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DESIGNING AND TESTING A MULTI-STOCK SPATIAL MANAGEMENT PROCEDURE FOR ATLANTIC BLUEFIN TUNA

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SUMMARY

The MPx CMP was updated and tuned to three biomass targets for the western stock and then run for both the deterministic and stochastic operating models of the reference set. Yield and biomass metrics showed a linear trade-off in the west among the tuned CMPs. The CMPs provided almost identical performance with respect to eastern stock and East area metrics. Operating models that assumed a single historical and future recruitment regime (recruitment level II) often led to simulations dropping below half BMSY for the Western stock. Stock status outcomes were generally worse under the stochastic operating models in comparison to the deterministic operating models. Two demonstration exceptional circumstances protocols were investigated. The protocol based on the level and slope of the GOM_LAR_SUV index provide a high probability of detecting western stock levels below 50% BMSY.

RÉSUMÉ

La CMP MPx a été mise à jour et calibrée sur trois objectifs de biomasse pour le stock occidental, puis exécutée pour le modèle opérationnel déterministe et pour le modèle opérationnel stochastique du jeu de référence. Les mesures de la production et de la biomasse ont montré une compensation linéaire à l'Ouest parmi les CMP calibrées. Les CMP ont fourni des performances presque identiques en ce qui concerne le stock de l'Est et les mesures de la zone Est. Les modèles opérationnels qui supposaient un seul régime de recrutement historique et futur (niveau de recrutement II) ont souvent conduit à des simulations descendant en dessous de la moitié de BPME pour le stock occidental. Les résultats concernant l'état des stocks étaient généralement plus mauvais avec les modèles opérationnels stochastiques qu'avec les modèles opérationnels déterministes. Deux démonstrations de protocoles de circonstances exceptionnelles ont été étudiées. Le protocole basé sur le niveau et la pente de l'indice GOM_LAR_SUV offre une forte probabilité de détecter des niveaux de stocks occidentaux inférieurs à 50% de B_{PME}.

RESUMEN

El CMP MPx fue actualizado y calibrado a tres objetivos de biomasa para el stock occidental y, posteriormente, ejecutado tanto para el modelo operativo determinista como para el estocástico del conjunto de referencia. Las mediciones del rendimiento y la biomasa presentaban una compensación de factores lineal en el oeste entre los CMP calibrados. Los CMP presentaba un desempeño casi idéntico respecto al stock oriental y las mediciones de la zona oriental. Los modelos operativos que asumían un único régimen de reclutamiento histórico y futuro (reclutamiento de nivel II) a menudo conducían a simulaciones que caían por debajo de la mitad de B_{RMS} para el stock occidental. Los resultados del estado del stock eran, por lo general, peores con los modelos operativos estocásticos en comparación con los modelos operativos deterministas. Se investigaron dos demostraciones de protocolos de circunstancias excepcionales. El protocolo basado en el nivel y la pendiente del índice GOM_LAR_SUV presentaba una elevada probabilidad de detectar niveles del stock occidental por debajo del 50 % de B_{RMS}.

KEYWORDS

Management Strategy Evaluation, bluefin tuna, operating model, management procedure

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Introduction

The MP approach to managing North Atlantic tuna provides an opportunity to move past the current assessment paradigm where management advice (which is necessarily by East / West area) is based on data that are also distinct by East / West area. Genetics, tagging and microconstituent data have long confirmed that there are at least two spawning stocks of Atlantic bluefin tuna, they exhibit extensive mixing in the Atlantic Ocean outside of their natal spawning grounds in the Gulf of Mexico and Mediterranean and they differ markedly in their magnitude (at unfished levels the Eastern stock is around 6-10 times larger than the Western stock). These observations suggest that if catch advice by area is to be based on estimates of vulnerable biomass in a given area, these should be responsive to varying augmentation from the stock originating from the other side of the ocean.

In this paper I describe a multi-stock, multi-area MP (‘MPx’) that uses spawning indices to estimate stock-specific vulnerable biomass which in conjunction with assumed rates of mixing is used to predict the vulnerable biomass of each stock in each area (**Figure 1**). These regional estimates of vulnerable biomass are combined with independent regional estimates derived from catch rate indices. Together these indices inform regional vulnerable biomass B, and fishing mortality rate F (since we also have observations of regional catches). TAC adjustments are made according to a novel harvest control rule that uses estimated fishing rate relative to FMSY and vulnerable biomass relative to BMSY to locate the stock at approximately MSY levels. The harvest control rule is intended to be responsive with respect to fluctuations in stock-specific productivity, allowing for increased yields where production is high and throttling of TAC given periods of lower productivity.

