Model based CMPs using multi-model inference

Second Intersessional Meeting of the ICCAT Bluefin Tuna MSE group

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Background

- The reference set of operating models for ABFT encompasses a range of uncertainties about:
    - Current stock status;
    - East/West stock mixing; and
    - Population parameters, including
        - past and future recruitment/productivity,
        - unfished/initial biomass

CMP design overview

We designed CMPs that estimated stock and area specific biomass using muti-model ensembles of multi-stock Delay Difference assessment models.

- Assessment models (AMs) were all tuned to fit historical biomass from a subset of 5 OMs from the reference grid

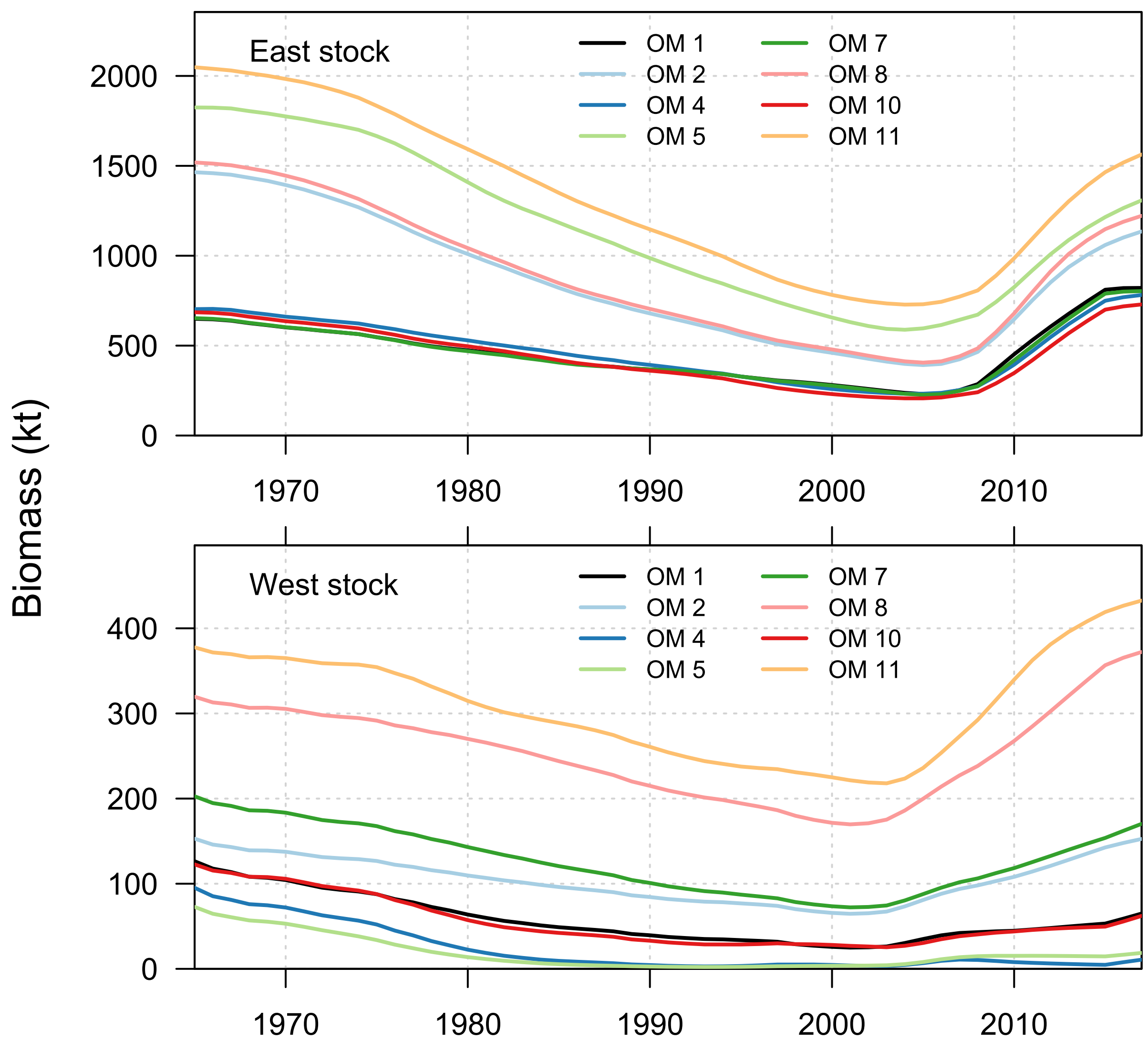
- Biological reference points were estimated from each AM, and used in Harvest Control Rules to produce TACs from estimated biomass

- TACs were then averaged to produce a final TAC for each area

DD model allows us to emulate age-structured AMs, and produces reference points that are often reasonable approximations

AMs are tuned to 5 OM biomass histories

- We chose 5 OMs (1, 2, 4, 7, 11) to span the range of biomass histories for both E and W stocks
- This gives 5 AMs: one for each OM
- Ensures that AMs give reasonable biological parameter estimates at start of projection period, given short index series



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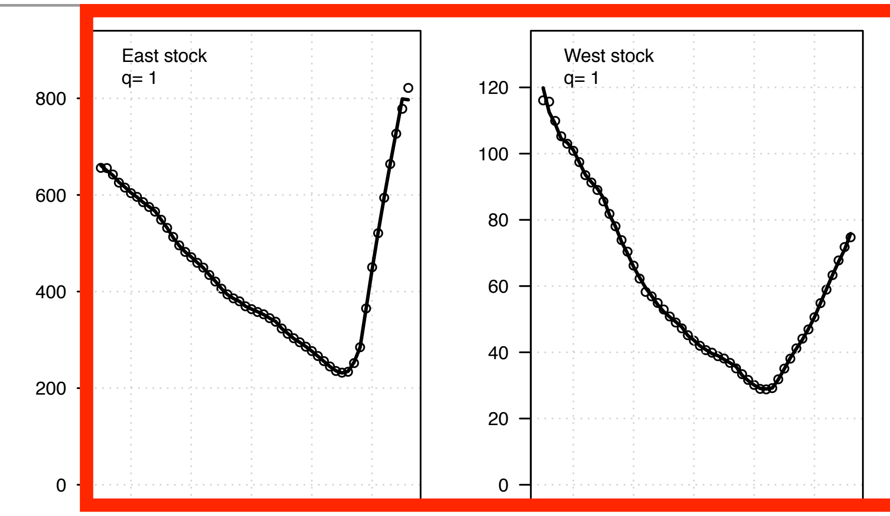

OM Biomass

Biomass (kt)

