REPORT OF THE 2022 INTERSESSIONAL MEETING OF BLUEFIN TUNA MSE TECHNICAL SUB-GROUP

(Online, 3-6 May 2022)

1. Opening, adoption of Agenda, meeting arrangements and assignment of rapporteurs

The 2022 Intersessional Meeting of the Bluefin Tuna MSE Technical Sub-Group ("the Group") was held online from 3 to 6 May 2022. The Rapporteur for the western Atlantic bluefin tuna stock (BFT), Dr. John Walter (USA), opened the meeting and served as Chair. The Executive Secretary and the SCRS Chair, Dr. Gary Melvin (Canada), welcomed the participants. The Chair proceeded to review the Agenda which was adopted after some changes (**Appendix 1**). Due to the time constraints, the Group focused on the main outputs from the meeting in this report.

The List of Participants is included in **Appendix 2**. The List of Documents and Presentations provided at the meeting is attached as **Appendix 3**. The abstracts of all SCRS documents and presentations provided at the meeting are included in **Appendix 4**. The following served as rapporteurs:

Sections	*Rapporteur*
Items 1, 9	A. Kimoto
Items 2-4	C. Peterson
Items 5-7	S. Miller
Item 8	T. Carruthers

2. Summary of developments on ABFT-MSE from the BFT Species Group (BFTSG)

2.1 Update

The Group noted that summaries of major developments and current BFT MSE progress from the BFTSG can be found in the short Communications 4-pager (Anon. 2022, Appendix 7). Eight Candidate Management Procedures (CMPs) are currently still supported.

Quilt plots were highlighted as the major basis for CMP comparison. A value for B_{lim} was identified (40% dynamic SSB_{MSY}); these included an associated performance statistic (LD*: Lowest Depletion over years 11-30). At the *2022 Intersessional meeting of Panel 2* (9-10 May 2022), the SCRS expects Panel 2 to decide upon a probability of not falling below B_{lim}. It was also noted that CMP developers have the autonomy to withdraw CMPs at their discretion.

2.2 Update from MSE Consultant

The MSE consultant presented updates on results since the last technical meeting and performances of revised CMPs (SCRS/P/2022/021). New performance metrics were added to the ABTMSE package (v.7.6.4) including POF, PNOF, PGK, PNRK, AvC20, and Br20 (see Anon. 2022, Appendix 6 TSD for descriptions); the Shiny app (https://apps.bluematterscience.com/ABTMSE_Performance/) was updated accordingly.

The MSE consultant presented updated stochastic results for tuning level 2a (i.e., Br30=1.25 for the West and Br30=1.5 for the East). The Group further noted the importance of presenting spawning biomass and especially TAC trajectory plots to managers and stakeholders as they provide more comprehensive information on the overall behaviour of each CMP.

The Group expressed concern that CMP performance could be unrealistically optimistic due to omniscience (i.e., a thorough understanding of the testing reference OM grid), in which case CMPs designed with an understanding of the reference grid Operating Model (OM) 'testing arena' could achieve unrealistically high performance that would not be replicated for scenarios outside the grid. To date, the MSE consultant has not found evidence for omniscience within any CMPs.

2.3 MSE versus best assessment paradigm

The Group again emphasized the distinction between the MSE and best assessment paradigms. MSE is primarily a "stress test", and not necessarily a best prediction of the future. Consequently, many CMPs should be expected to have greater variability in resulting performance statistics within the MSE paradigm, as they are testing for robustness, rather than attempting to characterize the most plausible or likely outcomes, as would be the case for a standard stock assessment. In contrast to most assessments that are designed to forecast the most likely future conditions, MSE is specifically designed to encompass a wide range of scenarios. The most plausible scenarios form the reference grid over which CMPs are tested. Less likely, but important scenarios become robustness tests or additional hurdles over which CMPs are tested. These may not necessarily be pass-fail situations, but they provide critical context for potential failure points for the CMPs. Hence results for MSE for certain performance statistics, though similarly named, might not be comparable to their best assessment counterparts.

3. Unfinished work from the Bluefin tuna Species Group meeting

3.1 CMP Tuning level

Four of the CMPs had been tuned to each of the four tuning levels (i.e., West 1.25 – East 1.25, West 1.25 – East 1.5, West 1.5 – East 1.25, and West 1.5 – East 1.5). Across all these tuning levels, the relative rankings of CMPs for various key performance statistics were largely preserved. Accordingly, as had been indicated in previous meetings, the Group continues to be of the view that the tuning level does not need to be decided upon at this point because relative CMP rankings do not change greatly for alternate tuning.

3.2 Effect of alternate limits on allowable TAC change

Panel 2 requested that developers evaluate TAC change constraint scenarios of: +20%/-30%; +20%/-20%; +20%/-10% and no limits but left the prioritization of these to developers to determine what might be a realistic allocation of resources to this testing.

One CMP developer evaluated results across all of the requested % TAC change scenarios for the second tuning level (**Figures 1** and **2**). Allowing for greater % change on TACs allowed for increased safety, largely because the CMP could respond more rapidly to decreases in biomass. On the other hand, unlimited flexibility in TAC change resulted in rather extreme fluctuations in TAC, likely to be outside of desirable ranges.

An additional CMP developer also evaluated the safety-stability trade off by exploring +20%/-20%, +20%/-30% and +50%/-50% TAC change scenarios. Similarly, to the results summarized above, allowing for increased variability in TAC changes resulted in improved safety due to more responsive decreases in TAC but did not result in appreciable improvements in yield and came at a substantial cost to yield stability.

The SCRS notes that across both CMPs evaluated the +20%/-30% restriction in TAC change provides a useful compromise, allowing adequate safety as well as acceptable stability in yield.

3.3 Index presentation

The Group has heard many concerns on the composition of the set of indices that were used as inputs for the CMPs. Consequently, the Group heard a presentation by the lead of the BFT Technical Sub-group on Abundance Indices to explain why some indices were not supported by the MSE Technical Sub-group for inclusion in CMPs. There were two indices (i.e., CAN GSL HL and US RR >177) that were poorly fit (**Figure 3**) in the OM conditioning (including having high standard deviation and autocorrelation (**Table 1**), strong residual patterns (**Figure 4**), and the highest consecutive set of residual runs for each OM). It had consequently been determined that these indices violated the assumption that they were proportional to total stock biomass throughout the historical period, and consequently these indices could not be reliably projected for the MSE. Therefore, they were not recommended for use for empirical CMPs, as their lack of predictive reliability meant that they could not be used for simulation testing.

The Group emphasized that index inclusion or exclusion for use in CMPs is not a decision point for Panel 2. Panel 2 will have the ability to select CMPs based on the composition of indices used within them, should they desire. Demonstration of the process of index selection for CMP consideration will be included as extra material for the presentation for Panel 2, in the event that more background is requested.

3.4 Exceptional circumstances

The Group noted that ranges of indices resulting from the MSE simulations would be measured and serve to flag Exceptional Circumstances. If, after MP implementation, an index falls outside such a range of values generated in the MSE, that would trigger an exceptional circumstance. Exceptional circumstances provisions will be discussed and developed further in 2023, after final acceptance of an MP by the Commission.

3.5 Sensitivity tests to weighting schemes and further robustness tests

A new sensitivity weighting scheme of the reference grid, reflecting alternate weighting of recruitment scenarios, was proposed. The proposal was to:

- Essentially equally weight long-term (years 11-30) recruitment assumptions: R1 30%, R2 50%, R3 20%. The purpose of this was to evaluate the sensitivity of CMP performance to alternative weighting schemes for the recruitment assumptions.

CMP performance results would be reweighted in the Shiny app using existing CMP tunings.

A method to compare results under robustness tests will be developed to readily flag CMPs that perform differentially. This could be achieved through a simple percent difference from the primary performance statistics. This examination will occur once the top performing CMPs have been identified. At that time, the Group will have to determine which robustness tests should be presented to the Commission, focusing on how performance under robustness tests will form part of selecting a final set of MPs. Should the BFTSG identify further robustness tests that might be necessary, these can be considered once the top performing CMPs are obtained.

4. Additional changes to CMPs

CMP updates / revisions were provided by each CMP developer. Mathematical descriptions are available in **Appendix 5**.

- FZ / EH: FZ uses an ensemble index to improve performance; an updated mathematical description is to be provided. Note that the updated FZ is labeled 'EH' on Shiny app v7.6.4, 2022-05-03, but will replace FZ in moving forward. The updated CMP differs from the previous version in the following respects:

  - West
    - The indicator of SSB has been changed so that biomass scale depends on CAN SWNS RR rather than on US-MEX GOM PLL;
    - The reference years for biomass are now 2021 to 2016;
    - The biomass reference value is adjusted according to the composite trend in the US RR 66-144, CAN SWNS RR and US-MEX GOM PLL indices (which are respectively small, medium and large fish indices). For each index the mean for the most recent 3 years is calculated to determine the overall average. In the same an overall average is calculated for the reference period, and the ratio of the current to the reference period is used to scale the reference biomass value.

  - East
    - There are no index substitutions for the East, and the same approach is applied as described above using the W-MED LAR survey for the reference biomass value; the composite trend is based on the FR AER survey, JPN LL NEAtl2 and W-MED LAR survey.

- LW: no update to the mathematics; this has been retuned with updated package; the developer highlighted the tradeoff between stability and safety.

- PW: the PW CMP has been updated to incorporate East relative abundances in the measure of West relative abundance. The weight of East abundance in the West was up-weighted from the last meeting to reduce the immediate decline in West catch. See updated mathematical description for details.

- TC/AI: no update to mathematics; retuned with updated package.

- TN: no change; 10% allowable downward TAC change as requested from Panel 2.

- EA: updated mathematical description provided.

- BR: see SCRS doc (SCRS/2022/087 and SCRS/2022/088); changed control parameter values to get better performance; specifically smooths the catch trajectory by starting with a higher intended fishing mortality which is subsequently reduced over the first 5-10 years. Unintentionally upweighted CAN and US indices but this had low impact on CMP results. SCRS/2022/088 reports this impact of change in index weighting, though care should be taken not to read too much into this single comparison of a weighting change.

The floor was opened to CMP developers to discuss challenges and improvement strategies for continued development. Topics discussed included tactics for improving safety and stability, utilization of a phase-in approach, and that stakeholder feedback would be helpful in moving forward.

Candidate Management Procedures (CMPs), indicating in red where changes have occurred since the 2022 March Panel 2 meeting.

CMP	Indices used		Formulae for calculating TACs	References
	EAST	WEST		
EH	FR AER SUV2 JPN LL NEAtl2 W-MED LAR SUV	US RR 66-144, CAN SWNS RR US-MEX GOM PLL	TACs are product of stock-specific F0.1 estimates and estimate of CAN SWNS RR for the West and W-MED LAR SUV for the East.	SCRS/2020/144 SCRS/2021/122
AI	All	All	Artificial intelligence MP that fishes regional biomass at a fixed harvest rate.	SCRS/2021/028
BR	FR AER SUV2 W-MED LAR SUV MOR POR TRAP JPN LL NEAtl2	GOM LAR SUV US RR 66-144 US-MEX GOM PLL JPN LL West2 CAN SWNS RR	TACs set using a relative harvest rate for a reference year (2018) applied to the 2-year moving average of a combined master abundance index. In recent refinement, the weighting range across individual indices has been reduced, resulting in improved performance. More recently still, some limited time dependence has been introduced into the TAC formulae to allow for a smoother transition from current TACs to those to be generated in the initial years of the MP application.	SCRS/2021/121 SCRS/2021/152 SCRS/2022/082
EA	FR AER SUV2 W-MED LAR SUV MOR POR TRAP JPN LL NEAtl2	GOM LAR SUV JPN LL West2 US RR 66-144 US-MEX GOM PLL	Adjust TAC based on ratio of current and target abundance index.	SCRS/2021/032 SCRS/2021/P/046
LW	W-MED LAR SUV JPN LL NEAtl	GOM LAR SUV MEXUS_LL	TAC is adjusted based on comparing current relative harvest rate to reference period (2019) relative harvest rate.	SCRS/2021/127
~~**NC**~~	~~MOR POR TRAP~~	~~US-MEX GOM PLL~~	~~No longer supported~~	~~SCRS/2021/122~~
PW	JPN LL NEAtl2 W-MED LAR SUV	US-MEX GOM PLL GOM LAR SUV	TAC is adjusted based on comparing current relative harvest rate to reference period (2019) relative harvest rate.	SCRS/2021/155 SCRS/2022/078
TC	MOR POR TRAP JPN LL NEAtl2 W-MED LAR SUV GBYP AER SUV BAR	US RR 66-144	TAC is adjusted based on F/F_{MSY} and B/B_{MSY}.	SCRS/2020/150 SCRS/2020/165
TN	JPN LL NEAtl2	JPN LL West2	Both area TACs calculated based on their respective JPN_LL moving averages.	SCRS/2020/151 SCRS/2021/041 SCRS/2022/074

East indices: FR AER SUV2 – French aerial survey in the Mediterranean; JPN LL NEAtl2 – Japanese longline index in the Northeast Atlantic; W-MED LAR SUV – Larval survey in the western Mediterranean; MOR POR Trap – Moroccan-Portuguese trap index; GBYP AER SUV BAR – GBYP aerial survey in the Balearics.
West indices: US RR 66-144 – U.S. recreational rod & reel index for fish 66-144 cm; CAN SWNS RR – Canadian South-west Nova Scotia handline index; US-MEX GOM PLL – U.S. & Mexico combined longline index for the Gulf of Mexico; GOM LAR SUV – U.S. larval survey in the Gulf of Mexico; JPN LL West2 - Japanese longline index for the West Atlantic.

5. Path forward for the BFT MSE process

As discussed during the *2022 Eastern Atlantic and Mediterranean Bluefin Tuna Data Preparatory Meeting (including BFT MSE)* (18-26 April 2022) (Anon. 2022), the path forward for the MSE for the remainder of this year is outlined in Table 2.

The path forward for beyond the MP adoption involves outlining a number of key future steps that will include:

1. Routine application of the MP on pre-specified time frames (currently 2 years).

2. Specification of Exceptional Circumstances provisions that specify situations when the MP can be overridden, e.g. analysis of indicators, indices are outside ranges tested, inability to update an index for multiple years, natural disasters, or other situations, both foreseen or unforeseen, that preclude the implementation of the MP. As has been standard practice, the BFTSG will consider annual reviews of the abundance indices.

3. Less frequent "stock assessments" will occur on a predetermined interval as 'health' or 'status' checks and to inform reconditioning for MP review. The exact format and nature of these assessments are still to be determined, but they will not be critically necessary for setting TACs.

4. Management procedure review/revision and MSE reconditioning which includes refitting to new data, and incorporation of new information or new methodology such as ground-breaking science. This would also possibly be triggered by Exceptional Circumstances coming into play.

Possible timeframes for the above events could resemble Table 3 in Anon. 2022 with the exact timing of stock assessments and MSE reconditioning being a decision point for the Commission under advice of the SCRS.

