# Status of the Bluefin tuna Management Strategy Evaluation

Principle, uncertainty grid & operating models, performance statistics, various candidate harvest strategies

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AZTI – Marine Research

*Joint MEDAC and SWWAC meeting - Workshop on Eastern Bluefin tuna Harvest Strategy, 19th July, 2021.*

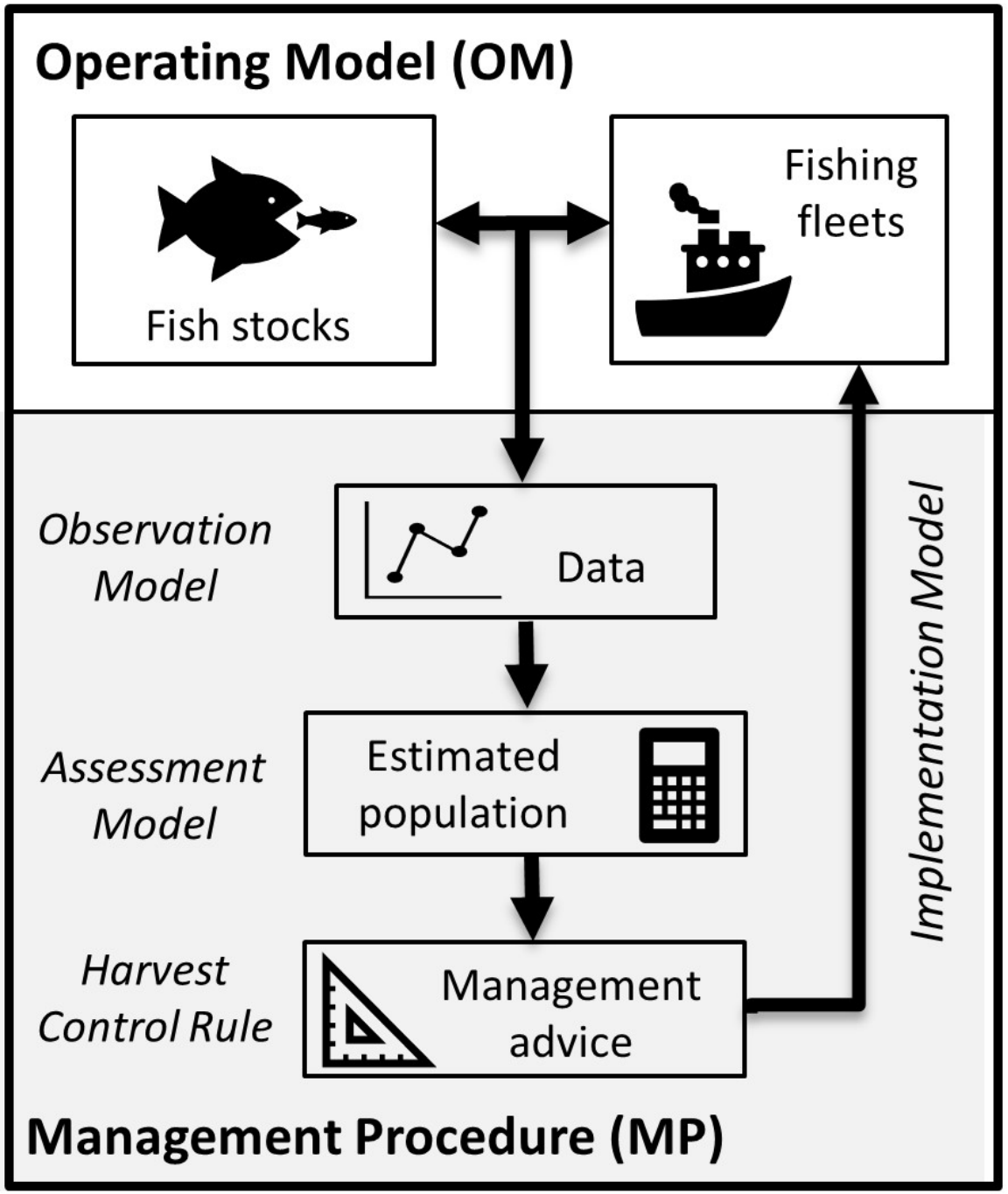
# Management Strategy Evaluation

## What is that?

# MSE

- A simulation approach that formalizes the introduction of uncertainty into the decision-making process

- The objective is to identify the management strategies that are robust to uncertainty before they are put in place

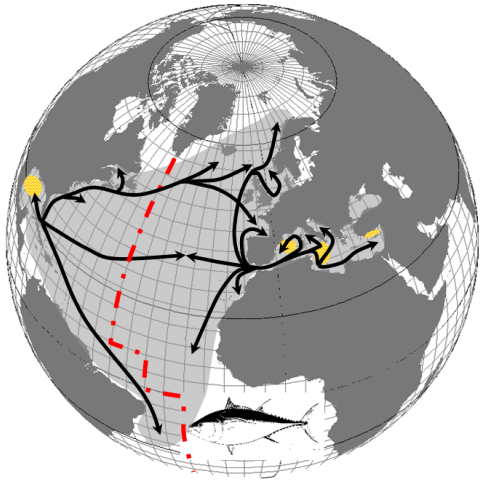


# MSE - Steps

- Identification of management objectives
- Identification of statistical indicators of performance
- Hypotheses for operating models (OMs)
- Conditioning of the OMs using data and knowledge
- Weighting of hypotheses depending plausibility
- Identifying candidate management procedures (MPs) / harvest strategies (HS)
- Projecting the OMs forward in time using the MPs as a feedback controller: impact of management
- Identifying the elements of MPs that best meet management objectives

# MSE for Atlantic BFT

# Some background on Bluefin



**Atlantic Bluefin tuna (*Thunnus thynnus*; ABFT) is challenging**

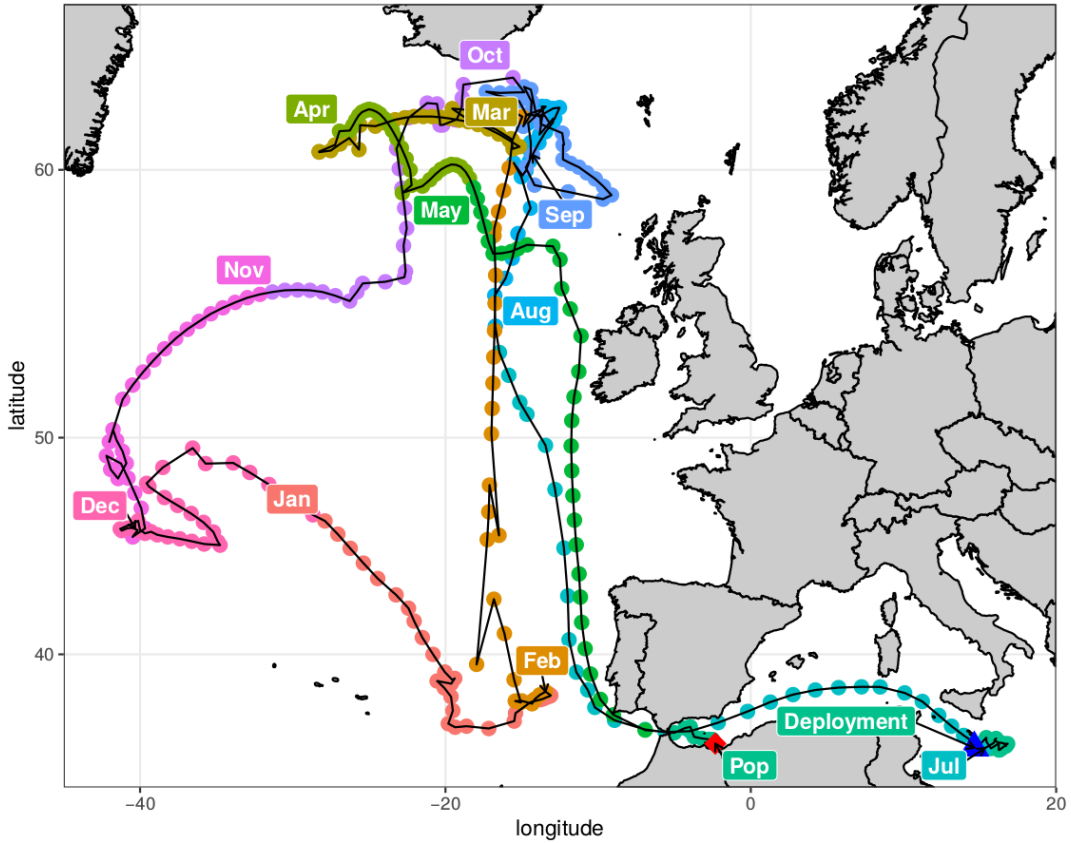
- Emblematic large migratory species: complex spatial dynamics
- Migration in and out of the Med, not fully understood

**Exploitation**

- Very valuable fishery
- Complex exploitation history
- International fishery >20 countries
- Specific exploitation process (Fattening farms)

**Management**

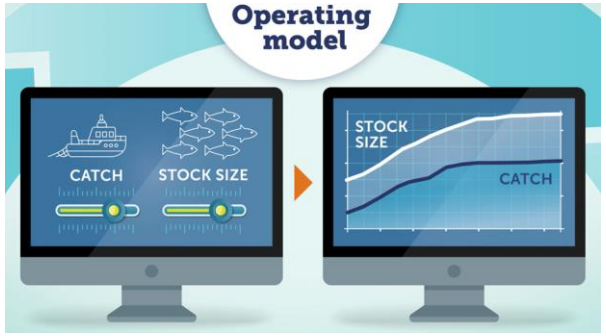
- Managed in two independent stocks: East and West
- Stocks are mixing, pop structure still under research
- Western fishery catch eastern fish
- 90% of total catch are Eastern, Western smaller stock
- 60% of East TAC = Med Purse seiners