Fit of AM 1 to OM 1

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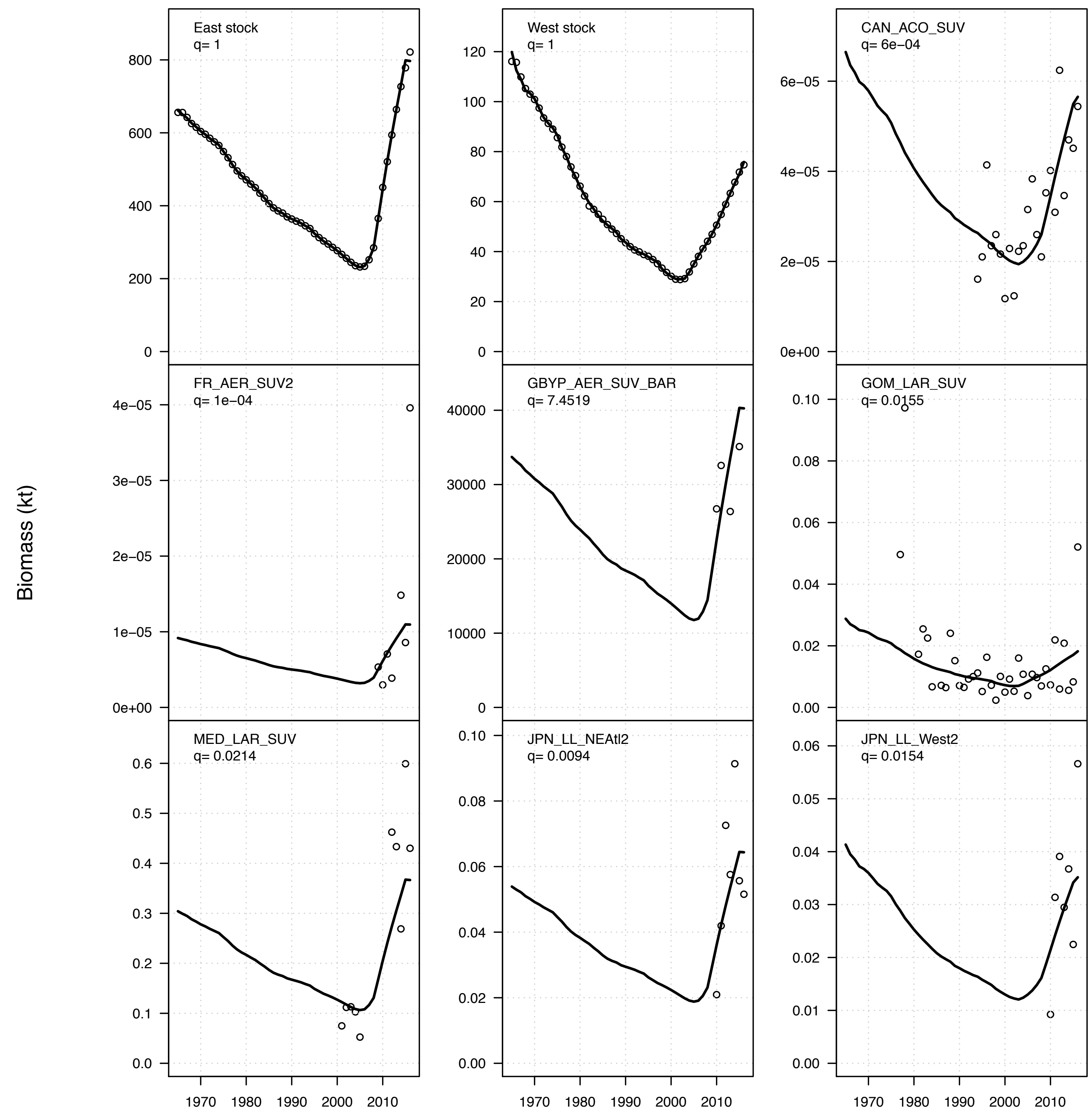
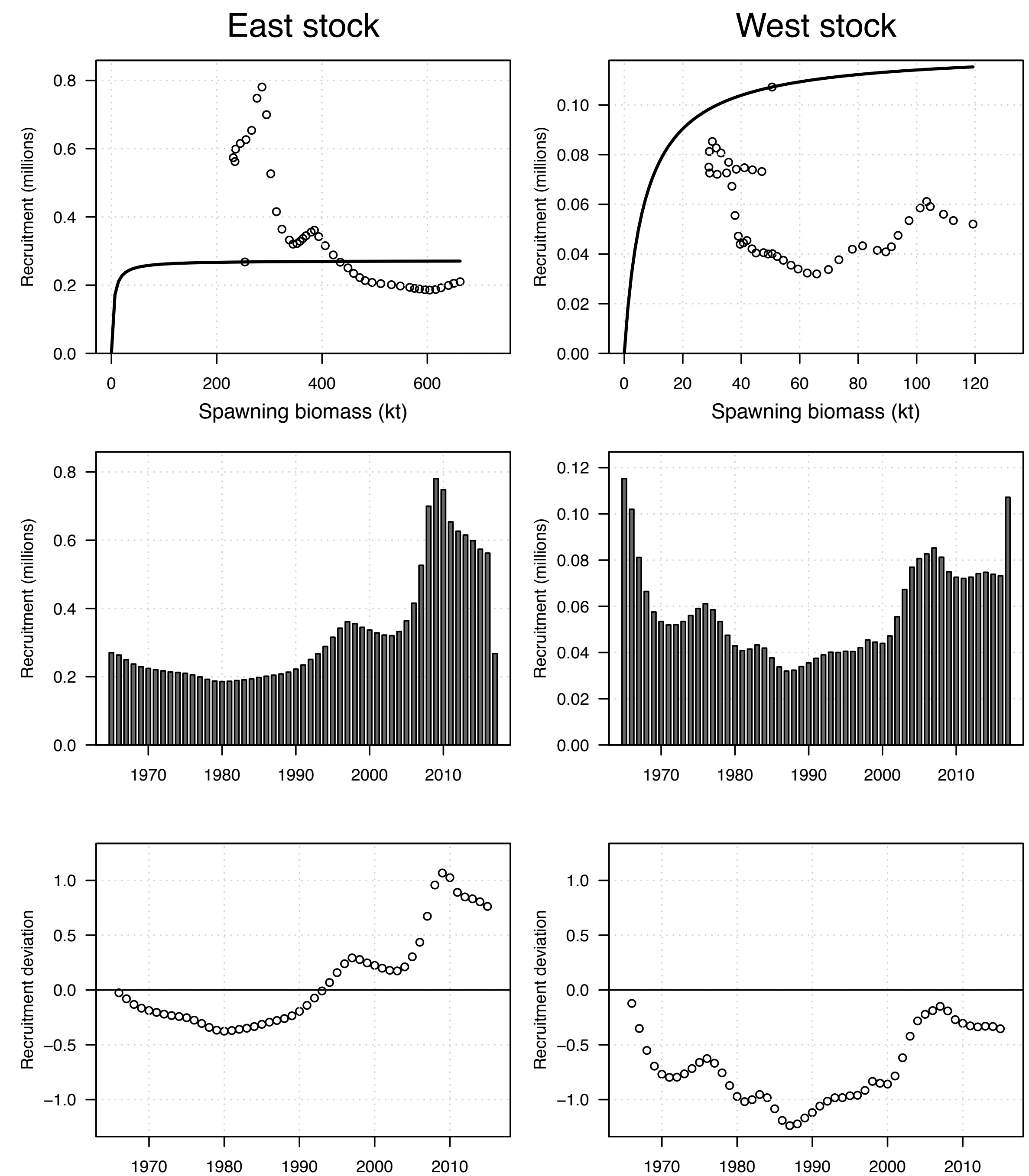