6. Material for the Panel 2 meeting

6.1 Key decision points for Panel 2

a) Panel 2 Approval of operational management objectives and performance statistics;
b) Panel 2 Approval of the processes for development tuning and performance tuning;
c) BFTSG recommendations for narrowing (culling) of CMPs to retain a reduced subset for further consideration.

6.2 1-pager/4-pager/ summary BFT MSE process presentation

The 4-pager (**Appendix 6**) has been submitted to the *2022 Intersessional meeting of Panel 2* (9-10 May 2022) as an official document, and it is designed to facilitate the decision-making process. Based on the Group's discussions in this meeting (e.g., performance statistics weighting, phase-in period), a number of substantive revisions were made to the 2022 April BFTSG's version of the 4-pager (Anon. 2022, Appendix 7), so that the revised summary will be translated and transmitted to Panel 2 as soon as possible. The Atlantic Bluefin tuna MSE - Background & Structure document (PA2_24/2022) from the *2022 Intersessional meeting of Panel 2* (1-3 March 2022) remains valid, and will also be posted as a meeting document. A 1-pager will not be developed at this time.

Notably, the following main decision points for the *2022 Intersessional meeting of Panel 2* (9-10 May 2022) were identified, along with some other listed discussion points:

- Define operational management objectives.
- Approve a two-step process for CMP development and performance tuning processes.
- Approve a process for culling CMPs.
- Weighting of key performance statistics for this stage of the process (developmental tuning).

- Develop process for obtaining feedback from stakeholders.

Two presentations were developed for the *2022 Intersessional meeting of Panel 2* (9-10 May 2022), as discussed in Section 7.

6.3 CMP culling

The Group discussed the process for culling CMPs that do not meet satisficing ("must-meet") criteria. Satisficing criteria will be finalized with the identification of operational performance objectives. The Group noted that any CMP with LD*<0.4 at the percentile determined by Panel 2 will likely be eliminated in satisficing. In particular, as noted by Panel 2 in the report of the *2019 Intersessional meeting of Panel 2* (4-7 March 2019) "There should be no more than a 15% chance of the stock falling below B_{LIM} at any point during the 30-year evaluation period." Accordingly, developers were challenged to meet LD*15% ≥ 0.4, particularly if they do not already meet this criterion. CMP developers should consider whether their CMPs can be refined to meet satisficing criteria and, if not, these CMPs could be removed from further consideration either by developers or by Panel 2.

The Group discussed the potential need for another meeting with the Commission (between May and September 2022) to make additional decisions regarding the initial cull of CMPs to 2-4 remaining contenders. The need for an additional dedicated Panel 2 meeting in contrast to off-line communication and refining the decision-making process at the May meeting was considered. In lieu of another meeting later in the year and given extensive concerns over workload, the Group agreed to be as efficient as possible in providing Panel 2 with clear decision points, including a proposal to define a culling process, at the *2022 Intersessional meeting of Panel 2* (9-10 May 2022). Ambassador meetings scheduled for this year will be helpful to provide updates to Panel 2 members on progress and to answer questions. The Group also agreed that it would be beneficial to add a second day to the *2022 Forth Intersessional meeting of Panel 2 on BFT-MSE* (14 October 2022).

7. Communications/Ambassador material

7.1 Key plots and outputs

7.1.1 Performance Metrics

New performance metrics, including POF, PNOF, PGK, PNRK, AvC20, Br20 (see Anon. 2022, Appendix 6 TSD for descriptions), were added to the updated ABTMSE package (v. 7.6.4), and average relative harvest rate (U_{bar} = U/U_{MSY}) and the proportion of years that relative harvest rate exceeds 1 over 30 years (POF30) will be reflected in the updated Shiny apps. This will require all developers to recompile their CMP results to include these statistics in an updated package version.

For complete description of all existing performance statistics see Table 10.1 of TSD (Anon. 2022, Appendix 6).

7.1.2 Presentation Materials

The Group used the CMP developer's live-demonstration of the Shiny app to demonstrate the use of worm plots. Note that worm plots (or spaghetti plots) differ from median trajectory plots by presenting multiple iterations of time series of projections from a single OM (see "By Sim Proj" tab on Shiny app). The Group supported presentation of worm plots to Panel 2.

The Group also used this demonstration to illustrate median trajectories and worm plots by different recruitment scenarios. Specifically, the Group highlighted the "superman effect" (a current strong recruitment event in the East) and its associated effect on trajectories in recruitment scenario 1, with this to be contrasted with the lower recruitments estimated in Recruitment level 2 resulting in a decrease in near-term projected catches. The Group noted a key distinction between typical stock assessments and the MSE is that the MSE projections are for the purposes of testing and choosing CMPs. The ultimate TAC advice is determined by the values of the indices and the responsiveness of the chosen CMP to these indices once their values become available. Hence, the reason for multiple different recruitment scenarios is to ensure that the CMPs are tested to evaluate whether they are robust to these recruitment scenarios, in the event that they do occur. As an improved means of conveying this distinction, the Group supported separating CMP trajectories by recruitment scenario for presentation to Panel 2 (**Figure 5**), to demonstrate the robustness and adaptability of the CMPs to various plausible future conditions.

The Group further noted that the current 50-year projection period displayed in the Shiny app may be longer than necessary (or reliable), and hence proposed to trim projection period to 35 years into the future to cover period evaluated by key performance statistics, including the Overfished Trend (OFT).

7.1.3 Worm Plots

Worm plots are useful because they show trajectories that could happen and how those trajectories would vary with CMP (**Figure 5**). The plots clearly demonstrate the variability in TAC and biomass trajectories that could occur under a CMP and one or more operating models. While the worm plots are useful to help understand the CMP performance, questions were raised about how these plots would be used within the CMP culling process. It was noted that these plots will be most useful when the CMPs have been reduced to a smaller number. Once there are fewer CMPS to compare, it will be easier to meaningfully compare plots of their relative catch performance over time. Worm plots were critical for final MP selection at the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), where inter alia the MP selected had a median TAC trajectory near the middle of the range of worms.

The Group requested to view worm plots across recruitment scenarios for a single CMP. Recruitment scenario-specific worm plots showed that time series variability was largely a function of the recruitment dynamics. For appropriate interpretation of these worm plots, the Group noted that it was important to (1) view the plots through the lens of a two area / multi-stock dynamic, wherein western catch is also reflecting eastern stock biomass due to mixing, and (2) consider that the SSB worm plots were presented using dynamic SSB ratio rather than raw biomass; SSB worm plots presented using raw biomass would be more variable and better reflect observed catches, but use of dynamic SSB ratio provides a better reflection of resource status.

7.1.4 Quilt plots

Substantial discussion surrounded the quilt plots, as the Group anticipated that these plots would be a main tool for decision making. The Group highlighted that the CMPs are a “package deal,” meaning that the same CMP must be selected for both the East and West areas.

Quilt plots should be properly formatted to reflect the CMP ranking and satisficing criteria, including explicit consideration of color-scheme for performance statistics that fall below satisficing criteria; the selection of the performance metrics (columns) included in each plot; the redundancy, weight, and importance of each metric with respect to CMP selection; and the columns (performance metrics) which should be colored or not colored.

Quilt Coloring

The coloring of the quilt plot has also been of concern, and the Group welcomed proposals for new color schemes. The Group ultimately selected the following default color scheme:

- A single-color scheme where results are ordered with different shades of the same color was proposed. However, green was not supported as the color, because it comes with preconceived “good” performance. Blue or grey were considered acceptable alternatives.

The MSE consultant noted that alternate coloring options could be built into the Shiny app if desired.

Quilt performance metric correlations

The Group tasked a small group with refining the composition of the quilt plots to better reflect the stated management objectives (status, safety, stability, yield) and reduce redundancy of performance metrics within the plot. The Group agreed to include five different performance statistics in the primary quilt plot (**Figure 6**), namely PGK (mean), AvC10 (50%), AvC30 (50%), VarC (50%) and LD (15%). Three example weighting schemes for CMP ranking were put forward for presentation to Panel 2.

Weighting scheme	***Status PGK (mean)***	***Short term Yield AvC10 (50%)***	***Long term 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

A second quilt plot (**Figure 7**) was produced to display other important performance statistics, without concern for correlations among them: C1 (50%), AvC20 (50%), Br20 (50%), AvgBr (50%), Br30 (5%), LD (5%), LD (10%), POF (mean), PNRK (mean), OFT (P>0).

Quilt summary statistic

The Group noted that Panel 2 had requested that SCRS not make decisions on how CMPs should be ranked based upon their performance relative to management objectives or present a statistic that reflected those rankings, since decisions on how to prioritize management objectives is the purview of Panel 2. Nevertheless, the Group agreed that the presentation of results should be as clear as possible to facilitate the decisions of Panel 2. For this purpose, as noted previously, the Group decided to present to Panel 2 three example weighting schemes for illustration purposes. In that context, the Group agreed that it was appropriate to show a summary ranking statistic specific to each particular weighting scheme example. The MSE consultant agreed to add an option to view this statistic (TOTAL) on the Shiny App.

Since the second quilt plot (**Figure 7**) contains multiple correlated performance statistics (**Figure 8**), no summary statistic was included. CMPs were instead ordered according to that from the primary quilt plot (**Figure 6**).

Updated quilt plots can be found on the updated Shiny app (https://apps.bluematterscience.com/ABTMSE_Performance2/).

7.2 Develop presentation to Panel 2

The BFT Chairs solicited feedback from the BFTSG on a number of issues related to the presentation of material. The purpose of this solicitation was to gauge whether the initial material was likely to be of use in conveying key points and to identify key issues that may come up in Panel 2. The Chair specifically asked for perspectives on how the catch-stability trade off might be interpreted and for the merits of a 'phase-in period' to reduce the immediate large changes (especially downward) in TACs following CMP implementation. Some participants commented that stability in catches would be important and a desired feature of CMPs, provided it does not compromise other performance. In particular, a phase in period for TACs may be desirable if there is little loss of overall performance.

Presentation materials were prepared by the BFT Communications team and posted with meeting materials.

7.3 BFT-MSE Ambassadors programme

Ambassador sessions are tentatively scheduled for July and October 2022. It was noted that considerable time and effort goes into planning and convening the Ambassador sessions, so that it needs to be clear what the objectives are for the two different Ambassador series.

8. Update of trial specification document (TSD)

TSD was updated to reflect revised performance statistics at 2022 eastern Atlantic and Mediterranean bluefin tuna data preparatory meeting (including BFT MSE) (18-26 April 2022) (Anon. 2022, Appendix 6) and includes a description on how U_{MSY} is calculated. The description of indices was updated to reflect newly available data.

9. Adoption of the report

The Report of the 2022 Intersessional meeting of Bluefin Tuna MSE Technical Sub-Group was adopted. Drs Walter and Rodríguez-Marín and the SCRS Chair thanked the participants and the Secretariat for their hard work and collaboration to finalize the report on time. The meeting was adjourned.

References

Anonymous. 2022. Report of the 2022 eastern Atlantic and Mediterranean bluefin tuna data preparatory meeting (including BFT MSE) (Online, 18-26 April 2022).

Table 1. Average values across all OMs for each index (rows) for each of the 4 statistics for the time series of residuals of the fit to the data (Standard Deviation (ST.Dev), Autocorrelation (A.C.), P-value for the runs test (Runs p), and Length of longest run (where a run is a consecutive sequence of years on the same side of the "0 axis") in the last 10 years (Max run 10). The colors show good (green), acceptable (yellow), and poor (orange) diagnostic values.

East

	Strata	Area	Proposed	n	St.Dev	A.C.	Runs p	Max run 10	St.Err	Prop. Crs.
MED_LAR_SUV	7	MED	Yes	14	0.7	NA	NA	NA	0.19	0.63
FR_AER_SUV2	7	MED	Yes	10	0.54	NA	NA	NA	0.17	0.71
JPN_LL_NEAtl2	5	NATL	Yes	10	0.32	0.41	0.25	4.88	0.1	0.26
MOR_POR_TRAP	4	SATL	Yes	8	0.36	0.13	0.66	3.5	0.13	0.53

West

	Strata	Area	Proposed	n	St.Dev	A.C.	Runs p	Max run 10	St.Err	Prop. Crs.
GOM_LAR_SUV	1	GOM	Yes	40	0.53	-0.26	0.16	2.25	0.08	0.65
US_RR_66_144	2	WATL	Yes	25	0.52	0.55	0.2	5	0.1	0.34
CAN SWNS	2	WATL	Yes	24	0.36	0.7	0.01	7.31	0.07	0.19
CAN GSL	3	GSL	Yes	32	0.81	0.7	0	9.44	0.14	0.17
JPN_LL_West2	2	WATL	Yes	10	0.57	0.11	0.51	3.69	0.18	0.42
MEXUS_GOM_PLL	1	GOM	Yes	26	0.48	0.02	0.66	3.81	0.09	0.56
US_RR_177	2	WATL	Yes	27	0.74	0.77	0.02	6.31	0.14	0.15
US_RR_115_144	2	WATL	Yes	25	0.78	0.05	0.45	4.5	0.16	0.42
US_RR_66_114	2	WATL	Yes	25	0.63	0.55	0.1	5.38	0.13	0.3

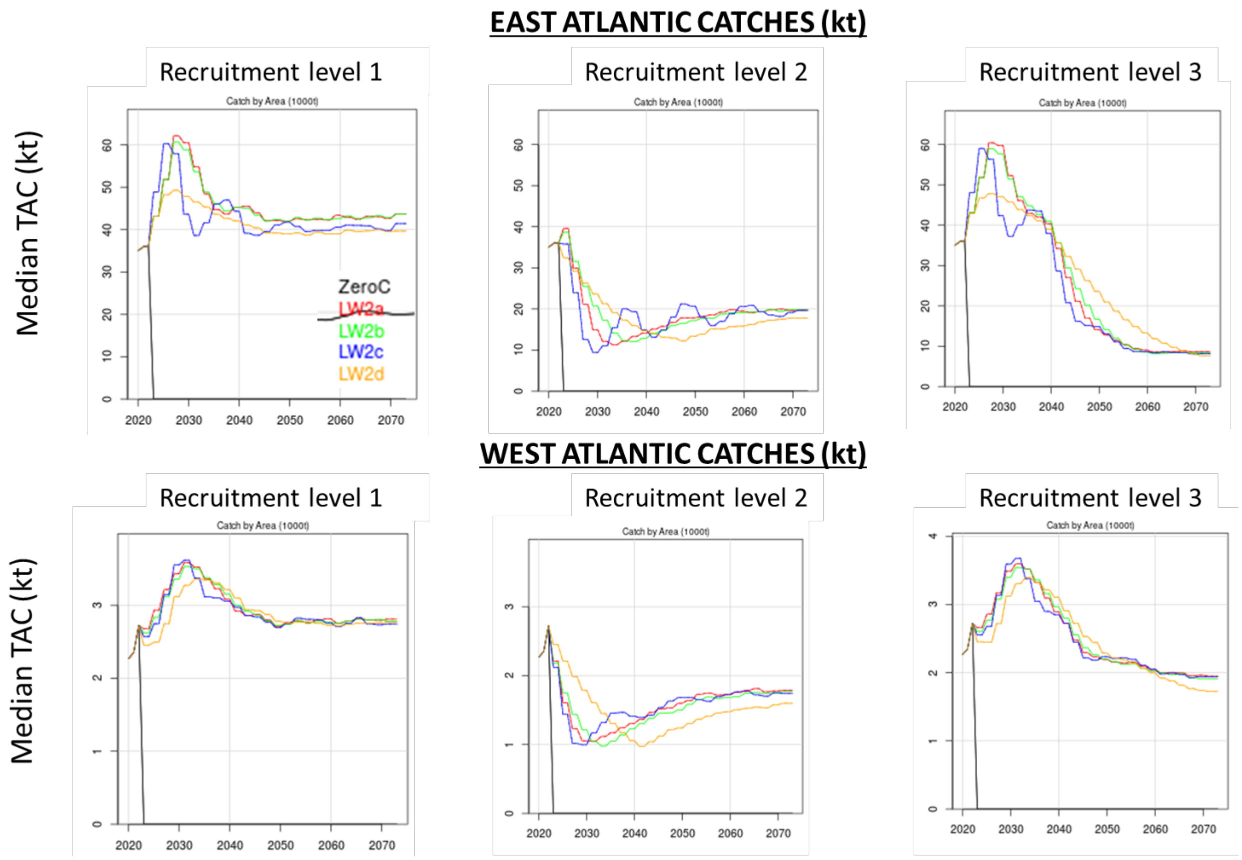

Figure 1. Median TAC timeseries plots separated by recruitment scenario for tuning level 2 for each TAC constraint (where a, b, c, and d signify +30/-20, +20/-20; no limits; and +20/-10, respectively).

