain, 4-7 March 2019.

ICCAT 2021. Report of the first 2021 intersessional meeting of the Bluefin tuna species group (including W-BFT data preparatory). Online, 5-13 April, 2021.

Lauretta, M. and Walter, J. (2020) Atlantic bluefin tuna constant harvest rate and index-based candidate management procedures; tuning to ABT-MSE package 6.6.16. SCRS/2020/127

Table 1. Brief descriptions of the CMPs contributed to the ranking sensitivity analysis. This table is edited from Appendix 5 in ICCAT (2021), which was written by the authors of this document.

CMP Name	***Description***	***Authors***	***Citation***	***Tuning Parameter***
BR	Empirical CMP that uses a 2-year lagged moving average of a weighted combination of several management indices to set TACs scaled to a reference relative harvest rate	Doug Butterworth, Melissa Jacobs, Rebecca Rademeyer, Mitsuyo Miyagawa	SCRS/2020/147	Relative harvest rate multipliers α and β
LW	Constant target harvest rate approach. Calculates a moving average relative harvest rate from catch and larval indices, and attempts to guide it towards a reference value using TAC adjustments.	Matt Lauretta, Cassidy Peterson, John Walter	SCRS/2020/127	Relative harvest rate multipliers *m*
AH	Constant harvest rate approach. Calculates F_0.1 fishing mortality rate for each area, then applies to a biomass estimate derived from the larval survey.	Alex Hanke	SCRS/2020/144	Catchability parameters *q* that transform indices into a biomass estimate

Table 2. Alternative tuning targets derived from three interpretations of the ICCAT commissioners' conservation objective for the Atlantic Bluefin Tuna stocks. In each of the three metrics, the function $\mathbb{1}(X)$ is the indicator function, which takes value 1 when X is true, and 0 when X is false.

	Conservation Target	Probability Equation
Year30	ABT stocks are healthy with 60% probability at the end of the first 30 projection years;	$P(\mathrm{H}_{30}) = \frac{\sum_{i=1}^{48} \mathbb{1}(B_{\mathrm{i},30} > B_{MSY}) \cdot \mathbb{1}(F_{\mathrm{i},30} < F_{MSY})}{48}$
All30	ABT stocks are healthy with 60% probability across the first 30 projection years;	$P(H_{1:30}) = \frac{\sum_{t=1}^{30} \sum_{i=1}^{48} \mathbb{1}(B_{\mathrm{i,t}} > B_{MSY}) \cdot \mathbb{1}(F_{\mathrm{i,t}} < F_{MSY})}{30 \cdot 48}$
Each30	ABT stocks are healthy with 60% probability in each of the first 30 projection years	$\min_{t=1:30} P(H_t) = \min_{\mathrm{t}=1:30} \frac{\sum_{i=1}^{48} \mathbb{1}(B_{\mathrm{i,t}} > B_{MSY}) \cdot \mathbb{1}(F_{\mathrm{i,t}} < F_{MSY})}{48}$

Table 3. Tuning grids and final tuned parameters for the BR CMP. Catch caps are given after the bounds of each parameter grid range. Step sizes for parameters in All30 grid searches are not listed in table headers, with alpha steps of 1.0 for the first refinement, and 1 for the second refinement, and beta steps of 0.2 in the second refinement.

Targ	*Initial coarse grid (steps = 0.5, 0.1)*	*First refinement (steps = 0.2)*	*Second refinement (steps = 0.2,0.1)*	*Final Tuned Parameters*
Year30	α = 2.5 – 4.5, 45kt β = 0.8 – 1.2, 2.35 kt	α = 3.4 – 4.4, 45 kt β = 0.8 – 1.2, 2.35 kt		α = 3.80, 45 kt β = 1.01, 2.35 kt
All30		α = 2.5 – 7.5, 50 kt β = 0.8 – 1.2, no cap	α = 6 – 10, 55 kt β = 0.8 – 1.6, no cap	α = 10, 55 kt β = 1.2, no cap
Each30		α = 3.4 – 4.4, 45 kt β = 0.8 – 1.2, 2.35 kt		α = 3.80, 45 kt β = 1.00, 2.35 kt

Table 4. Tuning grids and final tuned parameters for the LW CMP.