Fit of AM 1 to OM 1

AMs use AR1 random walk in recruitment process errors

- Better tracks OMs with dynamic Stock-Recruit regimes

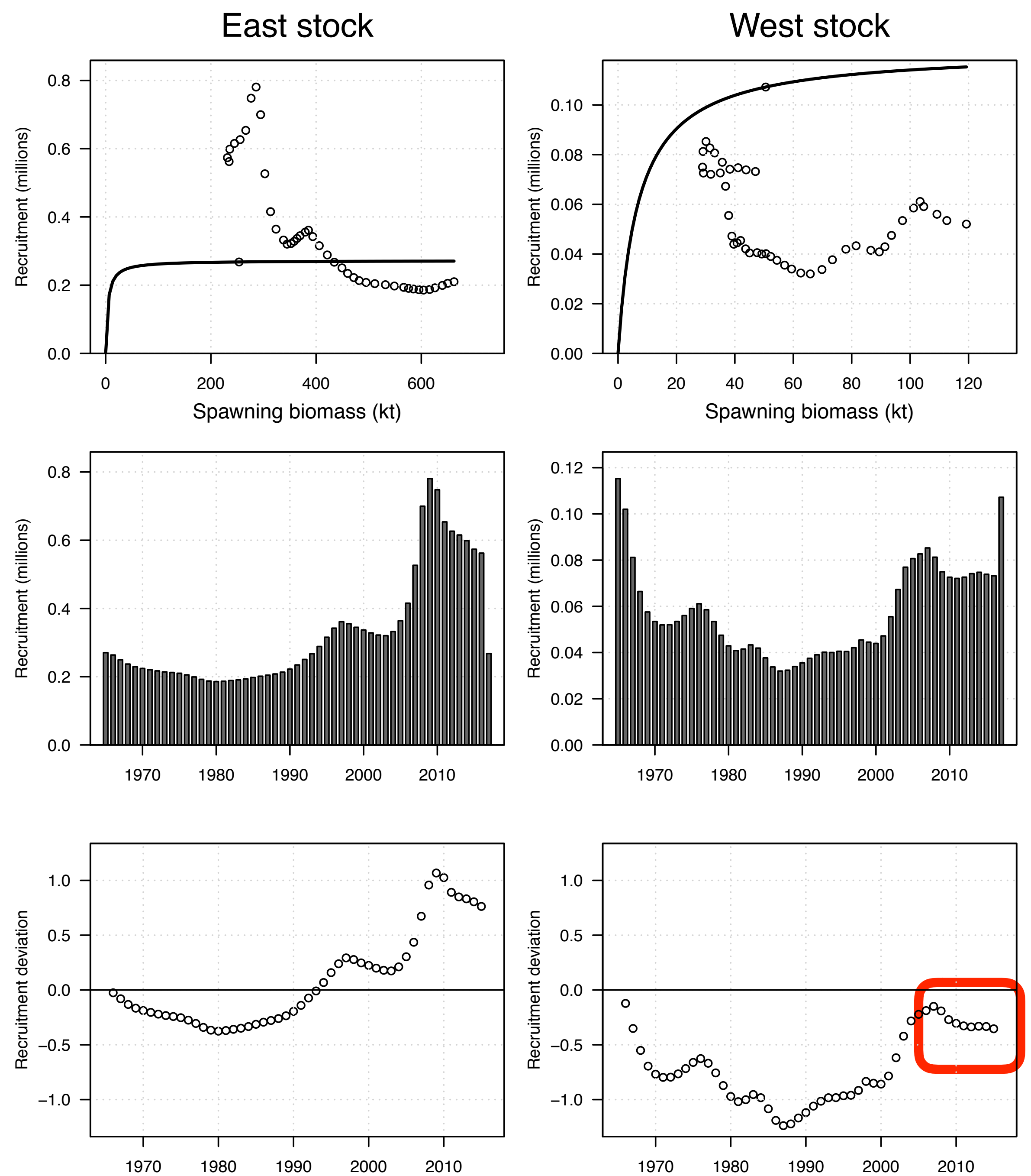
- Short-term biomass projections for use in HCRs will incorporate recruitment that is more like “last-year”, rather than just off SR curve



Fit of AM 1 to OM 1

AMs use AR1 random walk in recruitment process errors

- Better tracks OMs with dynamic Stock-Recruit regimes
- Reduces effect of using average recruitment in projections: short-term biomass projections for use in HCRs will use recruitment that is more like “last-year” than S-R curve

