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RESULTS, FEATURES, AND INTERPRETATIONS OF THE FOUR REMAINING BFT MSE CANDIDATE MANAGEMENT PROCEDURES

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SUMMARY

*This document presents results from across the four remaining CMPs for the BFT MSE: BR, TC, LW and FO. The document illustrates tradeoffs, key decision points for Panel 2, and the essential components of each CMP. CMP rank ordering is largely conserved across the different variants of 2 versus 3-year TAC setting interval, PGK60% or PGK70%. For the operational management objective related to Safety (LD*10 or LD*15%) we indicate the challenges associated with tuning to low values of LD*10% due to the starting conditions of a number of operating models. For practical reasons, should the Commission want to choose a CMP along the yield versus safety status, this could more effectively be done through the PGK60- PGK70% axis.*

RÉSUMÉ

*Ce document présente les résultats obtenus des quatre CMP restantes pour la MSE pour le thon rouge : BR, TC, LW et FO. Ce document illustre les compromis, les points de décision clés pour la Sous-commission 2 ainsi que les composantes essentielles de chaque CMP. L'ordre de classement des CMP est largement maintenu dans les différentes variantes de l'intervalle d'établissement d'un TAC de 2 ans par rapport à un intervalle de 3 ans, PGK60% ou PGK70%. Pour l'objectif de gestion opérationnelle concernant la Sécurité (LD*10 ou LD*15%), nous indiquons les difficultés liées au calibrage aux faibles valeurs de LD*10% en raison des conditions de départ de plusieurs modèles opérationnels. Pour des raisons d'ordre pratique, si la Commission souhaite choisir une CMP sur l'état de production par opposition à la sécurité, cela pourrait être réalisé de façon plus efficace à travers l'axe PGK60- PGK70%.*

RESUMEN

*Este documento presenta los resultados de los cuatro CMP restantes para la MSE para el atún rojo: BR, TC, LW y FO. El documento ilustra la compensación de factores, los puntos de decisión clave para la Subcomisión 2 y los componentes esenciales de cada CMP. El orden de clasificación del CMP se conserva en gran medida a través de las diferentes variantes del intervalo de fijación del TAC de dos años frente al de tres años, PGK60% o PGK70%. Para el objetivo de ordenación operativo relacionado con la seguridad (LD*10 o LD*15%) indicamos los retos asociados con la calibración con respecto a valores bajos de LD*10% debido a las condiciones de partida de una serie de modelos operativos. Por razones prácticas, en caso de que la Comisión quiera elegir un CMP en función del rendimiento frente al estado de seguridad, esto podría hacerse de manera más eficaz través del eje PGK60- PGK70%.*

KEYWORDS

Atlantic Bluefin Tuna, Management Strategy Evaluation, Candidate Management Procedures

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Introduction

In this paper we describe the results of the four remaining candidate management procedures for the Atlantic Bluefin Tuna MSE. We further discuss and subsequently present what results or analyses need to be explored to respond to Panel 2 requests and to ensure robustness of the final CMPs for decision-making.

Methods

CMP development tuning

Originally six developer teams began CMP development of nine different CMPs. Through a process of objective performance testing or development tuning to common targets, the CMPs were further refined and improved. The purpose of development tuning is to place each CMP on a common or level playing field to then be able to evaluate its performance relative to other CMPs. The competitive and evolutionary process of CMP refinement resulted in improvement of each CMP at every stage as developer teams borrowed what worked and shed what did not improve performance. The progress of development tuning occurred over multiple MSE Technical Team meetings, primarily held online over the course of 2020-2022 (reference meeting reports). At multiple Panel 2 meetings, the SCRS provided results of development tuning and obtained feedback on desired performance characteristics; notably minimum performance standards for a CMP to be considered were: (1) going below a biomass limit reference point (B_{lim}) with a less than 15% or 10% probability; and, (2) for the probability of being in the green zone of the Kobe matrix at the end of the 30-year projection period (PGK) to be a minimum of 60%. During the course of development tuning, two CMPs (EA and TN) consistently had difficulty meeting these criteria, so that their developers discontinued supporting them.

CMP performance tuning

The second stage in CMP development is to performance tune or to optimize CMP performance across the operational management objectives. Originally, SCRS recommended tuning to LD*15 (setting the 15th percentile of the lowest depletion, in terms of spawning biomass relative to dynamic SSB_{MSY}, in projection years 11 - 30 equal to 0.4). However, initial results (SCRS-2022-126) indicated that this tuning resulted in PGK values well below 60%, so that PGK represented more of a limiting factor in tuning considerations. Given Panel 2's guidance to satisfy a minimum of 60%PGK and at least LD*15% coupled with the finding that tuning to 60% or 70%PGK nearly always met the LD*15% threshold, the SCRS determined that tuning to PGK was the best way forward. During the course of performance tuning, one CMP was removed by its developer as it was exceedingly time consuming to run (AI) and both the AI and PW CMPs were dropped because they did not reflect improved performance over the remaining CMPs.

Four candidate management procedures (CMPs, **Table 1**) remain (TC, BR, LW and FO). All CMPs have the following features:

- They calculate separate total allowable catches (TACs) for the West and East management areas.
- They include a 'phase-in' period where TAC changes are limited to a 20% increase and 10% decrease for two cycles in the case of a 2-year management cycle, or one cycle for the 3-year management cycle. Hence, the phase-in period is, respectively, for four or three years in total.

Individual CMPs, their features that should be understood, and the indices used by each (**Table 2**), which may be of use in selecting procedures or their settings, are described in more detail below:

BR — BR is a control rule that modifies the TAC based on the current values of indices compared to their values in 2017, with the aim of maintaining a constant harvest rate; however, this is with the exception of the initial years of TAC setting where the CMP deviates from a constant harvest rate to achieve greater TAC stability. All indices are used for each area to calculate a 3-year moving average. Indices are, broadly speaking, inverse variance weighted to achieve smoother TAC trends over time (SCRS/2021/121; SCRS/2021/152; SCRS/2022/082; SCRS/2022/126; SCRS/2022/154). BR performs well across most performance metrics.

LW — LW sets TAC advice that would maintain a constant harvest rate, which is calculated using 3-year moving averages. LW uses the W-MED LAR SUV and the JPN LL NEAtl2 indices in the East, and the GOM LAR SUV, US-MEX GOM PLL indices in the West. LW also has a feature where the Western TAC is partially a function of Eastern indices to account for the influx of Eastern stock fish into the Western area (SCRS/2020/127). LW performs well across most metrics, but uses only two 2 indices from each area.

TC — TC attempts to maintain a constant exploitation rate, with the TAC calculated for each area by multiplying the predicted area biomass by a constant harvest rate. The rule uses the JPN_LL_NEAtl2, MOR_POR_TRAP, MED_LAR_SUV, and GBYP_AER_SUV_BAR indices in the East, and the JPN_LL_West2, US_RR_66_14, and GOM_LAR_SUV indices in the West, to predict area biomass, while assuming a fixed fraction of the eastern stock enters the West area (SCRS/2020/150; SCRS/2020/165). TC results in highest fishery stability as measured by VarC, but at a cost of lower biomass and yield performance.

FO — FO sets TAC advice based on a fixed harvest rate of estimating F0.1, which is the fishing mortality rate at which the marginal yield-per-recruit is 10% of that for an unexploited stock. The F0.1 harvest rate is estimated from the relative abundance of young, medium, and old fish in each area, informed by the FR AER SUV2, JPN LL NEAtl2, and W-MED LAR SUV indices in the East, and the US RR 66-144, CAN SWNS RR and US-MEX GOM PLL in the West (SCRS/2020/144; SCRS/2021/122; SCRS/2022/156). One index from the opposite area is also used as part of the estimate of biomass in each area (East=W-MED LAR SUV; West = CAN SWNS RR). FO performs well across several performance metrics and uses several indices.

Each of the four CMPs was performance tuned to either 60 or 70% PGK along the following axes of management cycle length using the default +20%/-30% TAC stability provisions (i.e. the TAC cannot increase more than 20% or decrease more than 30% at each setting). All CMPs have an initial stability provision that enforces a +20/-10% allowable TAC change for the first 2 management cycles for 2-year cycles or the first cycle for 3-year management cycles. An additional run was conducted to allow for increased allowable percent decrease in TAC to -35% for the 3-year cycle and 60%PGK tuning target, as this allowed for some greater flexibility and improved performance:

CMP Variant	Management cycle length	PGK	TAC stability (after phase-in)
5a	2 years	60%	+20%/-30%
5b	3 years	60%	+20%/-30%
6a	2 years	70%	+20%/-30%
6b	3 years	70%	+20%/-30%
5c	3 years	60%	+20%/-35%

Additionally, developers were free to incorporate TAC stability provisions to achieve decreased TAC variability between TAC settings, and alternate tuning targets (i.e., LD*15%=0.4, LD*10%=0.4, PGK 60% while meeting the LD*15%=0.4 satisficing criterion). Several developers incorporated these into CMPs, and the decision about how much added stability to incorporate was left to developers' discretion to achieve their best possible CMP.

Path Forward for CMP selection: Initial Ranking Proposal

The MSE technical Working Group discussed ways in which CMP results could be presented to facilitate CMP selection by Panel 2. CMP selection includes both: (1) choice of the CMP algorithm (i.e., BR, FO, LW, or TC) and (2) choices of desired tuning and variant / configuration options (e.g., management period, tuning target, fishery stability provisions). Three alternatives paths to CMP selection were identified:

1. Choose the preferred CMP algorithm from the quilt plot (e.g., BR, FO, LW, TC), and then select amongst the various variants of the chosen algorithm (2-3 year management cycle, stability provisions, and risk-reward tradeoff; e.g., using PGK and LD* values).
2. Choose options (2-3 year management cycle, stability provisions, and risk-reward tradeoff; e.g., using PGK and LD* values), and then choose CMP (BR, FO, LW or TC).
3. Present all results, and allow Panel 2 to select the preferred CMP and options holistically.

Noting Panel 2's preference to see many options, the Working Group was of the view that all CMPs should be shown. However, Panel 2 may decide to consider only those that pass minimum satisficing criteria (PGK= 60% and LD*15%=0.40). CMP selection within each step may be assisted by the use of a rank ordering statistic.

Performance ranking and ordering of CMPs

CMPs were performance ranked by the default weighting scheme, below, where CMPs were tuned to the status metric (PGK, and therefore this metric was not included in the weighting scheme), and then yield (AvC10 and AvC30), stability (VarC), and safety (LD*) were equally weighted. Total ranking (as presented within the primary quilt plots; **Figures 1-2**) was calculated by transforming the relative performance across CMPs for each performance statistic to a scale of 0-1 (where 0 is best performance and 1 is worst performance). Rescaled results were then weighted following the default weighting scheme, summed across eastern and western management areas, and divided by the weighted sum. The scaled ranking scores were calculated across metrics and areas to obtain the total ranking score (*Tot*). This ranking approach enabled relative differences in performance to be preserved.

Examples of weighting schemes	*Status PGK (mean)*	*Yield AvC10 (50%)*	*Yield AvC30 (50%)*	*Stability VarC (50%)*	*Safety LD* (%TBD)*
Default: Equal across yield, stability, and safety	0	0.5	0.5	1	1
Sensitivity 1: Double weighting of safety	0	0.25	0.25	0.5	1
Sensitivity 2: Double weighting of yield	0	1	1	1	1

PGK: Probability of Green Kobe ($SSB > SSB_{MSY}$ & $U < U_{MSY}$) after 30 projected years
AvC10: Mean catches over first 10 projected years
AvC30: Mean catches over first 30 projected years
VarC: Average percentage variation in catches between management cycles
LD*: Lowest depletion, in terms of spawning biomass relative to dynamic SSB_{MSY}, in projection years 11 - 30

The mathematical notation for the ranking is as follows:

1. Rescale statistics across all CMPs within a single statistic to 0 - 1:
   a. Multiply all metrics where a higher value is better (AvC10, AvC30, LD*) by -1, so that the lower value is better.
   b. Calculate

$$z_{s,c} = \frac{x_{s,c} - min(x_s)}{max(x_s) - min(x_s)}$$

   where *x* is the performance statistic for CMP *c* and metric *s* within the quilt plot, *min* and *max* are the minimum and maximum values across CMPs for each metric, and *z* is the rescaled (0-1 scale) statistic for CMP *c* and metric *s*.
2. Calculate weighted sum across all eastern and western performance metrics and dividing by the sum of the weights

$$Tot_c = \frac{\sum_s z_{s,c} \times wt_s}{\sum_s wt_s}$$

   where Tot_c is the rescaled statistic for CMP *c*.

Note that since the *Tot* calculation is dependent on the set of CMPs selected to be presented within each quilt plot, the metric will change when CMPs are added or removed from the quilt. Lower *Tot* values indicate better CMP performance across default-weighted performance metrics. The resulting units of the quilt plot are not meaningful (e.g., *Tot* scores for two CMPs of 0.25 versus 0.5 does not necessarily mean that the lower-scoring CMP performs twice as well as the higher-scoring CMP).

The ranking approach applied in the ranking tables (**Tables 4, 6, 9-10**) was derived by sub-setting the complete quilt plot to provide the comparison desired (e.g., selecting all CMPs configured to a 2-year management cycle and comparing across PGK tuning targets of 60% and 70%). The performance statistics across each CMP type were averaged (e.g., average VarC across BR5a and BR6a). The Total rank statistic was then calculated as described above. Ranking tables show results only for CMP variants a (2-year management cycle) and b (3-year management cycle) for tuning levels 5 (PGK 60%) and 6 (PGK 70%).

Results

CMP performance was calculated primarily across four management objective axes: (1) stock status, (2) stock safety, (3) fishery yield and (4) fishery stability. Associated performance metrics include probability of remaining in the Green quadrant of the Kobe matrix ($SSB>SSB_{MSY}$ and $U<U_{MSY}$) after 30 projected years (PGK), lowest depletion (dynamic SSB/SSB_{MSY}) in projection years 11-30 (LD*), median catches over the first 10 and 30 projection years (AvC10 and AvC30, respectively), and average percentage variation in TAC between management cycles in the first 30 years (VarC), respectively. Performance statistics are calculated by taking the resulting performance for each simulation, weighting according to the operating model weight, then calculating the performance statistic across the full suite of simulation iterations. CMPs were ranked by relative performance with default weighting across each of the primary performance metrics and areas (*Tot* column in primary quilt plot, with lower *Tot* values denoting better performance; **Figures 1-2**).