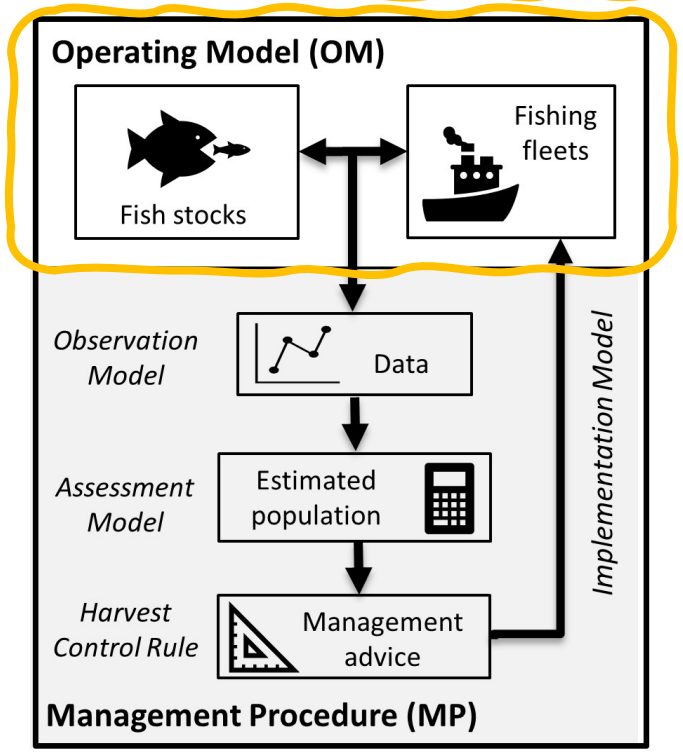


# BFT MSE – How is it organized?

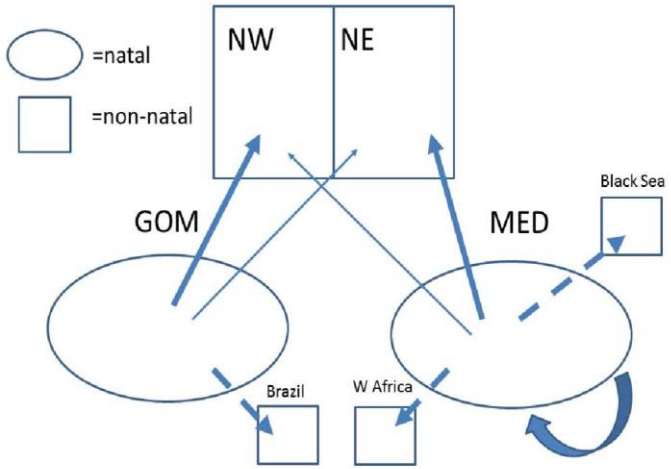
- Funded within the ICCAT research program (GBYP)
- One contractor in charge of the implementation
- Developed a complete R package
- Small technical group  that reports to the BFT Group, which makes the key decisions

# BFT MSE – The Operating Model(s) - OM

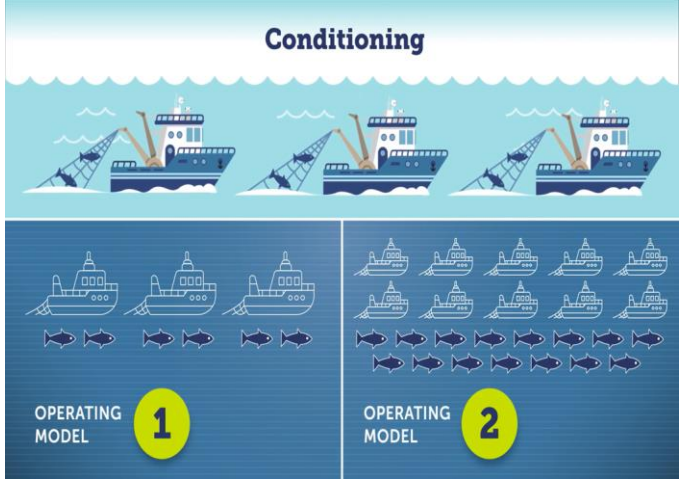



- Simulates the real stock and the fishery under certain hypothesis about their dynamics and interactions.
- Modifiable Multi-stock Model ('M3') - age structured.
- Equations complicated by the quarterly temporal structure.



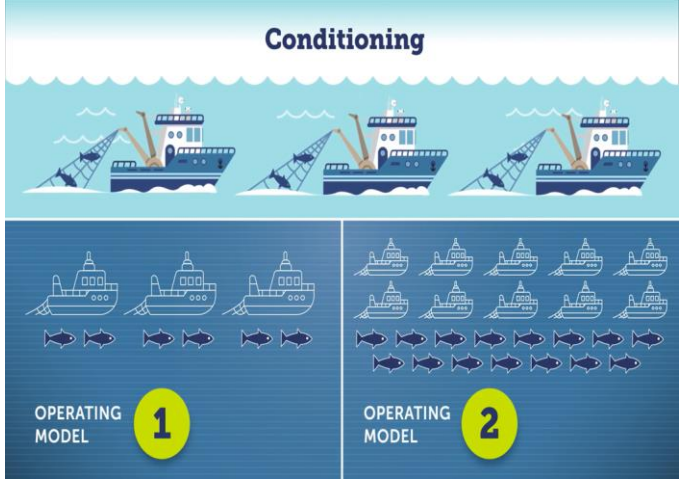
# BFT MSE – OM: fitting to data




- Fishery-dependent information – CPUEs

| No | Fleet | Area (East, Med, West) | Country | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|
| 1 | LLOTH | Med | all others except Japan | 1183.780 | 1809.660 | 2068.916 | 2310.204 |
| 1 | LLOTH | East | all others except Japan | 303.116 | 344.944 | 471.857 | 548.716 |
| 1 | LLOTH | West | all others except Japan | 223.705 | 288.546 | 288.546 | 288.546 |
| 18 | LLJPN | East | Japan | 1910.610 | 2279.000 | 2528.000 | 2801.000 |
| 18 | LLJPN | West | Japan | 345.827 | 407.480 | 407.480 | 407.480 |
| 4 | BBnew | East | France and Spain in Bay of Biscay | 867.174 | 1063.048 | 1176.124 | 1298.459 |
| 7 | PSMEDnew | Med | All PS except Croatia in Med | 13883.699 | 16293.163 | 18652.732 | 20837.709 |
| 8 | PSNOR | Med | Norway | 47.140 | 97.782 | 224.711 | 282.064 |
| 9 | PSHRV | Med | Croatia | 586.634 | 687.673 | 760.820 | 839.954 |
| 11 | PSWnew | West | USA,Canada | 0 | 0 | 0 | 0 |
| 13 | TPnew | East | Spain,Morocco and Portugal | 3362.447 | 4141.503 | 4616.081 | 5118.636 |
| 14 | RRCan | West | Canada | 344.120 | 427.690 | 427.690 | 427.690 |
| 15 | RRUSAFS | West | USA | 197.541 | 261.130 | 261.130 | 261.130 |
| 16 | RRUSAFB | West | USA | 597.108 | 878.632 | 878.632 | 878.632 |

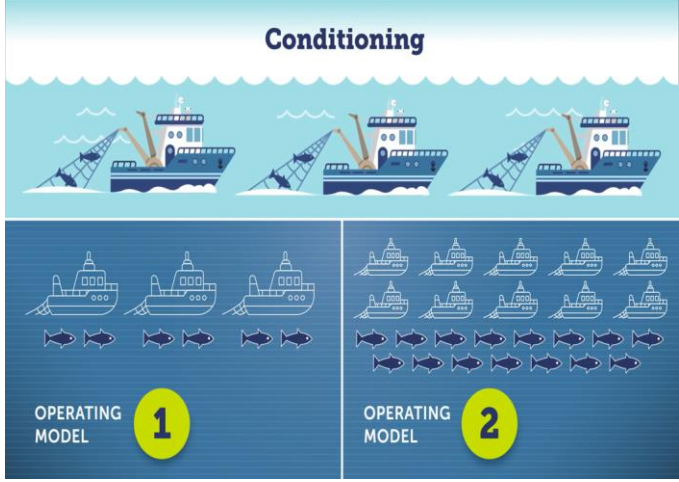
# BFT MSE – OM: fitting to data



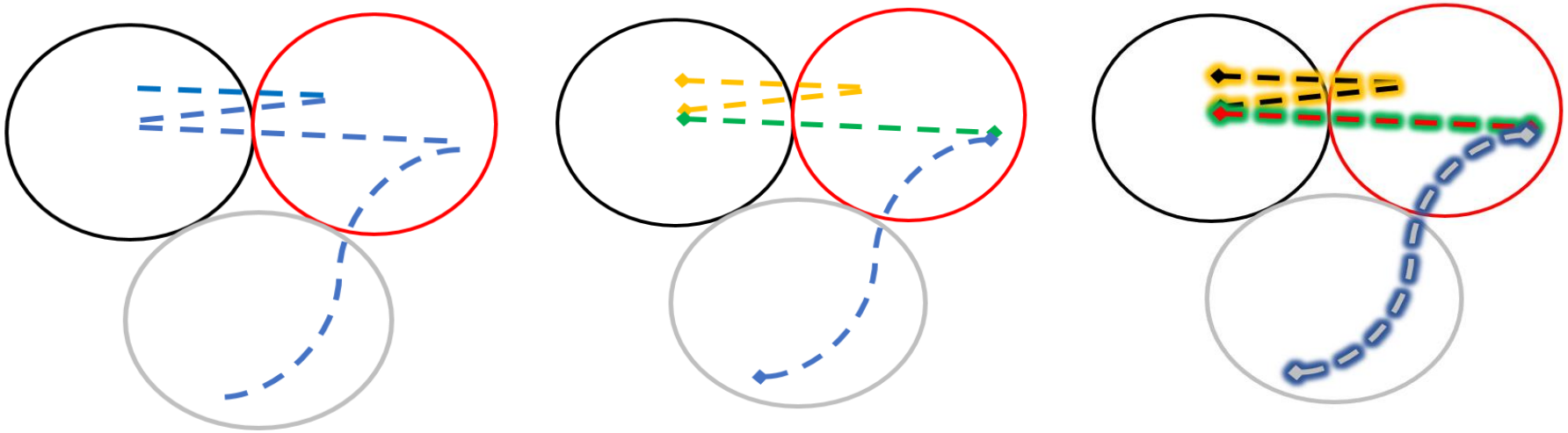

- Fishery- independent information:

| | Type |
|---|---|
| 1 | French aerial survey past |
| 2 | French aerial survey recent |
| 3 | Western Med Larval survey |
| 4 | Canadian acoustic survey |
| 5 | USA Larval survey |
| 6 | Aerial survey – GBYP* |