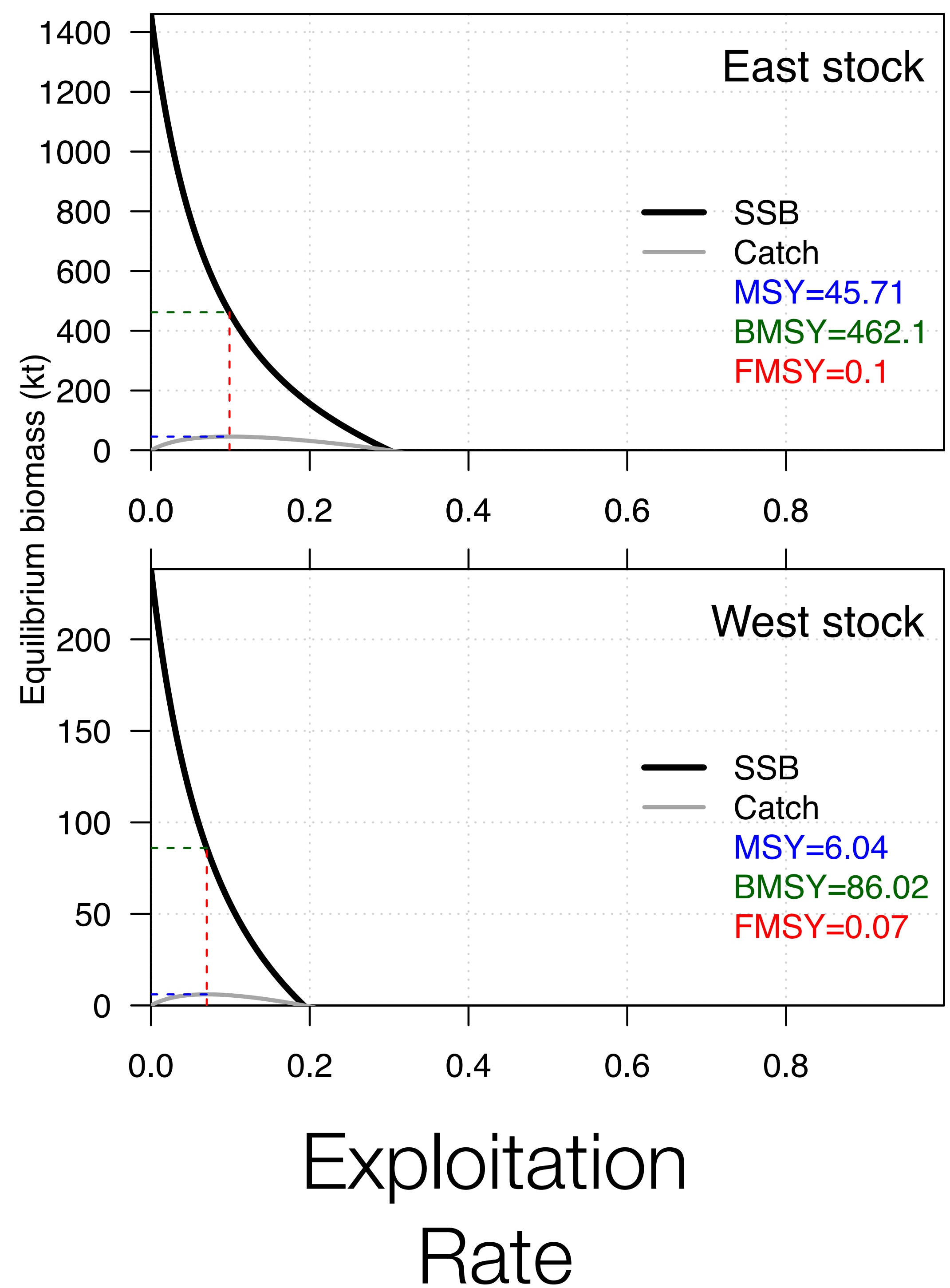


Fit of AM 1 to OM 1

DD reference points are estimated for both stock and area

- Our MP estimates biological reference points for each AM in the ensemble
- Reference points are calculated from DD model equilibria (Hilborn and Walters, 1992)
- Complexity mismatch (DD AM vs Age-structured OM) explains part of the difference here
- Area-based BRPs are biomass weighted averages of stock-based BRPs

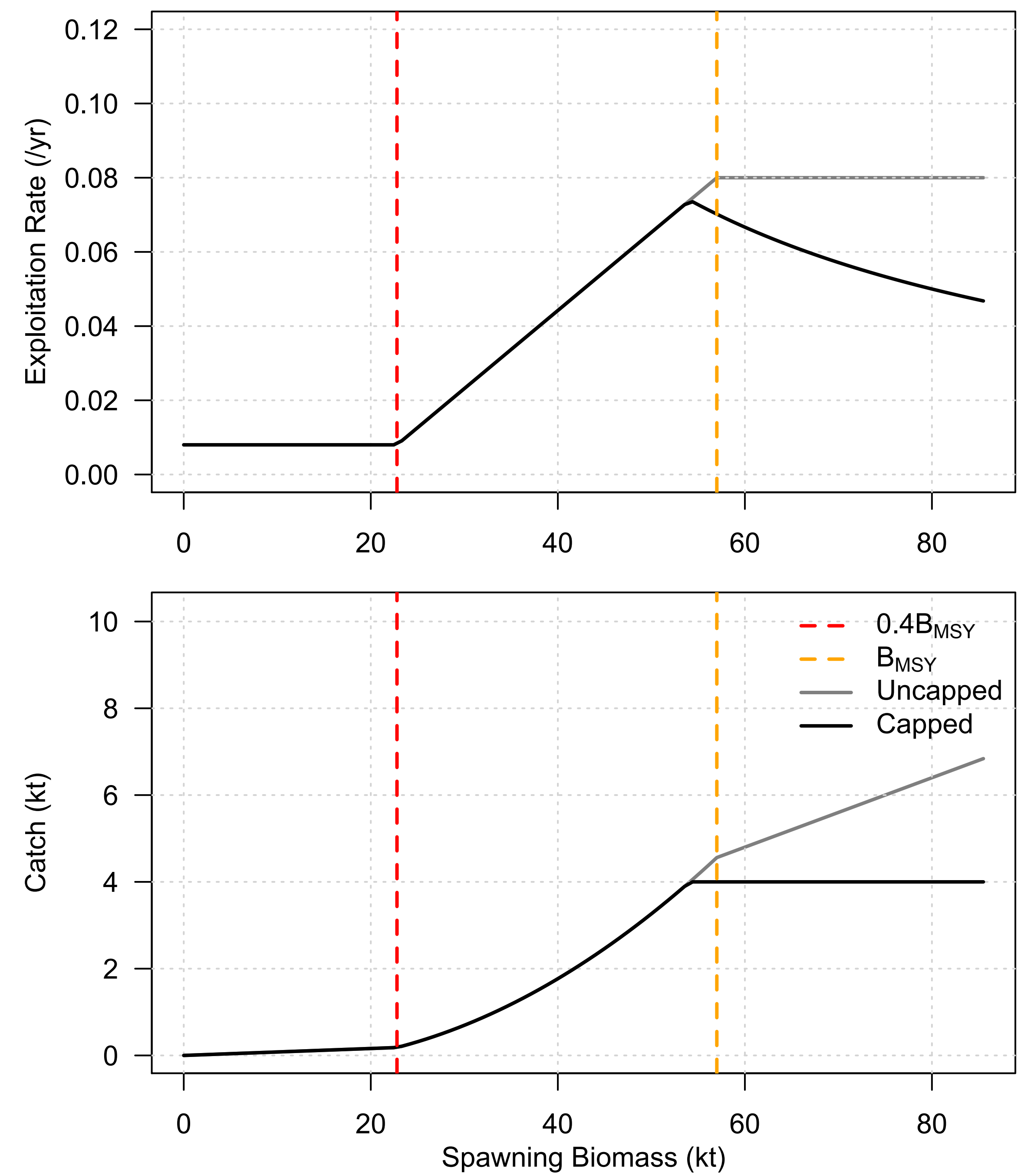
AM2 BRPs



Harvest control rules choose between area and stock based control points/HRs

- Basic HCR uses a constant fishing mortality rule up to a catch cap
- 2 HCRs are applied in each area, with target exploitation rate and control points based on:
    1. "Home-stock" estimates of ref points and M;
    2. Area mixed-stock estimates of ref points and M
- Tested $B_{proxy} = .4B_0$ for UCP

West stock HCR



Different CMPs we tested (so far)