Targ	*Initial coarse grid (step = 1)*	*First refinement (step = 0.05)*	*Second refinement (step = 0.05)*	*Final Tuned Parameters*
Year30	m_E, m_W = 5 - 10	m_E = 7.25 - 7.45 m_W = 8.30 - 8.50		m_E = 7.35 m_W = 8.45
All30		mE = 8.2 – 8.4 mW = 8.9 – 9.1		m_E = 8.2 m_W = 9.0
Each30		mE = 7.10 - 7.30 mW = 7.95 – 8.15	m_E = 7.30 - 7.50 m_W = 7.85 - 8.05	m_E = 7.35 m_W = 7.90

Table 5. Tuning grids and final tuned parameters for the AH CMP.

Targ	*Initial coarse grid (step = 0.1)*	*First refinement (step = 0.025)*	*Second refinement (step = 0.01)*	*Final Tuned Parameters*
Year30	q = 0.2 - 0.8	q_E = 0.250 - 0.400 q_W = 0.175 - 0.300	q_E = 0.34 – 0.38 q_W = 0.22 – 0.26	q_E = 0.368 q_W = 0.243
All30			q_E = 0.275 – 0.315 q_W = 0.210 – 0.250	q_E = 0.295 q_W = 0.230
Each30			q_E = 0.345 – 0.385 q_W = 0.240 – 0.280	q_E = 0.365 q_W = 0.256

Table 6. Median Br30, AvgBr, AvC30, Br30_5pc, and LD values for final tunings of each CMP under the three targets. Cells are colour coded to show the ranking of each CMP for each stock (Br30, AvgBr, Br30_5pc, LD) and area (AvC30), with ranked from highest in green, through yellow, and to orange for the lowest value. Biomass ratio and depletion values are unitless, while AvC30 is in 1000s of tonnes.

Br30	Year30		All30		Each30	
CMP/Stock	East	West	East	West	East	West
BR	1.19	1.20	0.78	0.91	1.19	1.21
LW	1.22	1.11	1.10	1.14	1.22	1.21
AH	1.20	1.13	0.97	1.06	1.19	1.16
AvgBr	**Year30**		**All30**		**Each30**	
CMP/Stock	**East**	**West**	**East**	**West**	**East**	**West**
BR	1.66	1.54	1.31	1.23	1.65	1.55
LW	1.41	1.13	1.28	1.13	1.41	1.20
AH	1.48	1.13	1.21	1.06	1.47	1.18
AvC30	**Year30**		**All30**		**Each30**	
CMP/Area	**East**	**West**	**East**	**West**	**East**	**West**
BR	41.8	3.0	51.5	3.6	41.8	3.0
LW	40.3	3.4	42.5	3.5	40.3	3.2
AH	39.9	3.2	45.6	3.3	40.2	3.1
Br30_5pc	**Year30**		**All30**		**Each30**	
CMP/Area	**East**	**West**	**East**	**West**	**East**	**West**
BR	0.44	0.51	0.03	0.34	0.44	0.51
LW	0.51	0.25	0.41	0.21	0.51	0.30
AH	0.67	0.56	0.48	0.47	0.66	0.59
LD	**Year30**		**All30**		**Each30**	
CMP/Area	**East**	**West**	**East**	**West**	**East**	**West**
BR	0.37	0.34	0.22	0.25	0.37	0.34
LW	0.38	0.28	0.34	0.26	0.38	0.31
AH	0.37	0.30	0.29	0.29	0.37	0.31