Worm plots (**Figure 3**) may be an important output to be presented to stakeholders as they provide valuable information about the CMP dynamics, their uncertainty, and the associated risk. Further, by presenting plausible future trajectories, they more realistically depict the temporal variability in the TAC, whereas medians (as for example in **Figure 11** below) mislead in this respect by appearing smoother (note that any medians presented here are NOT trajectories that could occur in reality, but instead are developed by connecting the median values for annual distributions). We suggest that worm plots should be presented to managers with only 35 projection years included to avoid misunderstandings arising regarding the future dynamics after this period, which is not taken into account in the CMP testing process. Furthermore, we note concerns when aggregating results across recruitment scenarios, because the resulting summarized trajectories are impacted by the regime shift assumption. The Shiny app has accordingly been updated to enable presentation of worm plots for each recruitment scenario separately.

Main trade-offs

Overall, the performance of most of the variations of the four CMPs remaining have achieved the minimum thresholds requested by Panel 2. It is important to consider the lower extreme values of various performance statistics (e.g., lower 5th percentile of Br30, which is defined as the depletion in terms of spawning stock biomass relative to dynamic spawning stock biomass that would achieve MSY after projection year 30), as performance tradeoffs are often not readily evident from median statistics.

Major findings include the tradeoffs between:

1. fishery stability (VarC) and stock safety (e.g., lower percentiles of Br30),
2. yield (AvC30) and stock status (Br30), and
3. yield (AvC30) and fishery stability (VarC).

These tradeoffs are more pronounced for the East than the West.

1. fishery stability (VarC) and stock safety (e.g., lower percentiles of Br30; **Figure 4**)

Reduced variability in catch could generally be achieved without a compensatory reduction in stock safety (**Figure 4**). However, lower bounds of observed Br30 (e.g., extreme percentiles) may drop slightly lower with large reductions in the variability of the catch.

2. yield (AvC30) versus stock status (Br30)

We identified the expected trade-off between yield and stock status, whereby higher yield resulted in reduced stock status (**Figure 5**).

3. yield (AvC30) versus fishery stability (VarC).

There was generally a tradeoff between total yield and fishery stability, whereby improved fishery stability could be achieved at the expense of increased cumulative yield (**Figure 6**).

Catch variability damping

Some CMPs (BR, FO) explored the TC approach of damping variability in catch (VarC). Notably, in BR and FO, relatively large reductions in catch variability (on the order of ½ of the VarC value for the un-damped counterparts) could be achieved with almost no impact on median stock status (Br30), safety (LD*), or yield (AvC30; **Figure 7**). However, more extreme reductions in VarC resulted in a slight decline in LD* statistics and may compromise yield for particularly productive OMs (**Figure 8**).

Two versus three year management cycles

Similar median biomass and yield outcomes were found when the management cycle increased from 2 years to 3 years, but we found lower LD*15% performance and increased VarC in the 3-year cycle. This behavior is expected as the CMP does not have the same capacity to respond quickly as for a 2-year management cycle. All CMPs tuned to PGK60% in a 3 year management cycle did not meet LD*15%=0.4 satisficing criteria (**Figure 9**).

Averaged across all 4 CMPs and across PGK 60% and 70%, moving from a 2- to 3-year management cycle, there is a maximum ~5% reduction in catch and a 4% and 15% reduction in LD*15% for the West and East, respectively. The VarC values increase, as expected, by between 14 and 12%, on average for East and West (**Table 3**). The directionality and magnitude of the changes vary somewhat by CMP. The relative rank order of CMPs remains unchanged (**Table 4**).

Butterworth and Rademeyer (2022c) showed that the reduction in safety performance statistics in a 3-year management cycle tuned to PGK 60% can be ameliorated by increasing the allowable TAC reduction from -30 to -35% (**Figures 10-11**). Because satisficing criteria can only be met when allowing a -35% TAC reduction in a 3-year management cycle with 60% PGK tuning target, this is no longer an explicit decision point for Panel 2, rather it is a requirement of this CMP variant.

Tuning to PGK 60 versus 70%

When compared across PGK tuning targets, CMP behavior was largely unchanged in relative terms and the tuning target scales performance statistics up/down along the risk/reward tradeoff (**Figure 12**). PGK of 60% (heavier fishing pressure) entails a higher probability of overfishing and/or of being overfished, but delivers greater catches, relative to PGK 70% (lower fishing pressure; **Table 5**).

Averaged across all four CMPs and across all management cycles, there is a maximum ~11.5% reduction in yield with commensurate improvement in safety when PGK changes from 60% to 70% (**Table 5**). This illustrates that this is a decision between less biological risk to the stock (better safety and status) compared to more yield (short-term and long term). The relative rank order of CMPs remains similar to the overall order (BR, FO, TC, LW) except that for PGK 70%, TC moves above FO (BR, TC, FO, LW; **Table 6**).

Satisficing and Tuning to LD*

We found that CMPs tuned to PGK 60% with a 3-year management period (5b CMP variant) all resulted in LD* statistics that did not meet the satisficing criteria of LD*15 ≥ 0.4 (**Figure 15**). As such, a BR variant was tuned to LD*15%=0.4 (7b CMP variant) to meet satisficing criteria and a LW variant was tuned to minimally meet both PGK 60% and LD*15%=0.4 satisficing criteria (LW7b). Both BR7b and LW7b CMPs ranked higher as compared to their corresponding 5b variants (**Figure 16**).

Further, TC was tuned to meet LD*15%=0.4 and to almost meet LD*10%=0.4 for a 2-year management cycle (TC7a and TC8a, respectively). Recall that LD* is the lowest depletion in terms of dynamic SSB/SSB_{MSY} over projection years 11-30, and LD*10 and LD*15 correspond to the 10th and 15th percentiles respectively of the LD* statistic across simulations. Accordingly, the LD* statistic is influenced by the starting-point and the subsequent path of the OM trajectories, such that if, in a a pessimistic OM, SSB falls below 40% dynamic SSB_{MSY} at any point and remains low after the 10th projection year (e.g., under a negative recruitment shift, as projected in recruitment scenarios 2 or 3), the resulting LD* statistics will be impacted. Lower percentiles of the LD* statistic, including LD*15% and LD*10%, are more likely to be affected by only a few OMs (e.g., consider that 5 poorly performing OMs comprise greater than 10% of the reference OM grid). A 15% probability of breaching the limit dynamic SSB reference point would constitute a higher risk to the stock as compared to a 10% probability.

We found that fishing intensity would have to be reduced substantially in the West to meet LD*10%=0.4 (**Table 7, Figure 17**). This reduction in catch and exploitation rate was accompanied by a disproportionately large increase in stability, as seen by PGK increasing to 92% in the West to meet LD*10% for TC7b. The requisite reduction in exploitation rate required to meet the LD*10%=0.4 tuning target is likely difficult to achieve and would likely compromise societal objectives. We accordingly recognize that PGK (probability of being in the Green Kobe region [$F<F_{MSY}$ AND $B>B_{MSY}$] after 30 projected years) is also a metric reflecting conservation objectives, and since it is measured only after 30 years, is not impacted by the path to recovery, if such a recovery is necessary for a particular OM.

Should the Commission wish to consider operational management objectives with greater precaution, we would recommend considering the PGK60% to PGK70% continuum, particularly since performance statistics are nearly exactly linear between PGK60% and PGK70%. To demonstrate this linearity, the BR CMP was tuned to PGK65% for both the 2-year and 3-year management cycle indicating that almost all performance statistics for PGK65% are very close to halfway between their values for PGK60% and PGK70% (**Table 8**). Similarly, LW was also tuned to PGK65% for a 2-year management cycle and the resulting performance statistics vary linearly with PGK tuning target (**Figure 18**). This therefore reflects a straightforward continuum along the yield versus status tradeoff.

Short term TAC advice validations

CMP developers and technical team members independently checked short-term TAC calculations. Explorations of the initial TACs indicate that, for some CMPs, initial East TACs could increase, even when indices decrease substantially in the short term. Future TAC performance will reflect changes in the indices; however, initial tuning settings for many of the CMPs are designed to eventually achieve *inter alia* a MSY fishing mortality rate, and are also based on OM conditioning. Hence, they may lead to increases in the TACs even if index values become appreciably lower in the short term. Such behavior may be magnified by the recent increases in the Eastern stock abundance as reflected in the operating models (**Figure 19**).

Importantly, under the more negative R2 scenarios, the TAC trajectory reacts by starting to drop after the first management cycle, while the biomass ceases declining and commences recovery in due course. The last two observed values for the Mediterranean larval and GBYP aerial surveys are well above the predicted values for these two surveys, reflecting large and positive "observation" errors (**Figure 19**). Hence, observations from these two surveys are expected to drop in the immediate future, having a negative impact on CMP-calculated catches. Should the future observations for these indices not fall by some appreciable extent, this could well give rise to justification for the declaration of "exceptional circumstances", and with that careful reconsideration of the CMP.

Robustness tests

Preliminary results (only looking at Br30 statistics) for CMP performance across the Robustness OM (ROM) grid are considered (**Figure 20**), noting that performance may not be directly comparable to corresponding reference OMs since the ROM grid contains only four "difficult" OMs compared to the 48 of the reference OM grid. Robustness test interpretation should take due account of the fact that robustness scenarios are, by definition, more extreme scenarios that are less plausible than those in the reference OM grid. The non-mutually exclusive ways in which robustness tests might be used for CMP selection was discussed. Options included:

1. Using robustness tests to distinguish between CMPs by comparing *relative* performance (if performance across the reference OM grid was similar).
2. Deferring in-depth investigation into CMP performance across ROM grid until next year, at which time a small group could analyze *absolute* performance of CMPs across the robustness grid.
3. Highlighting problematic robustness scenarios and using them to assist specification of exceptional circumstances. This could include prioritizing future research towards scenarios for which CMP performance deteriorates.

Recommendations for how ROM results should be presented in the future include: plotting results for the corresponding reference and robustness OMs side by side, annotating the Zeh plots with a horizontal line showing the B_{lim} reference point of $0.4B_{MSY}$, and identifying clear rules for comparing among CMP performance and flagging poor-performing CMP-ROM scenarios. Additional robustness test interpretation should also focus on other axes of the management objectives (e.g., yield) and additional performance statistics (e.g., LD*).

Further discussion on the use of ROM results is warranted. This discussion can be delayed until 2023, because:

- There is sufficient information in the reference grid OM results to inform on ranking amongst the four remaining CMPs.
- There was no indication from the robustness test results to suggest any change of that order was warranted.
- These robustness test results could be used to inform on research priorities; however, for reasons of time limitations, that discussion was postponed to 2023.

Participants at the MSE Technical team also expressed a desire to consider a robustness test exploration of the impact of tuning to alternate recruitment assumptions. Peterson et al. (2022) deterministically tuned the PW CMP to the 30-year biomass ratio (Br30) estimates to each individual recruitment scenario separately (R1, R2, R3), then to all recruitment scenarios (RA), and finally to recruitment levels 1 and 2 only (R12). They found that tuning to recruitment scenario 1 resulted in the most aggressive CMP, while tuning to recruitment scenario 2 resulted in the least aggressive CMP. Notably, the impact of including recruitment level 3 was minimal, as demonstrated by similar performance and outcomes of RA scenario compared to the R12 scenario (**Figure 21**).

Relative CMP ranking was additionally explored by viewing the quilt plots by recruitment level (**Figure 22**, where the top panel shows ranking across all recruitment scenarios and the bottom panel shows that ranking across recruitment scenarios 1 and 2). Though the relative ranking changes when ranking results across all recruitment scenarios (BR, FO, TC, LW) as compared to only recruitment scenarios 1 and 2 (BR, TC, FO, LW), BR remains the top-ranked CMP.

Overall trends across CMPs

The Working Group has proposed an initial ranking process that may facilitate CMP selection, which uses a total rank ordering statistic to facilitate quantitative comparisons. The total rank statistic (*Tot*) is a measure of overall ranking, calculated by summing weighted performance statistics (equal weight for VarC and LD*, and yield statistics weighted 50%). We acknowledge that CMP ranking is ultimately a subjective process, and will depend on the relative importance of each management objective and associated performance statistics. Notably, if higher weight is given to safety the relative ranking of CMP change slightly with LW moving into the number two rank (**Figure 23**). Higher weight on yield results in the same relative ranking as the default weight. In all weighting cases: default, double safety or double yield BR remains the top ranked CMP.

We find that any of the paths presented above to selecting an MP to recommend are defensible, as the relative rank order of CMPs is largely conserved across the different options (e.g. CMP 1, 2, 3 and 4 rank similarly across options such as 2- and 3-year management cycles; **Figure 16**). Consequently, Panel 2 may choose to proceed in either direction to select the final MP.

Furthermore, performance statistics vary linearly with different levels of PGK, following explorations of tuning BR and LW to PGK 65%. This means that values halfway between them will result in performance statistics almost identically halfway between the values obtained from tuning to PGK 60% and PGK 70% (**Table 8, Figure 18**).

The results generally support the following:

- Total scoring averaged across East and West indicate an ordering of (BR, FO, TC, LW; **Tables 9 - 10**).
- The relative ordering of CMPs (BR, FO, TC, LW) is largely conserved across the CMP options with the exception of the PGK70% tuning target (for which the order of FO and TC reverses), indicating that the decision of which CMP to choose is largely independent of the choice among other options (**Table 9**).
- The decision regarding the operational management objective for status (PGK) remains the most influential factor determining the risk-reward tradeoff and should be a primary consideration for Panel 2.
- TC performs better on catch variability but is weaker on risk. Should Panel 2 prefer additional stability, this can be achieved for several variants of the CMPs. Participants should pay close attention to the ‘worm’ plots (**Figure 3**) to understand what the TAC variability statistics mean in practice.