1. **DD_loCap:**
   With 20 kt / 2.5 kt caps in E/W respectively

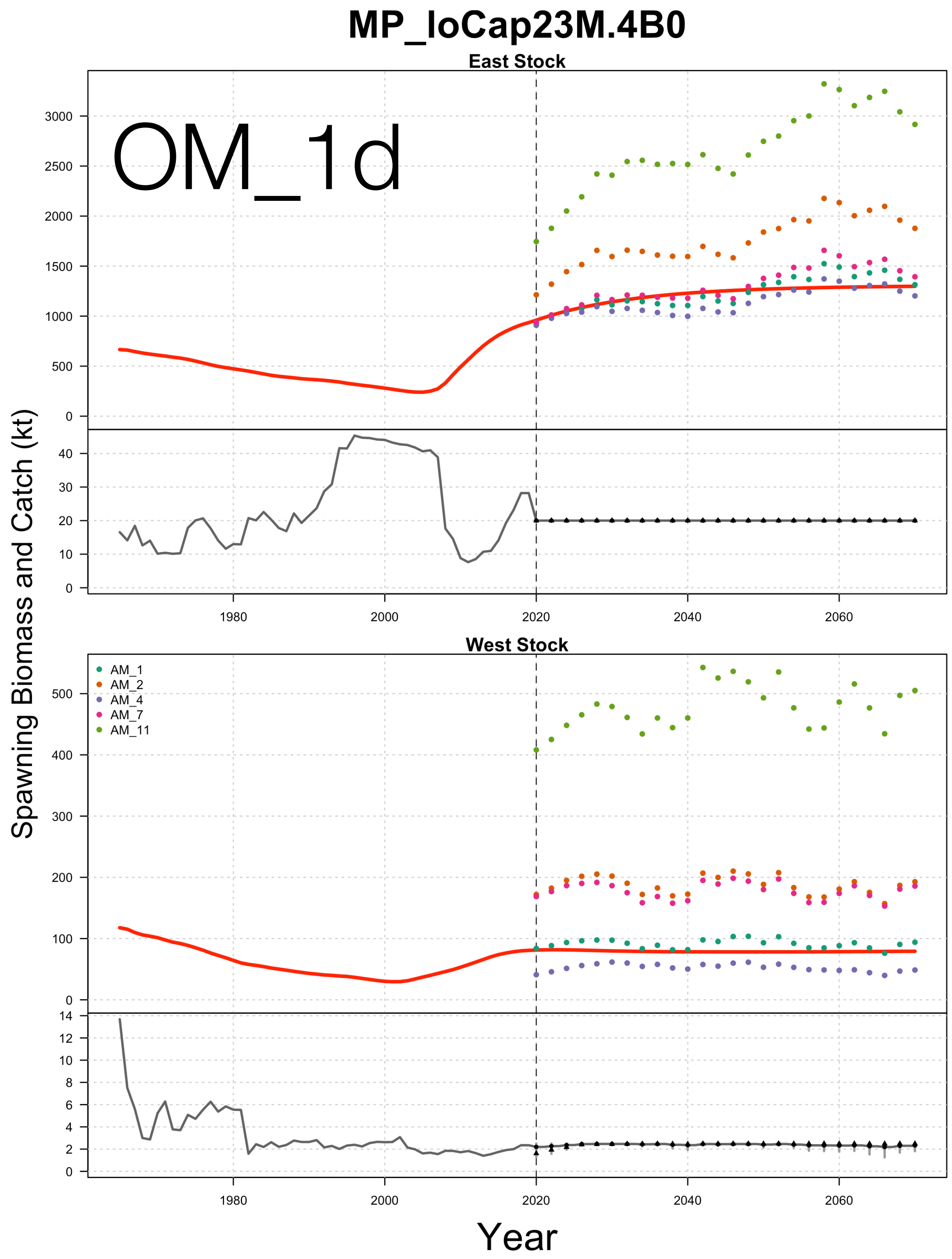
2. **DD_loCap23M**:
   As in 1. but with U_{max} = 2/3 M

3. **DD_hiCap23M**:
   As in 2. but with 25 kt / 4 kt caps in E/W respectively

4. **DD_loCap23M_.4B0**
   As in 2. but with UCP = .4B0 (B_{proxy} instead of B_{msy})

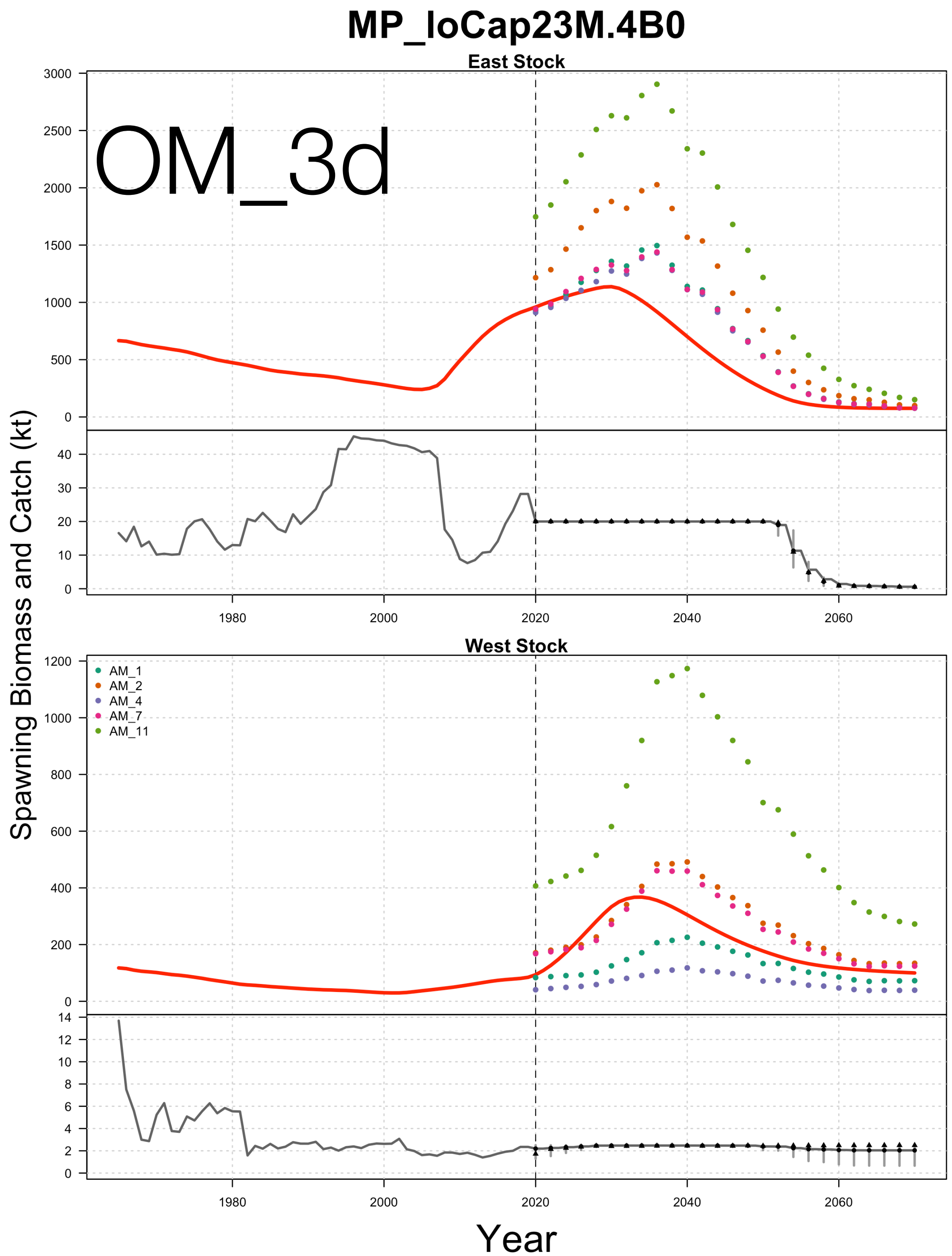
TACs produced by averaging over 5 HCR outputs, calculated from AM fits in projections