East Area/Stock Metrics

SCENARIO	AvC10	AvC30	VarC	LD 15%
20%UP 30% DOWN	56.71	57.20	13.64	0.60
20%UP 20%DOWN	55.74	57.45	12.64	0.53
NO LIMIT	52.99	55.43	20.48	0.66
20%UP 10%DOWN	47.95	51.67	10.00	0.39

West Area/Stock Metrics

SCANARIO	AvC10	AvC30	VarC	LD15%
20%UP 30% DOWN	3.69	3.66	13.67	0.51
20%UP 20%DOWN	3.63	3.66	12.86	0.47
NO LIMIT	3.62	3.68	18.12	0.53
20%UP 10%DOWN	3.30	3.58	10.55	0.37

Figure 2. Abbreviated 'Quilt' plot for LW configured with alternate allowable TAC constraints.

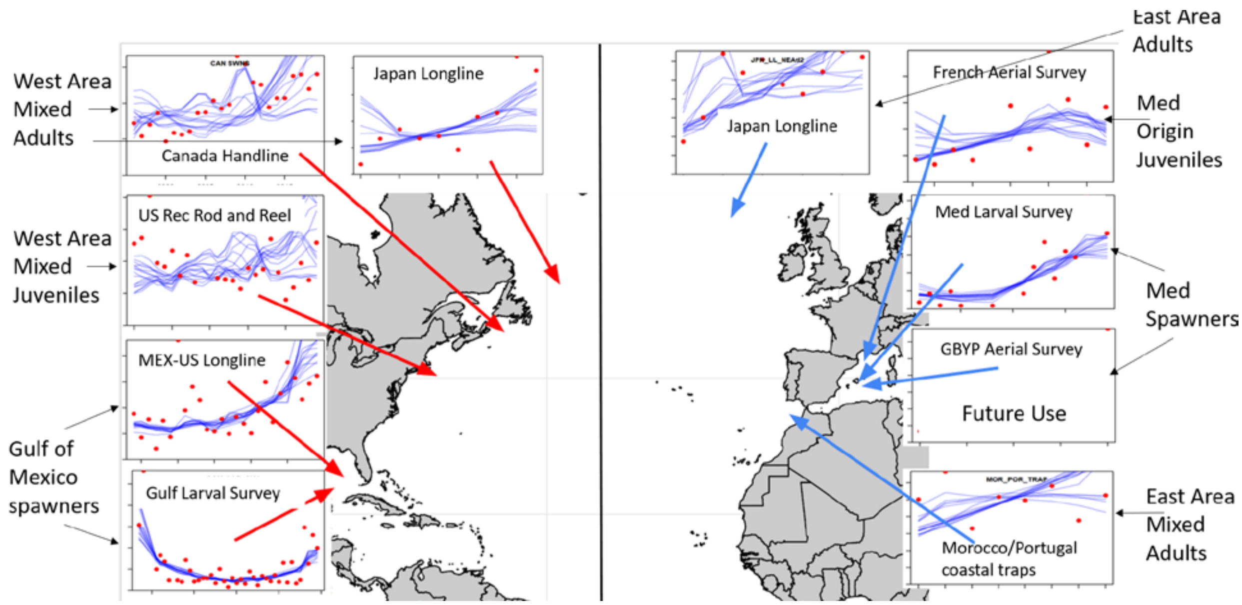

Figure 3. Fits (blue lines) to abundance indices (red points) in the OMs.

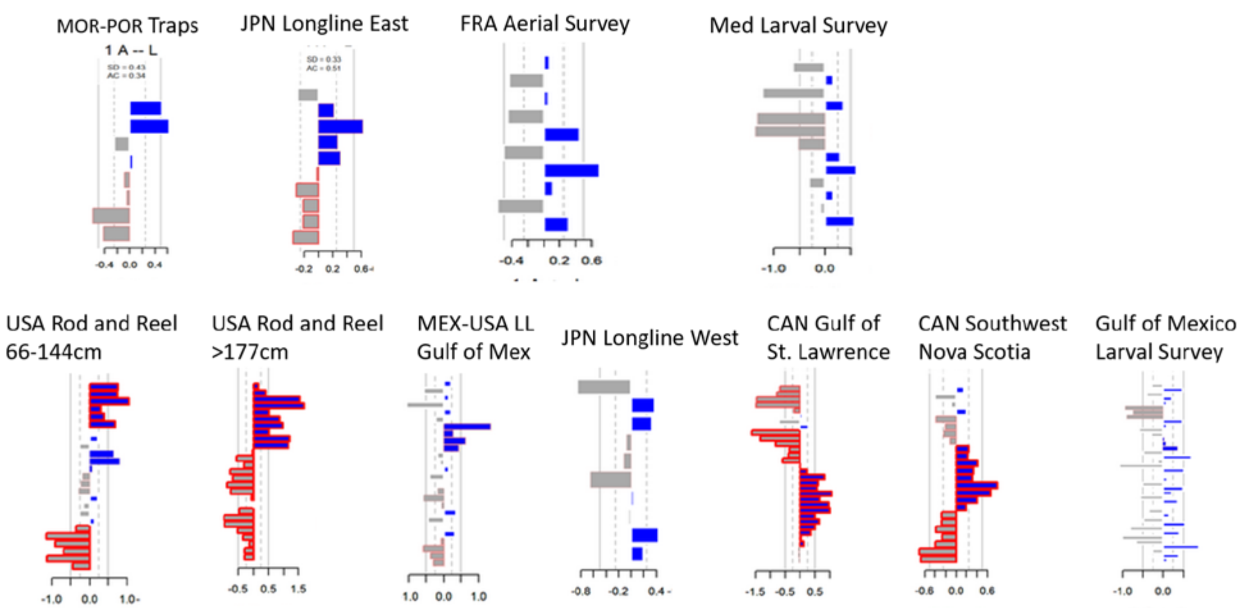

Figure 4. Example of index residuals in OMs.

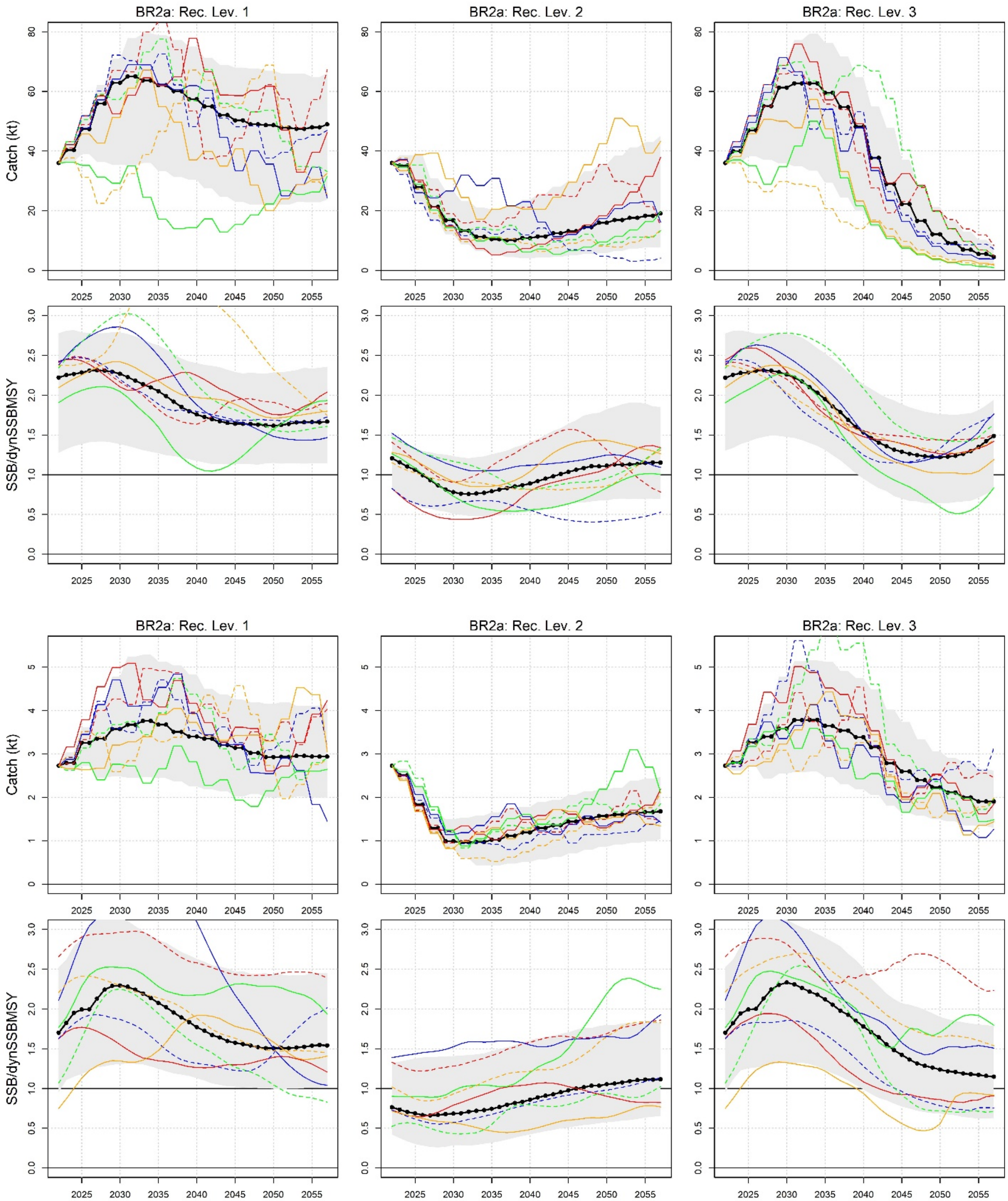

Figure 5. Worm plots by recruitment scenario for BR2a in the East (top) and West (bottom). Bolded black lines represent median trajectories and colored lines represent trajectories of specific iterations (color-grouped by OM). Shaded area represents 80% interquartile range of median "trajectory".

CMP	West					East					Tot
	PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	
BR2a	0.63	2.89	2.78	13.85	0.49	0.73	40.83	33.3	17.46	0.65	0.24
AI2a	0.61	2.93	2.67	16.38	0.54	0.69	42.05	38.26	16.53	0.63	0.29
TC2a	0.61	2.83	2.64	6.71	0.4	0.73	33.43	29.21	8.18	0.54	0.39
EA2a	0.62	3.42	2.74	15.87	0.36	0.71	38.77	29.65	15.45	0.48	0.43
EH2a	0.6	2.8	2.73	16.53	0.5	0.68	40.82	31.22	17.86	0.5	0.57
TN2a	0.64	3.42	2.59	18.64	0.28	0.71	42.21	29.79	16.02	0.39	0.62
PW2a	0.66	2.44	2.35	20.51	0.45	0.72	34.8	30.64	17.22	0.6	0.69
LW2a	0.6	2.65	2.54	15.61	0.51	0.72	34.25	30.09	17.15	0.6	0.7

Figure 6. Primary 'Quilt' plot for the West and East for tuning level 2 (i.e., Br30=1.25 for West and Br30=1.5 for East) using the default weighting scheme and ordered relative to the total column. Color scale represents relative performance from dark (best) to light (worst) within a column. This plot shows the top 5 performance statistics chosen on the basis of removing duplicative statistics and focusing on the four operational performance statistics of safety, status, stability and yield. The five statistics and associated percentiles are PGK: probability of being in the Kobe green quadrant (i.e., SSB>SSBMSY and U<UMSY) in year 30; AvC10: average catch (kilotons, kt) over years 1-10 (50%tile); AvC30: average catch (kt) over years 1-30 (50%tile); VarC: Variation in catch (kt) between 2-year management cycles (50%tile); LD*(15%): 15%tile of lowest depletion over years 11-30;. Insert weighting/ordering description. PGK is not weighted in the scoring as all CMPs are tuned to achieve similar biomass status. Ordering is achieved by scaling each column according to its minimum and maximum, within a column, giving a rank order from 0(best) to 1 (worst), weighting columns according to the default weighting, obtaining an average for West and East and then taking the average across East and West (Tot).