Minimum bounds for TAC changes

At each application of the MSE it may be desirable to set a minimum bound for the TAC change for administrative purposes. The Commission can set these minimum bounds at any values, though the Committee has experimentally tested values of 100mt (West) and 1000mt (East) for the BR CMP (**Appendix 1**). The BR CMP was tested for both 2 and 3-yr intervals and PGK 60% and 70% with a minimum TAC change of 100t (West) and 1000t (East) and found less than 2% difference in any of key performance statistics, with exception of VarC. This was implemented by putting an additional restriction on TAC change to override the MP-recommended TAC if such TAC was less than 100t in the West and 1000t in the East. Such values were simply chosen for illustrative purposes and are approximately 3% of current TACs. CMPs were not retuned, but rather simply the results recalculated (**Table 11**). While only the BR CMP was tested, given the minimal difference in the results for values up to those tested, the Committee considers that similar performance would be seen across the other CMPs and that Panel 2 could set this now or at a later date after the decision on which CMP is preferred.

Panel 2 could choose to implement such a restriction (or not) for one or both areas. Panel 2 could also choose any values, and any values less than 100t (W) and 1000t(E) would have even less impact on CMP performance than the results in **Table 11**. We anticipate that results would be similar across CMPs but others have not specifically tested them in final CMPs versions presented here. They have been part of previous CMP versions and so are simple to implement for any CMP.

Conclusions

Following the ranking protocol developed by the technical team working group, ranking of CMPs across both areas generally followed (1) BR, (2) FO, (3) TC, (4) LW. This ranking was largely preserved, regardless of the CMP selection approach (e.g., (1) selecting CMP algorithm, then the CMP specifications, (2) selecting CMP specifications, then the CMP algorithm, or (3) selecting across all CMP algorithms and specifications). Though the ranking shifts slightly for the second and third ranked CMPs with PGK 70%, BR still remains the top performing CMP.

The main trade-offs associated with managing Atlantic bluefin tuna are between (1) fishery stability and stock safety, (2) fishery yield and stock status, and (3) fishery yield and fishery stability. It is for the Commission to determine where to select within these management trade-off spaces.

Regarding the key decisions before the Panel 2 and the Commission, the decision regarding fishery yield and stock status is the most consequential in terms of yield, and is encompassed by the decision on the desired PGK tuning target. Other decisions regarding yield and fishery stability largely reflect CMP features such as the decision on a 2- versus 3-year management cycle and stability provisions. These are less consequential tradeoffs for yield versus stock status, and possibly the decision can be made on logistical considerations associated with more frequent compared to less frequent TAC adjustment. It is, however, to be noted that CMP performance deteriorates slightly for the longer management cycle.

The SCRS has recognized that previous MSE experience with RFMOs can be leveraged to inform the best way to present results to the Commission. Notably, results should be presented both quantitatively (e.g., quilt plot performance statistics) and qualitatively (e.g., worm plot trajectories), and decision points should be accompanied by the associated strategic implications of each decision (e.g., plain language clearly explaining why a particular choice matters and the potential trade-offs associated with the decision). Though qualitative statements have proven an efficient approach to convey the information on CMP performance in other arenas, the SCRS has emphasized that ultimately, Panel 2 is responsible for advising the Commission on recommendations for decisions to be made, and hence the SCRS has decided to refrain from making any recommendations on such policy-related matters.

The SCRS has also noted that a number of recommendations from SCRS regarding the timing of MSE review and how exceptional circumstances provisions will be specified are still under consideration, and will be reflected in the response to the Commission on MSE.

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Table 1. Table of Candidate Management Procedures (CMPs). All indices are referenced at the end of the table. AI (Artificial Intelligence) and PW (Peterson-Walter) CMPs have been discontinued by the developers due to the improved performance of the remaining CMPs.

CMP	Indices used EAST	Indices used WEST	Detailed description	Strengths/Weaknesses	References
FO	FR AER SUV2 JPN LL NEAtl2 W-MED LAR SUV	US RR 66-144, CAN SWNS RR US-MEX GOM PLL	Uses an estimated F0.1 applied to an estimate of biomass to provide TAC advice. The F0.1 estimate is based on the relative abundance of young, medium and old fish for each area (which is informed from the areas indices noted on the left). Estimated biomass for each area is derived from an index from that area and a period of reference years.	Strengths: • performs well across several indicators. • uses indices that represent various age class to calculate TAC.	SCRS/2020/144 SCRS/2021/122 SCRS/2022/156
BR	All	All	TACs are set based on relative harvest rates (with some slight initial time dependence) for a reference year (2017) applied to the 3-year moving average of a combined master abundance index for each of the West and East areas. These master indices are, broadly speaking, inverse variances weighted averages across the indices available for the area, with the final weightings chosen to achieve smoother TAC trends over time.	Strengths: • strong performance across most indicators. • Uses all indices.	SCRS/2021/121 SCRS/2021/152 SCRS/2022/082 SCRS/2022/126 SCRS/2022/154
LW	W-MED LAR SUV JPN LL NEAtl2	GOM LAR SUV US-MEX GOM PLL	LW uses a 3-yr average of catch divided by relative SSB to estimate a constant harvest rate metric. All four indices on the East are used for the West area to account for stock mixing; Med larval and JPN East LL are used for the East area.	Strengths: • performs well across several indicators. Weaknesses: • has struggled to achieve some of PA2 identified thresholds for PGK.	SCRS/2020/127
TC	MOR POR TRAP JPN LL NEAtl2 W-MED LAR SUV GBYP AER SUV BAR	US RR 66-144 JPN_LL_ West2 GOM_LAR_ SUV	Two fishery indices for each area (West: JPN_LL_West2, US_RR_66_144. East: JPN_LL_NEAtl2, MOR_POR_TRAP) and three stock-specific fishery independent indices (West: GOM_LAR_SUV. East: MED_LAR_SUV, GBYP_AER_SUV_BAR) are used to predict area biomass assuming a fixed rate of stock mixing (e.g., a fixed fraction of the eastern stock enters the West area). The TAC is calculated for each area by multiplying the predicted area biomass by a constant harvest rate.	Strengths: • highest stability. Weaknesses: • increased stability causes somewhat lower biomass and yield performance.	SCRS/2020/150 SCRS/2020/165

Table 2. Details of the indices used by CMPs.

Index Label	Index	Flag	Gear	Details	Recommend for CMPs
Western Indices					
CAN SWNS RR	Canadian Southwest Nova Scotia handline index	Canada	Rod and Reel	1996-2020, Q3, W Atl	Yes
US RR 66-144	U.S. recreational rod & reel index for fish 66-144 cm	US	Rod and Reel	1995-2020, Q3, W Atl	Yes
JPN LL West2	Japanese longline index for the West Atlantic	Japan	Longline	2010-2020, Q4, W Atl	Yes
US-MEX GOM PLL	U.S. & Mexico combined longline index for the Gulf of Mexico	US-Mexico	Longline	1994-2019, Q2, GOM	Yes
GOM LAR SUV	U.S. larval survey in the Gulf of Mexico	Fishery Independent	Fishery Independent	1977-2021 (gaps 1979-1980, 1985, 2020), Q2, GOM	Yes
Eastern Indices					
MOR POR TRAP	Moroccan - Portuguese trap index	Morocco / Portugal	Trap	2012-2020, Q2, S Atl	Yes
JPN LL NEAtl2	Japanese longline index in the Northeast Atlantic	Japan	Longline	2010-2019, Q4, N Atl	Yes
FR AER SUV2	French aerial survey in the Mediterranean	Fishery Independent	Fishery Independent	2009-2021 (gap 2013), Q3, Med	Yes
GBYP AER SUV BAR**	GBYP aerial survey in the Balearic	Fishery Independent	Fishery Independent	2010-2018 (gaps 2012, 2014, 2016), Q2, Med	Yes
W-MED LAR SUV	Larval survey in the western Mediterranean	Fishery Independent	Fishery Independent	2001-2019 (gaps 2006, 2007, 2009, 2011), Q2, Med	Yes

*** Only the Balearic component is used for SSB (because there are problems with consistency regarding patchy or low biomass inference in other strata surveyed). Note that this survey awaits update, hence the zero weight at this time.*

Table 3. Performance statistics averaged across four CMPs and PGK 60% and 70% for 2- and 3-year management cycles. Percent differences are shown relative to a 2-year management cycle.

mgmt cycle (yrs)	**W_AvC10 (50%)**	**W_AvC30 (50%)**	**W_VarC (50%)**	**W_LD* (15%)**	**E_AvC10 (50%)**	**E_AvC30 (50%)**	**E_VarC (50%)**	**E_LD* (15%)**
2	**2.55**	**2.29**	**11.82**	**0.44**	**43.23**	**35.88**	**14.85**	**0.47**
3	**2.43**	**2.26**	**13.25**	**0.42**	**42.53**	**35.98**	**16.91**	**0.40**
	-4.71%	**-1.53%**	**12.11%**	**-3.70%**	**-1.62%**	**0.27%**	**13.85%**	**-14.78%**

Table 4. Relative performance results for the four CMPs for 2-year vs. 3-year management cycles. Ranking is based on the *Tot* column in the primary quilt plots, but the value of *Tot* should be seen as a qualitative not quantitative measure. The relative ranking of CMPs (BR, FO, TC, LW) remains unchanged between the 2- and 3-year management cycles.

	2-year variants	3-year variants
1	BR	BR
2	FO	FO
3	TC	TC
4	LW	LW

Table 5. Performance statistics averaged across four CMPs and the 2- and 3-year management cycles for PGK 60% and PGK 70%. Percentage differences are shown relative to PGK 60% tuning target.

	W_AvC10 (50%)	**W_AvC30 (50%)**	**W_VarC (50%)**	**W_LD* (15%)**	**E_AvC10 (50%)**	**E_AvC30 (50%)**	**E_VarC (50%)**	**E_LD* (15%)**
PGK 60%	**2.60**	**2.40**	**12.63**	**0.42**	**45.49**	**37.92**	**16.19**	**0.40**
PGK 70%	**2.37**	**2.15**	**12.44**	**0.45**	**40.27**	**33.94**	**15.57**	**0.48**
	-8.93%	**-10.22%**	**-1.51%**	**6.91%**	**-11.49%**	**-10.50%**	**-3.81%**	**18.01%**

Table 6. Relative performance results for the four CMPs and their variants for the East and West combined. Ranking is based on the *Tot* column in the primary quilt plots, but the value of *Tot* should be seen as a qualitative not quantitative measure. The relative ranking of CMPs (BR, FO, TC, LW) remains unchanged, except for PGK=70%, where the second and third ranked CMPs switch places.

	All variants	2-year	3-year	PGK=60%	PGK=70%
1	BR	BR	BR	BR	BR
2	FO	FO	FO	FO	TC
3	TC	TC	TC	TC	FO
4	LW	LW	LW	LW	LW

Table 7. Performance results for the TC CMP for two separate tunings - TC7a tuned to LD*15% and TC8a tuned to LD*10%. Both have a 2-year management cycle.

CMP	LD*10	LD*15	PGK	AvC10 (t)	AvC30 (t)	VarC
East						
TC7a	0.33	0.4	59%	41,780	36,790	10.1%
TC8a	0.4	0.47	67%	38,480	34,300	9.6%
West						
TC7a	0.26	0.4	61%	2,630	2,360	7.5%
TC8a	0.39	0.55	92%	1,240	710	12.8%

Table 8. Performance results for the BR CMP for two additional tunings to PGK65% for the 2- (a) and 3- (b) year management cycles to illustrate the linearity between PGK60% and PGK70%. The values in grey are the average between the 5a and 6a tunings. In other words, if one wanted to compromise between PGK60% and PGK70%, CMP performance at PGK65% would be almost exactly the average for every performance statistic.

	TAC inter.	PKG	Br30	LD*15%	LD*10%	AvC30	C1	VarC
EAST								
New package - 0.6 vs 0.65 vs 0.7 PKG and 2 yr intervals								
BR5a	2	**0.60**	1.17 (0.44; 2.15)	0.45	0.38	41.42 (12.29; 75.35)	40.57	15.60 (8.73; 22.76)
BR9a	2	**0.65**	1.24 (0.51; 2.24)	0.48	0.41	39.78 (12.00; 72.02)	40.57	15.17 (8.20; 22.58)
average	2	0.65	1.25 (0.51; 2.25)	0.48	0.41	39.78 (12.03; 71.78)	40.57	15.12 (8.14; 22.67)
BR6a	2	**0.70**	1.32 (0.58; 2.34)	0.51	0.43	38.13 (11.77; 68.21)	40.57	14.63 (7.55; 22.58)
New package - 0.6 vs 0.65 vs 0.7 PKG and 3 yr intervals								
BR5b	3	**0.60**	1.17 (0.25; 2.22)	0.38	0.30	41.17 (13.20; 71.21)	40.57	17.96 (10.00; 25.71)
BR9b	3	**0.66**	1.25 (0.34; 2.31)	0.41	0.33	39.19 (12.94; 67.73)	40.57	17.72 (9.28; 26.10)
average	3	0.65	1.26 (0.34; 2.32)	0.41	0.33	39.19 (12.97; 67.64)	40.57	17.55 (9.15; 25.75)
BR6b	3	**0.70**	1.34 (0.42; 2.42)	0.44	0.36	37.20 (12.73; 64.07)	40.57	17.14 (8.29; 25.78)
WEST								
New package - 0.6 vs 0.65 vs 0.7 PKG and 2 yr intervals								
BR5a	2	**0.60**	1.25 (0.46; 2.37)	0.42	0.29	2.43 (0.90; 3.60)	2.69	8.81 (4.95; 21.38)
BR9a	2	**0.65**	1.33 (0.51; 2.46)	0.44	0.29	2.32 (0.89; 3.44)	2.69	8.38 (4.81; 20.82)
average	2	0.65	1.33 (0.50; 2.45)	0.44	0.30	2.32 (0.89; 3.44)	2.69	8.51 (4.84; 21.23)
BR6a	2	**0.71**	1.41 (0.54; 2.53)	0.45	0.30	2.20 (0.87; 3.27)	2.69	8.21 (4.72; 21.07)
New package - 0.6 vs 0.65 vs 0.7 PKG and 3 yr intervals								
BR5b	3	**0.60**	1.28 (0.38; 2.40)	0.40	0.27	2.40 (0.94; 3.53)	2.69	10.37 (5.51; 24.16)
BR9b	3	**0.65**	1.36 (0.43; 2.48)	0.42	0.27	2.29 (0.92; 3.37)	2.69	10.02 (5.26; 24.35)
average	3	0.65	1.37 (0.42; 2.49)	0.42	0.28	2.29 (0.93; 3.37)	2.69	10.06 (5.36; 24.51)
BR6b	3	**0.70**	1.45 (0.46; 2.57)	0.43	0.28	2.18 (0.91; 3.20)	2.69	9.75 (5.20; 24.86)

Table 9. Relative performance results for the 4 CMPs and their variants for the East and West combined. Ranking is based on the *Tot* column in the primary quilt plots, but the value of *Tot* should be seen as a qualitative not quantitative measure. The relative ranking of CMPs (BR, FO, TC, LW) remains unchanged, except for PGK=70%, where the second and third ranked CMPs switch places.