Methods

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:

$$\tilde{I}^{A}_{a,i} = S(I^{A}_{a,i}, \omega)$$
$$\tilde{I}^{S}_{a,i} = S\left(I^{S}_{a,i}, \omega\right)$$
$$\tilde{C}_{a} = S(C_{a}, \omega)$$

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 $\theta^{mix}_{s=East\_stock,a=West}$ 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:

(1) $$B^{S}_{a,t} = \frac{\sum_s \sum_i \tilde{I}^{S}_{s,i,t} q^{S}_{s,i} \theta^{mix}_{s,a}}{n_{s,i}}$$

(2) $$B^{A}_{a,t} = \frac{\sum_s \sum_i \tilde{I}^{A}_{a,i,t} q^{A}_{a,i}}{\mathrm{n}_{a,\mathrm{i}}}$$

The *q* parameters are calibrated to 2016 estimates spawning biomass (by stock) θ^{S}_{s}, and vulnerable biomass (by area) θ^{A}_{a}:

(3) $$q^{S}_{s} = \frac{\theta^{S}_{s,2016}}{\tilde{I}^{S}_{s,2016}}$$

(4) $$q_a^A = \frac{\theta_{a,2016}^A}{\bar{I}_{a,2016}^A}$$

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*

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

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

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:

(7) $$\Delta_{a,t}^B = exp\left(\frac{1}{2}\left[ln\left(\frac{B_{a,t}^S}{\theta_a^{BMSY}}\right) + ln\left(\frac{B_{a,t}^A}{\theta_a^{BMSY}}\right)\right]\right)$$

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

(8) $$\Delta_{a,t}^F = \exp\left(\frac{1}{2}\left[ln\left(\frac{F_{a,t}^S}{\bar{\theta}_a^{FMSY}}\right) + ln\left(\frac{F_{a,t}^A}{\bar{\theta}_a^{FMSY}}\right)\right]\right)$$

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 $\varphi_{a,t}$:

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

where the factor $\varphi_{a,t}$ is determined by adjustments for fishing rate $\delta_{a,t}^F$ and stock status $\delta_{a,t}^B$:

(10) $$\tilde{\varphi}_{a,t} = \delta_{a,t}^F\ \delta_{a,t}^B$$

The adjustment to *F* is the inverse of *F*/*FMSY* ($\Delta_{a,t}^F$) 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 $\delta_{a,t}^F$ is the inverse of $\Delta_{a,t}^F$ and hence recommends *FMSY* fishing rate (and depends on the assumption that biomass will be comparable at t+1) (**Figure 3**).

(11) $$\delta_{a,t}^F = \alpha^F\ exp\left(\ \beta^F\ ln\left(1/\Delta_{a,t}^F\right)\right)$$

The adjustment according to biomass is exponentially related to the disparity between current biomass and BMSY. The term $|\Delta_{a,t}^B - 1|$ 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 $\delta_{a,t}^B$ is invariant to β^B (e.g. **Figure 3**).

(12) $$\delta_{a,t}^B = \begin{cases} exp\left[\left(\alpha^B|\Delta_{a,t}^B - 1|\right)^{\beta^B}\right] & 1 < \Delta_{a,t}^B \\ exp\left[-\left(\alpha^B|\Delta_{a,t}^B - 1|\right)^{\beta^B}\right] & \Delta_{a,t}^B \leq 1 \end{cases}$$

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 (See **Figures 4 and 5**).

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}:

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

Index recalibration rule

Downward adjustments to the $\tilde{\theta}_a^{FMSY}$ parameter are made when stock-specific indices decline. The index calibration rule occurs in each projected year. In each instance the last γ^n years of smoothed catch and spawning biomass indices are extracted. When the slope in the log spawning biomass index is negative a downward adjustment in target FMSY is applied:

$$\tilde{\theta}_a^{FMSY} = \theta_a^{FMSY} \prod_y exp\left(\gamma^a slope\left(\ln\left(\tilde{I}_{y=\{y-4,\ y-3,\ y-2,\ y-1\},a}\right)\right)\right)$$

Tunings

Three derivatives of the MPx CMP were developed for demonstration purposes. The θ_{West}^{FMSY} parameter was tuned in order to achieve three levels of median Br30 (biomass relative to BMSY after 30 projection years) for the western stock over all deterministic operating models #1 (**Table 1**). The three CMPs: TC1, TC2, TC3 corresponded to median Br30 levels of 1.00, 1.25 and 1.5, respectively.

A demonstration exceptional circumstances protocol

Simulated index observations and the fraction of the western stock numbers in the West Atlantic region were monitored to evaluate whether these could be used to detect situations where western stock levels were depleted.

Results

The outcomes of the various tunings to Western Stock Br30 provided almost identical outcomes in the East in terms of both yield and biomass (**Tables 3a, 3b, 4a, 4b**).