East

CMP	C1 (50%)	AvC20 (50%)	AvgBr (50%)	Br20 (50%)	Br30 (5%)	LD (5%)	LD (10%)	POF (Mean)	PNRK (Mean)	OFT (P>0)	Tot
BR2a	38.19	34.6	1.53	1.38	0.71	0.48	0.58	0.06	0.98	0.95	0.23
AI2a	33.43	40.99	1.54	1.49	0.44	0.4	0.53	0.12	0.89	0.85	0.53
TC2a	37.26	28.84	1.63	1.58	0.52	0.37	0.47	0.07	0.94	0.9	0.37
EA2a	43.2	29.99	1.56	1.47	0.43	0.31	0.41	0.08	0.93	0.92	0.45
EH2a	43.2	30.74	1.51	1.43	0.45	0.33	0.42	0.12	0.91	0.91	0.55
TN2a	39.98	27.75	1.55	1.44	0.31	0.21	0.3	0.08	0.92	0.92	0.6
PW2a	43.2	30.3	1.57	1.49	0.56	0.44	0.53	0.08	0.95	0.92	0.33
LW2a	43.2	29.92	1.57	1.51	0.56	0.44	0.54	0.08	0.95	0.92	0.29

West

CMP	C1 (50%)	AvC20 (50%)	AvgBr (50%)	Br20 (50%)	Br30 (5%)	LD (5%)	LD (10%)	POF (Mean)	PNRK (Mean)	OFT (P>0)	Tot
BR2a	2.68	2.84	1.39	1.29	0.56	0.29	0.4	0.2	0.86	0.87	0.34
AI2a	2.82	2.73	1.41	1.34	0.66	0.33	0.43	0.24	0.89	0.89	0.2
TC2a	2.68	2.59	1.41	1.41	0.35	0.18	0.27	0.28	0.78	0.86	0.45
EA2a	2.83	2.66	1.34	1.21	0.32	0.18	0.27	0.19	0.85	0.88	0.47
EH2a	2.21	2.78	1.39	1.29	0.54	0.31	0.41	0.24	0.82	0.86	0.43
TN2a	3.27	2.46	1.33	1.24	0.1	0.05	0.17	0.16	0.86	0.9	0.52
PW2a	2.36	2.26	1.29	1.16	0.48	0.28	0.37	0.11	0.94	0.94	0.44
LW2a	2.51	2.55	1.41	1.31	0.5	0.29	0.38	0.25	0.81	0.84	0.46

Figure 7. A second 'Quilt' plot depicting C1: catch in the first year of CMP application (50%), AvC20: average catch (kilotons, kt) over years 11-20 (50%tile), Br20: Depletion (spawning biomass relative to dynamic SSB_{MSY}) in projection year 20 (50%), AvgBr: spawning biomass relative to dynamic SSB_{MSY} over projection years 11-30 (50%), LD* (5%): 5%tile of lowest depletion over years 11-30; LD* (10%) 10%tile of lowest depletion over years 11-30, Br30: Depletion (spawning biomass relative to dynamic SSB_{MSY}) in projection year 30 (5%); POF: Probability of Overfishing ($U > U_{MSY}$) after 30 projected years (mean), PNRK: Probability of not Red Kobe ($SSB > SSB_{MSY}$ or $U < U_{MSY}$) after 30 projected years (mean), OFT: Overfished trend, SSB trend over projection years 31 - 35 when Br30 < 1. CMPs are ordered according to rank order in Primary 'Quilt' plot (**Figure 6**). The 'a' for each CMP refers to the +20/-30 stability tuning.

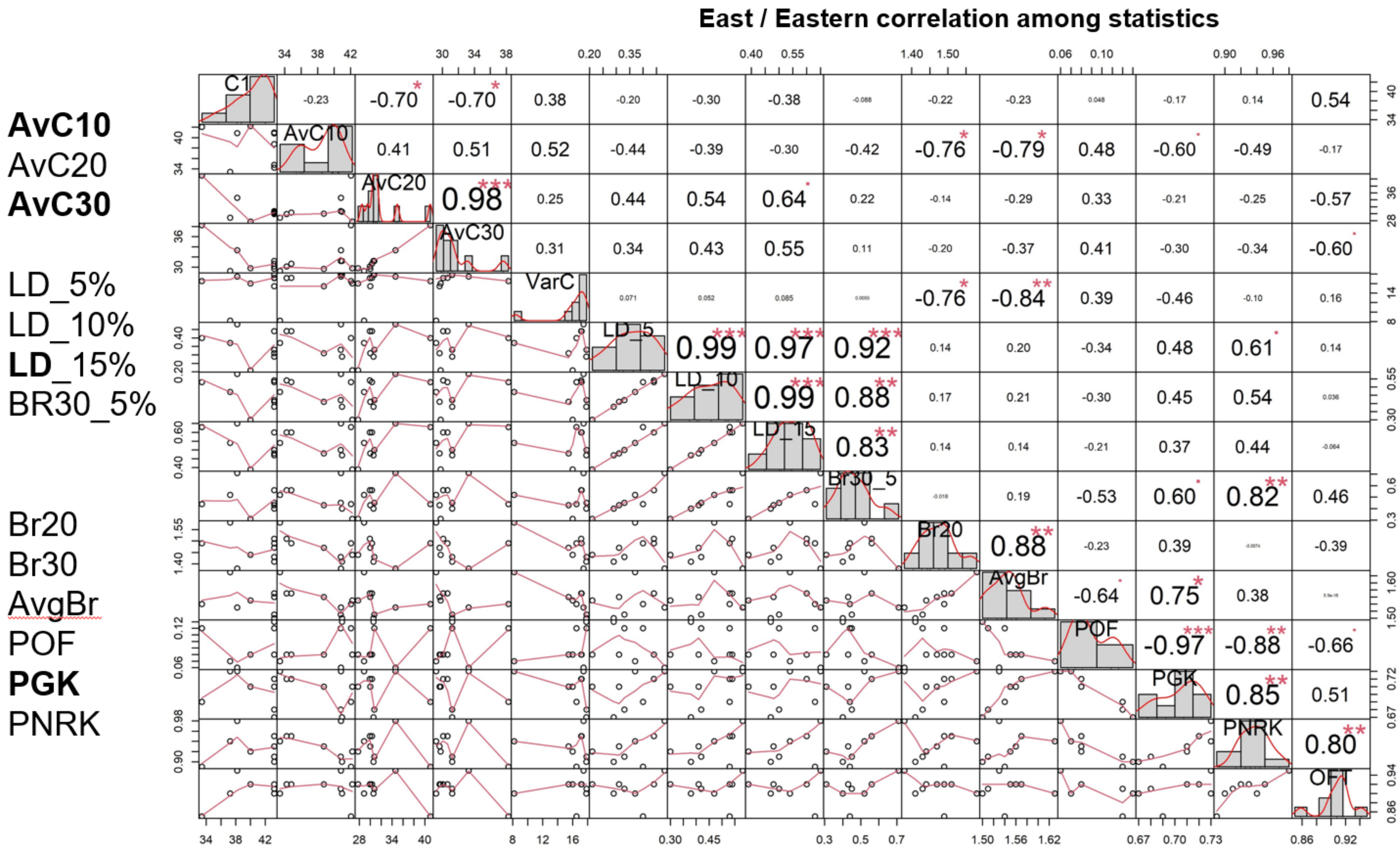

Figure 8. Correlation among performance metrics.

Appendix 1

Agenda

1. Opening, adoption of agenda and meeting arrangements and assignment of rapporteurs

2. Summary of developments on ABFT-MSE from the BFTSG

    2.1 Update
    2.2 Update from MSE Consultant
    2.3 MSE Versus Best Assessment Paradigm

3. Unfinished work from BFTSG meeting

    3.1 CMP Tuning level
    3.2 Effect of Alternate Limits on Allowable TAC Change
    3.3 Index Presentation
    3.4 Exceptional Circumstances
    3.5 Sensitivity tests to weighting schemes and further robustness tests

4. Additional changes to CMPs

5. Path forward for the BFT MSE process

6. Material for the Panel 2 meeting

    6.1 Key decision points for Panel 2
    6.2 1-pager/4-pager/ summary BFT MSE process presentation
    6.3 CMP Culling

7. Communications/Ambassador material

    7.1 Key plots and outputs

        7.1.1 Performance Metrics
        7.1.2 Presentation Materials
        7.1.3 Worm Plots
        7.1.4 Quilt Plots

    7.2 Develop presentation to Panel 2
    7.3 ABFT-MSE Ambassadors programme

8. Update of trial specification document (TSD)

9. Adoption of the report and closure

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Appendix 3

List of Papers and Presentations

Number	Title	Authors
SCRS/2022/087	Refinements of the BR CMP as at May 2022	Butterworth D.S., and Rademeyer R.A.
SCRS/2022/088	Update of BR CMP to include intended indices weights	Butterworth D.S., and Rademeyer R.A.

SCRS/P/2022/021	Updated CMP results	Carruthers T. R.

Appendix 4

SCRS Document and Presentations Abstracts as provided by the authors

SCRS/2022/087 **-** The results of refinements of the control parameter values of the version of the BR CMP presented at the April 2022 BFT WG meeting are reported. These refinements largely achieve their objectives of getting median C1values closer to the 2022 TACs and of smoothing TAC trajectories.

SCRS/2022/088 **-** Results are provided to compare the BR results in Butterworth and Rademeyer (2022), for which the abundance indices were inadvertently mis-weighted, with those when the intended weighting is used. Broadly speaking, the corrected results hardly differ, except for an earlier drop in the median TAC for the West area during the 2030s.

SCRS/P/2022/021 **-** This presentation contains the update of CMP results (TC, BR, AI, PW, LW, FZ, EA, EH), by incorporating new performance metrics requested by the BFT SG in May 2022 in ABFT-MSE ver 7.6.4. New performance metrics are POF: probability of overfishing ($U > U_{MSY}$), PNOF: probability of not overfishing ($U < U_{MSY}$), PGK: probability green Kobe ($U < U_{MSY}$ AND $B > B_{MSY}$), PNRK: probability not red Kobe ($U < U_{MSY}$ OR $B > B_{MSY}$), AvC20: Average catches over first 20 projection years, Br20: B / B_{MSY} in projection year 20. All CMPs run at least 2a (1.25 **-** 1.50, max 30% down, max 20% up) are presented.

Appendix 5

Mathematical descriptions for CMPs

BR CMPs (UTC)

Authors: Butterworth and Rademeyer
Documents: SCRS/2021/152, SCRS/2022/082

The CMP is empirical, based on inputs related to abundance indices which are first standardised for magnitude, then aggregated by way of a weighted average of all indices available for the East and the West areas, and finally smoothed over years to reduce observation error variability effects. TACs are then set based on the concept of taking a fixed proportion of the abundance present, as indicated by these aggregated and smoothed abundance indices. The details are set out below.

Aggregate abundance indices

An aggregate abundance index is developed for each of the East and the West areas by first standardising each index available for that area to an average value of 1 over the past years for which the index appeared reasonably stable[1], and then taking a weighted average of the results for each index, where the weight is inversely proportional to the variance of the residuals used to generate future values of that index in the future modified to take into account the loss of information content as a result of autocorrelation. The mathematical details are as follows.

$J_y^{E/W}$ is an average index over *n* series (*n*=5 for the East area and *n*=5 for the West area) [2]:

$$J_y^{E/W} = \frac{\sum_i^n w_i \times I_y^{i*}}{\sum_i^n w_i} \tag{A1}$$

Where

$w_i = \frac{1}{(\sigma^i)^2}$ for the west and i.e. inverse effective variance weighting)

$w_i = \frac{1}{\sqrt{\sigma^i}}$ for the east (i.e. inverse effective variance to the power ¼ weighting).

and where the standardised index for each index series (*i*) is:

$$I_y^{i*} = {I_y^i}\Big/{Average\ of\ historical\ I_y^i}$$
(A2)

σ^i is computed as

$$\sigma^i = \frac{SD^i}{1-AC^i}$$

where SD^i is the standard deviation of the residuals in log space and AC^i is their autocorrelation, averaged over the OMs, as used for generating future pseudo-data. Table 1 lists these values for σ^i.

2017 is used for the "average of historical I_y^i".

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[1] These years are for the Eastern indices: 2014-2017 for FR_AER_SUV2, 2012-2016 for MED_LAR_SUV, 2015-2018 for GBYP_AER_SUV_BAR, 2012-2018 for MOR_POR_TRAP and 2012-2019 for JPN_LL_NEAtl2; and for the Western indices: 2006-2017 for GOM_LAR_SURV, 2006-2018 for all US_RR and MEXUS_GOM_PLL indices, 2010-2019 for JPN_LL_West2 and 2006-2017 for CAN_SWNS.
[2] For the aerial surveys, there is no value for 2013, (French) and 2018 (Mediterranean). These years were omitted from this averaging where relevant. Note also that the GBYP aerial survey has not been included at this stage.

The actual index used in the CMPs, $J_{av,y}^{E/W}$, is the average over the last three years for which data would be available at the time the MP would be applied, hence:

$$J_{av,y}^{E/W} = \frac{1}{3}\left(J_{y}^{E/W} + J_{y-1}^{E/W} + J_{y-2}^{E/W}\right)$$

(A3)

where the $J_{av,y}^{E/W}$ applies either to the East or to the West area.

CMP specifications

The BR Fixed Proportion CMPs tested set the TAC every second year simply as a multiple of the J_{av} value for the area at the time (see Figure 1), but subject to the change in the TAC for each area being restricted to a maximum of 20% (up or down). The formulae are given below.

For the East area:

$$TAC_{E,y} = \begin{cases} \left(\frac{TAC_{E,2020}}{J_{E,2017}}\right) \cdot \alpha \cdot J_{av,y-2}^{E} & \text{for } J_{av,y}^{E} \geq T^{E} \\ \left(\frac{TAC_{E,2020}}{J_{E,2017}}\right) \cdot \alpha \cdot \frac{\left(J_{av,y-2}^{E}\right)^2}{T^{E}} & \text{for } J_{av,y}^{E} < T^{E} \end{cases}$$

(A4a)

For the West area:

$$TAC_{W,y} = \begin{cases} \left(\frac{TAC_{W,2020}}{J_{W,2017}}\right) \cdot \beta \cdot J_{av,y-2}^{W} & \text{for } J_{av,y}^{W} \geq T^{W} \\ \left(\frac{TAC_{W,2020}}{J_{W,2017}}\right) \cdot \beta \cdot \frac{\left(J_{av,y-2}^{W}\right)^2}{T^{W}} & \text{for } J_{av,y}^{W} < T^{W} \end{cases}$$

(A4b)

Note that in equation (A4a), setting $\alpha = 1$ will amount to keeping the TAC the same as for 2020 until the abundance indices change. If α or $\beta > 1$ harvesting will be more intensive than at present, and for α or $\beta < 1$ it will be less intensive.

Below T, the law is parabolic rather than linear at low abundance (i.e. below some threshold, so as to reduce the proportion taken by the fishery as abundance drops); this is to better enable resource recovery in the event of unintended depletion of the stock. For the results presented here, the choices $T^{E} = 1$ and $T^{W} = 1$ have been made.

Constraints on the extent of TAC increase and decrease

Maximum increase (note that this section has been changed from earlier versions):

For the West area, the maximum increase is fixed at 20%:
If $TAC_{i,y} \geq 1.2 * TAC_{i,y-1}$ then

$$TAC_{W,y} = 1.2 * TAC_{W,y-1} \quad \text{(A5a)}$$

For the East area, unless otherwise specified, the maximum increase allowed from one TAC to the next is a function of the immediate past trend in the indices, s_{y}^{E}:

$$maxincr = \begin{cases} 0 & s_{y}^{E} \leq 0 \\ \text{linear btw 0 and 0.2} & 0 < s_{y}^{E} < 0.1 \\ 0.2 & 0.1 \leq s_{y}^{E} \end{cases} \quad \text{(A5b)}$$

where

s_{y}^{E} is a measure of the immediate past trend in the average index J_{y}^{E} (equation A1), computed by linearly regressing lnJ_{y}^{E} *vs* year *y'* for y'=y-6 to y'=y-2 to yield the regression slope s_{y}^{E}.