- AM succesfully follows OM1_d biomass for the projection period, indicating that AM is tuned well
- A little optimistic for the East stock towards the end of the projection
- TACs are basically the same over the projection period for all 5 AMs

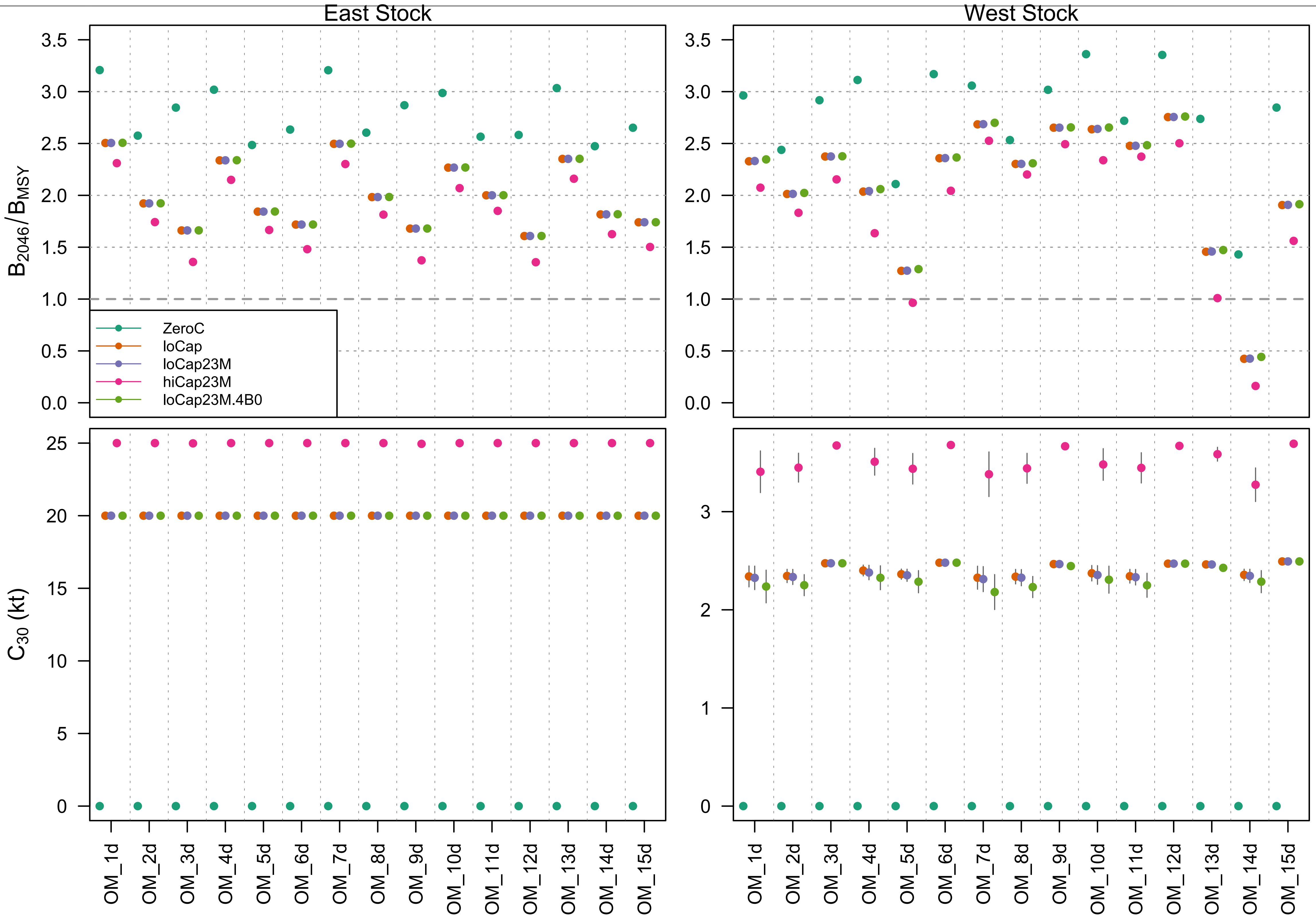


TACs produced by averaging over 5 HCR outputs, calculated from AM fits in projections

- All AMs have trouble following decline of East stock, failing to arrest decline
- AMs have generally optimistic biomass estimates for both stocks
- TACs start to look different between AMs, allowing model averaging to have more of an effect