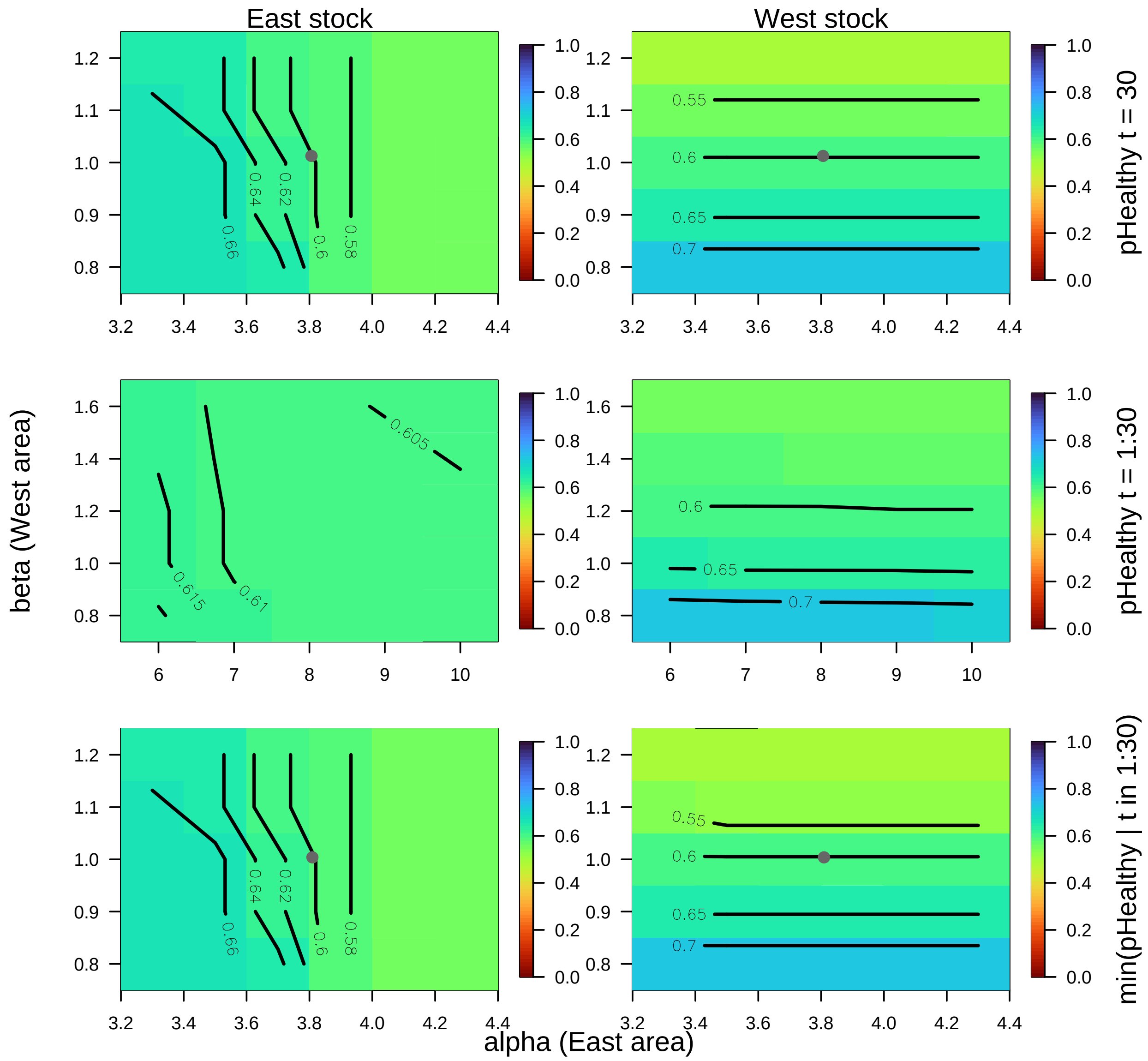

Figure 1. BR CMP performance metric response surfaces for probability of a healthy East stock (left hand column) and West stock (right hand column) under alternative interpretations of ICCAT commissioners conservation performance metrics 1 (top row), 2 (middle row), and 3 (bottom row) over the initial coarse grid of tuning parameters. Colours and contour lines indicate probabilities of healthy stocks for each target, and the grey point in each panel shows the estimated optimal parameter value producing a target value of 60% probability for both East and West stocks, if 60% was observed within the range of tested parameter values.