# BFT MSE – OM: fitting to data

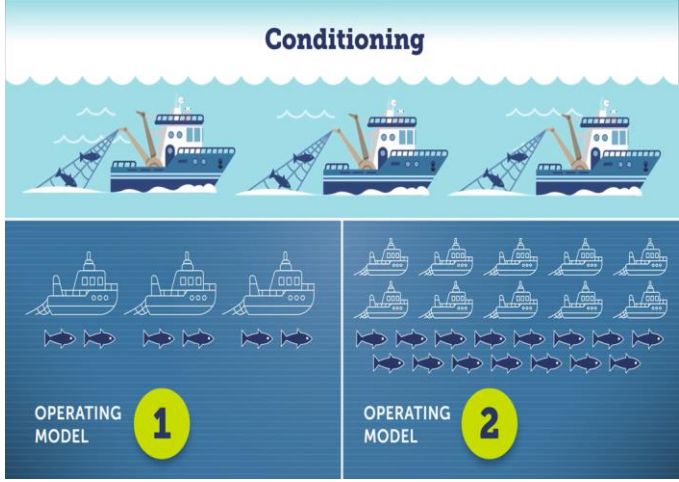



- E-TAGs for Spatial Transitions



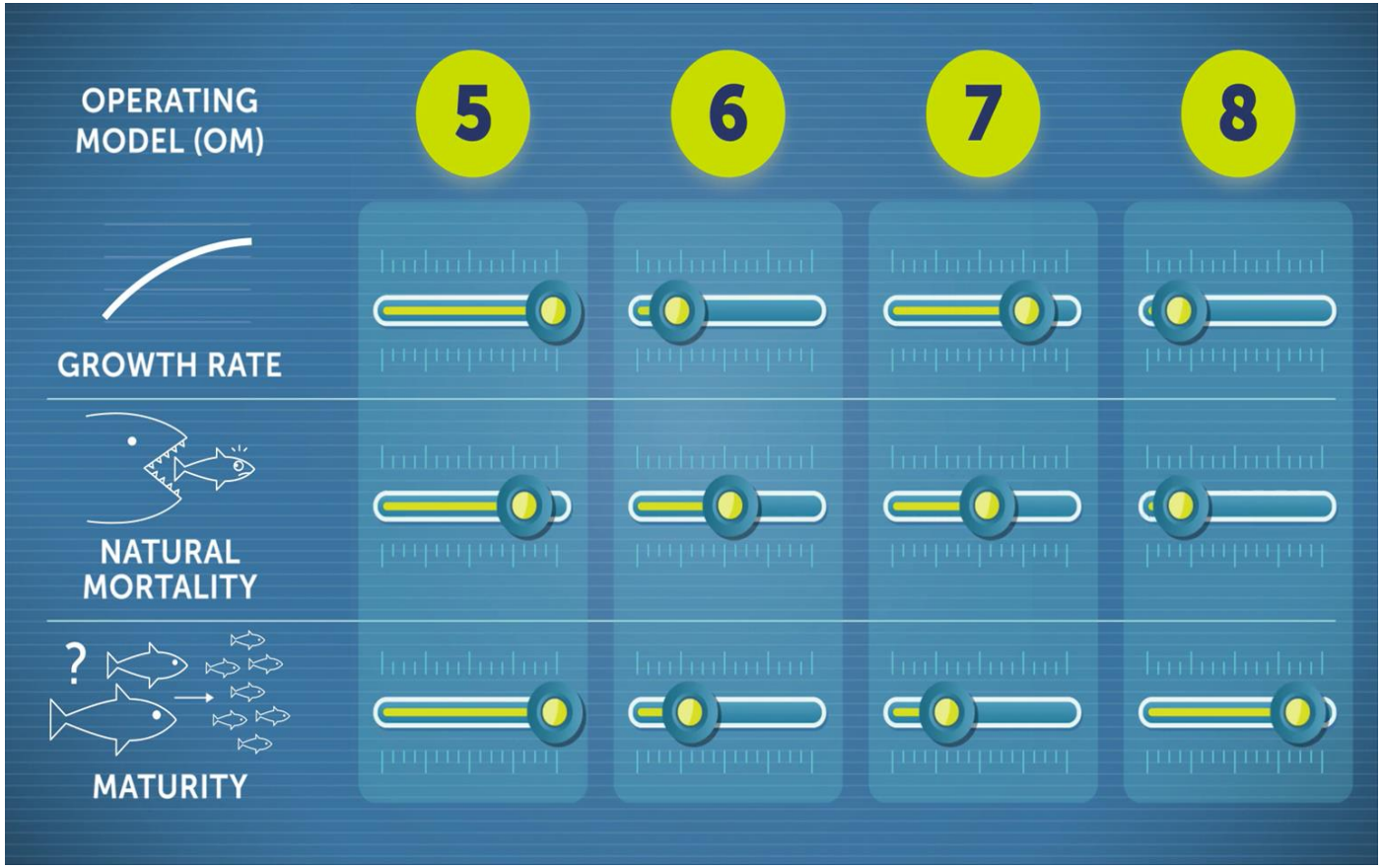
- NOAA, DFO, WWF, AZTI, UNIMAR, IEO, UCA, FEDERCOOPESCA, COMBIOMA, GBYP, IFREMER, Stanford University: 1307 tags, 598 tag transitions

# BFT MSE – OM: fitting to data




- Stock of Origin data from :
  - OTOLITHS MICROCHEMISTRY
  - GENETICS
- Others
  - Length-comp
  - Total catch
  - Index of SSB

# BFT MSE – OM: Uncertainty axes



# BFT MSE – OM: Uncertainty axes

| Factor: Recruitment | | |
|---|---|---|
| | Western stock | Eastern stock |
| level 1 | B-H with h=0.6 (“high R0”) switches to h = 0.9 (“low R0”) starting from 1975 | 50-87 B-H h=0.98 switches to 88+ B-H h=0.98 |
| level 2 | B-H with h=0.6 fixed, high R0 | B-H with h=0.7 fixed, high R0 |
| level 3 | Historically as in level 1. In projections, “low R0” switches back to “high R0” after 10 years | Historically as in level 1. In projections, 88+ B-H with h=0.98 switches back to 50-87 B-H with h=0.98 after 10 years |
| | | |
| Factor: Spawning fraction/Natural mortality rate for both stocks | | |
| level A | Younger spawning (E+W same)/High natural mortality | |
| level B | Older spawning (different for the 2 stocks)/Low natural mortality (with senescence) | |
| | | |
| Factor: Scale* | | |
| | West area | East area |
| level -- | 15kt | 200kt |
| level -+ | 15kt | 400kt |
| level +- | 50kt | 200kt |
| level ++ | 50kt | 400kt |
| | | |
| Factor: Length composition weighting in likelihood | | |
| level L | 0.05 | |
| level H | 1 | |

Reference Grid:
48 OMs

# BFT MSE – OM: Uncertainty axes

| **Length Comp Wt** | **L** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Scale** | -- | | -+ | | +- | | ++ | |
| **Spawn. Frac. / M** | A | B | A | B | A | B | A | B |
| **Recruitment: 1** | OM_1 | OM_4 | OM_7 | OM_10 | OM_13 | OM_16 | OM_19 | OM_22 |
| **Recruitment: 2** | OM_2 | OM_5 | OM_8 | OM_11 | OM_14 | OM_17 | OM_20 | OM_23 |
| **Recruitment: 3** | OM_3 | OM_6 | OM_9 | OM_12 | OM_15 | OM_18 | OM_21 | OM_24 |
| **Length Comp Wt** | **H** | | | | | | | |
| **Scale** | -- | | -+ | | +- | | ++ | |
| **Spawn. Frac. / M** | A | B | A | B | A | B | A | B |
| **Recruitment: 1** | OM_25 | OM_28 | OM_31 | OM_34 | OM_37 | OM_40 | OM_43 | OM_46 |
| **Recruitment: 2** | OM_26 | OM_29 | OM_32 | OM_35 | OM_38 | OM_41 | OM_44 | OM_47 |
| **Recruitment: 3** | OM_27 | OM_30 | OM_33 | OM_36 | OM_39 | OM_42 | OM_45 | OM_48 |

# BFT MSE – OM: Robustness test

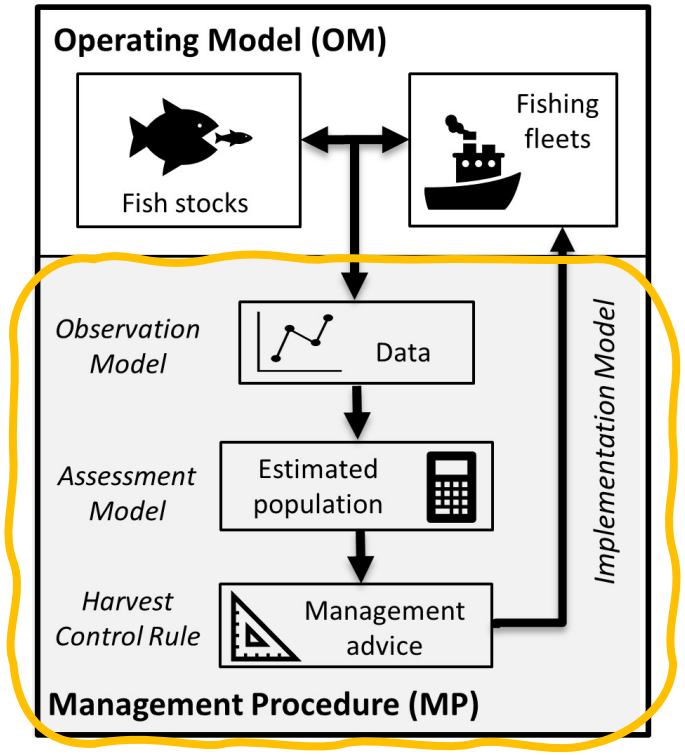
| Priority | Robustness test description |
|---|---|
| 1 | Western stock growth curve for eastern stock. |
| 2 | Catchability Increases. CPUE-based indices are subject to a 2% annual increase in catchability in the future. |
| 3 | Unreported overages. Future catches in both the West and East areas are 20% larger than the TAC as a result of IUU fishing (not known and hence not accounted for by the CMP). |
| 4 | High western mixing. The old mixing axis factor level 2: 20% western stock biomass in East area on average from 1965-2016. |
| 5 | 'Brazilian catches'. Catches in the South Atlantic, including relatively high takes during the 1950s and 60s, are reallocated from the western stock to the eastern stock. |
| 6 | Time varying mixing. Eastern stock mixing alternates between 2.5%and 7.5% every three years. |
| 7 | Non-linear indices. Hyperstability in OM fits to data is simulated in projection years for all indices. |
| 8 | Persistent change in mixing. Eastern mixing increases from 2.5% to 7.5% after 10 years. |
| 9 | Varying time of regime change in R3. |
| 10 | Intermediate parameter levels for M, growth, maturity, scale, regime shifts. |
| 11 | Zero eastern stock mixing. No Eastern stock in the West area. |
| 12 | Upweight US_RR_66_144 |

# BFT MSE – OM: Plausibility weighting

- Delphi approach
- through an online Poll (deadline February 14th)
- Poll characteristics:
    - Blind
    - Reflecting authorship
    - Default score for levels within an axis, and justification required when differing from it.