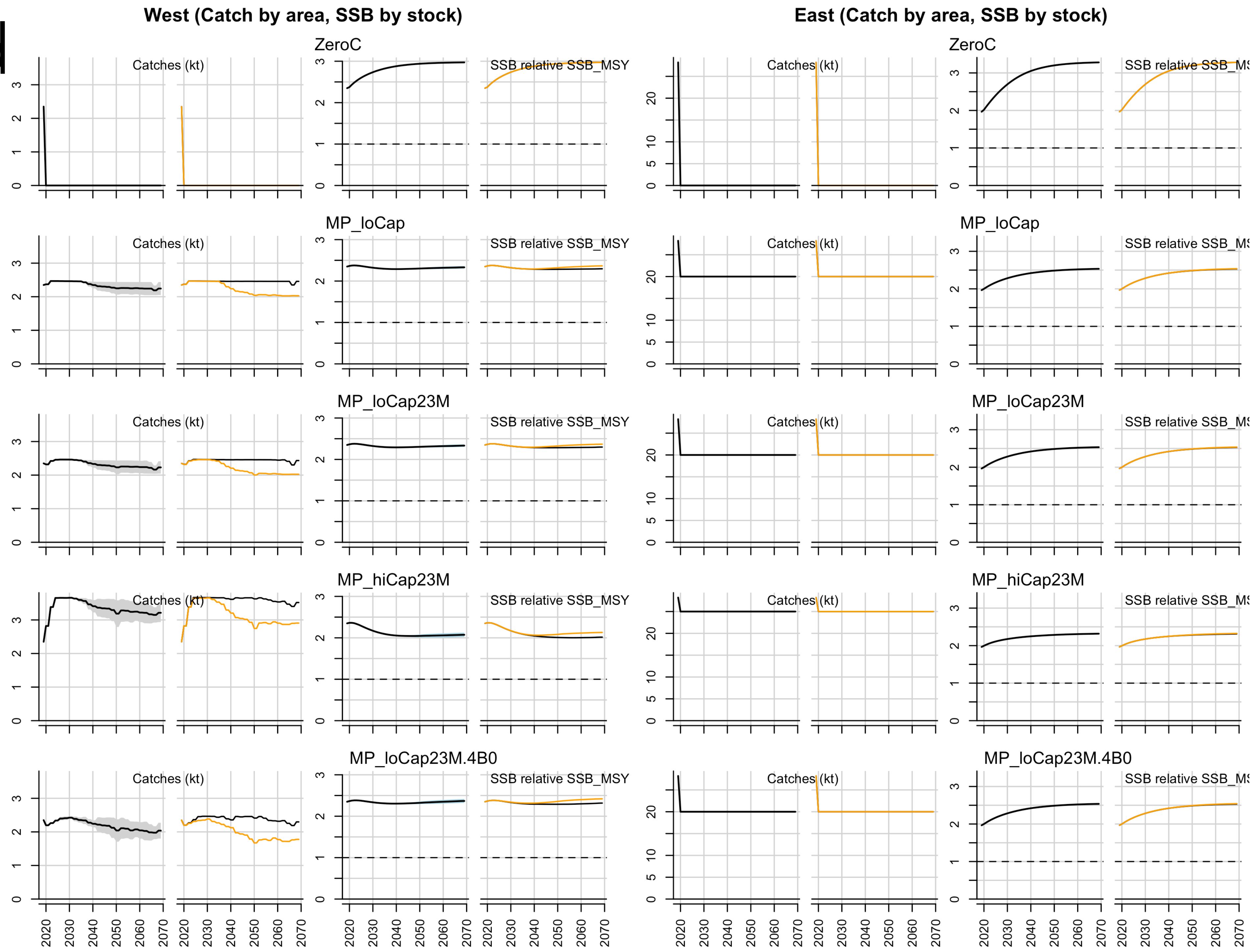


MPs do reasonably well on biomass and catch objectives



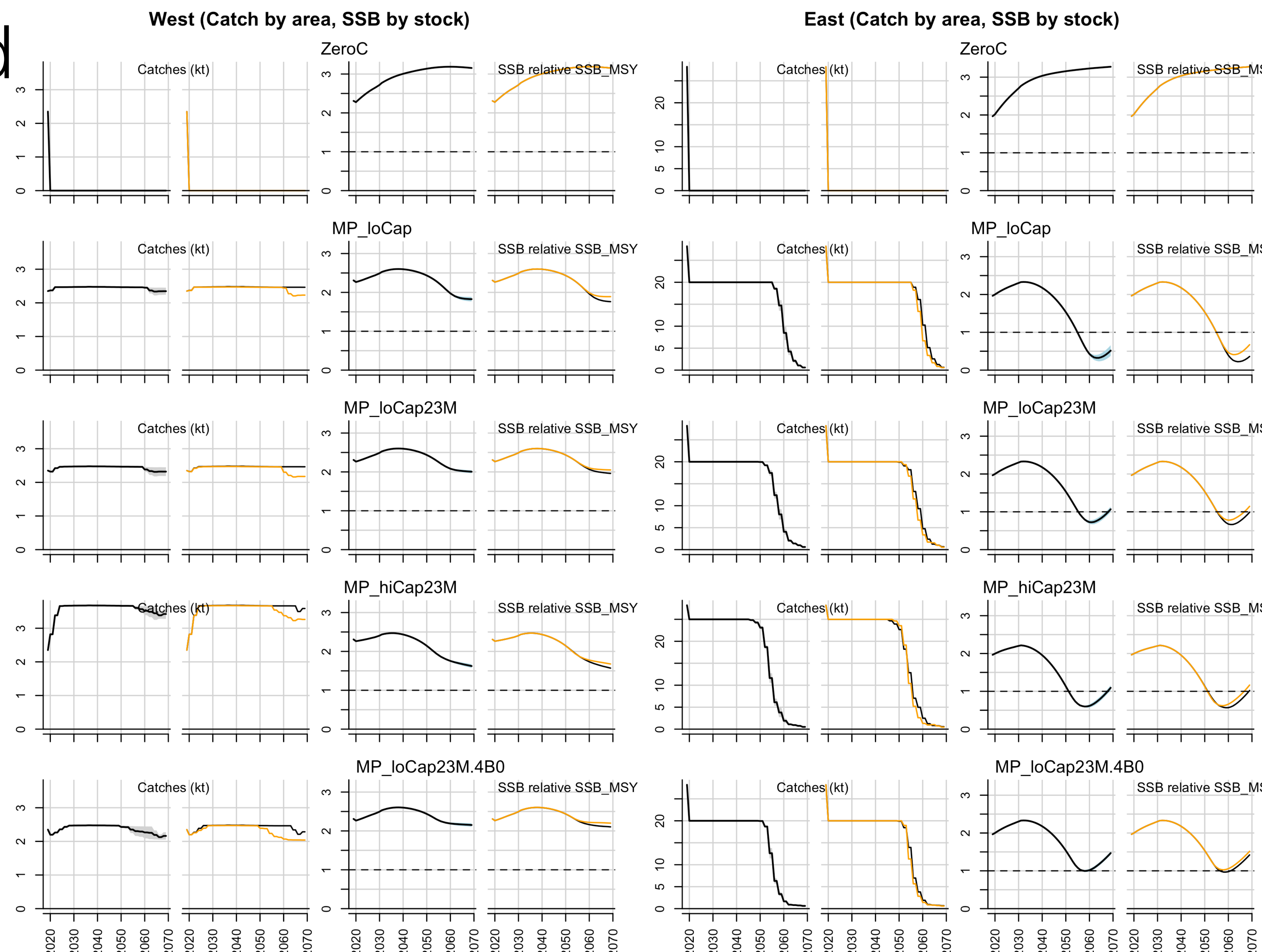
MPs are very precautionary on OM1_d

OM1_d



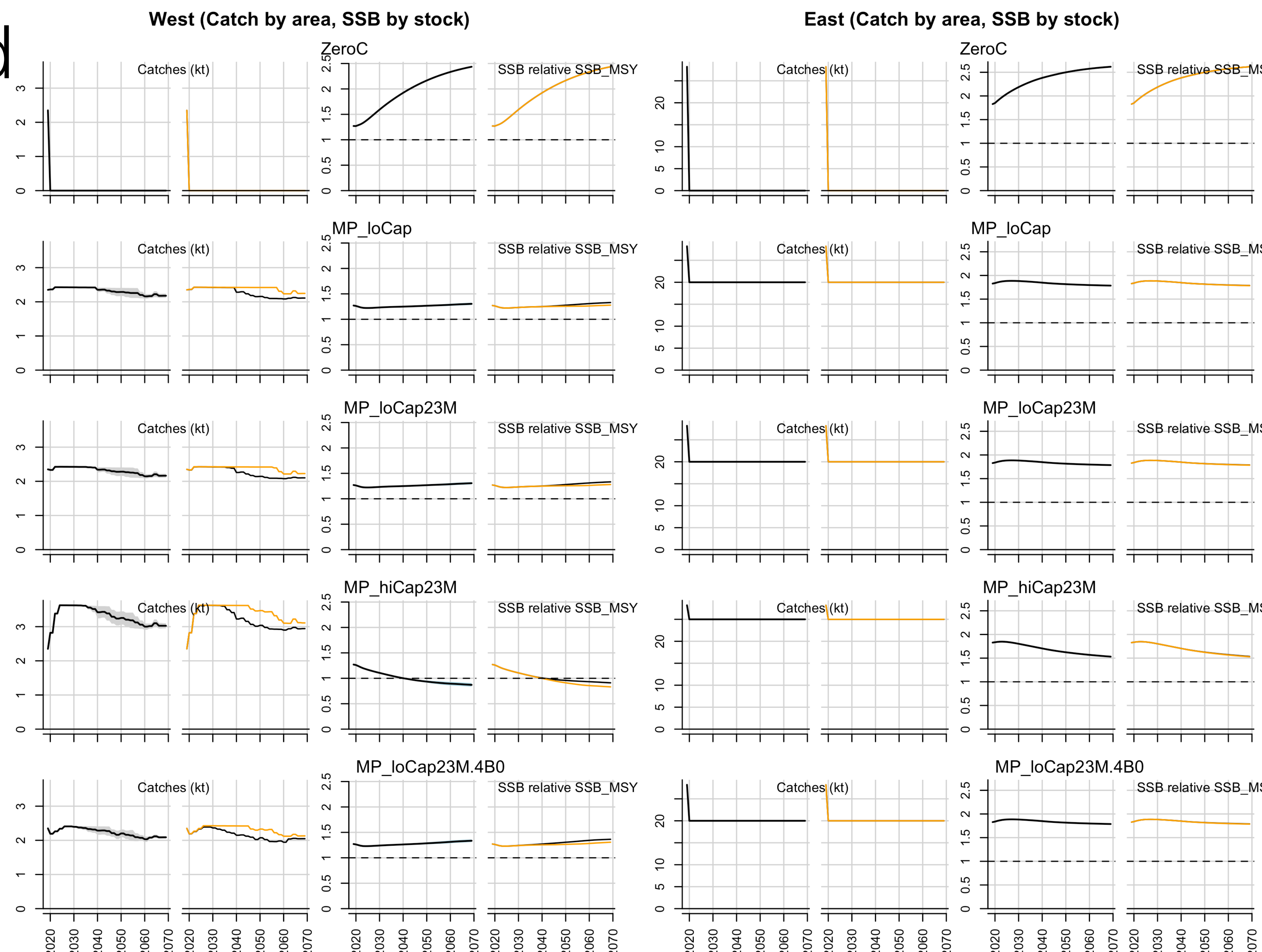
Why so precautionary? We were trying to rescue OM_3d