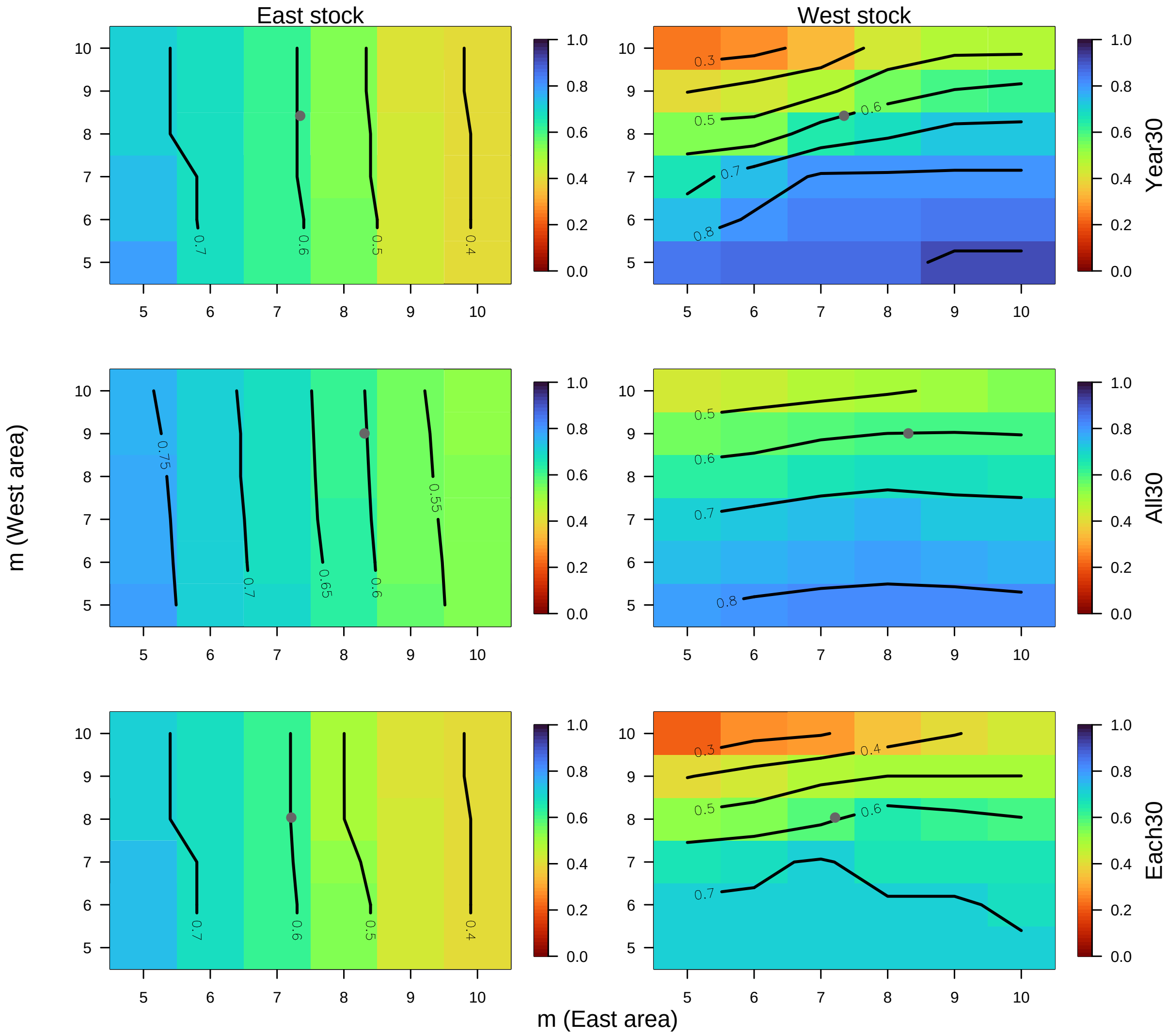

Figure 2. LW CMP performance metric response surfaces for probability of a healthy East stock (left hand column) and West stock (right hand column) under alternative interpretations of ICCAT commissioners conservation performance metrics 1 (top row), 2 (middle row), and 3 (bottom row) over the initial coarse grid of tuning parameters. Colours and contour lines indicate performance metric values, and the grey point in each panel shows the estimated optimal parameter value producing a target value of 60% probability.