If $TAC_{E,y} \geq (1 + maxincr) * TAC_{i,y-1}$

then $TAC_{i,y} = (1 + maxincr) * TAC_{i,y-1}$ (A5c)

Maximum decrease:

If $TAC_{i,y} \leq 0.8 * TAC_{i,y-1}$

then $TAC_{i,y} = (1 - maxdecr) * TAC_{i,y-1}$ (A6)

where

$$maxdecr = \begin{cases} 0.2 & J^i_{av,y-2} \geq J_{i,2017} \\ \text{linear btw 0.2 and } D & 0.5J_{i,2017} < J^i_{av,y-2} < J_{i,2017} \\ D & J^i_{av,y-2} \leq 0.5J_{i,2017} \end{cases} \quad \text{(A7)}$$

where D= 0.3 in implementations.

Maximum TAC

A cap on the maximum allowable TAC is set. This can potentially improve performance, particularly in the event of a shift to a lower productivity regime. By ensuring that TACs have not risen so high that they cannot be reduced sufficiently rapidly following such an event to adjust for the lower resource productivity. In investigations to date, this has been found to be useful to implement for the East area, where TACs can otherwise rise to in excess of 70 kt. The cap for the East area is set at 55 000t.

Table A1: σ^i (averaged over the OMs) values used in weighting when averaging over the indices to provide composite indices for the East and the West areas (see following equation A2).

EAST Index name	σ^i	w_i $(=\frac{1}{(\sigma^i)^2})$	WEST Index name	σ^i	w_i $(=\frac{1}{\sqrt{\sigma^i}})$
FR_AER_SUV2	0.49	1.43	GOM_LAR_SUV	1.48	0.46
MED_LAR_SUV	0.57	1.33	US_RR_66_144	0.57	3.12
GBYP_AER_SUV_BAR	0.99	1.01	MEXUS_GOM_PLL2	0.88	1.28
MOR_POR_TRAP	1.37	0.85	JPN_LL_West2	1.09	0.84
JPN_LL_NEAtl2	3.49	0.54	CAN_SWNS	0.36	7.57

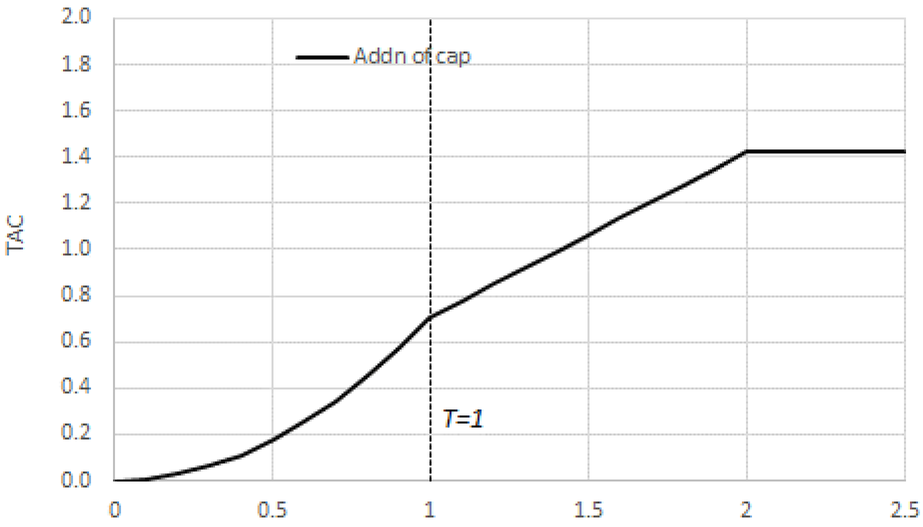

Figure A1. Illustrative relationship (the "catch control law") of *TAC* against $J_{av,y}$ for the BR CMPs, which includes the parabolic decrease below T and the capping of the TAC so as not to exceed some maximum value.

EA_x CMPs (EU)

Authors: Andonegi, Rueda, Rouyer, Gordoa, Arrizabalaga, and Rodriguez-Marín
Documents: SCRS/2021/032

EA_x CMPs are empirical, based on inputs related to abundance indices which are first standardized for magnitude, then aggregated by way of a weighted average of all indices available for the East and the West areas. TACs are then set based on the concept of taking a fixed proportion of the abundance present, as indicated by these aggregated abundance indices.

Data sets

Four indices have been selected for each stock, aiming at best reflecting the dynamics of each of the stocks. For the East:

- French Aerial Survey (1. FR_AER_SUV2)
- Mediterranean Larval (2. MED_LAR_SUV)
- Moroccan-Portuguese Trap (5. MOR_POR_TRAP)
- North East Atlantic Japanese Longline (6. JPN_LL_NEAtl2)

And for the West:

- Gulf of Mexico Larval (3.GOM_LAR_SUV)
- West Japanese Longline (10.JPN_LL_West2)
- US Rod & Reel 66-144 (13.US_RR_66_144)
- USA-MEX Long Line standardized spatial (14.MEXUS_GOM_PLL)

Status Estimator: the aggregated abundance index

An aggregated abundance index *Irat*, computed as the weighted mean of all indices *n* (*n*=4 for both areas), is developed for each of the East and the West areas. It is calculated as follows:

$$Irat_y = \sum_i^n w_i * I_{i,y}^* / Targ$$

where w_i are the weights used for each index *i*. The weight of each of the indices is inversely proportional to the variance of the residuals being calculated as:

$$w_i = 1/\sigma_i^2$$

and $\sigma_i = SD_i/(1 - AC_i)$

where SD is the standard deviation and AC the lag 1 autocorrelation of residuals.

Targ is the value of the target Br30 for each specific tuning level.

The standardised index for each index series *i* is:

$$I_{i,y}^* = {}^{I_{i,y}}\!\Big/_{Average\ of\ historical\ I_{i,t-4}}$$

where *t* is the last year of the historical data (2019).

The actual index used for both the East and the West area, is the average over the last three years for which data would be available at the time the MP would be applied:

$$Irat_{av,y} = {}^{1}\!/_{3}\ (Irat_y + Irat_{y-1} + Irat_{y-2})$$

The Harvest Control Rule (HRC)

The EAx cMPs tested set the TAC every second year subject to a varying percentage of maximum up and down TAC change (Delta up and Delta down) for each area as follows:

$$TAC_y = \begin{cases} TAC_{y-2} * (1\text{–}\,\mathrm{Deltadown}) \quad if\ Irat < (1 - Deltadown) \\ TAC_{y-2} * (1 + \mathrm{Deltaup}) \quad if\ Irat > (1 + Deltaup) \\ TAC_{y-2} * \mathrm{Irat} \quad if\ Irat \geq (1 - \mathrm{Deltadown})\mathrm{and}\ Irat \leq (1 + \mathrm{Deltaup}) \end{cases}$$

Table 1. Indices used to estimate the aggregated index for each ABF area, together with the σ and w values.

	Sigma (σ)	Weight (w)
EAST		
FR_AER_SUV2	0.5	4.0
MED_LAR_SUR	1.03	0.95
MOR_POR_TRAP	0.53	3.59
JPN_LL_NEAtl2	0.62	2.62
WEST		
GOM_LAR_SUR	0.54	3.43
US_RR_66-144	1.16	0.744
MEXUS_GOM_PLL	0.52	3.68
JPN_LL_West2	0.57	3.045

TN_x CMPs (JPN)

Authors: Tsukahara and Nakatsuka
Documents: SCRS/2021/041, SCRS/2022/074

Used index:
(West TAC) JPN_LL_West2
(East TAC) JPN_LL_NEAtl2

Tuning parameters (Those must be positive values.)
k_1_E: adjustment value for increase of TAC in eastern Atlantic
k_2_E: adjustment value for decrease of TAC in eastern Atlantic
k_1_W: adjustment value for increase of TAC in western Atlantic
k_2_W: adjustment value for decrease of TAC in western Atlantic

For the sake of simplicity, the formulation is described without suffix of area in the index and the tuning parameter. The respective index rate for JPN_LL_West2 and JPN_LL_NEAtl2 are calculated by bellow:

$$Index\ rate = \frac{mean(Index[y-2{:}y-4])}{mean(Index[y-5{:}y-7])} \tag{1}$$

, then New TAC is calculated by the trend of index. When index shows increase trend, which mean index rate are 1 and over, new TAC is calculated by below:

$$New\ TAC = Current\ TAC * \min(\{1 + max\ change\ rate\ of\ TAC\}, \{1 + (Index\ ratio - 1) * k_1\}\ ))$$

On the other hand, when index shows decrease trend, which mean index rate is less than 1, new TAC is calculated by below:

$$New\ TAC = Current\ TAC * \max\left(\{1 - max\ change\ rate\ of\ TAC\}, \left\{1 - \frac{(1 - Index\ ratio)}{k_2}\right\}\right))$$

When k_1 is set to higher than 1, the increase of TAC become bigger than multiplication by original index rate, and vice versa. When k_2 is set to higher than 1, the decrease of TAC become smaller than original multiplication by original index rate. Therefore, higher values of parameters on both, k_1 and k_2, lead to more aggressive CMPs, while lower values of parameters make CMP precautionary. There is a possibility to have negative TAC value when adjustment with small k_2 value, although maximum change rate of TAC prevents TAC from getting the negative values.

LW & PW CMPs (NOAA)

Authors: Peterson, Lauretta, and Walter
Documents: SCRS/2021/155, SCRS/2022/078

LW and PW are based on constant harvest rate (ConstU) strategies for both the east and west stocks. In the MSE, the indices of abundance are assumed to be proportional to vulnerable biomass, i.e. the base parameterization assumes time-invariant catchability. Therefore, a relative harvest rate for each stock can be calculated as follows:

$$harvest\ rate = catch/abundance$$

$$relative\ abundance = catchability * abundance$$

$$relative\ harvest\ rate = \frac{catch}{relative\ abundance}$$

Under this approach, management procedures for east and west stocks were designed to apply a constant harvest rate strategy tracking catches and indices of relative abundance.

$$U_{target_i} = \frac{C_{target}}{I_{target_i}} \cdot x$$

$$C_{target} = \overline{C_{target\_years}}\ ; I_{target} = \overline{I_{target\_years}}$$

where
U=relative harvest rate
C=catch in mt
I=averaged relative abundance index for index i
t=model year, and
x=constant multiplier
target years = 52:54 for LW & 53:55 for PW

$$U_{current_i} = \frac{C_{current}}{I_{current_i}}$$

$$C_{current} = \overline{C_{t-2:t-0}}; I_{current_i} = \overline{I_{t-2:t-0}}$$

$$\Delta_{ratio} = FUN_i\left(\frac{U_{target_i}}{U_{current_i}}\right)$$

where *FUN* is a function to summarize across ratios for each index (e.g., mean or minimum).

$$TAC_{t+1:t+3} = \Delta_{ratio} \cdot TAC_{t-2:t-0}$$

where
TAC=total allowable catch limit

Subsequent restrictions (e.g., TAC caps, allowable annual % TAC change) were implemented, as necessary.

LW Particulars

For the West stock, the GOM_LAR_SUV and MexUS_GOM_PLL indices are used, and for the East stock, the MED_LAR_SUV and JPN_LL_NEAtl2 indices are used. FUN used to summarize across *Δratio*s for each index was mean.

The notable distinction of the LW and PW cMPs are that each accounts for eastern biomass in the West. LW replaces calculation of $I_{current}$ and I_{target} with

$$I_{target_{west}} = \frac{I_{west\ i,t50:t52}}{I_{west_{i,t1:t52}}} + \frac{I_{east_{i,t50:t52}}}{I_{east_{i,t1:t52}}}$$

$$I_{current_{west}} = \frac{I_{west_{i,t-2:t-0}}}{I_{west_{i,t0:t}}} + \frac{I_{east\ i,t50:t52}}{I_{east_{i,t0:t}}}$$

PW Particulars

For the West stock, the GOM_LAR_SUV and MexUS_GOM_PLL indices are used, and for the East stock, the MED_LAR_SUV and JPN_LL_NEAtl2 indices are used. FUN used to summarize across *Δratio*s for each index was mean.

The way in which PW accounts for eastern biomass in the West is by adjusting western $I_{current}$ by eastern relative abundance ratio (I_{E_ratio}):

$$I_{E\_ratio} = \begin{cases} \frac{I_{current_{east}}}{I_{target_{east}}} & if\ \frac{I_{current_{east}}}{I_{target_{east}}} \geq 1 \\ 1 & if\ \frac{I_{current_{east}}}{I_{target_{east}}} < 1 \end{cases}$$

$$Multiplier_E = \left(\left(I_{E_{ratio}} - 1\right) * m\right) + 1$$

where
m =1.2.

Current western relative exploitation rate was then calculated by

$$U_{current_{west}} = \frac{C_{current_{west}}}{I_{current_{west}} \times Multiplier_E}$$

FZ, FP, FV, FX, FU, FY, NC CMPs (DFO)

Authors: Hanke and Duprey
Documents: SCRS/2021/156

An $F_{0.1}$ based cMP

This cMP sets the TAC using an estimate of $F_{0.1}$ and the current abundance of the stock. The $F_{0.1}$ calculation depends on choosing 3 indicators from each management area that index the relative abundance of young, middle aged and older stock components. Prior to use, these indicators are subjected to a range normalization and the average value for the most recent 3 years is determined:

$$I'_{sm} = (I_{sm} - \min(I_{sm}))/(\max(I_{sm}) - \min(I_{sm}))$$

$$I'_{md} = (I_{md} - \min(I_{md}))/(\max(I_{md}) - \min(I_{md}))$$

$$I'_{lg} = \left(I_{lg} - \min\left(I_{lg}\right)\right)/(\max\left(I_{lg}\right) - \min\left(I_{lg}\right))$$

$$\overline{I'_{sm}} = \frac{1}{3}\sum_{N-2}^{N} I'_{sm}$$

$$\overline{I'_{md}} = \frac{1}{3}\sum_{N-2}^{N} I'_{md}$$

$$\overline{I'_{lg}} = \frac{1}{3}\sum_{N-2}^{N} I'_{lg}$$

$$I_{tot} = \overline{I'_{sm}} + \overline{I'_{md}} + \overline{I'_{lg}}$$

$F_{0.1}$ is a calculation based on a yield-per-recruit analysis from *fishmethods* (Nelson, 2019) that follows the modified Thompson-Bell algorithm :

$$Z_a = M_i + PR_a * F_a$$

$$N_{a+1} = N_a * e^{-Z_a}$$

$$\overline{N}_a = (1 - e^{-Z_a}) * \frac{N_a}{Z_a}$$

$$\overline{N}_{a+} = \frac{N_{a+}}{Z_{a+}}$$

$$C_a = (N_a - N_{a+1}) * \frac{PR_a * F_a}{Z_a}$$

$$Y_a = \overline{W}_a C_a = PR_a * \overline{F}_a B_a$$

where the ages *a* for each management area are as defined in the 2015 VPA,

Y_a, C_a, N_a, B_a = Yield, Catch, Numbers and Biomass at age respectively,

W_a = Weight at age is from the 2015 VPA for the west and 2017 VPA for the east,

F_a = Fishing mortality at age,

M_a = Natural mortality at age scaled to the Lorenzen function (Walter et. al. 2018),

Z_a= Total mortality at age (F_a+M_a),

$PRe_{1:10}$ = the partial recruitment vector applied to fishing mortality (F) to obtain partial F-at-age is calculated from the east MP indicators,

$PRw_{1:16}$ = the partial recruitment vector applied to fishing mortality (F) to obtain partial F-at-age is calculated from the east MP indicators,

q = an index and stock specific tuning parameter.