	All variants	2-year	3-year	PGK=60%	PGK=70%
1	BR	BR	BR	BR	BR
2	FO	FO	FO	FO	TC
3	TC	TC	TC	TC	FO
4	LW	LW	LW	LW	LW

Table 10. Relative performance results for the 4 CMPs and their variants, presented separately for the East and West. Ranking is based on the *Tot* column in the primary quilt plots, but the value of *Tot* should be seen as a qualitative not quantitative measure. The relative ranking of CMPs (BR, FO, TC, LW) remains unchanged, except for PGK=70%, where the second and third ranked CMPs switch places.

	East					West				
	All variants	2-year	3-year	PGK = 60%	PGK = 70%	All variants	2-year	3-year	PGK = 60%	PGK = 70%
1	BR	BR	BR	BR	BR	BR	BR	BR	BR	BR
2	FO	FO	FO	FO	FO	TC	TC	TC	TC	TC
3	TC	TC	TC	LW	TC	FO	FO	FO	FO	FO
4	LW	LW	LW	TC	LW	LW	LW	LW	LW	LW

Table 11. BR CMPs run with a minimum TAC change provision of 100t for the Western area and 1000t for the Eastern area. The results indicate very minor differences between the original CMPs and those run with a minimum TAC change provision.

	TAC inter.	PKG	Br30	LD*15%	LD*10%	AvC30	C1	VarC
EAST								
New package - 0.6 vs 0.7 PKG and 2 vs 3 yr intervals								
BR5a	2	**0.60**	1.17 (0.44; 2.15)	0.45	0.38	41.42 (12.29; 75.35)	40.57	15.60 (8.73; 22.76)
BR5b	3	**0.60**	1.17 (0.25; 2.22)	0.38	0.30	41.17 (13.20; 71.21)	40.57	17.96 (10.00; 25.71)
BR6a	2	**0.70**	1.32 (0.58; 2.34)	0.51	0.43	38.13 (11.77; 68.21)	40.57	14.63 (7.55; 22.58)
BR6b	3	**0.70**	1.34 (0.42; 2.42)	0.44	0.36	37.20 (12.73; 64.07)	40.57	17.14 (8.29; 25.78)
WITH MIN CHANGE = 1000mt								
BR5a	2	0.60	1.18 (0.44; 2.16)	0.45	0.38	41.33 (11.24; 75.38)	40.57	15.98 (8.95; 26.12)
BR5b	3	0.60	1.16 (0.25; 2.22)	0.38	0.29	41.17 (12.99; 71.21)	40.57	18.31 (10.03; 26.66)
BR6a	2	0.70	1.32 (0.58; 2.34)	0.51	0.43	38.08 (10.95; 68.21)	40.57	15.18 (7.68; 25.78)
BR6b	3	0.70	1.34 (0.41; 2.43)	0.44	0.36	37.28 (12.65; 64.07)	40.57	17.57 (8.33; 27.37)
Percentage change								
BR5a	2	0.00	-0.85 (0.00; -0.47)	0.00	0.00	0.22 (8.54; -0.04)	0.00	-2.44 -(2.52; -14.76)
BR5b	3	0.00	0.85 (0.00; 0.00)	0.00	3.33	0.00 (1.59; 0.00)	0.00	-1.95 -(0.30; -3.70)
BR6a	2	0.00	0.00 (0.00; 0.00)	0.00	0.00	0.13 (6.97; 0.00)	0.00	-3.76 -(1.72; -14.17)
BR6b	3	0.00	0.00 (2.38; -0.41)	0.00	0.00	-0.22 (0.63; 0.00)	0.00	-2.51 -(0.48; -6.17)
WEST								
New package - 0.6 vs 0.7 PKG and 2 vs 3 yr intervals								
BR5a	2	**0.60**	1.25 (0.46; 2.37)	0.42	0.29	2.43 (0.90; 3.60)	2.69	8.81 (4.95; 21.38)
BR5b	3	**0.60**	1.28 (0.38; 2.40)	0.40	0.27	2.40 (0.94; 3.53)	2.69	10.37 (5.51; 24.16)
BR6a	2	**0.71**	1.41 (0.54; 2.53)	0.45	0.30	2.20 (0.87; 3.27)	2.69	8.21 (4.72; 21.07)
BR6b	3	**0.70**	1.45 (0.46; 2.57)	0.43	0.28	2.18 (0.91; 3.20)	2.69	9.75 (5.20; 24.86)
WITH MIN CHANGE = 100mt								
BR5a	2	**0.60**	1.25 (0.46; 2.37)	0.42	0.28	2.44 (0.81; 3.61)	2.73	10.00 (4.70; 30.00)
BR5b	3	**0.61**	1.27 (0.38; 2.40)	0.40	0.26	2.41 (0.91; 3.54)	2.73	10.95 (4.79; 28.94)
BR6a	2	**0.71**	1.42 (0.55; 2.53)	0.45	0.29	2.20 (0.81; 3.27)	2.73	9.61 (4.28; 30.00)
BR6b	3	**0.70**	1.44 (0.45; 2.58)	0.43	0.27	2.19 (0.91; 3.20)	2.73	10.97 (4.40; 30.00)
Percentage change								
BR5a	2	0.00	0.00 (0.00; 0.00)	0.00	3.45	-0.41 (10.00; -0.28)	-1.49	-13.51 (5.05; -40.32)
BR5b	3	-1.67	0.78 (0.00; 0.00)	0.00	3.70	-0.42 (3.19; -0.28)	-1.49	-5.59 (13.07; -19.78)
BR6a	2	0.00	-0.71 -(1.85; 0.00)	0.00	3.33	0.00 (6.90; 0.00)	-1.49	-17.05 (9.32; -42.38)
BR6b	3	0.00	0.69 (2.17; -0.39)	0.00	3.57	-0.46 (0.00; 0.00)	-1.49	-12.51 (15.38; -20.68)

CMP	Type	Tuning	Variant	West					East					Tot
				PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	
BR5a	BR	5	a	0.6	2.77	2.43	8.81	0.42	0.6	51.97	41.42	15.6	0.45	0.26
FS5a	FS	5	a	0.62	2.77	2.53	11.02	0.41	0.6	44.79	37.5	11.71	0.42	0.37
TC5a	TC	5	a	0.6	2.67	2.4	7.51	0.4	0.6	41.07	36.18	10.01	0.41	0.4
TK5a	TK	5	a	0.61	2.69	2.39	8.09	0.39	0.6	41.01	35.86	12.44	0.43	0.44
FO5a	FO	5	a	0.61	2.89	2.59	14.86	0.4	0.6	46.88	37.19	16.68	0.45	0.45
BR5b	BR	5	b	0.6	2.7	2.4	10.37	0.4	0.6	47.75	41.17	17.96	0.38	0.51
LW5a	LW	5	a	0.6	2.41	2.25	16.52	0.48	0.6	43.96	36.33	18.35	0.45	0.56
TC5b	TC	5	b	0.61	2.59	2.38	8.49	0.37	0.6	40.12	35.76	11.84	0.34	0.63
TK5b	TK	5	b	0.6	2.61	2.37	9.03	0.37	0.61	40.48	35.4	14.32	0.35	0.67
FO5b	FO	5	b	0.61	2.59	2.51	17.12	0.4	0.6	47.15	38.29	19.35	0.37	0.7
LW5b	LW	5	b	0.6	2.21	2.22	17.34	0.46	0.6	45.02	37.04	19.72	0.37	0.76

CMP	Type	Tuning	Variant	East										Tot
				C1 (50%)	AvC20 (50%)	AvgBr (50%)	Br20 (50%)	Br30 (5%)	LD (5%)	LD (10%)	POF (Mean)	PNRK (Mean)	OFT (P>0)	
BR5a	BR	5	a	40.57	47.63	1.21	1.15	0.44	0.27	0.38	0.11	0.93	0.88	0.23
FS5a	FS	5	a	38.29	43.4	1.41	1.38	0.26	0.21	0.33	0.24	0.79	0.8	0.54
TC5a	TC	5	a	41.28	39.02	1.38	1.36	0.38	0.24	0.35	0.18	0.85	0.83	0.39
TK5a	TK	5	a	43.2	38.55	1.33	1.3	0.42	0.24	0.36	0.14	0.91	0.87	0.3
FO5a	FO	5	a	38.29	43.88	1.39	1.35	0.3	0.25	0.36	0.25	0.8	0.83	0.45
BR5b	BR	5	b	40.57	48.09	1.26	1.22	0.25	0.17	0.3	0.15	0.87	0.82	0.56
LW5a	LW	5	a	43.2	40.46	1.33	1.3	0.41	0.27	0.37	0.18	0.87	0.87	0.31
TC5b	TC	5	b	40.78	38.43	1.42	1.39	0.26	0.16	0.26	0.17	0.84	0.81	0.59
TK5b	TK	5	b	43.2	37.69	1.36	1.33	0.28	0.15	0.27	0.14	0.88	0.84	0.56
FO5b	FO	5	b	38.29	44.97	1.36	1.33	0.18	0.16	0.28	0.24	0.78	0.79	0.72
LW5b	LW	5	b	43.2	41.73	1.3	1.26	0.28	0.18	0.28	0.17	0.86	0.84	0.58

CMP	Type	Tuning	Variant	West										Tot
				C1 (50%)	AvC20 (50%)	AvgBr (50%)	Br20 (50%)	Br30 (5%)	LD (5%)	LD (10%)	POF (Mean)	PNRK (Mean)	OFT (P>0)	
BR5a	BR	5	a	2.69	2.46	1.37	1.33	0.46	0.2	0.29	0.18	0.86	0.85	0.48
FS5a	FS	5	a	2.84	2.74	1.4	1.35	0.38	0.17	0.26	0.17	0.87	0.88	0.36
TC5a	TC	5	a	2.65	2.53	1.44	1.43	0.35	0.17	0.26	0.24	0.81	0.87	0.57
TK5a	TK	5	a	2.66	2.54	1.43	1.43	0.43	0.18	0.27	0.21	0.84	0.86	0.44
FO5a	FO	5	a	2.96	2.81	1.37	1.31	0.37	0.16	0.25	0.19	0.86	0.88	0.49
BR5b	BR	5	b	2.69	2.43	1.42	1.39	0.38	0.17	0.27	0.17	0.87	0.84	0.49
LW5a	LW	5	a	2.45	2.39	1.41	1.37	0.48	0.22	0.32	0.21	0.85	0.86	0.39
TC5b	TC	5	b	2.62	2.49	1.46	1.45	0.28	0.13	0.23	0.22	0.83	0.87	0.6
TK5b	TK	5	b	2.63	2.5	1.46	1.46	0.33	0.14	0.24	0.19	0.87	0.86	0.44
FO5b	FO	5	b	2.96	2.7	1.39	1.34	0.31	0.14	0.25	0.19	0.85	0.87	0.58
LW5b	LW	5	b	2.45	2.36	1.43	1.4	0.43	0.2	0.3	0.21	0.84	0.84	0.5

Figure 1. Quilt plot designed to *present* key performance metrics and relative ranking of each CMP (top panel) and two secondary quilt plots with additional desired performance metrics for the East (middle panel) and West (bottom panel). All CMPs presented were tuned to **PGK=60%** in each area (denoted as **tuning level 5**).