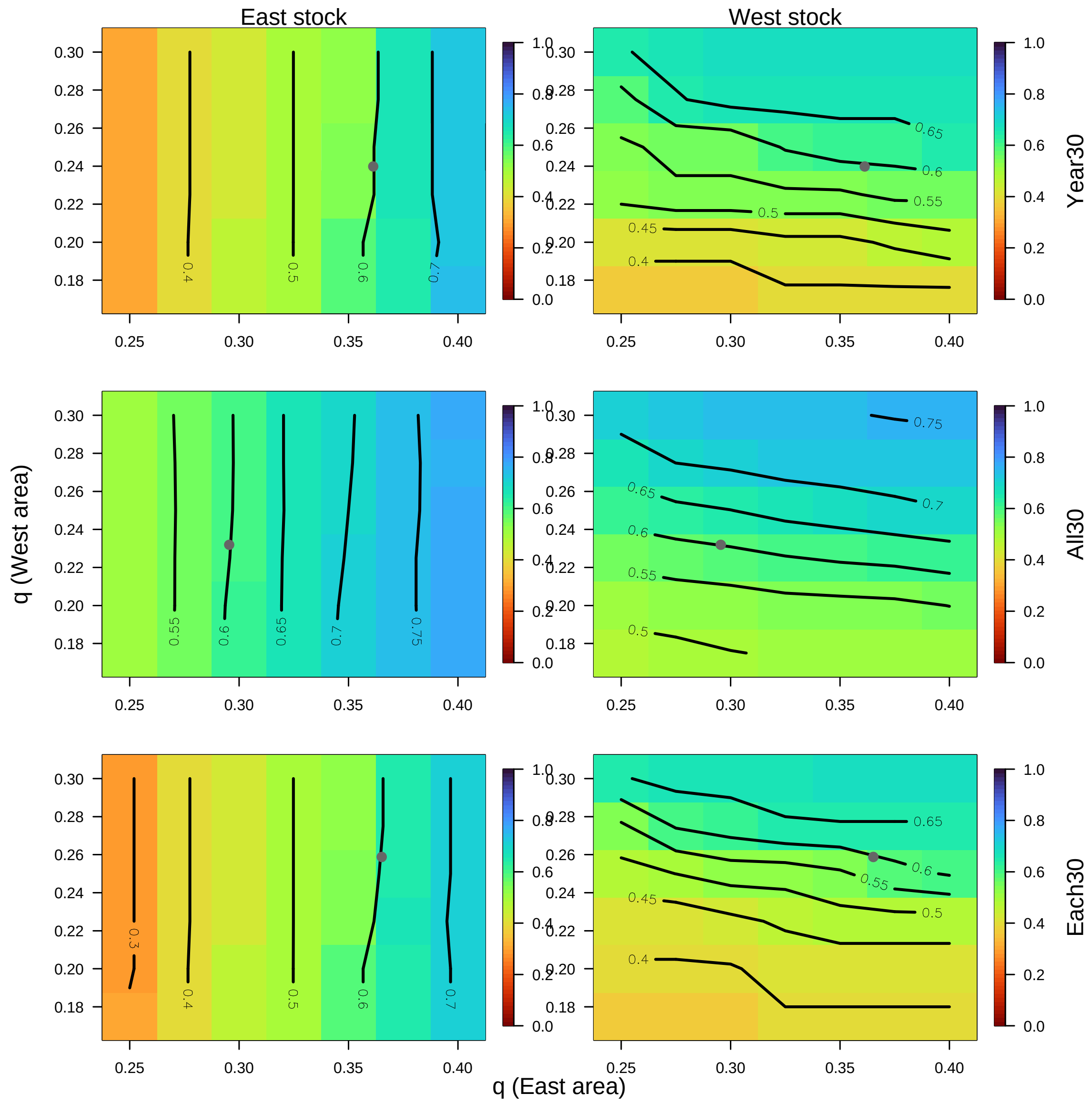

Figure 3. AH CMP performance metric response surfaces for probability of a healthy East stock (left hand column) and West stock (right hand column) under alternative interpretations of ICCAT commissioners conservation performance metrics 1 (top row), 2 (middle row), and 3 (bottom row) over the initial coarse grid of tuning parameters. Colours and contour lines indicate performance metric values, and the grey point in each panel shows the estimated optimal parameter value producing a target value of 60% probability.