East values

$$a = \{1,2,3,4,5,6,7,8,9,10)\}$$

$$W_{1:10} = \{3.0, 10.0, 19.0, 35.0, 50.0, 69.0, 90.0, 113.0, 138.0, 205.0)\}$$

$$M_{1:10} = \{0.40, 0.33, 0.27, 0.23, 0.20, 0.18, 0.16, 0.14, 0.13, 0.12\}$$

$$PRe_{1:10} = \left\{ \frac{\overline{I'_{sm}}}{I_{tot_{1:4}}} \; \frac{\overline{I'_{md}}}{I_{tot_{5:6}}} \; \frac{\overline{I'_{lg}}}{I_{tot_{7:10}}} \right\}$$

$$I_{sm,md,lg} = \{ FR\_AER\_SUV2, JPN\_LL\_NEAtl2, MED\_LAR\_SUV \}$$

$$I_{bm} = \{ MED\_LAR\_SUV \}$$

$$q = 1.875\mathrm{E} - 7$$

West values

$$a = \{1,2,3,4,5,6,7,8,9,1011,12,13,14,15,16)\}$$

$$W_{1:16} = \{3.1,9.8,15.1,19.9,43.3,60.5,89.9,111.6,144.8,174,201.1,225.5,247.7,264,283.5,340\}$$

$$M_{1:16} = \{0.40, 0.33, 0.27, 0.23, 0.20, 0.18, 0.16, 0.14, 0.13, 0.12, 0.12, 0.11, 0.11, 0.11, 0.11, 0.11\}$$

$$PRw_{1:16} = \left\{ \frac{\overline{I'_{sm}}}{I_{tot_{1:4}}} \; \frac{\overline{I'_{md}}}{I_{tot_{5:6}}} \; \frac{\overline{I'_{lg}}}{I_{tot_{7:16}}} \right\}$$

$$I_{sm,md,lg} = \{ US\_RR\_66\_144, CAN\ SWNS, MEXUS\_GOM\_PLL \}$$

$$I_{bm} = \{ MEXUS\_GOM\_PLL \}$$

$$q = 2.136444\mathrm{e} - 07$$

The $F_{0.1}$ estimate is based on yield-per-recruit calculation for F ranging from 0 to 10 in increments of 0.01. The last age in the a vector is a plus group and the oldest age in the plus group is 35.

Eastern and Western area TAC

$$TAC_{N+1} = \begin{cases} F_{0.1} * \dfrac{I_{bm,N}}{q}, \; I_{tot} > 0 \\ 0.2 * \dfrac{I_{bm,N}}{q}, I_{tot} = 0 \end{cases}$$

Constraint on TAC increase (upper=1.26, lower=0.6)

$$TAC_{N+1} = TAC_N * \left(0.6 + \frac{1}{1.5 + e^{-8*\left(\frac{TAC_{N+1} - TAC_N}{TAC_N}\right)}} \right)$$

A simple indicator based cMP

This cMP tracks the relative abundance of an indicator and sets a TAC based on the ratio of the most recent 3 years of index values relative to the 3 years prior to that.

Eastern management procedure index

$$I_{bm} = \{\, MOR\_POR\_TRAP \,\}$$

Western management procedure index

$$I_{bm} = \{\, MEXUS\_GOM\_PLL \,\}$$

The basis for the TAC calculation is the I_{ratio} estimate and depends on the most recent 6 years of index values:

$$I_{ratio} = \left(\frac{1}{3}\sum\nolimits_{N-2}^{N} I_{bm}\right) \Big/ \left(\frac{1}{3}\sum\nolimits_{N-5}^{N-3} I_{bm}\right)$$

Index-Catch difference

In order to avoid situations where the population is changing faster than the trend in catch, the difference between the scaled index and catch is used to make an adjustment that attempts to make the two more similar. See figure 1 for example.

$$Scale(x) = \frac{(x - \overline{x})}{sd(x)}$$

$$Diff = abs(Scale(I_{bm}) - Scale(C_{obs})\,)$$

where C_{obs} is a vector of observed catches.

$$\Delta Diff = \frac{Diff_N}{Diff_{N-1}}$$

Western area TAC

$$TAC_{N+1} = \begin{cases} TAC_N, & I_{ratio} \geq 1 \ \wedge \ (\Delta Diff \leq 1 \ \vee \ \Delta Diff \geq 2) \\ 1.05 * TAC_N, & I_{ratio} \geq 1 \ \wedge \ (1 < \Delta Diff < 2) \\ I_{ratio} * 1.05 * TAC_N, & I_{ratio} < 1 \ \wedge \ (\Delta Diff \leq 1 \ \vee \ \Delta Diff \geq 2) \\ I_{ratio} * 0.9648 * TAC_N, & I_{ratio} < 1 \ \wedge \ (1 < \Delta Diff < 2) \end{cases}$$

Eastern area TAC

$$TAC_{N+1} = \begin{cases} TAC_N, & I_{ratio} \geq 1 \ \wedge \ (\Delta Diff \leq 1 \ \vee \ \Delta Diff \geq 2) \\ 1.05 * TAC_N, & I_{ratio} \geq 1 \ \wedge \ (1 < \Delta Diff < 2) \\ I_{ratio} * 1.072 * TAC_N, & I_{ratio} < 1 \ \wedge \ (\Delta Diff \leq 1 \ \vee \ \Delta Diff \geq 2) \\ I_{ratio} * 0.9648 * TAC_N, & I_{ratio} < 1 \ \wedge \ (1 < \Delta Diff < 2) \end{cases}$$

TC & AI (BM)

Authors: Carruthers
Documents: SCRS/2021/165 (TC)

TC

Fixed harvest rate, index-based CMP accounting for stock mixing

Data smoothing

In order to reduce noise in both indices and catches, the MP uses a polynomial ('loess') smoothing function *S()*. Smoothed catches $\tilde{C}$ and smoothed are (A) and stock (S) indices $\tilde{I}$ are calculated from the raw observed catches C and indices I by area a and index type i, using the same smoothing parameter ω:

$$\tilde{I}_{a,i}^{A} = S(I_{a,i}^{A}, \omega) \quad (1)$$
$$\tilde{I}_{a,i}^{S} = S(I_{a,i}^{S}, \omega) \quad (2)$$
$$\tilde{C}_{a} = S(C_{a}, \omega) \quad (3)$$

The function is parameterized such that the approximate number of smoothing parameters is a linear function of the length of the time series. The effect of the ratio of smoothing parameters to length of the time series ω, is illustrated in Figure 1.

Vulnerable biomass and fishing rate estimation

A multi-stock, multi-area management procedure 'MPx', was designed to provide TAC advice in a given time period t using Stock biomass indices (I^S) by stock s and Catch Rate Indices (I^A) by area a, calibrated to current stock assessments of vulnerable biomass B (estimates of catchability q for stock and area indices) (Figure 2). In order to, for example, interpret West area biomass in terms of Eastern stock biomass, an estimate of stock mixing is required $\theta_{s=East\_stock,a=West}^{mix}$ that is the fraction of Eastern stock biomass that can be expected to be vulnerable to fishing in the West area. Where there are more than one spawning stock index ($n_{s,i} > 1$) or more than one area index ($n_{a,i} > 1$) overall biomass estimates were the mean of those from the multiple indices:

$$B_{a,t}^{S} = \frac{\sum_s \sum_i \tilde{I}_{s,i,t}^{S} q_{s,i}^{S} \theta_{s,a}^{mix}}{n_{s,i}} \quad (4)$$

$$B_{a,t}^{A} = \frac{\sum_s \sum_i \tilde{I}_{a,i,t}^{A} q_{a,i}^{A}}{\mathrm{n}_{a,\mathrm{i}}} \quad (5)$$

The q parameters are calibrated to 2016 estimates spawning biomass (by stock) θ_s^S, and vulnerable biomass (by area) θ_a^A:

$$q_s^S = \frac{\theta_{s,2016}^{S}}{\tilde{I}_{s,2016}^{S}} \quad (6)$$

$$q_a^A = \frac{\theta_{a,2016}^{A}}{\tilde{I}_{a,2016}^{A}} \quad (7)$$

The estimates of vulnerable biomass B arising from the calibrated indices can be used to estimate the fishing mortality rate using observations of catches C

$$F_{a,t}^{A} = -\ln\left(1 - \frac{C_{a,t}}{B_{a,t}^{A}}\right) \quad (8)$$

$$F_{a,t}^{S} = -\ln\left(1 - \frac{C_{a,t}}{B_{a,t}^{S}}\right) \quad (9)$$

Combining inference from SSB and CPUE indices

Assessment estimates of vulnerable biomass at MSY (θ^{BMSY}) can be used to calculate current vulnerable biomass relative to *BMSY,* here inference from catch rate and spawning indices is equally weighted as the geometric mean:

$$\Delta^B_{a,t} = exp\left(\frac{1}{2}\left[ln\left(\frac{B^S_{a,t}}{\theta^{BMSY}_a}\right) + ln\left(\frac{B^A_{a,t}}{\theta^{BMSY}_a}\right)\right]\right) \quad (10)$$

The same approach was used to combined estimates of F relative to *FMSY*:

$$\Delta^F_{a,t} = \exp\left(\frac{1}{2}\left[ln\left(\frac{F^S_{a,t}}{\theta^{FMSY}_a}\right) + ln\left(\frac{F^A_{a,t}}{\theta^{FMSY}_a}\right)\right]\right) \quad (11)$$

A harvest control rule for TAC adjustment based on estimates of B/BMSY and F/FMSY

TACs in the following year are based on TAC in the previous time step multiplied by a factor $\varphi_{a,t}$:

$$TAC_{a,t+1} = TAC_{a,t}\,\varphi_{a,t} \quad (12)$$

where the factor $\varphi_{a,t}$ is determined by adjustments for fishing rate $\delta^F_{a,t}$ and stock status $\delta^B_{a,t}$:

$$\tilde{\varphi}_{a,t} = \delta^F_{a,t}\,\delta^B_{a,t} \quad (13)$$

The adjustment to F is the inverse of $F/FMSY$ ($\Delta^F_{a,t}$) where the magnitude of the adjustment is determined by β^F. The parameter α^F controls the target F level where $F/FMSY$ = 1 and $B/BMSY$ = 1. For example, at a value of 0.8, the MP deliberately aims to underfish at 80% of *FMSY* when the stock is at *BMSY* and current F is *FMSY*. Note that when α^F=1 and β^F = 1 the F adjustment $\delta^F_{a,t}$ is the inverse of $\Delta^F_{a,t}$ and hence recommends *FMSY* fishing rate (and depends on the assumption that biomass will be comparable at t+1).

$$\delta^F_{a,t} = \alpha^F\,exp\left(\beta^F\,ln\left(1/\Delta^F_{a,t}\right)\right) \quad (14)$$

The adjustment according to biomass is exponentially related to the disparity between current biomass and BMSY. The term $|\Delta^B_{a,t} - 1|$ is the positive absolute difference (modulus). The magnitude of the adjustment for biomass is controlled by the parameter α^B while the (extent of the TAC change for biomass levels far from BMSY) is controlled by the exponent β^B. This is analogous to a traditional harvest control rule (e.g. '40-10') and throttles fishing rates at low stock sizes to speed recovery while also increasing fishing rates at high stock sizes to exploit additional biomass (Figure 3). When α^B = 0 there is no biomass adjustment and $\delta^B_{a,t}$ is invariant to β^B.

$$\delta^B_{a,t} = \begin{cases} exp\left[\left(\alpha^B|\Delta^B_{a,t} - 1|\right)^{\beta^B}\right] & 1 < \Delta^B_{a,t} \\ exp\left[-\left(\alpha^B|\Delta^B_{a,t} - 1|\right)^{\beta^B}\right] & \Delta^B_{a,t} \leq 1 \end{cases} \quad (15)$$

This generalized TAC harvest control rule can accommodate a wide range of control schemes of varying sensitivity to estimates of current exploitation rate and stock status.

TAC adjustment limits

The maximum rate of TAC adjustment is determined by θ^{down} and θ^{up} and the minimum amount is controlled by θ^{min}:

$$\hat{\varphi}_{a,t} = \begin{cases} \theta^{down} & \tilde{\varphi}_{a,t} < \theta^{down} \\ \tilde{\varphi}_{a,t} & \theta^{down} < \tilde{\varphi}_{a,t} < (1-\theta^{min}) \\ 1 & (1-\theta^{min}) < \tilde{\varphi}_{a,t} < (1+\theta^{min}) \\ \tilde{\varphi}_{a,t} & (1+\theta^{min}) < \tilde{\varphi}_{a,t} < \theta^{up} \\ \theta^{up} & \theta^{up} < \tilde{\varphi}_{a,t} \end{cases} \tag{16}$$

Table 1. The input data, parameters of the current default MPx managment procedure.

	Description	**Value**
Biomass calculation		
$\mathrm{I}^{S}_{East\_stock}$	Spawning stock biomass index for eastern stock	MED_LAR_SUV (#2), GBYP_AER_SUV_BAR (#5)
$\mathrm{I}^{S}_{West\_stock}$	Spawning stock biomass index for western stock	GOM_LAR_SUV (#4)
I^{A}_{East}	Vulnerable biomass catch rate index for eastern area	MOR_POR_TRAP (#6), JPN_LL_NEATL2 (#7)
I^{A}_{West}	Vulnerable biomass catch rate index for western area	US_RR_177 (#10), JPN_LL_West2 (#12)
θ^{BMSY}_{East}	Eastern area biomass at maximum sustainable yield	800 kt
θ^{BMSY}_{West}	Western area biomass at maximum sustainable yield	20 kt
θ^{FMSY}_{East}	Eastern area harvest rate at MSY	0.06
θ^{FMSY}_{West}	Western area fishing mortality rate at MSY	*tuned* (0.004 – 0.04)
$\theta^{S}_{East\_stock,recent}$	Mean Vuln. biomass of eastern stock in 2013-2017	800 kt
$\theta^{S}_{West\_stock,recent}$	Mean Vuln. biomass of western stock in 2013-2017	20 kt
$\theta^{A}_{East,recent}$	Mean Vuln. biomass in eastern area in 2013-2017	730 kt
$\theta^{A}_{West,recent}$	Mean Vuln. biomass in western area in 2013-2017	120 kt
$\theta^{mix}_{West,East}$	Fraction of western stock in eastern area	0.1
$\theta^{mix}_{East,West}$	Fraction of eastern stock in western area	0.05
Harvest control rule		
α^{B}	The magnitude of the adjustment for biomass relative to BMSY	0 (no biomass adjustment)
β^{B}	Exponent parameter controlling extent of the adjustment for biomass relative to BMSY	NA (given α^{B} = 0)
α^{F}	Target fishing mortality rate (fraction of FMSY) at F/FMSY = 1 and B/BMSY =1	1
β^{F}	The magnitude of the adjustment for fishing rate relative to FMSY	0.33
Data smoothers		
ω	The ratio of the No. polynomial smoothing parameters to the number of years of time series data. I.e. loess(dat, enp.target = $\omega \cdot n_t$)	0.15

Table 1. Continued.