CMP	Type	Tuning	Variant	West PGK (Mean)	West AvC10 (50%)	West AvC30 (50%)	West VarC (50%)	West LD (15%)	East PGK (Mean)	East AvC10 (50%)	East AvC30 (50%)	East VarC (50%)	East LD (15%)	Tot
BR6a	BR	6	a	0.71	2.57	2.2	8.21	0.45	0.7	46.49	38.13	14.63	0.51	0.26
TC6a	TC	6	a	0.71	2.37	2.13	7.09	0.45	0.7	36.33	32.27	9.41	0.49	0.38
TK6a	TK	6	a	0.7	2.42	2.15	7.59	0.44	0.7	37.47	32.4	11.98	0.48	0.45
FO6a	FO	6	a	0.71	2.66	2.37	15.03	0.41	0.7	42.71	33.46	16.45	0.52	0.5
BR6b	BR	6	b	0.7	2.55	2.18	9.75	0.43	0.7	43.27	37.2	17.14	0.44	0.53
TC6b	TC	6	b	0.71	2.33	2.1	8.22	0.43	0.71	35.89	31.69	11.05	0.43	0.59
LW6a	LW	6	a	0.7	2.04	1.97	16.5	0.5	0.7	36.41	32.08	17.68	0.51	0.63
TK6b	TK	6	b	0.7	2.35	2.11	8.61	0.42	0.7	36.98	31.57	13.9	0.42	0.67
FO6b	FO	6	b	0.71	2.43	2.3	17.27	0.42	0.7	43.08	34.46	19.13	0.46	0.7
LW6b	LW	6	b	0.7	2.02	1.97	17.42	0.47	0.7	37.94	32.22	19.08	0.44	0.83

CMP	Type	Tuning	Variant	East C1 (50%)	East AvC20 (50%)	East AvgBr (50%)	East Br20 (50%)	East Br30 (5%)	East LD (5%)	East LD (10%)	East POF (Mean)	East PNRK (Mean)	East OFT (P>0)	Tot
BR6a	BR	6	a	40.57	44.29	1.34	1.29	0.58	0.33	0.43	0.06	0.97	0.92	0.25
TC6a	TC	6	a	38.91	34.38	1.52	1.51	0.49	0.32	0.42	0.09	0.93	0.89	0.4
TK6a	TK	6	a	43.2	34.63	1.45	1.43	0.53	0.29	0.4	0.08	0.95	0.91	0.4
FO6a	FO	6	a	38.29	38.87	1.52	1.49	0.45	0.34	0.45	0.13	0.9	0.89	0.44
BR6b	BR	6	b	40.57	41.81	1.38	1.35	0.42	0.25	0.36	0.08	0.93	0.87	0.64
TC6b	TC	6	b	38.29	33.86	1.56	1.55	0.42	0.25	0.35	0.07	0.93	0.87	0.54
LW6a	LW	6	a	43.2	34.79	1.48	1.47	0.51	0.32	0.43	0.09	0.94	0.91	0.36
TK6b	TK	6	b	42.16	33.8	1.49	1.46	0.42	0.21	0.33	0.06	0.94	0.88	0.61
FO6b	FO	6	b	38.29	40.19	1.49	1.46	0.35	0.26	0.37	0.13	0.89	0.87	0.7
LW6b	LW	6	b	43.2	35.78	1.46	1.42	0.41	0.23	0.35	0.07	0.94	0.89	0.59

CMP	Type	Tuning	Variant	West C1 (50%)	West AvC20 (50%)	West AvgBr (50%)	West Br20 (50%)	West Br30 (5%)	West LD (5%)	West LD (10%)	West POF (Mean)	West PNRK (Mean)	West OFT (P>0)	Tot
BR6a	BR	6	a	2.69	2.38	1.5	1.47	0.54	0.2	0.3	0.09	0.94	0.92	0.4
TC6a	TC	6	a	2.5	2.23	1.56	1.57	0.46	0.21	0.3	0.12	0.91	0.92	0.53
TK6a	TK	6	a	2.53	2.27	1.55	1.55	0.51	0.2	0.29	0.12	0.92	0.92	0.51
FO6a	FO	6	a	2.96	2.55	1.48	1.45	0.42	0.16	0.25	0.08	0.94	0.93	0.52
BR6b	BR	6	b	2.69	2.11	1.53	1.51	0.46	0.18	0.28	0.09	0.94	0.92	0.51
TC6b	TC	6	b	2.46	2.2	1.59	1.6	0.4	0.18	0.28	0.11	0.92	0.93	0.47
LW6a	LW	6	a	2.45	2.07	1.56	1.54	0.55	0.23	0.33	0.12	0.93	0.92	0.39
TK6b	TK	6	b	2.48	2.22	1.59	1.58	0.43	0.17	0.28	0.1	0.94	0.93	0.38
FO6b	FO	6	b	2.96	2.44	1.5	1.47	0.38	0.15	0.25	0.08	0.94	0.93	0.55
LW6b	LW	6	b	2.45	2.06	1.57	1.56	0.49	0.21	0.3	0.12	0.93	0.91	0.53

Figure 2. Quilt plot designed to present key performance metrics and relative ranking of each CMP (top panel) and two secondary quilt plots with additional desired performance metrics for the East (middle panel) and West (bottom panel). All CMPs presented were tuned to **PGK=70%** in each area (denoted as tuning level 6).

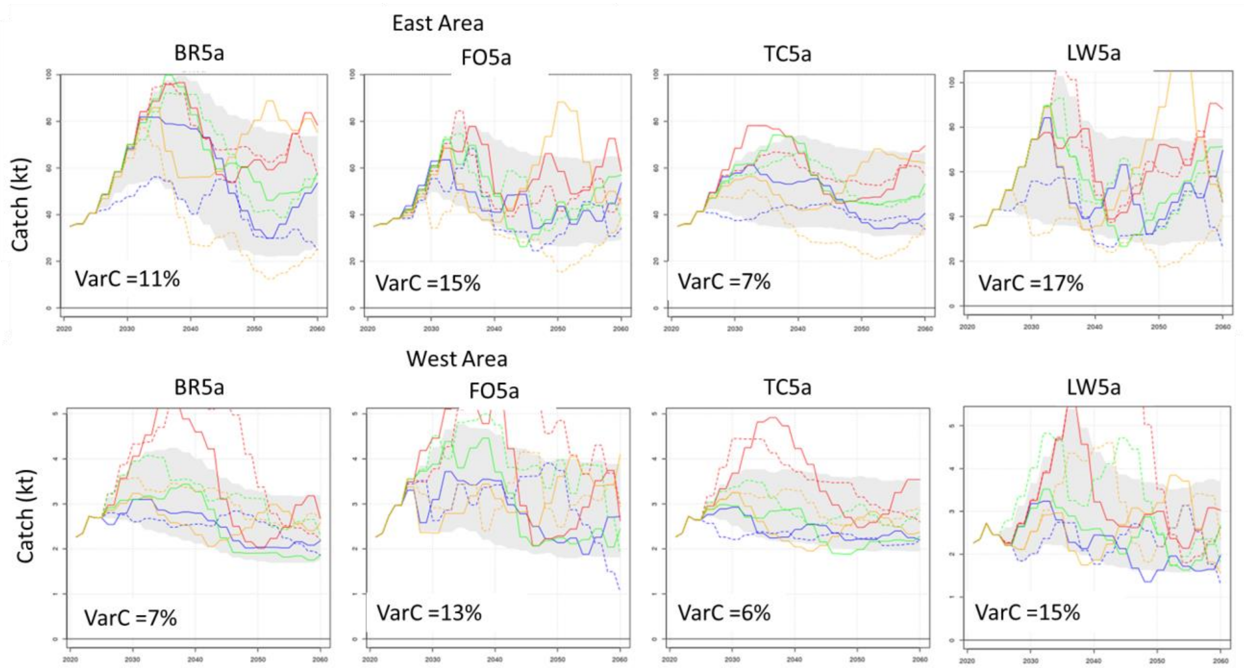


Figure 3. Worm plots of catch for the East (top) and West (bottom) across BR (left), FO (left center), TC (right center), and LW (right) CMPs across **the first (more positive) recruitment scenarios (R1) of the reference OM grid**. The shaded area is the 80% interquantile range. Thin lines are individual simulations. Note that the individual simulation lines correspond across CMPs and areas (e.g., represent the same simulated scenarios, having made use of identical sequences of generated random numbers). Corresponding VarC statistics are included in each plot.

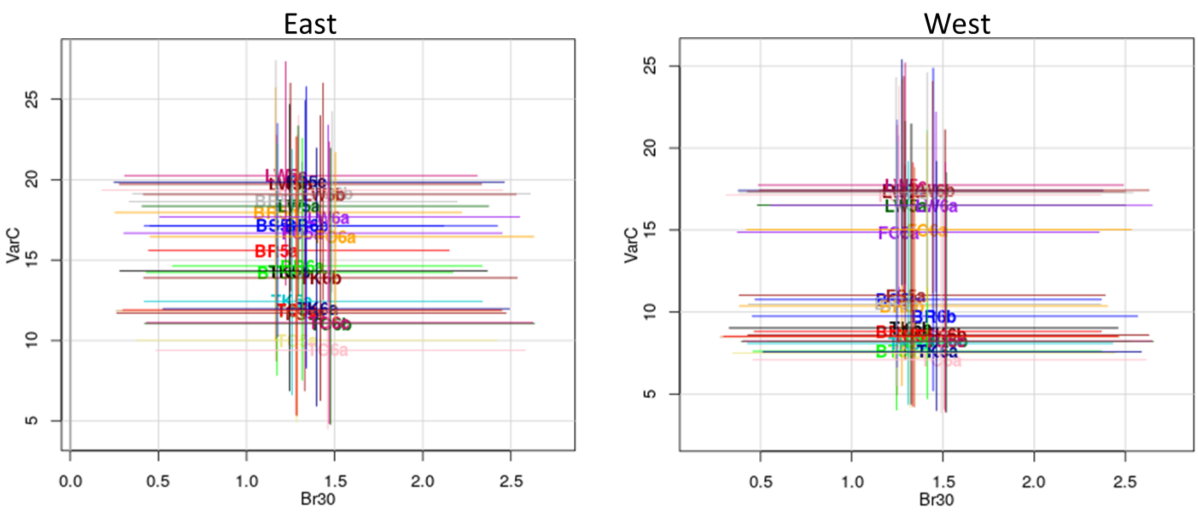


Figure 4. Plot demonstrating the trade-off between fishery stability (VarC) and stock safety (e.g., Br30 90th percentile probability bounds). CMP labels indicate median performance for the corresponding CMP across the full reference grid of OMs, and lines correspond to 90th percentiles.

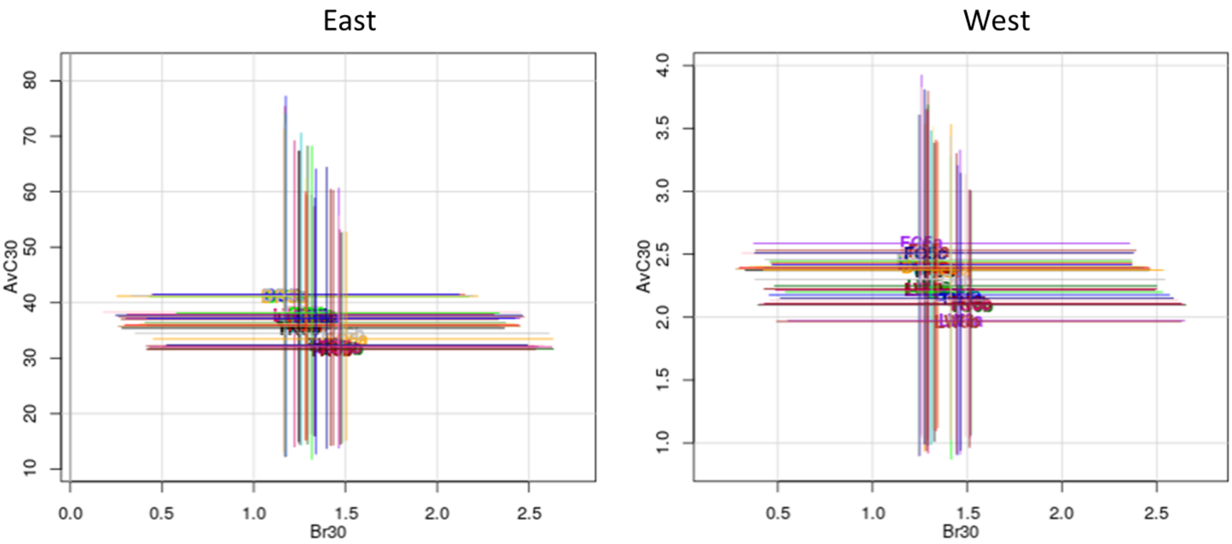


Figure 5. Plot demonstrating the trade-off between yield (AvC30) and stock status (Br30). CMP labels indicate median performance for the corresponding CMP across the full reference grid of OMs, and lines correspond to 90th percentiles.

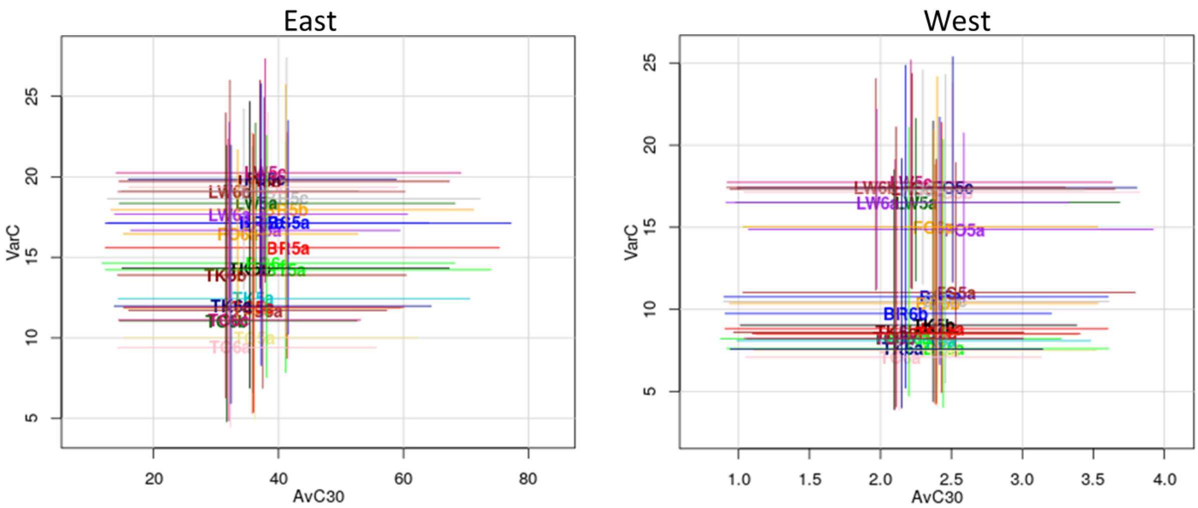


Figure 6. Plot demonstrating the trade-off between yield (AvC30) and fishery stability (VarC). CMP labels indicate median performance for the corresponding CMP across the full reference grid of OMs, and lines correspond to 90th percentiles.