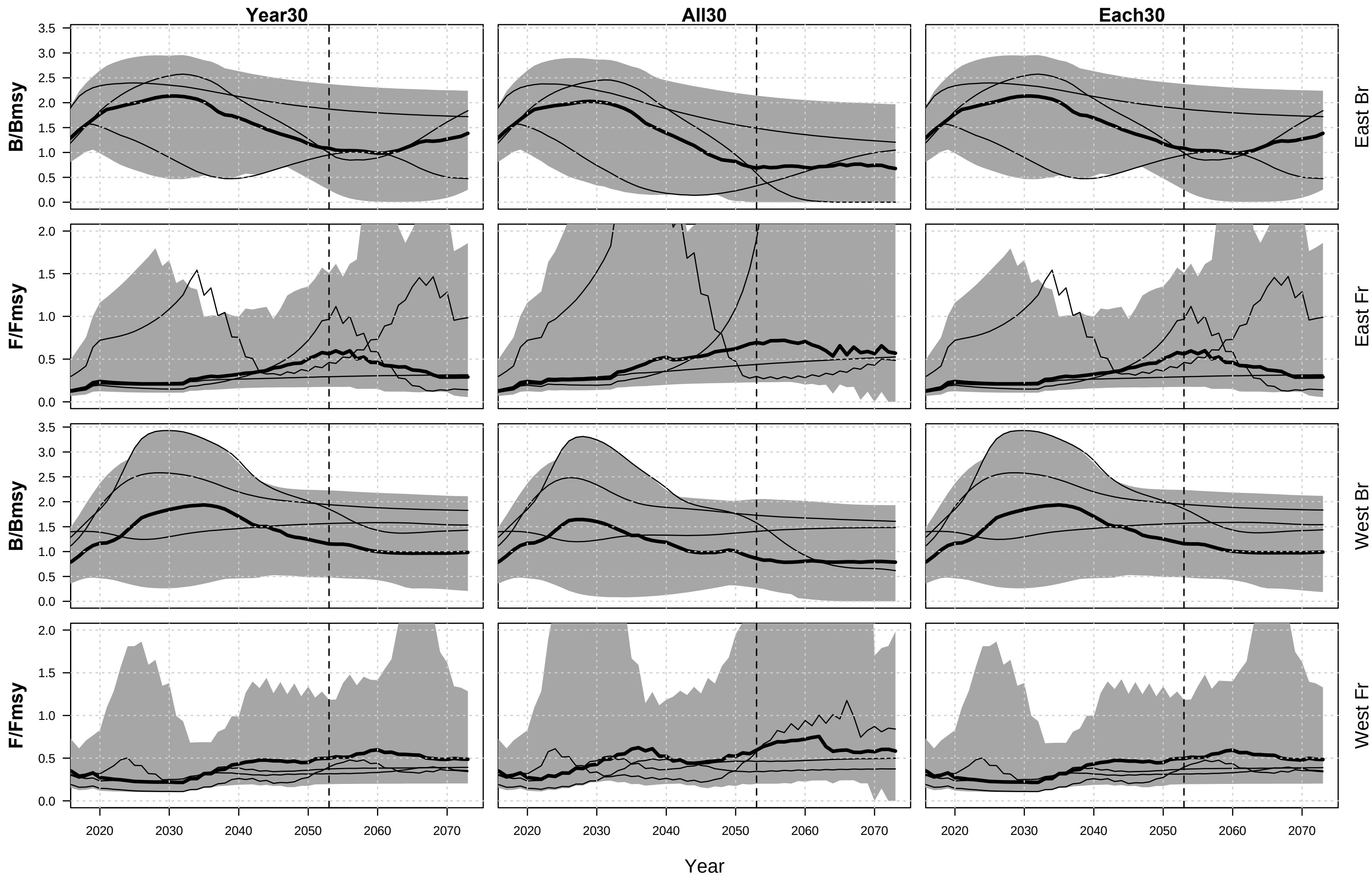

Figure 4. BR CMP biomass ratio (Br, first and third rows) and fishing mortality ratio (Fr, second and fourth rows) simulation envelopes over the 48 ABT operating models for the projection period when tuned to meet 60% probability for the Year30 (left hand column), All30 (middle column), and Each30 (right hand column) targets. Envelopes show the central 90% of the operating models (grey region), medians (thick black line) and three randomly drawn replicates (thin black lines), with the 30th projection year (after a 4 year lag) marked by a vertical dashed line.