- Eligible participants: restricted to the attendees of 2020 December BFT meeting
- recruitment level R3 was considered less plausible than the other two R levels
- Process in standby

# BFT MSE – The Management Procedure(s) – MP / Harvest Strategies (HS)


Simulates different proceses:

- Data collection: observation model
- Assessment: Estimation/assessment model – status estimator
- Advice: Harvest Control Rules (HCR)
- Implementation.

41 cMPs

# BFT MSE – The Management Procedure(s) - MP

| CMP | Status estimator | Summary of HCR | References |
|---|---|---|---|
| AH | Biomass estimate calculated via larval indices and the associated catchability estimates. | TAC is a product of biomass estimate and F0.1 estimate. | SCRS/2020/144; SCRS/2021/122 |
| AI | Spawning and vulnerable biomass for each stock in each area are estimated by an artificial neural network. | Regional biomass fished at a fixed harvest rate. Uses CAPs, bottoms and variable TAC changes. | SCRS/2021/028 |
| BR | Weighted average of index J is used directly for each area, where weights are inverse variances (adjusted for autocorrelation) for each individual data series | TACs set using a relative harvest rate (Catch/J) from a reference year (2018) applied to the 2-year lagged moving average of the weighted index J. Quadratic decline in reference HR multipliers when J is below a nominated level. | SCRS/2021/121 |
| EA | Similar to BR, using a weighted average of index Icur. | Adjust TAC by ratio between Icur a target value T. | SCRS/2021/032; SCRS/2021/P/046 |
| HA | TAC is based on trend in indicator and biomass of a second indicator | Current index value relative mean of recent 3 years represents the harvest rate applied to the biomass estimated for a second indicator. | SCRS/2021/122 |
| LW | No biomass/stock status estimation, larval surveys used directly | Current relative HR is compared to the reference period relative HR, and TAC is adjusted based on their ratio. | SCRS/2020/129 |

# BFT MSE – The Management Procedure(s) - MP

| CMP | Status estimator | Summary of HCR | References |
|---|---|---|---|
| ND | No estimate used, just trends on indices. | TAC is updated using recent trend in indicator with restrictions on increase limited to 20%. | SCRS/2021/122 |
| PW | No biomass estimate is used | Current relative HR is compared to the reference period relative HR, and TAC is adjusted based on their (delta) ratio. | SCRS/2020/129 |
| SP | | | |
| TC | SSB and vulnerable B are estimated by averaging the available indices for the stock/area combination after scaling by 2016 estimates catchability. | TACy=TAC (y-1) but depending on F/Fmsy and B/Bmsy.Uses CAPs, bottoms and variable TAC changes. | SCRS/2020/150, SCRS/2020/165 |
| TN | Uses ratio Iratio of recent and lagged moving averages of indices to determine relative stock status | TAC calcualted based on the JPN_LL moving average, unless drastic drop of recruitment is detected by US_RR index. | SCRS/2020/151; SCRS/2021/041 |

# BFT MSE – Statistical indicators for performance

| | | |
|---|---|---|
| 1 | AvC10 | Mean catches over first 10 projected years |
| 2 | AvC30 | Mean catches over first 30 projected years |
| 3 | C10 | Mean catches over the first 10 projected years |
| 4 | C20 | Mean catches over projected years 11-20 |
| 5 | C30 | Mean catches over projected years 21-30 |
| 6 | D10 | Depletion (spawning biomass relative to dynamic B0) after the first 10 projected years |
| 7 | D20 | Depletion (spawning biomass relative to dynamic B0) after projection year 20 |
| 8 | D30 | Depletion (spawning biomass relative to dynamic B0) after projection yeare 30 |
| 9 | LD | Depletion (spawning biomass relative to dynamic B0) all projected years |
| 10 | DNC | Relative SSB (SSB relative to zero fishing) in final projection year |
| 11 | LDNC | Relative SSB (SSB relative to zero fishing) over all projection years |
| 12 | POS | Probability of Over-Fished status (B<BMSY) after 30 projected years |
| 13 | AAVC | Average Annual Variability in Yield over the first 30 projection years |
| 14 | AvgBr | Average Br (spawning biomass relative to dynamic SSBMSY) over projection years 11-30 |
| 15 | Br30 | Depletion (spawning biomass relative to dynamic BMSY) after projection yeare 30 |
| 16 | PGT | Probability Good trend: 1 minus probability of negative trend (Br31 â€“ Br35) and Br30 is less than 1 |

# ‘EA’ cMPs – updated progress

Andonegi E., Arrizabalaga H., Rouyer T., Gordoa A. and Rodriguez-Marín, E.

# cMPs for East and West BFT

| | EAST | WEST |
|---|---|---|
| Indices (weights) | • FR_AER_SUV2 (σ=0.76 -> w=1.740)<br>• MED_LAR_SUV (σ= 1.03 -> w=0.950)<br>• MOR_POR_TRAP (σ= 0.54 -> w=3.590)<br>• JPN_LL_NEAtl2 (σ= 0.62 -> w=2.610) | • GOM_LAR_SUV (σ= 0.70 -> w= 2.033)<br>• JPN_LL_West2 (σ= 0.57 -> w= 3.045)<br>• US_RR_66_144 (σ= 1.16 -> w= 0.744)<br>• MEXUS_GOM_PLL (σ= 0.52 -> w= 3.680) |
| Estimator (model) | • (a) Weighted mean – $EA_{2n+1}$(E) | • (a) Weighted mean – $EA_{2n+1}$(W) |
| $I_{tar}$ | • T (tuning) | • T (tuning) |
| Observation | • Perfect | • Perfect |
| Delta on TAC | • [-15%, +15%] | • [-15%, +15%] |





* $\sigma = \frac{STD}{(1-AC)}$ . STD and AC values are taken from SCRS/2021/124-Appendices F&G.

# cMPs for East and West BFT

Status estimator

$EA_{2n+1}$ cMP

$$I_{cur} = \frac{\sum_i^n w_i * I_{i,y}^*}{\sum_i^n w}$$

$$I_{cur\,av,y} = \frac{1}{3}\left(I_{cur\,y} + I_{cur\,y-1} + I_{cur\,y-2}\right)$$

where

$$I_{i,y}^* = \frac{I_{i,y}}{\sum_{y=1}^{i} I_{i,y}}$$

and

$$w = \frac{1}{\sigma_i^2}$$

# cMPs for East and West BFT

HCR

$$TAC_{y+1} = \begin{cases} TAC_y * I_{tar_n} & if \quad 0.85 < I_{tar_n} < 1.15 \\ TAC_y * 0.85 & if \quad I_{tar_n} \leq 0.85 \\ TAC_y * 1.15 & if \quad I_{tar_n} \geq 1.15 \end{cases}$$



where

$$I_{tar} = {}^{I_{cur}}/_{Targ}$$

and

$$I_{tar_n} = \gamma * I_{tar} + (1 - \gamma)$$

$$\gamma = 0.15$$

# Management objectives

| Br30 levels | | CMP tuning options (values are given in the order of West-East) | cMPs |
|---|---|---|---|
| Western | Eastern | Paired plus (n=4) | EA |
| 1.00 | 1.00 | 1.00 – 1.00 | EA1 |
| 1.25 | 1.25 | 1.25 – 1.25 | EA2, EA2_6, EA2_10 |
| | | 1.25- 1.50 | EA3, EA3_8, EA3_11 |
| 1.50 | 1.50 | 1.50 – 1.50 | EA4 |



| | |
|---|---|
| EA1 | EA_1 is CMP that uses weighted mean, tuned to Br30_W=1 & BR30_E=1 |
| EA2 | EA_2 is CMP that uses weighted mean, tuned to Br30_W=1.25 & BR30_E=1.25 |
| EA2_6 | EA_6 is CMP that uses weighted mean, with CAP in 40000, tuned to Br30_W=1.25 & BR30_E=1.25 |
| EA2_10 | EA_10 is CMP that uses weighted mean, with CAP in 40000, with lower TAC variation above 20000, tuned to Br30_W=1.25 & BR30_E=1.25 |
| EA3 | EA_3 is CMP that uses weighted mean, tuned to Br30_W=1.25 & BR30_E=1.50 |
| EA3_8 | EA_8 is CMP that uses weighted mean, with CAP in 40000, tuned to Br30_W=1.25 & BR30_E=1.50 |
| EA3_11 | EA_11 is CMP that uses weighted mean, with CAP in 40000, with lower TAC variation above 20000,tuned to Br30_W=1.25 & BR30_E=1.50 |
| EA4 | EA_4 is CMP that uses weighted mean, tuned to Br30_W=1.50 & BR30_E=1.50 |

# Results

Performance statistics

EAST

| | Br30 | AvC30 | AAVC |
|---|---|---|---|
| EA1 | 1.01 | 45.3 | 7.54 |
| EA2 | 1.26 | 41.37 | 6.54 |
| EA2_6 | 1.25 | 40.02 | 0 |
| EA2_10 | 1.26 | 38.83 | 1 |
| EA3 | 1.49 | 37.02 | 5.61 |
| EA3_8 | 1.49 | 39.62 | 0 |
| EA3_11 | 1.55 | 38.66 | 1 |
| EA4 | 1.5 | 37.33 | 5.75 |