Description		**Value**
TAC adjustment limits		
θ^{up}	The maximum fraction that TAC can increase	0.25
θ^{down}	The maximum fraction that TAC can decrease	0.25
θ^{min}	The minimum fractional change in TAC	0.025
θ^{TACmin}_{East}	Minimum TAC for the East area	10 kt
θ^{TACmin}_{West}	Minimum TAC for the West area	0.5 kt
θ^{TACmax}_{East}	Maximum TAC for the East area	80 kt
θ^{TACmax}_{West}	Maximum TAC for the West area	4.5 kt
$\theta^{TACmax\_near}_{West}$	Near-term maximum TAC for the West area	2 kt
$\theta^{n\_near}_{West}$	Western near-term period	25 years
Index recalibration rule		
γ^{n}	The length of the time series for detecting slope of indices	6
γ^{East}	The magnitude of F reduction in the East area in relation to the slope in Eastern stock biomass index	1
γ^{West}	The magnitude of F reduction in the West area in relation to the slope in Western stock biomass index	2

AI_CMP

Fixed harvest rate CMP using estimates of area-based vulnerable biomass from an artificial neural network. Details of the neural network configuration are available in Table 2.

Simulated datasets were generated by projecting nine constant fishing mortality rate CMPs for all 96 stochastic reference set operating models. These nine CMPs comprised high, medium and low harvest rates in the West area crossed with high, medium and low harvest rates in the East area. These simulations created a range of simulated outcomes for both stocks. The stochastic operating models include 48 simulations each. Over 9 CMPs this leads to 41,472 simulated projections (96 x 48 x 9). In each of these projections a single projection year was sampled, and for this year eight types of data were recorded:

(1) current index level of all 13 indices subject after Loess smoothing (13 data points);
(2) the mean level of the index in the projection to date (13 data points);
(3) the slope in the index in the first 4 projection years (13 data points);
(4) the slope in the index in the first 6 projection years (13 data points);
(5) mean catches over the last three years in both ocean areas (2 data points);
(6) mean catches in both ocean areas to date (2 data points);
(7) the projection year;
(8) the total simulated biomass in each ocean area of fish age 3 or older (2 data points).

This results in 57 independent variables (input layer features) and 1 dependent variable (the output layer - area biomass of fish age 3+) for training two neural networks, one for predicting total biomass of 3+ fish in the East area and another for predicting total biomass of age 3+ fish in the West area. Only one projection year was sampled per simulation to ensure all data points originate from independent time series. Random seeds were generated to ensure that the projected simulated data and dynamics were not the same as those used in MSE testing.

The wider dataset of 41,472 'observations' was split into three component datasets, a training set, a validation set and a testing set. The training set was used to fit the neural network using the backpropagation algorithm. The validation set was used to monitor training and where possible adjust meta parameters of the fitting and network design to improve accuracy. The testing set remained completely independent of the process of fitting or the selection of training hyperparameters that controlled the network fitting process. The split of these data was approximately 75% training, 20% validation, 5% testing.

Prior to fitting, data were all normalized to have mean 0 and standard deviation 1. The parameters of this data normalization was saved in the neural network design to ensure it was preserved when predictions are made from the new datasets provided to a CMP. To focus estimation on smaller stock sizes where CMP performance is most critical, the highest 10% of simulated biomasses were removed from the fitting (include many optimistically high outliers) and fit was conducted by minimizing mean squared error on log area biomass.

It has been shown that two hidden layers are sufficient to characterize the structure of any non-linear problem, and that at least two are required to capture complex hierarchical interactions. It follows that a three-layer (two hidden layers) neural network was investigated allowing for deep learning. As is typically the case in the design of neural networks, the width (number of nodes) and depth (number of hidden layers) was decided by ad-hoc experimentation as it is specific to each problem. In both East and West neural networks, relatively high accuracy was achieved with two hidden layers comprising 24 in the first layer and 24 in the second (Figures 1 and 2). This leads to 2,017 parameters per neural network which are the weights among the layers (the coloured lines of Figure 1), in addition to the biases in the hidden and output layers (one for each of the nodes in the lower three layers of nodes in Figure 1) (2,017 = 57 x 24 + 24 x 24 + 24 x 1 + 24 + 24 + 1). In general, the validation loss rate (the mean squared error in log total biomass of age 3+ fish) stopped improving after 350 epochs (iterations of fitting) (see Figure 2 for mean absolute error plots).

The neural networks were used in fixed harvest rate CMPs. The TACs in each area were set by the 3+ biomass estimate from the corresponding neural network multiplied by a tuning parameter that is the fixed harvest rate in each area. CMPs AI1, AI2 and AI3 were tuned to an eastern stock Br30 (spawning stock biomass, SSB relative to dynamic SSB MSY after 30 projected years) of approximately 1.55 and western stock Br30 of 1.00, 1.25 and 1.50, respectively. Similarly to other CMPs, the TAC advice arising from the A.I. CMPs were constrained by minimum (10kt East, 0.5kt West) and maximum (50kt East, 4kt West) levels in addition to maximum percentage increases (25%) and decreases (35%). If the new TAC is less than a 5% different from the previous TAC no change is implemented.

Table 2. Neural network configuration

Configuration	Used in this analysis	Alternatives
1. Software	KERAS R package (Falbel et al. 2021) + Tensorflow (2021) + NVIDIA CUDA (NVIDIA 2021)	neuralnet R package (Fritsch *et al.* 2016) nnet R package (Ripley 2016) (and many others)
2. Network type	Simple recurrent	Fully recurrent, Recursive, Multilayer perceptron, Convoluted, Bi-directional, Hierarchical, Stochastic, Long short-term memory, Sequence to sequence, Shallow, Echo state
3. Training algorithm (optimizer)	'rmsprop'	'adam', 'sgd', 'adamax', 'adadelta', 'adagrad'
4. Cost function	Mean squared error	Mean absolute error, mean squared, logarithmic error, mean absolute percentage error
5. Intensiveness of training	500 epochs (sufficient for stabilization of cost function, Figure 2)	-
6. Input data types	• Current index level (13 indices, each loess smoothed) • Index slope: first 4 yr. of projection • Index slope first 6 yrs of projection • Index • Mean index level in projection • Projection year number • Mean catch levels in projection (both East and West area)	
7. Output data	East / West Area specific biomass (age 3+)	Stock biomass, stock biomass x exploitation rate
8. Size of training / validation / testing data sets	31,519 / 7,880 / 2,074 (approx. 75% / 20% / 5%)	-
9. Network design **(number of neurons in consecutive layers demarked by ':') and Activation functions**	**Input layer**: 57 (data types) **Hidden layers**: 24:24 (2,401 parameters) **Output layer**: 1 **Activation functions:** rectified linear unit	Linear, sigmoid, hyperbolic, tangent
10. Neural net performance evaluation	**Validation**: cross-validation **Estimation performance**: mean squared error / mean absolute error **Management performance**: MSE testing with ABT-MSE package	

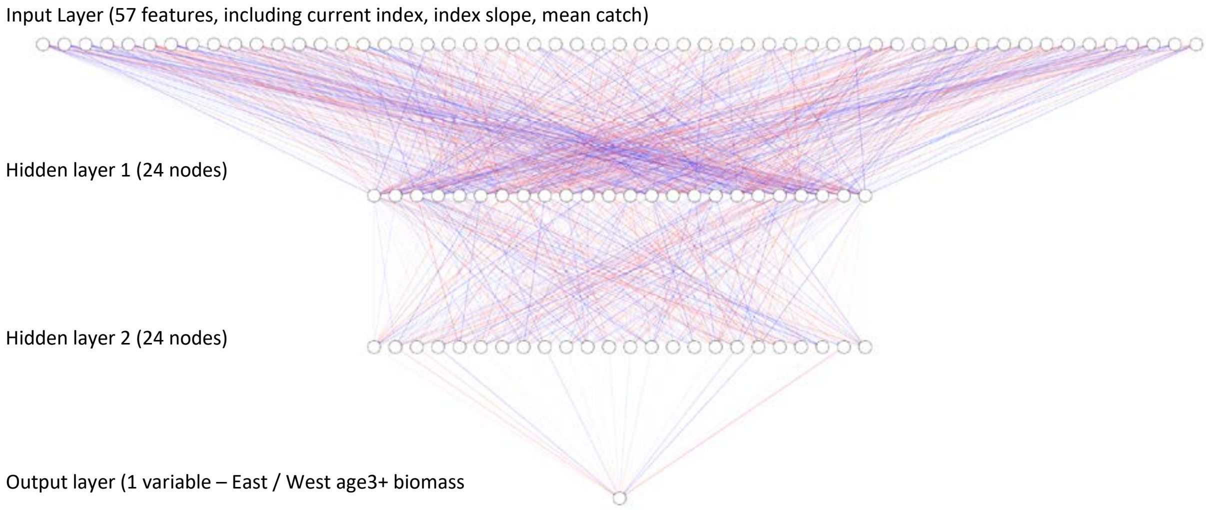

Figure 1. Neural network design. Lines represent estimated weights, circles represent nodes for which a bias is estimated per node for each hidden layer and the output layer.

Appendix 6

Atlantic Bluefin Tuna MSE – Results, Decisions, & Next Steps (5/6/2022)

Executive Summary

This document presents updated results of the Atlantic bluefin tuna management strategy evaluation (MSE). The intention is to provide sufficient knowledge to facilitate discussion among scientists, fishery managers and stakeholders, as well as decision-makers, at the 9-10 May 2022 meeting of Panel 2. This updated version of the summary is based on discussions at the 3-6 May 2022 Bluefin MSE Technical Team meeting.

Candidate Management Procedures

There are currently 8 candidate management procedures (CMPs)[3] under development by 6 different international teams (**Table 1**). All currently assume a 2-year management cycle and calculate separate total allowable catches (TACs) for the West and East management areas. The SCRS rigorously reviewed all western and eastern indices, resulting in two indices being deemed not usable in their present condition by the MSE. After this, the choice of indices used in each CMP has been at the discretion of developers with emphasis placed on whether the indices perform well in the CMPs. Scientific rationale for SCRS consideration of indices in CMPs will be provided to Panel 2. We present results from 8 CMPs to show key performance tradeoffs for management objectives in a 'quilt plot' (**Figure 1**) that ranks CMPs on 5 key performance statistics; a second plot (**Figure 2**) includes additional statistics.

The May Panel 2 agenda specifies three main decision points.

- Decision point 1 (PA2 Agenda Item 6.a): Agreement on operational management objectives percentages, timeframes and performance statistics (See **Table 2**).

- Decision point 2 (PA2 Agenda Item 6.b*)*: Does Panel 2 approve this proposed two-step process for Candidate Management Procedure development and performance tuning?

  Step 1: Development tuning for CMP comparison

  - CMPs are tested on a common Br30 performance level (currently 1.0, 1.25 or 1.5, for each stock).
  - SCRS will give advice on ordering CMPs across performance statistics corresponding to yield, status, safety and stability objectives. The SCRS proposes five key performance statistics (**Figure 1**) chosen on the basis of removing duplicative statistics and focusing on the four operational performance statistics of safety, status, stability and yield (both short term and long term). The remaining performance statistics are reported in **Figure 2**.
  - Panel 2 will evaluate relative performance of CMPs and may rank CMPs based on performance.

  Status: Development tuning is nearly complete. CMP performance initially seems similar across four CMPs evaluated at four tuning levels. *Therefore, specific tuning levels do not need to be selected by Panel 2 at this time. CMPs that are poorly performing could be recommended for removal by Panel 2, at this May meeting.*

[3] While 8 CMPs are under development, not all will be deemed to perform at the level necessary to be eligible candidates for MP adoption. For example, the Canadian development team have withdrawn one of their CMPs (i.e., NC) since the March PA2 meeting to focus their efforts on their other CMP that has better performance (i.e., EH).

Step 2: Performance tuning of retained list of CMPs to determine the final CMP specifications

- Once top performing CMPs are selected in step 1, they may be *performance tuned.*
- All CMPs include at least one adjustable setting to determine how heavily or lightly it applies fishing pressure to achieve desired performance on the risk-reward tradeoff (i.e., catch vs. biomass) for each of the East area/eastern stock and West area/western stock.
- The setting can be adjusted to achieve different median Br30 (e.g., 1.43, 1.36) across the grid of operating models to achieve higher yields while meeting safety, status, and stability objectives.

Status: Performance tuning has not yet begun and will occur following the May Panel 2 meeting and continue to the October Panel 2 meeting. The SCRS will provide feedback at its July and September meetings. At its October meeting, Panel 2 may first select a CMP and then select from within a range of tested performance tuning settings.

- Decision point 3 (PA2 Agenda Item 6.c): Does Panel 2 approve the following process for narrowing (culling) of CMPs?

- Panel 2 (in May) agrees to a set of performance statistics & descriptive tables/figures (e.g., quilt plots)
- Panel 2 (in May) agrees to minimum standards for CMP performance, which may include:
    - Less than X% chance of breaching B_{LIM}, where X is defined by Panel 2. The performance statistic LD* is recommended to evaluate status relative to B_{LIM} (40% of dynamic SSB_{MSY}).
    - Stock should have a greater than Y% probability[4] of being above SSB_{MSY} in year 30, where Y is defined by Panel 2.
    - A proposal for an overfishing metric (U/U_{MSY}) & probability of the green quadrant of the Kobe matrix in year 30.
    - Are there other specific and measurable objectives would Panel 2 like to use as minimum thresholds?

- Panel 2 (in May) may choose to exclude CMPs with unacceptable performance or structure.
- At its July and September meetings, the SCRS will review all CMPs and compare them to performance standards set by Panel 2 in May. CMPs deemed by SCRS to not perform satisfactorily may be culled by SCRS and not recommended to Panel 2 in October, with results and rationale provided.
- SCRS will use scientific rationale (e.g. lack of performance across robustness tests and substantially low ranking across performance statistics) for any decisions to cull CMPs.
- To assist SCRS to conduct such culling it requests further feedback from Panel 2 on what constitutes more desirable performance for CMPs that already meet minimum criteria.
- CMP developers may also withdraw their CMPs if they are not performing as desired.