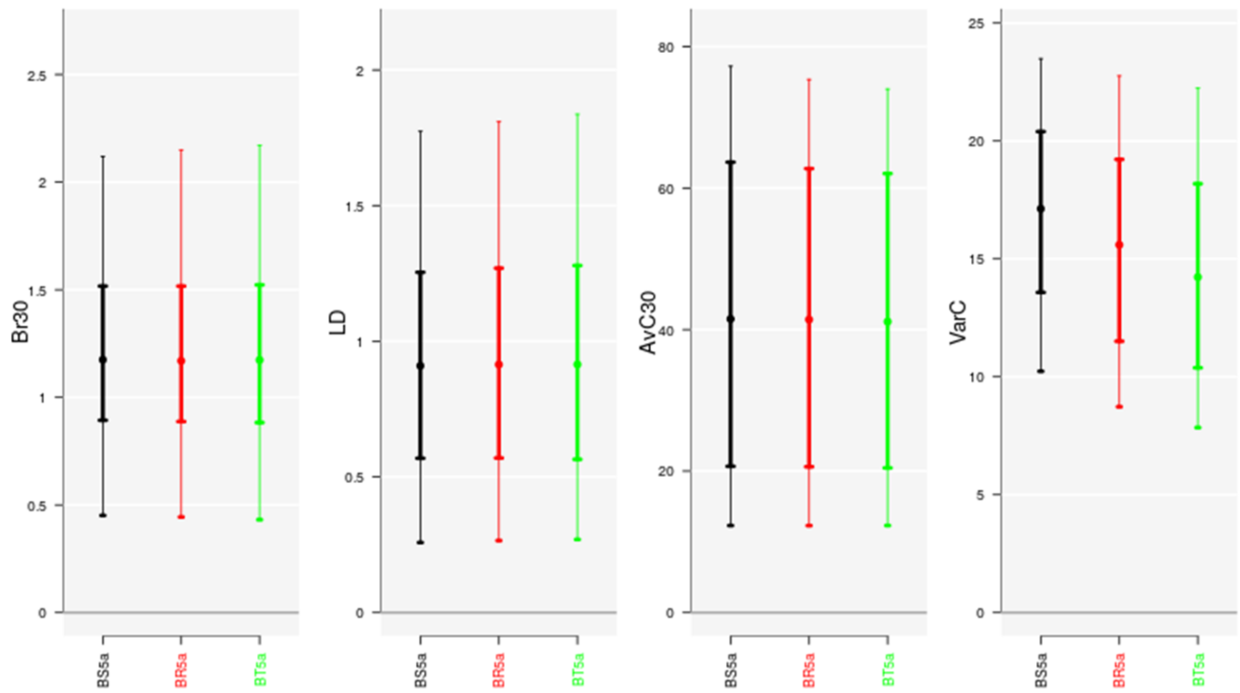


Figure 7. Zeh plot showing the median, interquartile, and 90% interquantile range for selected performance metrics integrated over all simulations and reference OMs for the East area. The CMPs shown are all variants of the BR CMP, where BR was tuned to PGK=60% in both areas (denoted by tuning level 5), with various levels of VarC damping, ranging from low damping (BS5a), intermediate damping (BR5a), and high damping (BT5a). Performance metrics presented are biomass status (Br30: spawning biomass relative to dynamic B_{MSY} after projection year 30), lowest depletion (LD*: spawning biomass relative to dynamic B_{MSY} in projection years 11 - 30), yield (AvC30: mean catches over first 30 projected years), and fishery stability (VarC: variability in yield between management cycles over the first 30 projection years).

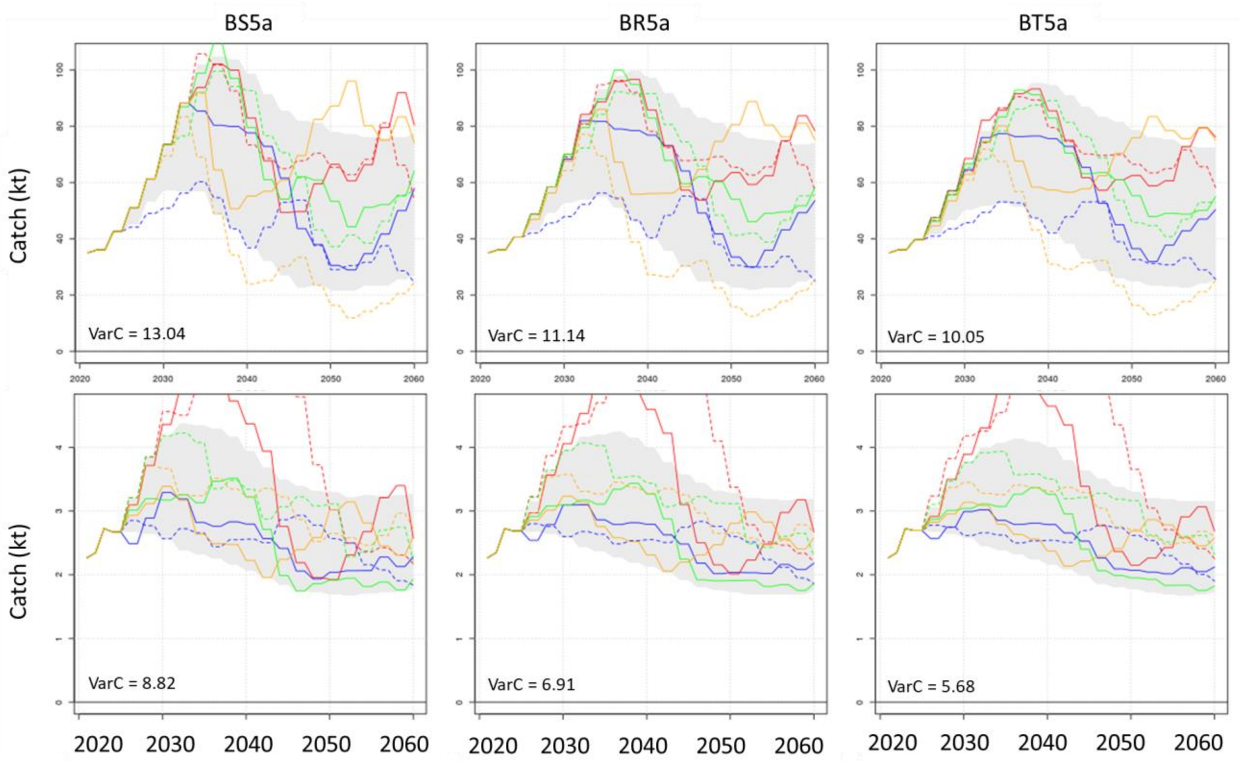


Figure 8. Worm plots of catch for the East (top) and West (bottom) across BS5a (low catch variability damping; left), BR5a (intermediate catch variability damping; center), and BT5a (high catch variability damping; right) across **the first (more positive) recruitment scenarios (R1) of the reference OM grid**. The shaded area is the 80% interquantile range. Thin lines are individual simulations. Note that the individual simulation lines correspond across CMPs and areas (e.g., represent the same simulated scenarios). Corresponding VarC statistics are included in each plot.

CMP	Type	Tuning	Variant	West					East					Tot
				PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	
BR5a	BR	5	a	0.6	2.77	2.43	8.81	0.42	0.6	51.97	41.42	15.6	0.45	0.26
BR5b	BR	5	b	0.6	2.7	2.4	10.37	0.4	0.6	47.75	41.17	17.96	0.38	0.51
FO5a	FO	5	a	0.61	2.89	2.59	14.86	0.4	0.6	46.88	37.19	16.68	0.45	0.46
FO5b	FO	5	b	0.61	2.59	2.51	17.12	0.4	0.6	47.15	38.29	19.35	0.37	0.7
LW5a	LW	5	a	0.6	2.41	2.25	16.52	0.48	0.6	43.96	36.33	18.35	0.45	0.56
LW5b	LW	5	b	0.6	2.21	2.22	17.34	0.46	0.6	45.02	37.04	19.72	0.37	0.76
TC5a	TC	5	a	0.6	2.67	2.4	7.51	0.4	0.6	41.07	36.18	10.01	0.41	0.41
TC5b	TC	5	b	0.61	2.59	2.38	8.49	0.37	0.6	40.12	35.76	11.84	0.34	0.63

Figure 9. Quilt plot depicting CMP performance across prioritized performance statistics reflecting status (PGK), yield (AvC10, AvC30), stability (VarC), and safety (LD*) in both the West (W) and East (E). The *Tot* column represents ranked relative performance across all performance statistics, where lower indicates better performance.

CMP	Type	Tuning	Variant	West PGK (Mean)	West AvC10 (50%)	West AvC30 (50%)	West VarC (50%)	West LD (15%)	East PGK (Mean)	East AvC10 (50%)	East AvC30 (50%)	East VarC (50%)	East LD (15%)	Tot
BR5c	BR	5	c	0.6	2.74	2.46	10.49	0.4	0.6	48.37	41.28	18.65	0.41	0.3
BR7b	BR	7	b	0.61	2.72	2.43	10.22	0.41	0.63	46.38	39.82	17.68	0.4	0.34
BR5b	BR	5	b	0.6	2.7	2.4	10.37	0.4	0.6	47.75	41.17	17.96	0.38	0.39
FO5c	FO	5	c	0.62	2.59	2.51	17.41	0.42	0.62	47.15	37.75	19.85	0.41	0.49
FO5b	FO	5	b	0.61	2.59	2.51	17.12	0.4	0.6	47.15	38.29	19.35	0.37	0.59
LW5c	LW	5	c	0.6	2.22	2.22	17.74	0.47	0.6	47.09	37.88	20.25	0.39	0.6
LW7b	LW	7	b	0.6	2.25	2.28	17.29	0.46	0.64	41.96	35.06	19.35	0.4	0.64
LW5b	LW	5	b	0.6	2.21	2.22	17.34	0.46	0.6	45.02	37.04	19.72	0.37	0.68
TC5c	TC	5	c	0.6	2.6	2.39	8.53	0.37	0.6	40.4	36.01	11.9	0.35	0.52
TC5b	TC	5	b	0.61	2.59	2.38	8.49	0.37	0.6	40.12	35.76	11.84	0.34	0.55

Figure 10. Performance statistics of BR CMP tuned to PGK 60% with a 3-year management cycle (b variants) with a default of a maximum -30% allowable TAC reduction compared to a maximum -35% allowable TAC reduction (c variants). BR7b represents a BR variant with a 3-year management cycle tuned to LD*15%=0.4, and LW7b is a 3-year management cycle LW variant tuned to minimally meet both PGK 60% and LD*15%=0.4 satisficing criteria (see **Figure 16** below).

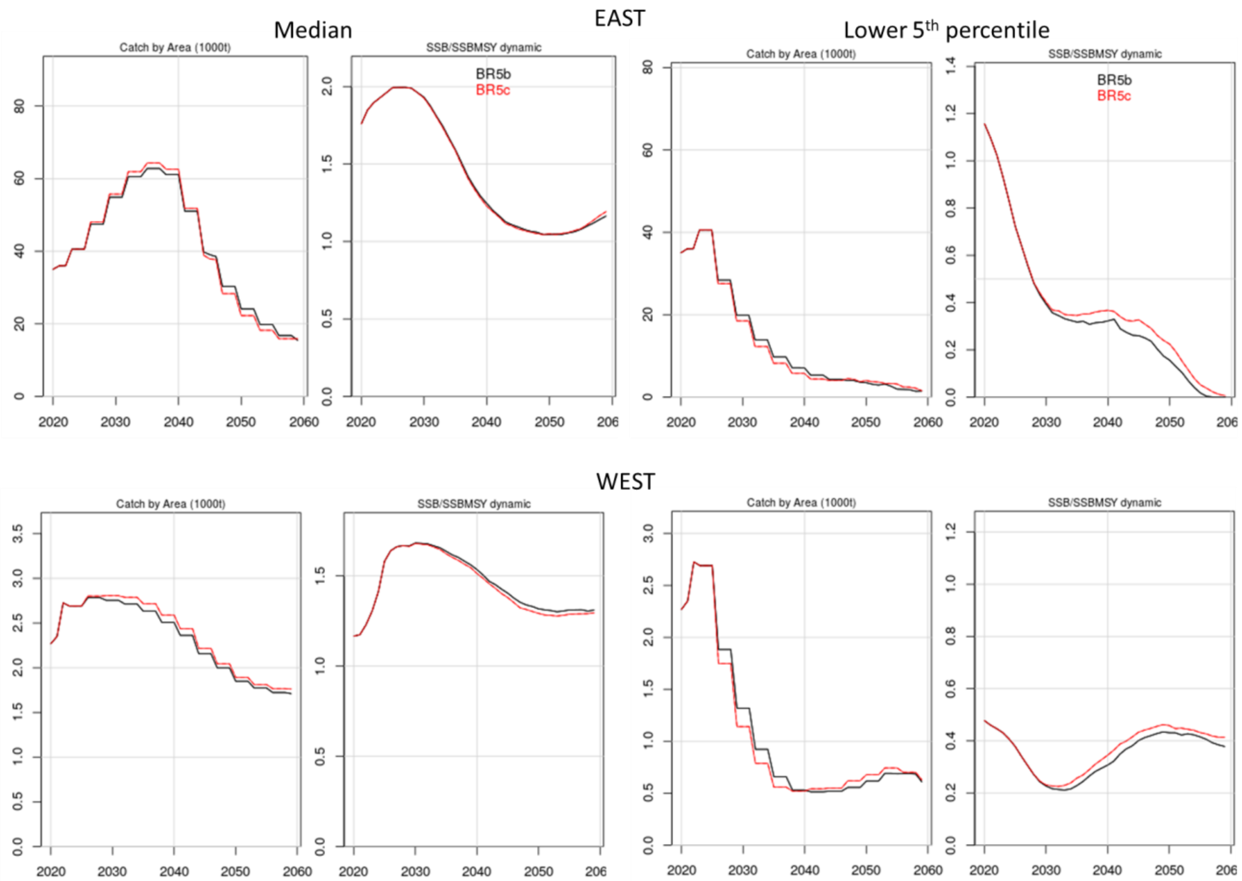


Figure 11. Median (left) and lower 5%ile (right) catch and SSB trajectories by area averaged over all OMs in the reference grid for BR5b (3-year TAC interval, tuning target PGK=0.6, maximum allowable TAC decrease of 30%) and for BR5c (as BR5b, but allowing for a maximum 35% downward TAC adjustment).