WEST

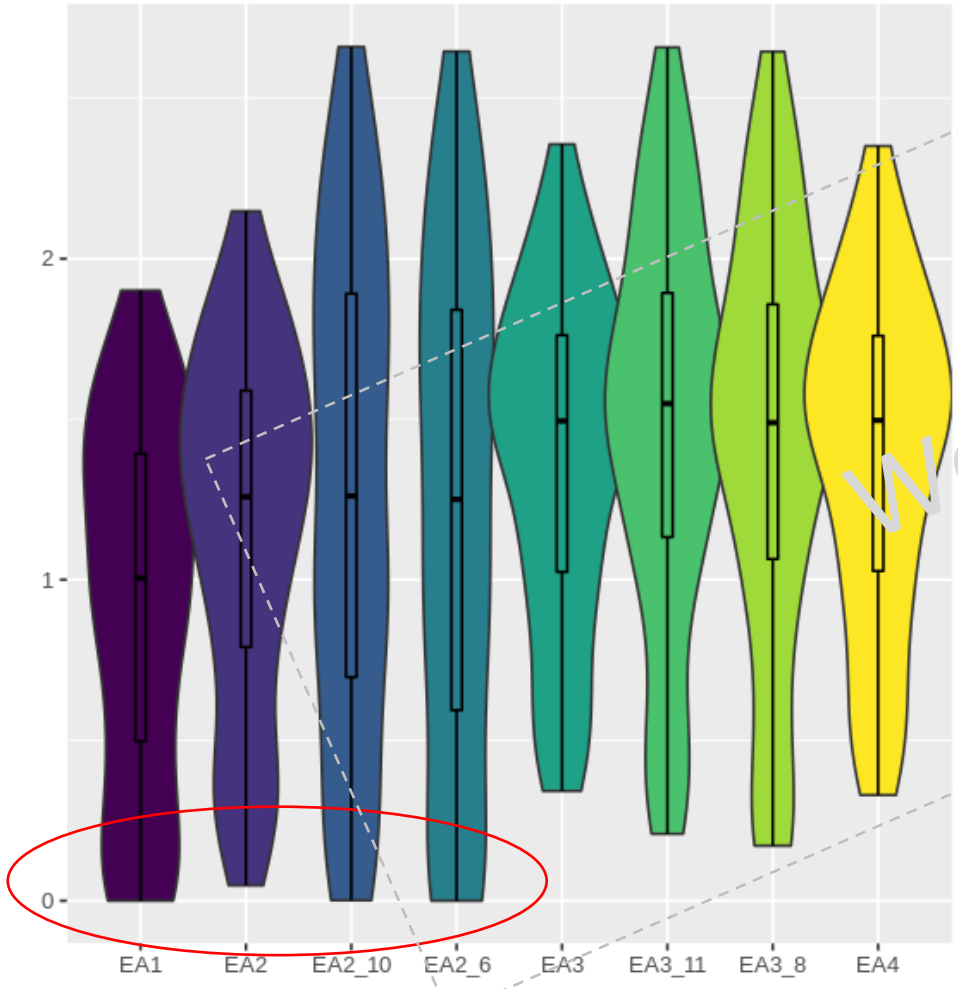
| | Br30 | AvC30 | AAVC |
|---|---|---|---|
| EA1 | 1.02 | 3.33 | 6.11 |
| EA2 | 1.25 | 2.26 | 5.37 |
| EA2_6 | 1.26 | 2.16 | 5.68 |
| EA2_10 | 1.25 | 2.2 | 5.67 |
| EA3 | 1.25 | 2.37 | 5.78 |
| EA3_8 | 1.25 | 2.32 | 5.54 |
| EA3_11 | 1.25 | 2.32 | 5.63 |
| EA4 | 1.5 | 1.86 | 4.95 |