[4] For a given development tuning, the probability of overfished status (POS), or probability $SSB<SSB_{MSY}$ in year 30, is a performance statistic.

- Decision point 4: Relative weighting of key performance statistics

  Purely to facilitate discussion, the SCRS puts forward three example weighting schemes for the key statistics of the primary quilt plot (**Table 3**). The ultimate decision to use one of the three examples or other weighting schemes (as well as, for example, selection of the percentage for LD*) is up to Panel 2. PGK is not weighted as the CMPs are tuned to achieve a common Status objective (Br30). The ranking in the quilt plot shown below uses the default ranking. The purpose of the relative weightings is to facilitate decision making but is not intended to be the sole criterion for CMP selection. See **Table 2** for more detailed descriptions of performance statistics.

- Additional Decision/Discussion points:

  - Are there other specific and measurable objectives that Panel 2 would like to use as minimum thresholds?
  - Are there any CMPs that Panel 2 would like to remove from consideration at this point?
  - Are there any additional features of CMPs that Panel 2 would like to see? CMP performance is not impacted by TAC caps.
  - Several CMPs indicate possible initial decreases in TAC which may be due to how CMPs are structured and how they behave during the transition period, and often not a result of underlying stock declines. Would Panel 2 like SCRS to explore a phase in period for those CMPs? Specifically, the SCRS proposes a time frame of the first two MP applications and limits for TAC change (+20 / -10) that may be desirable as constraints to build into CMPs.
  - A key aspect of the refinement of CMPs after the May Panel 2 meeting will involve making adjustments to the CMPs to provide anticipated future TAC trajectories in line with stakeholder preferences, both as regards short term stability and longer-term trends and variability. This will require dialogue with Panel 2 on how best to obtain feedback from CPCs to the SCRS to inform finalization of CMP development in good time before the September BFT MSE Technical Sub-group meeting to give developers sufficient time to refine CMPs.
  - Does Panel 2 require additional meeting time, either in July or as an extra day in October?

Next steps

After the May 9-10 Panel 2 meeting, there is one remaining meeting of Panel 2 to take place before the Commission Plenary, scheduled for October 14. The Bluefin Species Group will continue with additional Ambassador meetings in English, French and Spanish and materials will be translated into Arabic.

Other resources

Atlantic Bluefin Tuna MSE splash page, including interactive Shiny App (ENG only)
Harveststrategies.org MSE outreach materials (multiple languages)

Table 1. Table of Candidate Management Procedures (CMPs), indicating in red where changes have occurred since the March Panel 2 meeting.

CMP	Indices used		Formulae for calculating TACs	References
	EAST	WEST		
EH	FR AER SUV2 JPN LL NEAtl2 W-MED LAR SUV	US RR 66-144, CAN SWNS RR US-MEX GOM PLL	TACs are product of stock-specific F0.1 estimates and estimate of CAN SWNS RR for the West and W-MED LAR SUV for the East.	SCRS/2020/144 SCRS/2021/122
AI	All	All	Artificial intelligence MP that fishes regional biomass at a fixed harvest rate.	SCRS/2021/028
BR	FR AER SUV2 W-MED LAR SUV MOR POR TRAP JPN LL NEAtl2	GOM LAR SUV US RR 66-144 US-MEX GOM PLL JPN LL West2 CAN SWNS RR	TACs set using a relative harvest rate for a reference year (2018) applied to the 2-year moving average of a combined master abundance index. In recent refinement, the weighting range across individual indices has been reduced, resulting in improved performance. More recently still, some limited time dependence has been introduced into the TAC formulae to allow for a smoother transition from current TACs to those to be generated in the initial years of the MP application.	SCRS/2021/121 SCRS/2021/152 SCRS/2022/082
EA	FR AER SUV2 W-MED LAR SUV MOR POR TRAP JPN LL NEAtl2	GOM LAR SUV JPN LL West2 US RR 66-144 US-MEX GOM PLL	Adjust TAC based on ratio of current and target abundance index.	SCRS/2021/032 SCRS/2021/P/04 6
LW	W-MED LAR SUV JPN LL NEAtl	GOM LAR SUV MEXUS_LL	TAC is adjusted based on comparing current relative harvest rate to reference period (2019) relative harvest rate.	SCRS/2021/127
~~NC~~	~~MOR POR TRAP~~	~~US-MEX GOM PLL~~	~~No longer supported~~	~~SCRS/2021/122~~
PW	JPN LL NEAtl2 W-MED LAR SUV	US-MEX GOM PLL GOM LAR SUV	TAC is adjusted based on comparing current relative harvest rate to reference period (2019) relative harvest rate.	SCRS/2021/155 SCRS/2022/078
TC	MOR POR TRAP JPN LL NEAtl2 W-MED LAR SUV GBYP AER SUV BAR	US RR 66-144	TAC is adjusted based on F/F_{MSY} and B/B_{MSY}.	SCRS/2020/150 SCRS/2020/165
TN	JPN LL NEAtl2	JPN LL West2	Both area TACs calculated based on their respective JPN_LL moving averages.	SCRS/2020/151 SCRS/2021/041 SCRS/2022/074

East indices: FR AER SUV2 – French aerial survey in the Mediterranean; JPN LL NEAtl2 – Japanese longline index in the Northeast Atlantic; W-MED LAR SUV – Larval survey in the western Mediterranean; MOR POR Trap – Moroccan-Portuguese trap index; GBYP AER SUV BAR – GBYP aerial survey in the Balearics.
West indices: US RR 66-144 – U.S. recreational rod & reel index for fish 66-144 cm; CAN SWNS RR – Canadian South West Nova Scotia handline index; US-MEX GOM PLL – U.S. & Mexico combined longline index for the Gulf of Mexico; GOM LAR SUV – U.S. larval survey in the Gulf of Mexico; JPN LL West2 - Japanese longline index for the West Atlantic.

Table 2. Decision points relative to management objectives and performance statistics.

Management Objectives (Res. 18-03)	**Current Performance Statistics**	**Decision Points for Management Objectives**	**Decision Points for Performance Statistics**
Status The stock should have a greater than [__]% probability of occurring in the green quadrant of the Kobe matrix	**Br30** – Br [i.e., biomass ratio, or spawning stock biomass (SSB) relative to dynamic SSB_{MSY}[3]] after 30 years. **PGK**: probability of being in the Kobe green quadrant (i.e., SSB>$dSSB_{MSY}$ and U<U_{MSY}) in year 30. **U/U_{MSY}-** exploitation rate (U) in biomass divided by exploitation rate at MSY.[4] **Br20** – Br after 20 years. **AvgBr** – Average Br over projection years 11-30 **POF** – Probability of overfishing (U>U_{MSY}) after 30 projected years **PNRK -** Probability of not being in the red Kobe quadrant (SSB > SSB_{MSY} or U < U_{MSY}) after 30 projected years **OFT** – Overfished Trend, SSB trend if Br30<1.	• Probabilities (__% after 30 years)	• F-statistic: SCRS proposes an exploitation rate metric (U/U_{MSY})
Safety There should be a less than [__]% probability of the stock falling below B_{LIM} at any point during the 30 year evaluation period	**LD*** – Lowest depletion (i.e., SSB relative to dynamic SSB_{MSY}) over years 11-30 in the projection period. LD* value is evaluated relative to SCRS-adopted B_{LIM} (40% of dynamic SSB_{MSY}).[5]	• Probability of falling below B_{LIM} (Options: e.g. 5%, 10%,15%)	*None*
Yield Maximize overall catch levels	**AvC10** – Median TAC (t) over years 1-10 **AvC30** – Median TAC (t) over years 1-30 **C1-** TAC in first 2 years of MP (i.e., 2023-24) **AvC20** – Median TAC (t) over years 1-20	• None	*None*
Stability Any increase or decrease in TAC between management periods should be less than [__]%	**VarC** –Variation in TAC (%) between 2-year management cycles	• Probabilities (Options: no restriction, ±20, +20/-30) • 'Phase-in' period of +20/-10 for first 2 MP applications (i.e., currently 2023-26), then +20/-30	*None, if **VarC** is acceptable*

[3]Dynamic SSB_{MSY} is a set fraction of dynamic SSB_0, which is the spawning stock biomass that would occur in the absence of fishing, historically and in the future. Dynamic SSB_{MSY} can change over time since it is based on current recruitment levels, which fluctuate due to time-varying dynamics in the models.
[4]The exploitation rate (U) is annual catch (in tonnes) divided by the total annual biomass in tonnes. U_{MSY} is the fixed harvest rate (U) corresponding with SSB/SSB_{MSY}=1 at year 50.
[5]SCRS adopted a B_{LIM} of 40% of dynamic SSB_{MSY} for the purposes of the MSE for CMP testing and performance tuning. Status relative to B_{lim} is calculated as the lowest depletion (spawning biomass relative to dynamic SSB_{MSY}) over projection years 11-30 for which the CMP is applied across the plausibility weighted operating models. B_{LIM} is proposed as a performance statistic, not as an 'active' or functional trigger for determining a management action.

Table 3. To facilitate discussion, the SCRS puts forward three weighting schemes for the five key performance statistics for consideration by Panel 2. Weighting will influence CMP performance ranking.

Weighting scheme	***Status*** ***PGK*** ***(mean)***	***Short term Yield*** ***AvC10 (50%)***	***Long term 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

CMP	West					East					Tot
	PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	PGK (Mean)	AvC10 (50%)	AvC30 (50%)	VarC (50%)	LD (15%)	
BR2a	0.63	2.89	2.78	13.85	0.49	0.73	40.83	33.3	17.46	0.65	0.24
AI2a	0.61	2.93	2.67	16.38	0.54	0.69	42.05	38.26	16.53	0.63	0.29
TC2a	0.61	2.83	2.64	6.71	0.4	0.73	33.43	29.21	8.18	0.54	0.39
EA2a	0.62	3.42	2.74	15.87	0.36	0.71	38.77	29.65	15.45	0.48	0.43
EH2a	0.6	2.8	2.73	16.53	0.5	0.68	40.82	31.22	17.86	0.5	0.57
TN2a	0.64	3.42	2.59	18.64	0.28	0.71	42.21	29.79	16.02	0.39	0.62
PW2a	0.66	2.44	2.35	20.51	0.45	0.72	34.8	30.64	17.22	0.6	0.69
LW2a	0.6	2.65	2.54	15.61	0.51	0.72	34.25	30.09	17.15	0.6	0.7

Figure 1. Primary 'Quilt' plot for the West and East for tuning level 2 (i.e., Br30=1.25 for West and Br30=1.5 for East) using the default weighting scheme and ordered relative to the total column. Color scale represents relative performance from dark (best) to light (worst) within a column. This plot shows the top 5 performance statistics chosen on the basis of removing duplicative statistics and focusing on the four operational performance statistics of safety, status, stability and yield. The five statistics and associated percentiles are PGK: probability of being in the Kobe green quadrant (i.e., $SSB>SSB_{MSY}$ and $U<U_{MSY}$) in year 30; AvC10: average catch (kilotons, kt) over years 1-10 (50%tile); AvC30: average catch (kt) over years 1-30 (50%tile); VarC: Variation in catch (kt) between 2-year management cycles (50%tile); LD*(15%): 15%tile of lowest depletion over years 11-30. PGK is not weighted in the scoring as all CMPs are tuned to achieve similar biomass status. Ordering is achieved by scaling each column according to its minimum and maximum, within a column, giving a rank order from 0(best) to 1 (worst), weighting columns according to the default weighting, obtaining an average for West and East and then taking the average across East and West (Tot). See **Table 2** for more detailed descriptions of performance statistics. The 'a' for each CMP refers to the +20/-30 stability tuning.

West

CMP	West									
	C1 (50%)	AvC20 (50%)	AvgBr (50%)	Br20 (50%)	Br30 (5%)	LD (5%)	LD (10%)	POF (Mean)	PNRK (Mean)	OFT (P>0)
BR2a	2.68	2.84	1.39	1.29	0.56	0.29	0.4	0.2	0.86	0.87
AI2a	2.82	2.73	1.41	1.34	0.66	0.33	0.43	0.24	0.89	0.89
TC2a	2.68	2.59	1.41	1.41	0.35	0.18	0.27	0.28	0.78	0.86
EA2a	2.83	2.66	1.34	1.21	0.32	0.18	0.27	0.19	0.85	0.88
EH2a	2.21	2.78	1.39	1.29	0.54	0.31	0.41	0.24	0.82	0.86
TN2a	3.27	2.46	1.33	1.24	0.1	0.05	0.17	0.16	0.86	0.9
PW2a	2.36	2.26	1.29	1.16	0.48	0.28	0.37	0.11	0.94	0.94
LW2a	2.51	2.55	1.41	1.31	0.5	0.29	0.38	0.25	0.81	0.84

East

CMP	East									
	C1 (50%)	AvC20 (50%)	AvgBr (50%)	Br20 (50%)	Br30 (5%)	LD (5%)	LD (10%)	POF (Mean)	PNRK (Mean)	OFT (P>0)
BR2a	38.19	34.6	1.53	1.38	0.71	0.48	0.58	0.06	0.98	0.95
AI2a	33.43	40.99	1.54	1.49	0.44	0.4	0.53	0.12	0.89	0.85
TC2a	37.26	28.84	1.63	1.58	0.52	0.37	0.47	0.07	0.94	0.9
EA2a	43.2	29.99	1.56	1.47	0.43	0.31	0.41	0.08	0.93	0.92
EH2a	43.2	30.74	1.51	1.43	0.45	0.33	0.42	0.12	0.91	0.91
TN2a	39.98	27.75	1.55	1.44	0.31	0.21	0.3	0.08	0.92	0.92
PW2a	43.2	30.3	1.57	1.49	0.56	0.44	0.53	0.08	0.95	0.92
LW2a	43.2	29.92	1.57	1.51	0.56	0.44	0.54	0.08	0.95	0.92

Figure 2. Quilt plot #2 depicting C1: catch in the first year of CMP application (50%), AvC20: average catch (kilotons, kt) over years 11-20 (50%tile), Br20: Depletion (spawning biomass relative to dynamic SSB_{MSY}) in projection year 20 (50%), AvgBr: spawning biomass relative to dynamic SSB_{MSY} over projection years 11-30 (50%), LD* (5%): 5%tile of lowest depletion over years 11-30; LD* (10%) 10%tile of lowest depletion over years 11-30, Br30: Depletion (spawning biomass relative to dynamic SSB_{MSY}) in projection year 30 (5%); POF: Probability of Overfishing ($U > U_{MSY}$) after 30 projected years (mean), PNRK: Probability of not Red Kobe ($SSB > SSB_{MSY}$ or $U < U_{MSY}$) after 30 projected years (mean), OFT: Overfished trend, SSB trend over projection years 31 - 35 when Br30 < 1. See **Table 2** for more detailed descriptions of performance statistics. CMPs are ordered according to rank order in Quilt #1. The 'a' for each CMP refers to the +20/-30 stability tuning.