CMP	Type	Tuning	Variant	West					East					Tot
				PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	
BR6a	BR	6	a	0.71	2.57	2.2	8.21	0.45	0.7	46.49	38.13	14.63	0.51	0.36
BR5a	BR	5	a	0.6	2.77	2.43	8.81	0.42	0.6	51.97	41.42	15.6	0.45	0.42
FO6a	FO	6	a	0.71	2.66	2.37	15.03	0.41	0.7	42.71	33.46	16.45	0.52	0.59
FO5a	FO	5	a	0.61	2.89	2.59	14.86	0.4	0.6	46.88	37.19	16.68	0.45	0.61
LW5a	LW	5	a	0.6	2.41	2.25	16.52	0.48	0.6	43.96	36.33	18.35	0.45	0.65
LW6a	LW	6	a	0.7	2.04	1.97	16.5	0.5	0.7	36.41	32.08	17.68	0.51	0.67
TC6a	TC	6	a	0.71	2.37	2.13	7.09	0.45	0.7	36.33	32.27	9.41	0.49	0.41
TC5a	TC	5	a	0.6	2.67	2.4	7.51	0.4	0.6	41.07	36.18	10.01	0.41	0.5

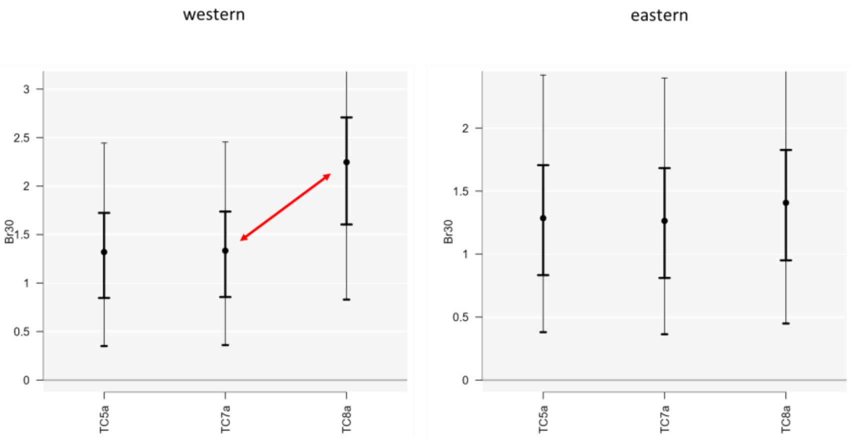
Figure 12. Quilt plot depicting CMP performance across prioritized performance statistics reflecting status (PGK), yield (AvC10, AvC30), stability (VarC), and safety (LD*) in both the West (W) and East (E) areas. The *Tot* column represents ranked relative performance across all performance statistics, where lower indicates better performance.

CMP	Type	Tuning	Variant	West					East					Tot
				PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	
BR5b	BR	5	b	0.6	2.7	2.4	10.37	0.4	0.6	47.75	41.17	17.96	0.38	0.31
FO5b	FO	5	b	0.61	2.59	2.51	17.12	0.4	0.6	47.15	38.29	19.35	0.37	0.54
TC5b	TC	5	b	0.61	2.59	2.38	8.49	0.37	0.6	40.12	35.76	11.84	0.34	0.56
LW5b	LW	5	b	0.6	2.21	2.22	17.34	0.46	0.6	45.02	37.04	19.72	0.37	0.64

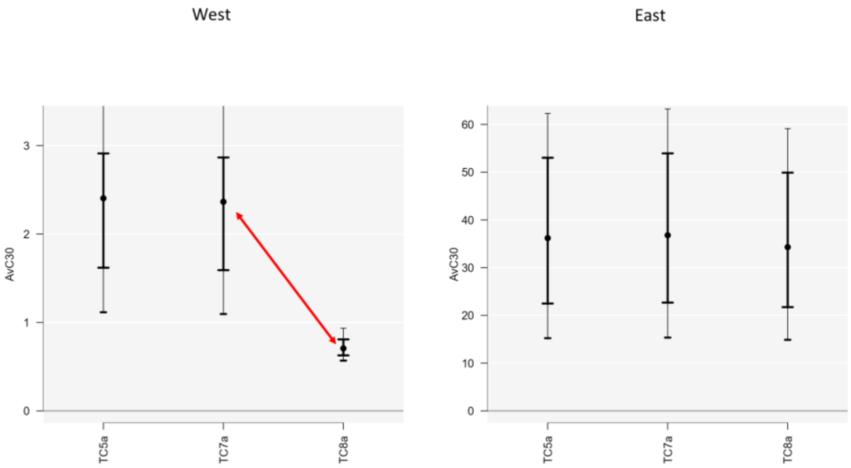
Figure 15. Quilt plot depicting CMP performance tuned to PGK 60% with a 3-year management period (5b CMP variant) across prioritized performance statistics reflecting status (PGK), yield (AvC10, AvC30), stability (VarC), and safety (LD*) in both the West (W) and East (E) areas. The *Tot* column represents ranked relative performance across all performance statistics, where lower values indicate better performance.

CMP	Type	Tuning	Variant	West					East					Tot
				PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	
BR7b	BR	7	b	0.61	2.72	2.43	10.22	0.41	0.63	46.38	39.82	17.68	0.4	0.18
BR5b	BR	5	b	0.6	2.7	2.4	10.37	0.4	0.6	47.75	41.17	17.96	0.38	0.32
LW7b	LW	7	b	0.6	2.25	2.28	17.29	0.46	0.64	41.96	35.06	19.35	0.4	0.6
LW5b	LW	5	b	0.6	2.21	2.22	17.34	0.46	0.6	45.02	37.04	19.72	0.37	0.76

Figure 16. Quilt plot depicting CMP performance tuned to PGK 60% with a 3-year management period (5b CMP variant) compared to corresponding CMP tuned to LD*15=0.4 with a 3-year management period (BR7b), or minimally tuned to meet LD*15=0.4 and PGK60% satisficing criteria (LW7b) across prioritized performance statistics reflecting status (PGK), yield (AvC10, AvC30), stability (VarC), and safety (LD*) in both the West (W) and East (E). The *Tot* column represents ranked relative performance across all performance statistics, where lower values indicate better performance.



a)



b)

Figure 17. Performance results for a) Biomass - Br30 and b) Yield - AvC30 for the TC CMP for three separate tunings - TC5a tuned to PGK=60%, TC7a tuned to LD*15%, and TC8a tuned to LD*10%. All have a 2-year management cycle. The west results are on the left, and the east results are on the right. The point indicates the median, the thick line indicates the 25/75%-iles, and the whiskers indicate the 5/95%-iles. Panel a) shows that the western stock status improves for LD*10%, with median Br30 values above twice the dynamic SSB_{MSY}, while Panel b) shows the disproportionate reduction in yield in the west area.

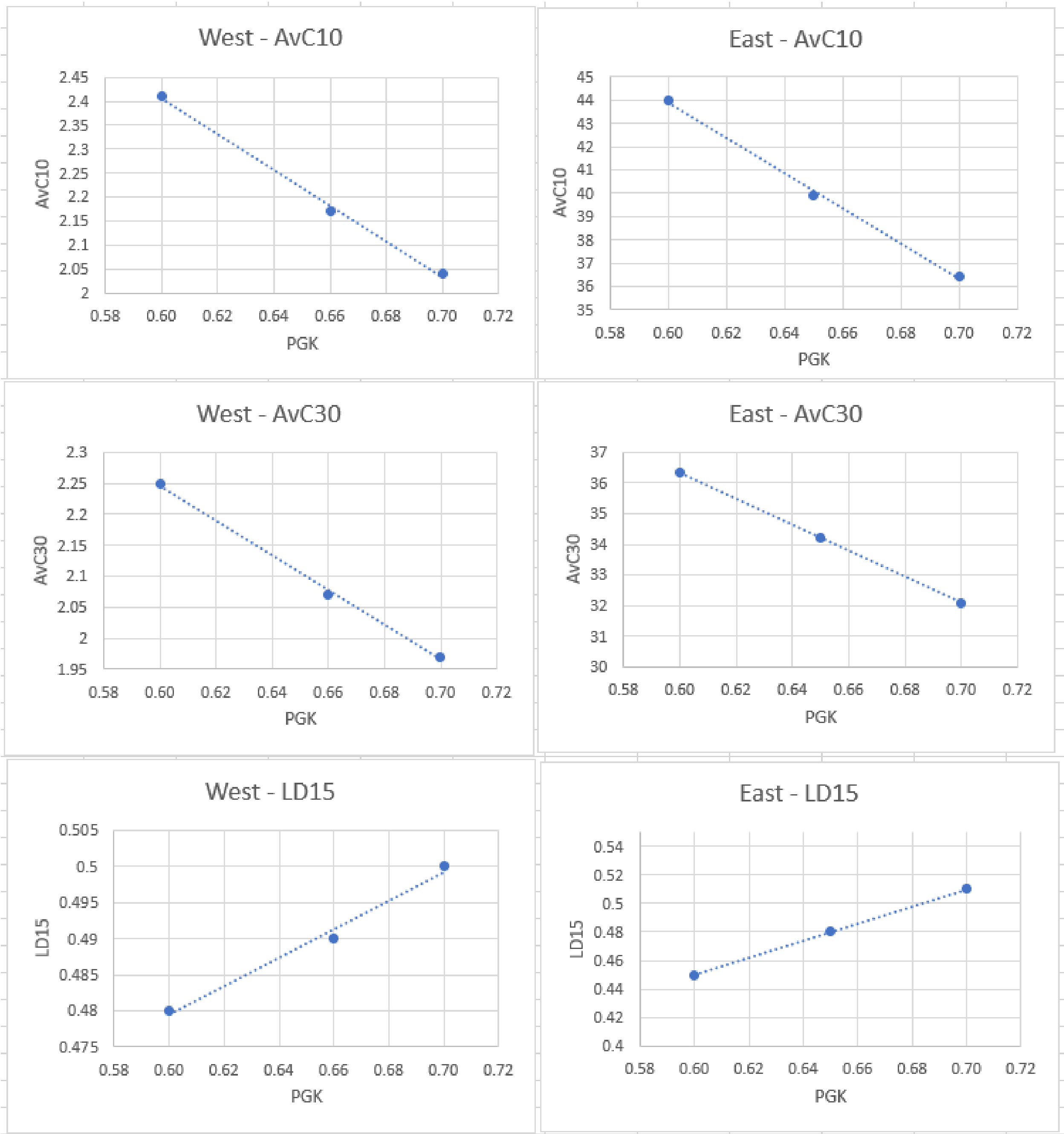


Figure 18. Resulting performance statistics as calculated from LW tuned to PGK60%, 65%, and 70%. Note that the response of each performance statistic is virtually linear. LW did not exactly meet PGK 65% but, with more time, could have. Results for PGK66% for the West are plotted to show the linear relationship between performance statistics and PGK within the range of 60 to 70%.

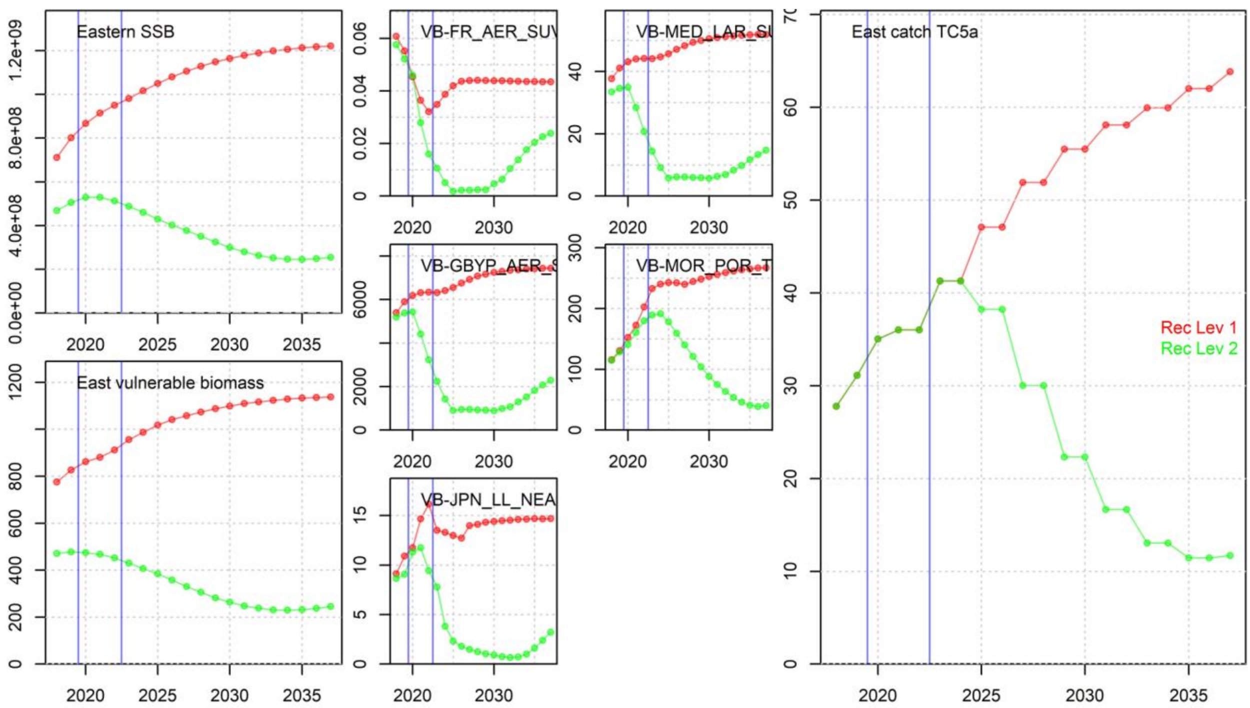


Figure 19. Deterministic projections of eastern stock SSB (top left), vulnerable biomass (bottom left), five indices of abundance (center), and resulting catch as specified by TC5a (right), as tuned to 60% PGK with a 2-year management cycle for recruitment levels 1 (red; more positive) and 2 (green; more negative). A vertical line is superimposed at the year 2019.5, which demarcates the end of the model conditioning period, and at the year 2022.5, indicating the start of the projection period in 2023. Though the vulnerable biomass declines following the start of the projection period in recruitment level 2, the lag in data used to prescribe TAC advice results in an increased catch for the first management period, regardless of the recruitment scenario.