# Results

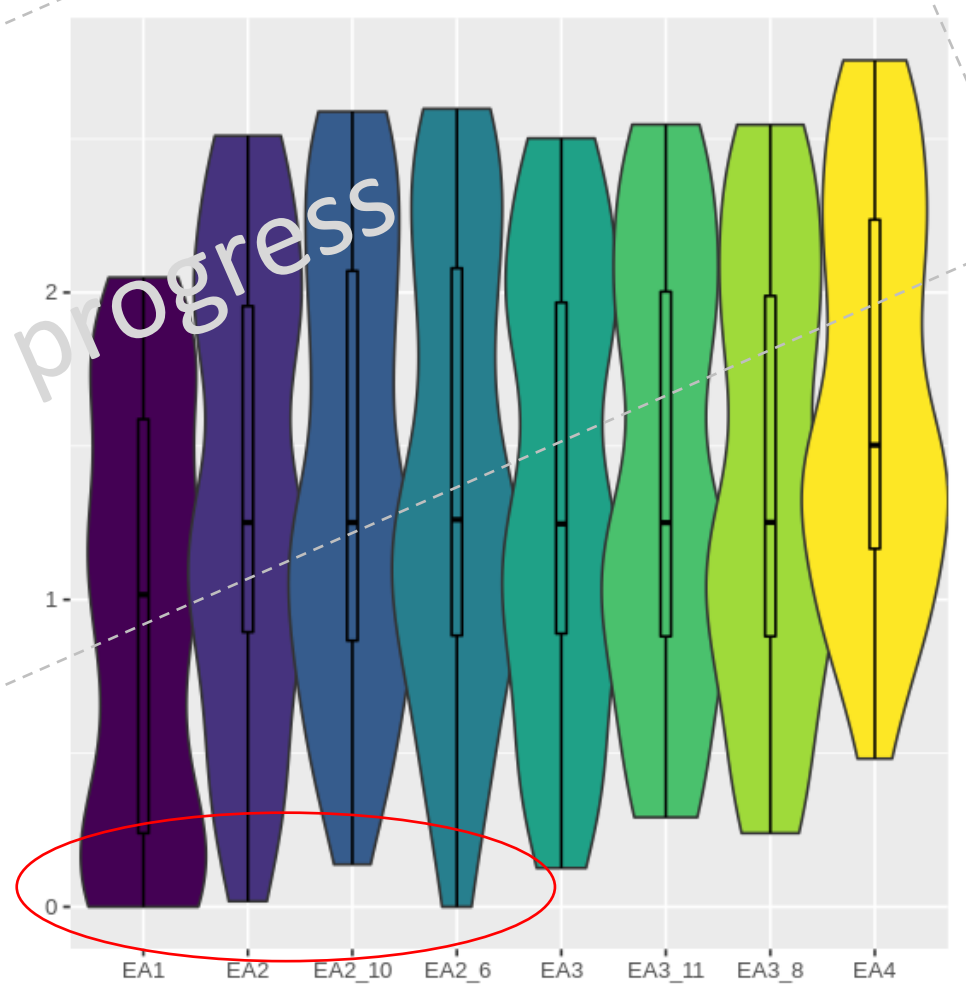
Performance statistics

BR30

EAST




WEST

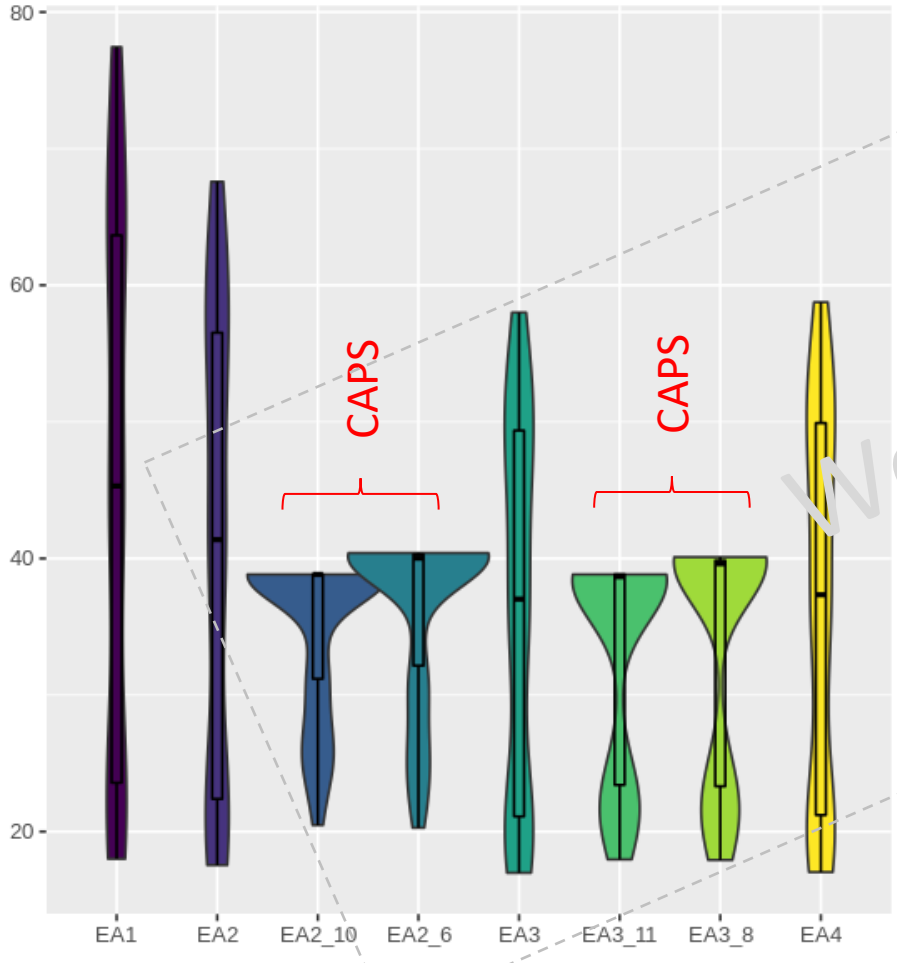


# Results

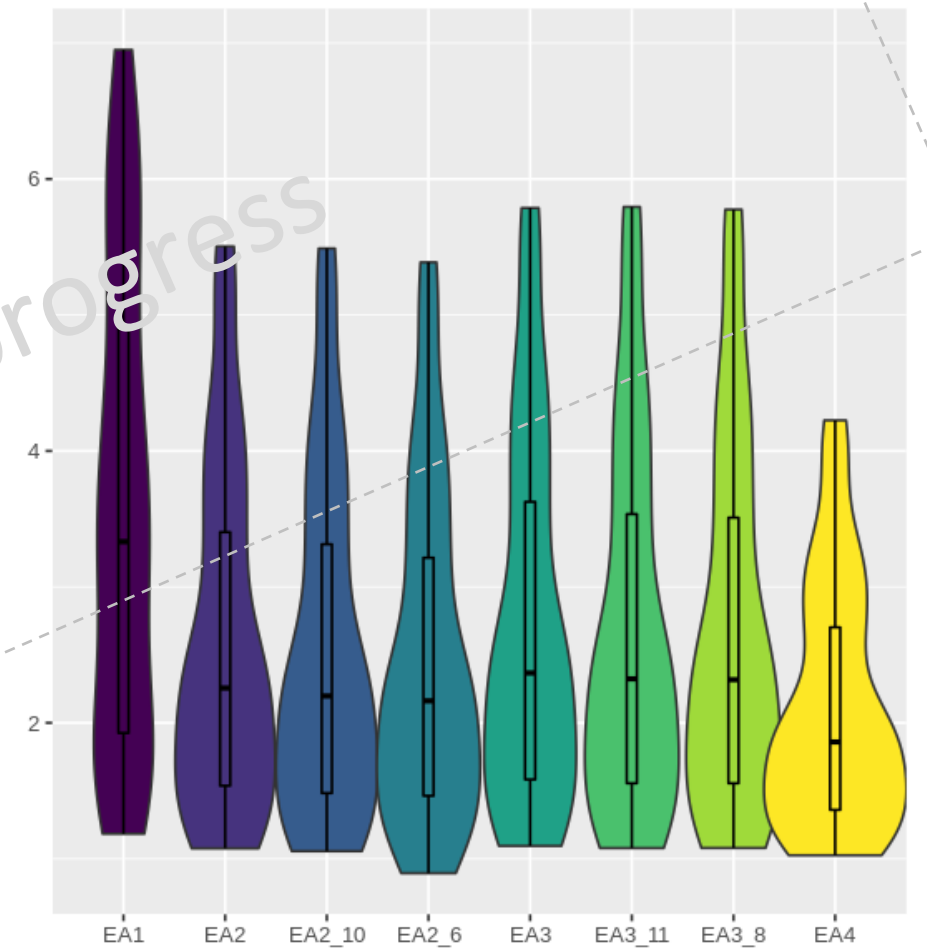
Performance statistics

AvC30

EAST



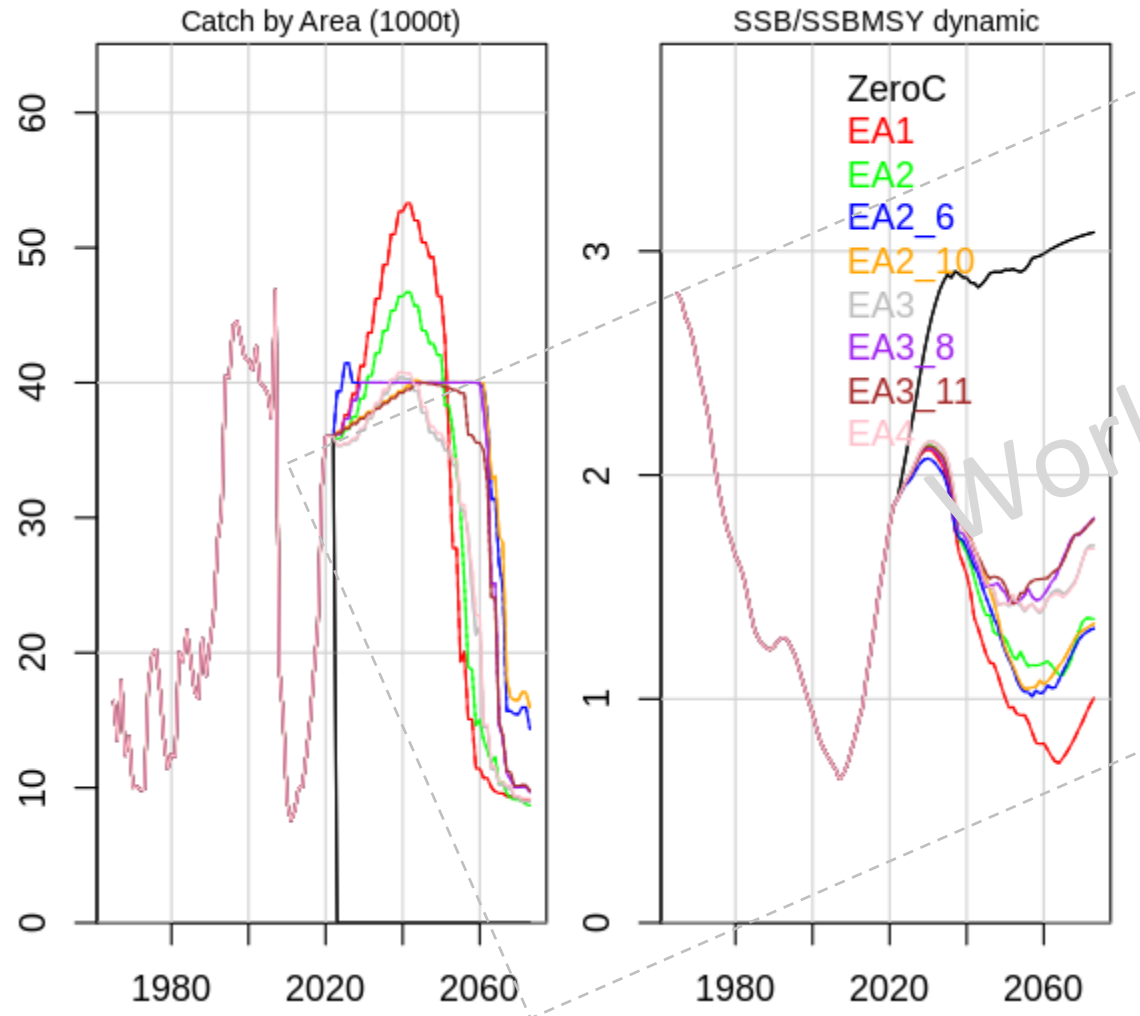

WEST



# Results

Projections…

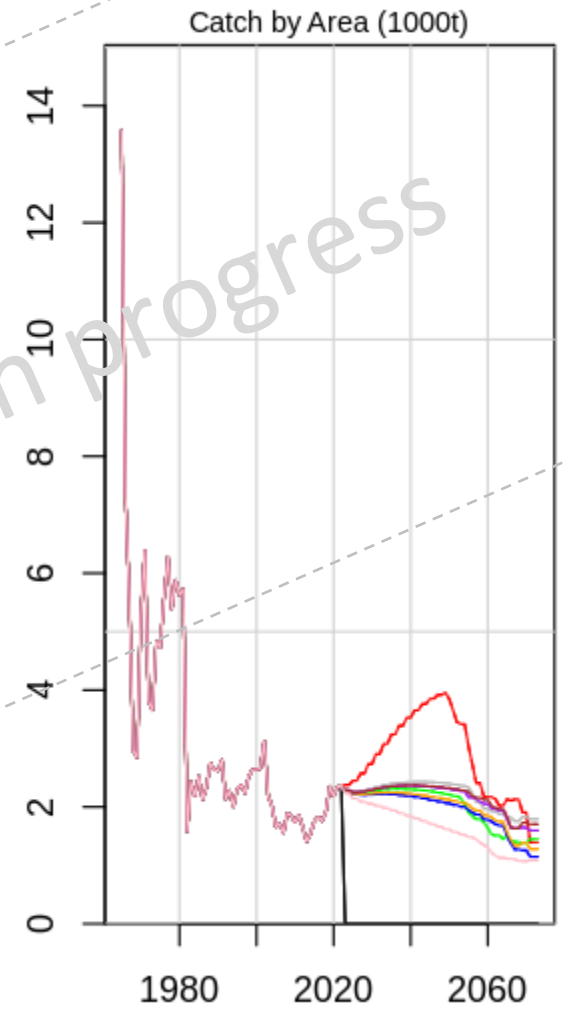
EAST

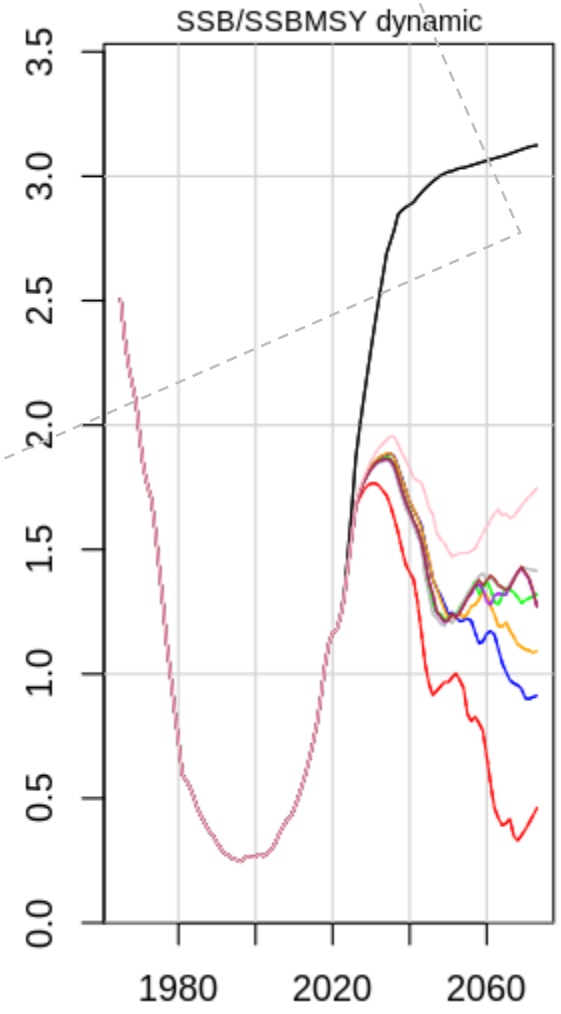






WEST