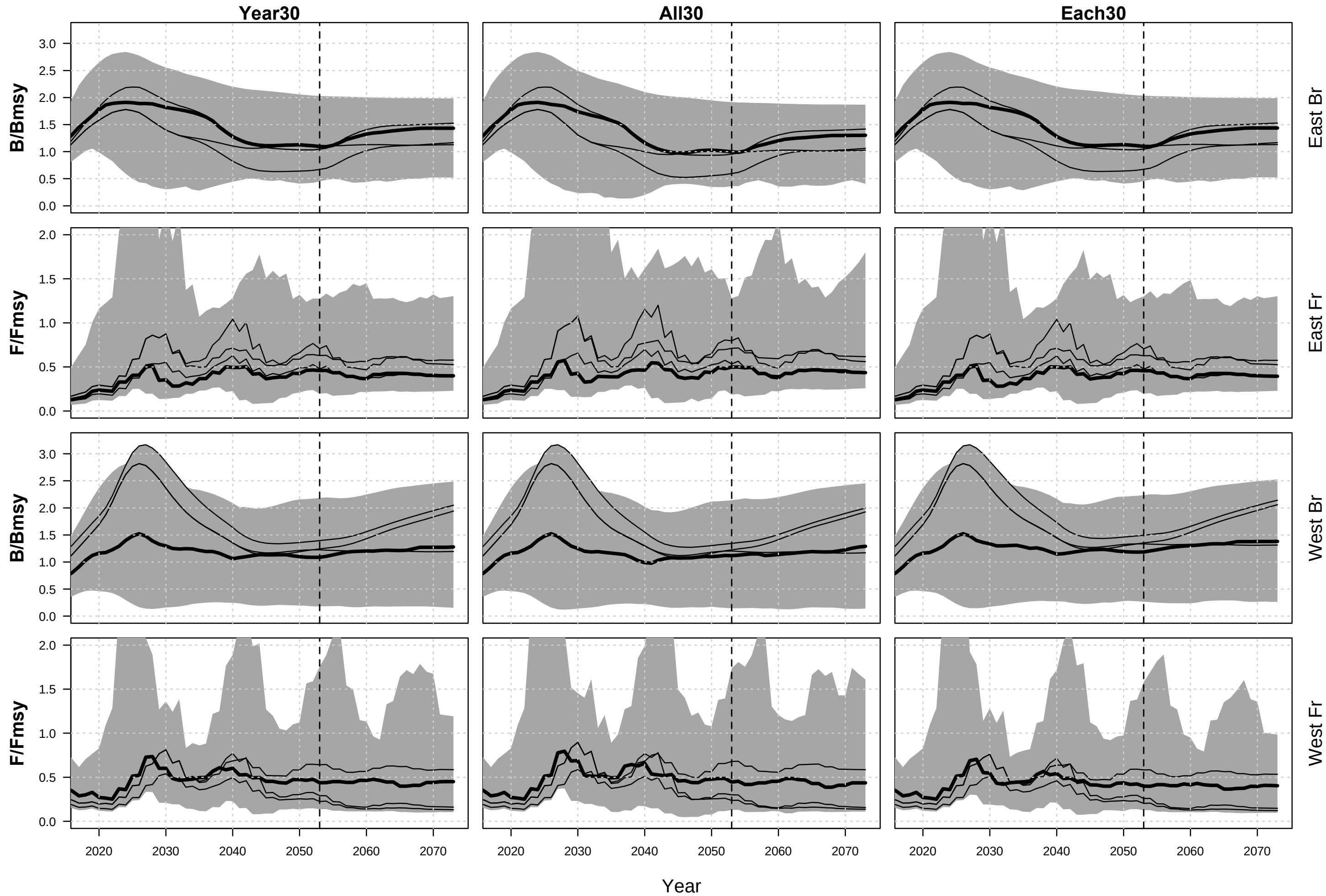

Figure 5. LW CMP biomass ratio (Br, first and third rows) and fishing mortality ratio (Fr, second and fourth rows) simulation envelopes over the 48 ABT operating models for the projection period when tuned to meet 60% probability for the Year30 (left hand column), All30 (middle column), and Each30 (right hand column) targets. Envelopes show the central 90% of the operating models (grey region), medians (thick black line) and three randomly drawn replicates (thin black lines), with the 30th projection year (after a 4 year lag) marked by a vertical dashed line.