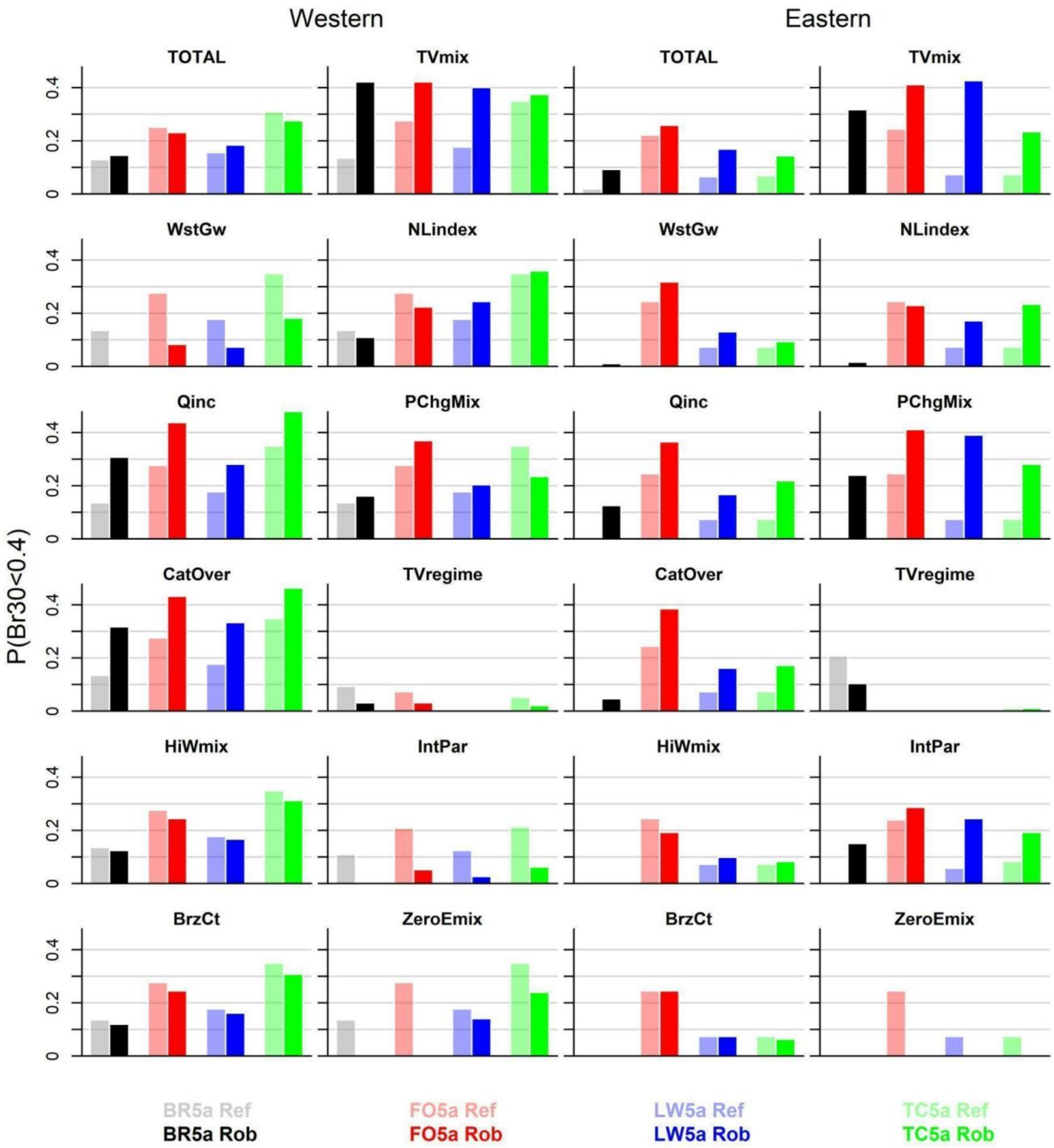


Figure 20. Robustness test performance (probability of Br30<0.4) for each robustness test. The shaded values are for the reference grid and the dark values are for **the** corresponding models in the set of robustness OMs.

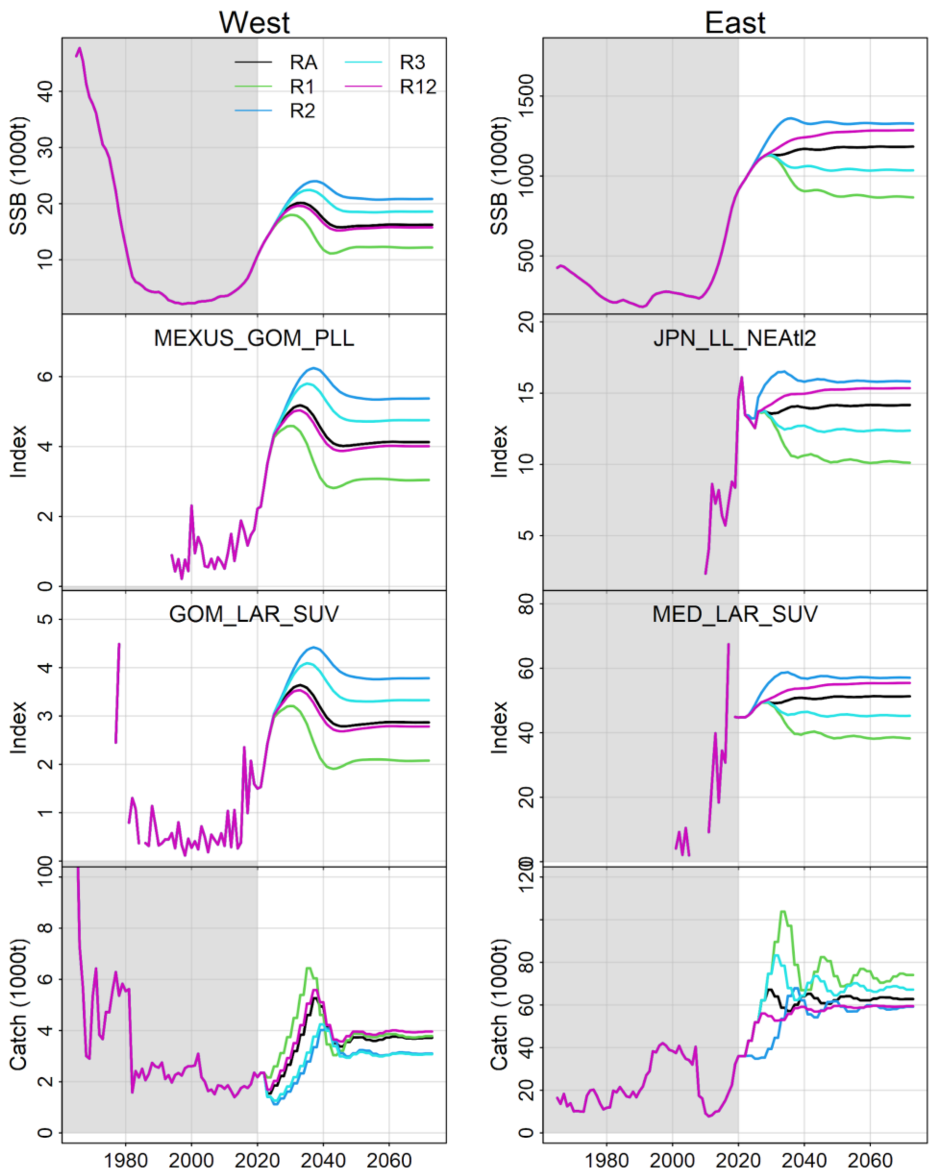


Figure 21. Spawning stock biomass (SSB, top), indices of abundance (middle), and catch (bottom) projections for the West (left) and East (right) resulting from PW CMPs deterministically tuned to alternate recruitment scenarios (RA, R1, R2, R3, R12, RA) on OM1. Notably, each CMP variant performed similarly (just more or less aggressively depending on the recruitment scenario(s) to which it was tuned), but the impact of recruitment scenario 3 was found to be minor, as indicated by the similarity of the RA (black) and R12 (pink) trajectories.

CMP	Type	Tuning	Variant	West PGK (Mean)	West AvC10 (50%)	West AvC30 (50%)	West VarC (50%)	West LD (15%)	East PGK (Mean)	East AvC10 (50%)	East AvC30 (50%)	East VarC (50%)	East LD (15%)	Tot
BR5a	BR	5	a	0.6	2.77	2.43	8.81	0.42	0.6	51.97	41.42	15.6	0.45	0.32
FO5a	FO	5	a	0.61	2.89	2.59	14.86	0.4	0.6	46.88	37.19	16.68	0.45	0.54
TC5a	TC	5	a	0.6	2.67	2.4	7.51	0.4	0.6	41.07	36.18	10.01	0.41	0.58
LW5a	LW	5	a	0.6	2.41	2.25	16.52	0.48	0.6	43.96	36.33	18.35	0.45	0.64

CMP	Type	Tuning	Variant	West PGK (Mean)	West AvC10 (50%)	West AvC30 (50%)	West VarC (50%)	West LD (15%)	East PGK (Mean)	East AvC10 (50%)	East AvC30 (50%)	East VarC (50%)	East LD (15%)	Tot
BR5a	BR	5	a	0.66	2.2	2.01	9.33	0.35	0.66	40.04	34.73	14.01	0.46	0.27
TC5a	TC	5	a	0.63	2.35	2.11	7.81	0.32	0.63	36.87	32.23	9.16	0.39	0.5
FO5a	FO	5	a	0.64	2.27	2.01	15.35	0.32	0.6	37.14	33.4	16.65	0.44	0.66
LW5a	LW	5	a	0.64	1.8	1.87	16.68	0.39	0.61	37.11	33.03	18.36	0.42	0.73

Figure 22. Quilt plot depicting CMP performance tuned to PGK 60% with a 2-year management period (5a CMP variant) as presented **across all 3 recruitment scenarios (top)** and **recruitment scenarios 1 and 2 only (bottom)**. Prioritized performance statistics reflect status (PGK), yield (AvC10, AvC30), stability (VarC), and safety (LD*) in both the West (W) and East (E). The *Tot* column represents ranked relative performance across all performance statistics, where lower indicates better performance.

CMP	Type	Tuning	Variant	West					East					Tot
				PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	
BR5a	BR	5	a	0.6	2.77	2.43	8.81	0.42	0.6	51.97	41.42	15.6	0.45	0.32
FO5a	FO	5	a	0.61	2.89	2.59	14.86	0.4	0.6	46.88	37.19	16.68	0.45	0.54
TC5a	TC	5	a	0.6	2.67	2.4	7.51	0.4	0.6	41.07	36.18	10.01	0.41	0.58
LW5a	LW	5	a	0.6	2.41	2.25	16.52	0.48	0.6	43.96	36.33	18.35	0.45	0.64

CMP	Type	Tuning	Variant	West					East					Tot
				PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	
BR5a	BR	5	a	0.6	2.77	2.43	8.81	0.42	0.6	51.97	41.42	15.6	0.45	0.33
LW5a	LW	5	a	0.6	2.41	2.25	16.52	0.48	0.6	43.96	36.33	18.35	0.45	0.48
FO5a	FO	5	a	0.61	2.89	2.59	14.86	0.4	0.6	46.88	37.19	16.68	0.45	0.53
TC5a	TC	5	a	0.6	2.67	2.4	7.51	0.4	0.6	41.07	36.18	10.01	0.41	0.69

CMP	Type	Tuning	Variant	West					East					Tot
				PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	
BR5a	BR	5	a	0.6	2.77	2.43	8.81	0.42	0.6	51.97	41.42	15.6	0.45	0.29
FO5a	FO	5	a	0.61	2.89	2.59	14.86	0.4	0.6	46.88	37.19	16.68	0.45	0.49
TC5a	TC	5	a	0.6	2.67	2.4	7.51	0.4	0.6	41.07	36.18	10.01	0.41	0.63
LW5a	LW	5	a	0.6	2.41	2.25	16.52	0.48	0.6	43.96	36.33	18.35	0.45	0.71

Figure 23. Quilt plots depicting CMP performance tuned to PGK 60% with a 2-year management cycle (5a CMP variant) where ranking follows alternate weighting of performance metrics: **default weighting** (AvC10 and AvC30 weight is equal to 0.5, VarC and LD weight is equal to 1; **top**), **double safety** (AvC10 and AvC30 weight is equal to 0.55, VarC weight is equal to 0.5, and LD weight is equal to 1; **middle**), **double yield** (AvC10, AvC30, VarC, and LD weight is equal to 1; **bottom**). Prioritized performance statistics reflect status (PGK), yield (AvC10, AvC30), stability (VarC), and safety (LD*) in both the West (W) and East (E). The *Tot* column represents ranked relative performance across all performance statistics following the corresponding weighting scheme, where lower indicates better performance.

Appendix 1

Equations used in the BR CMP to impose a minimum TAC change.

Constraints on the extent of TAC increase and decrease

TAC variation reduction adjustment

$$\Delta TAC^{E/w} = \frac{TAC_y^{E/W}}{TAC_{y-1}^{E/W}} \quad (1)$$

with $TAC_y^{E/W}$ from equation A4 of doc SCRS/2022/183.

$\Delta TAC^{E/w}$ is then modified:

$$\Delta TAC^{E/W\prime} = \exp\left(ln\left(\Delta TAC^{E/W}\right) VarCadj\right) \quad (2)$$

Maximum change

If $\Delta TAC^{E/W\prime} > \left(1 + maxUp^{E/W}\right)$,
then $\Delta TAC^{E/W\prime} = \left(1 + maxUp^{E/W}\right)$ or
if $\Delta TAC^{E/W\prime} < \left(1 - maxDown^{E/W}\right)$,
then $\Delta TAC^{E/W\prime} = \left(1 - maxDown^{E/W}\right)$.

The TAC is then computed as:

$$\Delta TAC_y^{E/W\prime} = TAC_{y-1}^{E/W} \cdot \Delta TAC^{E/W} \quad (3)$$

Minimum change
If $\left|TAC_{y-1}^{E/W} - TAC_y^{E/W\prime}\right| < minC^{E/W}$
then $TAC_y^{E/W'} = TAC_{y-1}^{E/W}$

Current parameter value choices

$VarCadj = 0.5$
$maxUp^{E/W} = 0.20$
$maxDown^{E/W} = 0.30$ for a 2-yr cycle
$maxDown^{E/w} = 0.35$ for a 3-yr cycle
$minC^E = 1000mt$
$minC^W = 100mt$