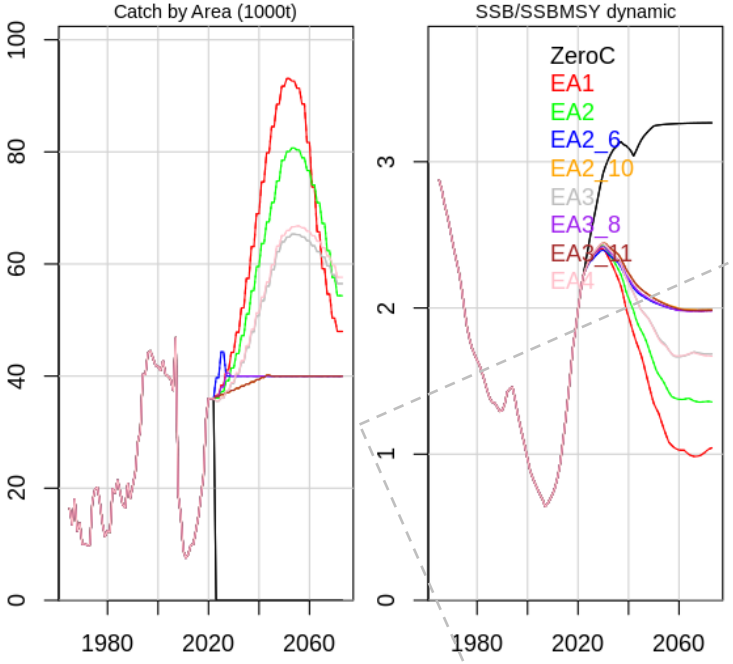


# Results

Projections by R-type… EAST

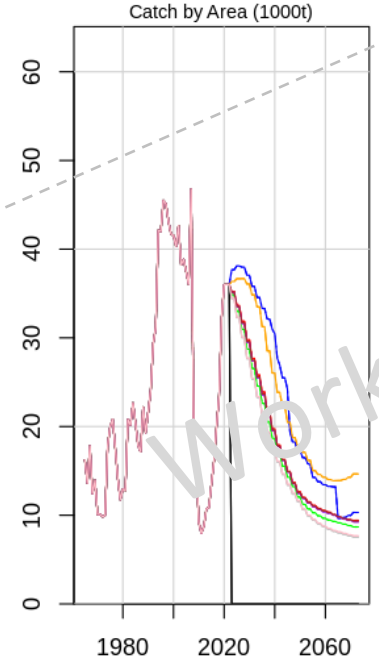
R1

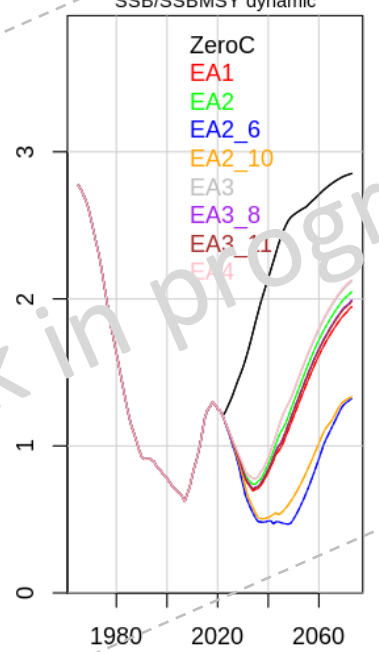




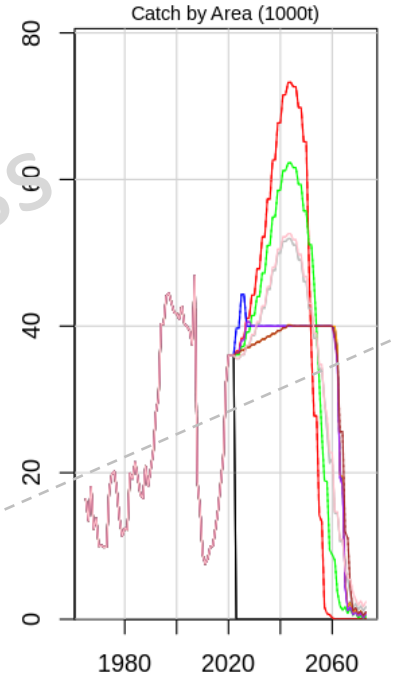


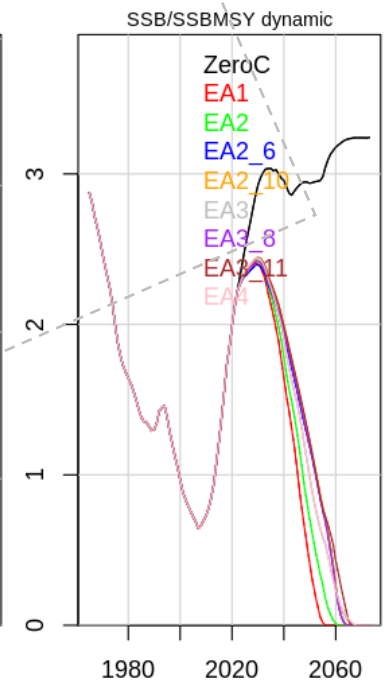
R2




R3



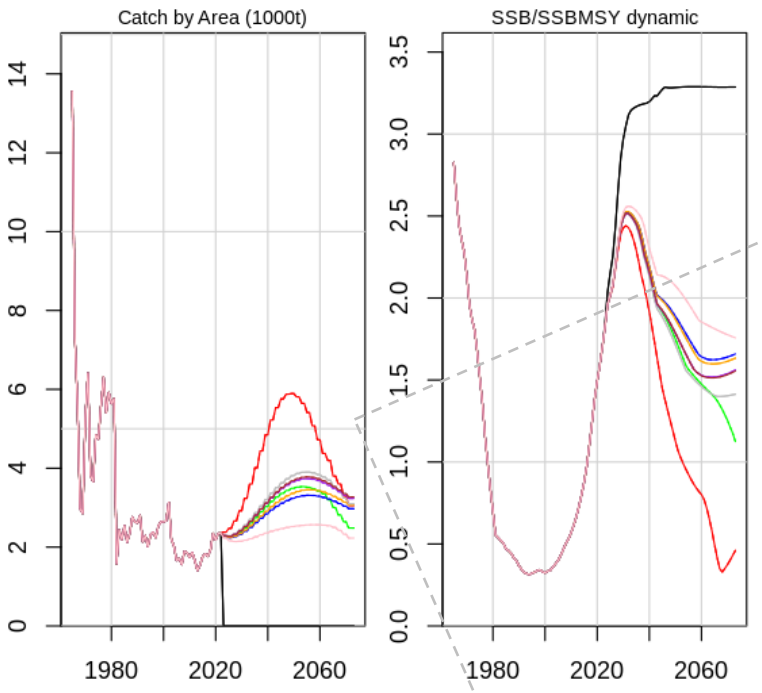



Recruitment axis still most important influence on CMP biomass and yield performance.