OM3_d



Worst reference grid case is still fairly good on West stock

OM_5d



Challenges with multi-model based MPs

- Time!! Deterministic OMs are fast, but waiting for 5 AMs to converge is still a bottleneck - even on multicore workstations. About 3h20mins for 4 CMPs on a stochastic OM (23 cores)

- Had to learn our way around to the most efficient MP design to avoid running MP twice per time step - meant that HCRs had to be the same for both stocks (***for now***)

- East stock B_{msy} estimates were very negatively biased under AMs tuned to Group 1 recruitment OMs (OM_1, OM_4 and OM_7) - this is the reason we introduced B_{proxy}, though it didn't save OM_3d!

Next steps

- Waiting for stochastic OMs to complete for more detailed performance metrics

- Update base CMP function to allow different HCRs for each stock - become slightly more aggressive in the East as it looks like most OMs can handle it.

- Add option for $F_{0.1}$ maximum exploitation rate

- Try to improve responsiveness of TACs

Thanks to

- Co-authors, Steve Rossi and Sean Cox (SFU/LFR)
- Grantly Galland and Shana Miller (Pew)
- Tom for writing a nice package
- ICCAT for having me!
- SABS for hosting.

Extra slides

DD model equilibria

Survival
$$S^{(f)} = e^{-M-f}$$

Average Weight
$$\overline{w}^{(f)} = \frac{S^{(f)} * \alpha + w^{(k)}(1 - S^{(f)})}{1 - \rho S^{(f)}}$$

Unfished Numbers and Recruitment
$$N_0 = B_0 / \overline{w}^{(f=0)}$$
$$R_0 = (1 - S^{(f=0)})N_0$$

BH parameters
$$a = \frac{4hR_0}{B_0(1-h)}, \quad b = \frac{5h-1}{B_0(1-h)}$$

Eq. Biomass
$$B^{(f)} = \frac{S^{(f)}(\alpha + \rho\overline{w}^{(f)}) + \overline{w}^{(f)}(aw^{(k)} - 1)}{b(\overline{w}^{(f)} - \rho S^{(f)}\overline{w}^{(f)} - \alpha S^{(f)})}$$

Eq. Recruitment
$$R^{(f)} = \frac{aB^{(f)}}{1 + bB^{(f)}}$$

Eq. Yield
$$Y^{(f)} = \frac{f}{M+f}(1 - e^{-M-f})B^{(f)}$$

Model initialisation and catch apportionment

Free parameters $$\theta_s = \{\log F_{s,0}, \log B_{s,0}, q_g, \tau_g, \vec{\omega}_{s,t}\}$$

Initial Model states
$$B_{s,1} = B_s^{(f=F_{s,0})}$$
$$N_{s,1} = N_s^{(f=F_{s,0})}$$
$$R_{s,1} = R_s^{(f=F_{s,0})}$$

Area specific biomass
(t >= 1)
$$B_{s,a,t} = p_{s,a} \cdot B_{s,t}$$
$$B_{a,t} = \sum_s B_{s,a,t}$$

Stock-specific Catch
(t >= 1)
$$C_{s,t} = \sum_a \frac{B_{s,a,t}}{B_{a,t}} C_{a,t}$$

Population Dynamics

Time steps t >= 2

Recruitment

$$R_{s,t} = \begin{cases} R_{s,1} e^{\omega_{s,t-k_s} - \sigma_s^2/2} & t \le k_s \\ \dfrac{a_s B_{s,t-k_s}}{1 + b_s B_{s,t-k_s}} e^{\omega_{s,t-k_s} - \sigma_s^2/2} & t > k_s \end{cases}$$

Total Mortality

$$Z_{s,t-1} = M_s + F_{s,t-1}$$

Numbers

$$N_{s,t} = e^{-Z_{s,t-1}} N_{s,t-1} + R_{s,t}$$

Biomass

$$B_{s,t} = e^{-Z_{s,t-1}} (\alpha_s N_{s,t-1} + \rho_s B_{s,t-1}) + w_s^{(k)} R_{s,t}$$

Note: Stock specific $F_{s,t}$ values are solved for numerically

Observation and statistical models

Expected Indices

Spawner indices $\hat{I}_{g,t} = q_g \cdot B_{s,t}$

Area biomass indices $\hat{I}_{g,t} = q_g \cdot B_{a,t}$

Area numbers indices $\hat{I}_{g,t} = q_g \cdot N_{a,t}$

Statistical Models

Observations $\log I_{g,t} \sim N(\log \hat{I}_{g,t}, \tau_g)$

Recruitment process errors $\omega_{s,t} \sim N(0, \sigma_s)$

Harvest Control Rules

$$U_{targ} = \begin{cases} 0.1 \cdot U_{max} & B \le LCP \\ U_{max}(0.1 + 0.9 \dfrac{B}{UCP - LCP}) & LCP \le B \le UCP \\ U_{max} & UCP \le B \end{cases}$$

- LCPs were always 0.4UCP
- We tested $U_{max} = U_{msy}$ and $U_{max} = \frac{2M}{3}$

Requests for Tom

- Slot for OM label in MSE object
- Method to combine MSE objects to avoid rerunning MPs unnecessarily - OM label would help avoid combining two MSEs from different OMs