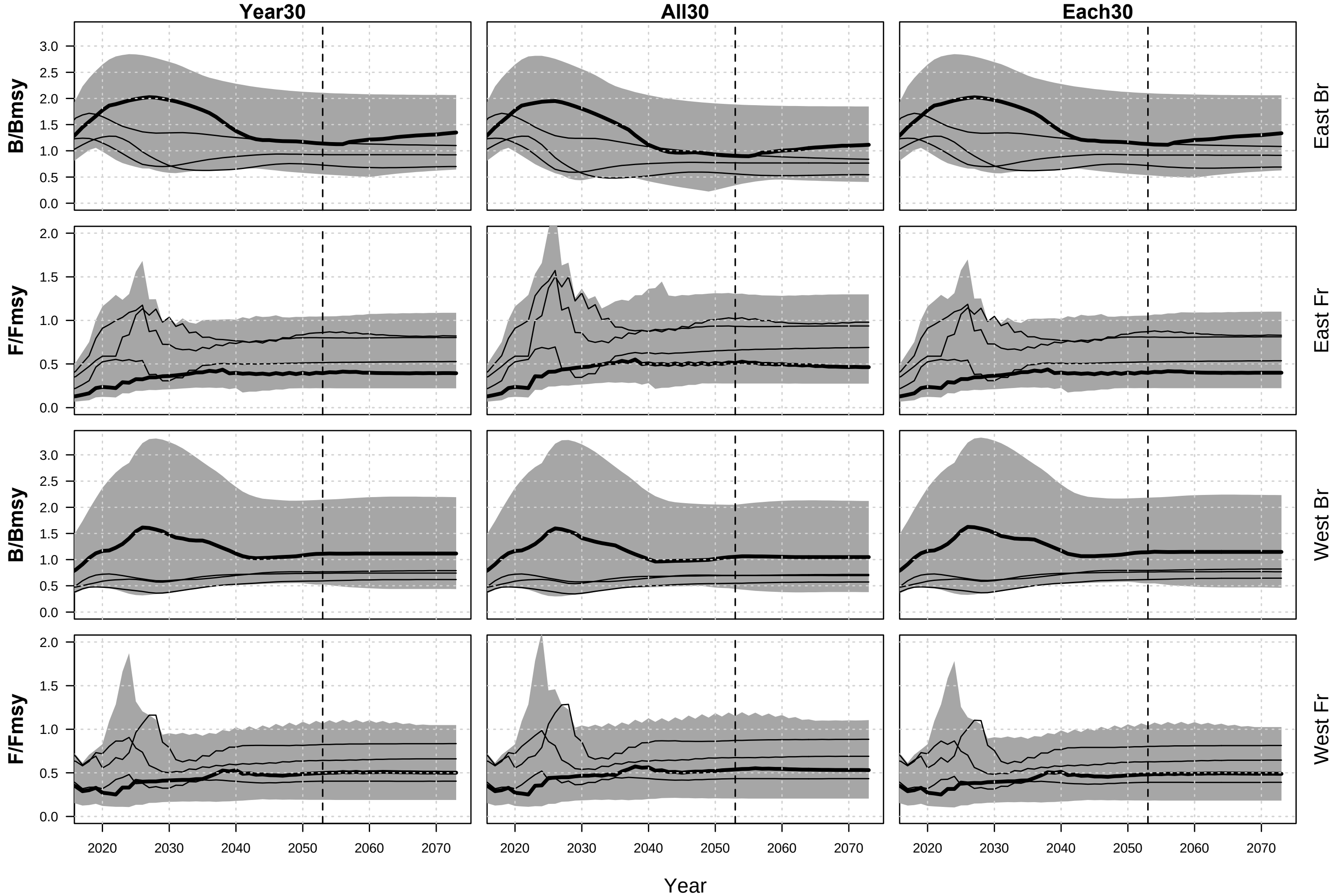

Figure 6. AH CMP biomass ratio (Br, first and third rows) and fishing mortality ratio (Fr, second and fourth rows) simulation envelopes over the 48 ABT operating models for the projection period when tuned to meet 60% probability for the Year30 (left hand column), All30 (middle column), and Each30 (right hand column) targets. Envelopes show the central 90% of the operating models (grey region), medians (thick black line) and three randomly drawn replicates (thin black lines), with the 30th projection year (after a 4 year lag) marked by a vertical dashed line.

Appendix A

Code repository for analysis

The code used to conduct this analysis and generate figures can be found at the following bitbucket repository:

https://bitbucket.org/lfr_code/tuninganalysis/