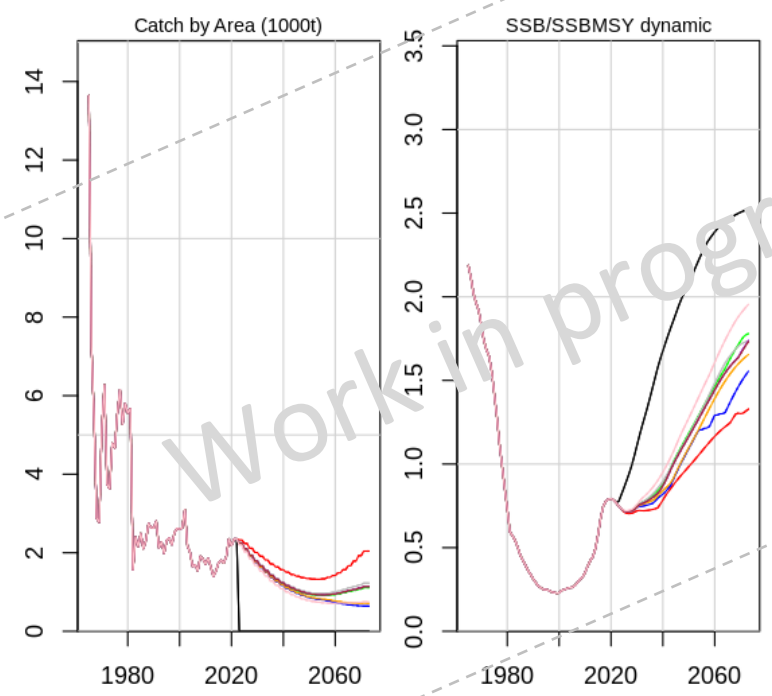
# Results

Projections by R-type… WEST

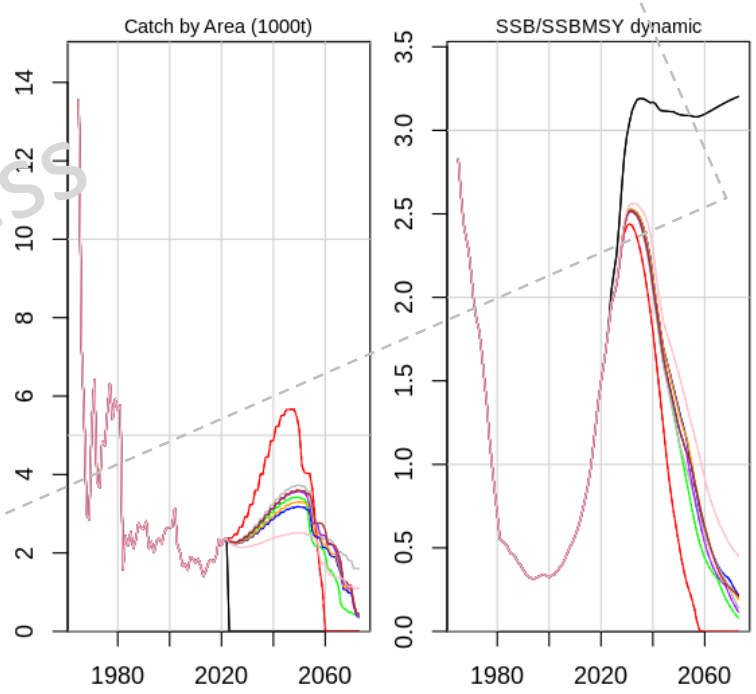
R1




R2



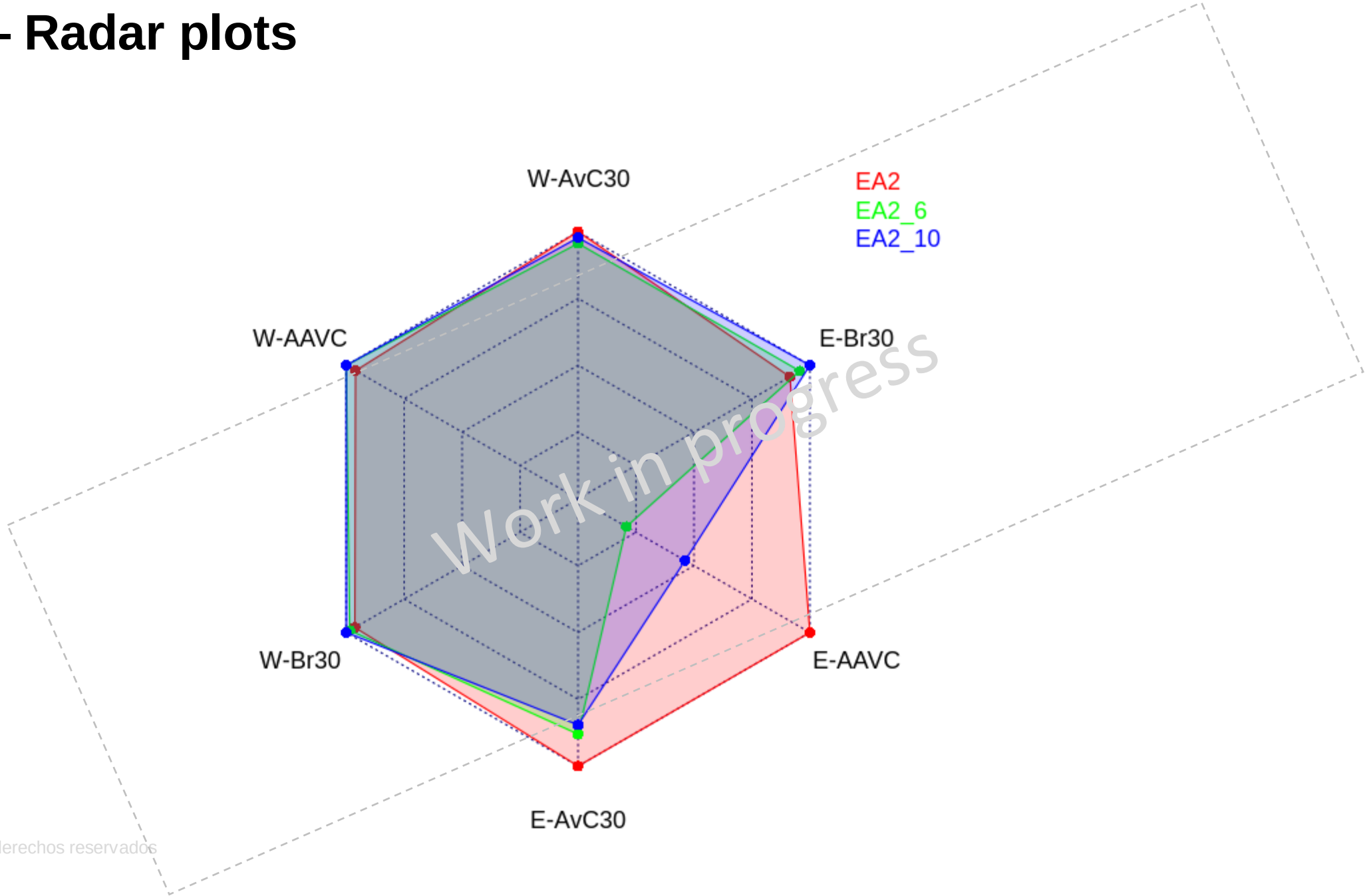

R3





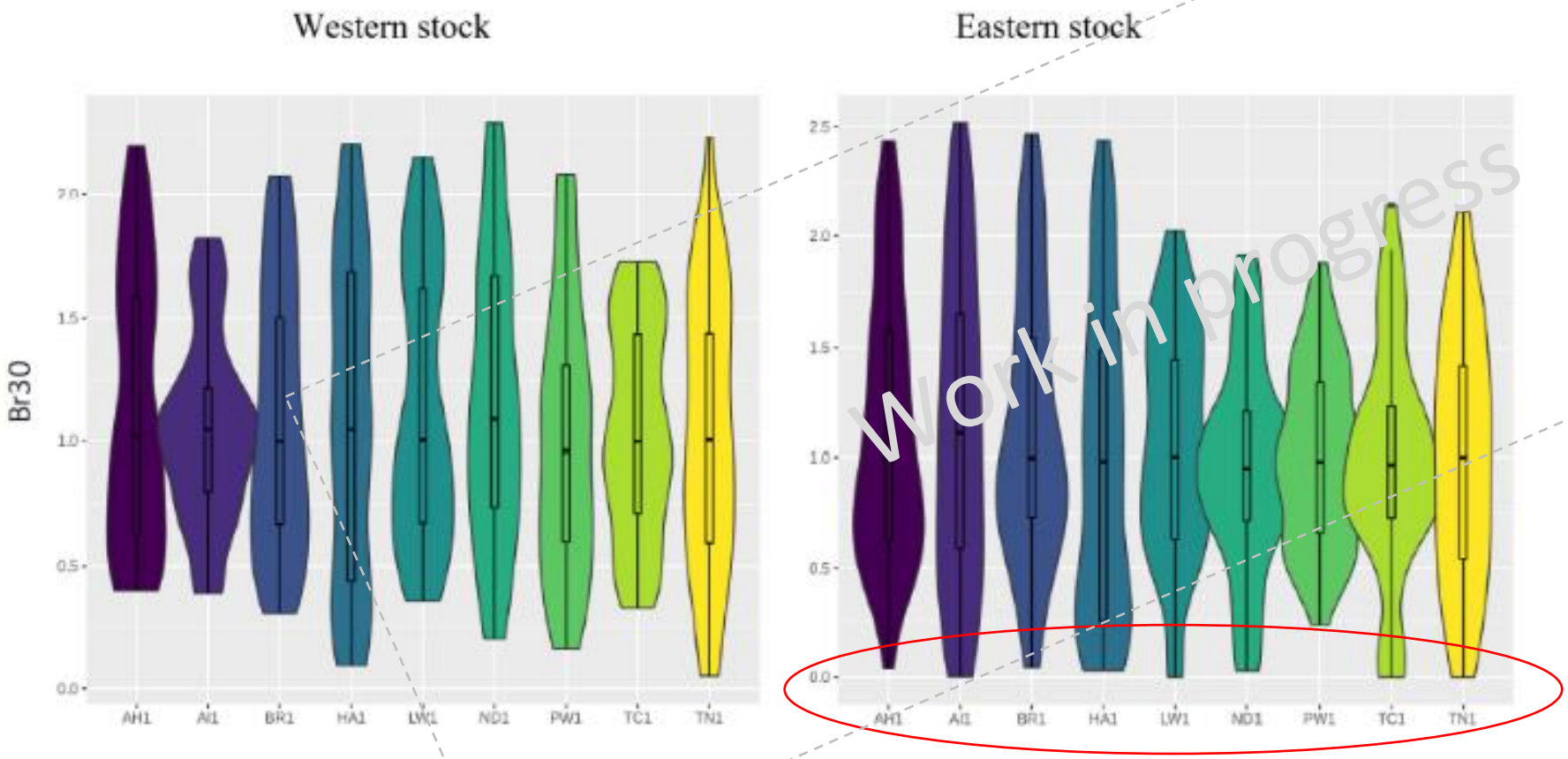

Recruitment axis still most important influence on CMP biomass and yield performance.

# Results – Radar plots



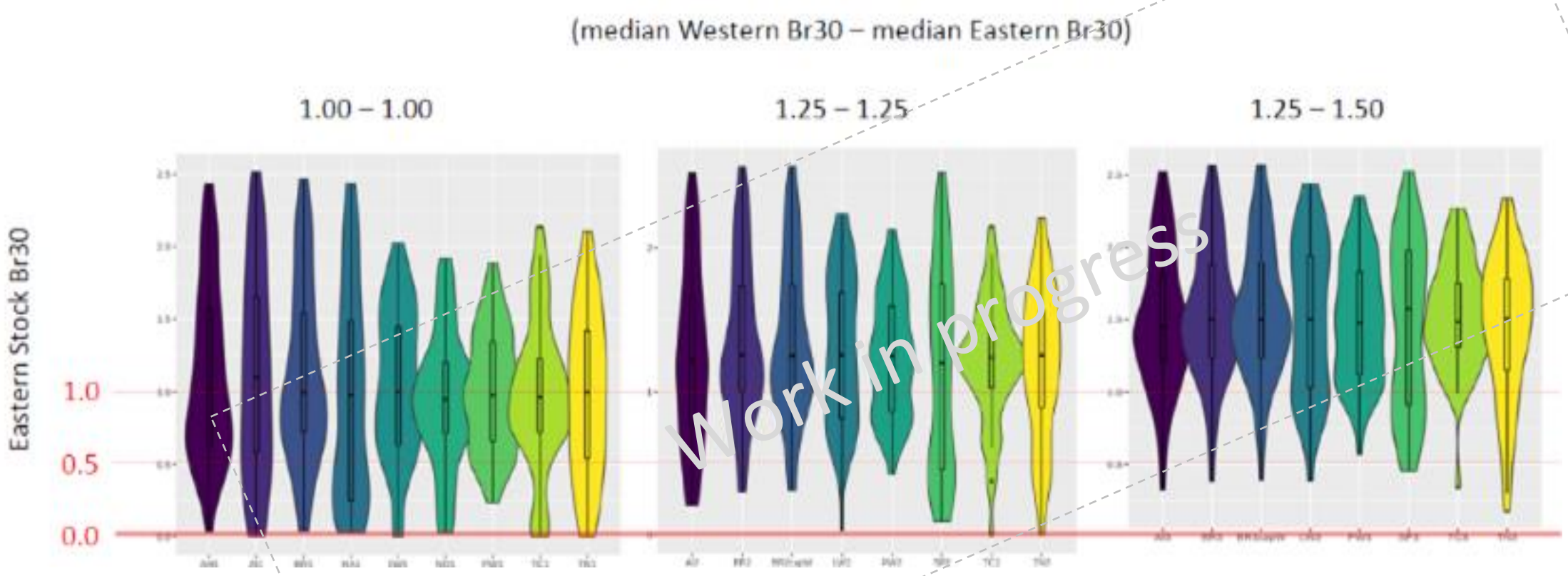
# Other cMPs

Br30=1 for both stocks




Some problems for the Eastern stock.

# Other cMPs




Also problems with the 1.25 tuning objective

# Other cMPs - ranking

| CMP | Mean Ranking | West area / western stock AvC30 0.00 | West area / western stock AAVC 0.00 | West area / western stock Br30 5% 1.94 | East area / Eastern stock AvC30 0.00 | East area / Eastern stock AAVC 0.00 | East area / Eastern stock Br30 5% 2.51 |
|---|---|---|---|---|---|---|---|
| ***Br30 1.25 - 1.50*** *(Western - Eastern) development tuning* | | | | | | | |
| AI3 | 2.3 | 3.33 | 6.70 | 0.84 | 39.71 | 0.00 | 0.66 |
| BR3 | 4.2 | 3.27 | 11.24 | 0.64 | 38.16 | 1.52 | 0.79 |
| BR3capW | 4.8 | 2.93 | 10.43 | 0.80 | 38.11 | 1.35 | 0.80 |
| LW3 | 5.5 | 2.89 | 6.05 | 0.83 | 33.77 | 12.41 | 0.83 |
| PW3 | 5.2 | 3.17 | 7.08 | 0.46 | 37.94 | 10.85 | 0.96 |
| SP3 | 5.2 | 3.12 | 2.17 | 0.57 | 36.65 | 1.63 | 0.65 |
| TN3 | 5.7 | 3.26 | 8.86 | 0.18 | 39.48 | 10.69 | 0.49 |
| TC3 | 3.3 | 3.36 | 6.70 | 0.65 | 37.16 | 7.42 | 1.01 |
| ***Br30 1.50 - 1.50*** *(Western - Eastern) development tuning* | | | | | | | |
| AI4 | 1.8 | 2.99 | 6.28 | 0.98 | 39.69 | 0.00 | 0.66 |
| BR4 | 4.0 | 2.51 | 9.86 | 0.86 | 38.14 | 1.32 | 0.80 |
| LW4 | 4.7 | 2.16 | 5.60 | 0.83 | 34.00 | 12.36 | 0.83 |
| PW4 | 4.2 | 2.53 | 8.41 | 0.68 | 38.28 | 10.93 | 0.96 |
| SP4 | 5.2 | 2.50 | 15.52 | 0.81 | 36.97 | 1.27 | 0.66 |
| TN4 | 4.7 | 2.90 | 8.98 | 0.34 | 39.68 | 10.87 | 0.50 |
| TC4 | 3.2 | 2.77 | 7.24 | 0.83 | 37.17 | 7.58 | 1.02 |

# Glossary

https://harveststrategies.org/what-are-harvest-strategies/glossary/


Eskerrik asko
Gracias
Merçi
Thanks