Mean Br30 scores for the Western Stock matches the tunings which related to median values among OMs, suggesting little skew in the distribution of the results (**Table 3a**).

The trade-off between West area mean yield over the 30 year projection and western stock biomass at the end of the projection Br30, was linear among the three CMP tunings (**Figure 8**). Relative to the mean, the uncertainty in outcomes widened as the CMP was more aggressively tuned (**Figure 6a**). The stochastic simulations for the same OMs led to comparable mean Br30 as the deterministic simulations. However, those simulations with the worst biological outcomes in deterministic runs, performed substantially worse in the stochastic simulations (**Figure 6a** and **Figure 6b**). This was true of both Western and Eastern stock Br30 scores. Where as biomass trajectories for TC2 were generally positive for the deterministic runs, in the stochastic runs this was not necessarily the case for the stochastic simulations and the envelop of future biomass outcomes was much wider and decreasing (**Figures 10a and 10b**).

In general, OMs for recruitment level 2 (constant historical and future recruitment regime) had the worst outcomes in terms of Br30 for all the tunings (**Figure 9a and 9b**). In some cases recruitment level 3 led to very low Br30 scores for the East and West stocks also. The lowest Br30 scores were generally always in the West, regardless of the operating model.

The GOM_LAR_SUV index provided some basis for detecting low stock sizes among the stochastic simulations of OMs #1-12 given the TC3 CMP (**Table 5, Figure 11**). In 99.6% of cases where simulated biomass dropped below 0.25 BMSY, the EC protocol was triggered. For 72.8% of simulations between 0.25 and 0.5 BMSY, the EC protocol was triggered. In 7% of simulations where stock levels were above BMSY, the EC protocol was triggered.

When using smoothed values of the same index combined with its 6-year slope, EC protocols were considerably more sensitive detecting all simulations under 25% BMSY and 94.3% of simulations under half of BMSY.

Discussion

The tentative results of this set of CMP tunings underlines the key role of certain OMs in determining biomass outcomes. In some cases, operating models provide a very difficult test of a management system and may require exceptional circumstances protocols to have confidence in their use. A demonstration application of these only showed high probabilities of triggering the protocols for the most depleted western stock levels (biomass less than 0.5 BMSY).

Alternative CMPs tuned to varying western biomass outcomes did not lead to any appreciable difference in outcomes in the East area and Eastern stock, emphasizing that west area management has little impact on eastern outcomes.

It was not possible to tune the MPx CMP to the desired level of a median Br30 equal to 1.00 among all reference set OMs. Due to maximum catch constraints the lowest median Br30 achievable was 1.06. This result underlines that MP rigidity may provide robustness benefits while preventing like-for-like comparisons among tuned CMPs.

Acknowledgments

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

Description		Value
Biomass calculation		
$I^{S}_{East\_stock}$	Spawning stock biomass index for eastern stock	MED_LAR_SUV (#2), GBYP_AER_SUV_BAR (#5)
$I^{S}_{West\_stock}$	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_{East}^{TACmin}	Minimum TAC for the East area	10 kt
θ_{West}^{TACmin}	Minimum TAC for the West area	0.5 kt
θ_{East}^{TACmax}	Maximum TAC for the East area	80 kt
θ_{West}^{TACmax}	Maximum TAC for the West area	4.5 kt
$\theta_{West}^{TACmax\_near}$	Near-term maximum TAC for the West area	2 kt
$\theta_{West}^{n\_near}$	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

Table 2. Parameter values for each of the three MPx tunings. The intended tuning for TC1 was Br30 = 1.00, but this was not possible to achieve given maximum catch constraints for the West Area.

Tuning	CMP name	θ_{West}^{FMSY}
Br30 = 1.06 (West stock)	TC1	0.040200
Br30 = 1.25 (West stock)	TC2	0.010070
Br30 = 1.50 (West stock)	TC3	0.003887

Table 3a. West Area (AvC30, AAVC) / Western Stock (D30, Br30) performance metrics, averaged over all reference set operating models. AvC30 is the mean catch over all simulations and operating models, D30 is the depletion after 30 years (SSB / dynamic SSB0), AAVC average annual variability in catches (AAVC) over the first 30 projected years ($AAVC = \frac{1}{30}\sum_{y=2022}^{2051} \left|C_y - C_{y-1}\right| / C_{y-1}$), Br30 is biomass relative to dynamic SSBMSY in projection year 30.

	AvC30	D30	AAVC	Br30
ZeroC-ZeroC	0	0.75	0	2.78
TC1-TC1	2	0.31	0	1.06
TC2-TC2	1.44	0.39	6.33	1.25
TC3-TC3	0.87	0.47	5.87	1.51

Table 3b. As **Table 3a** but for the East Area (AvC30, AAVC) / Eastern Stock (D30, Br30).

	AvC30	D30	AAVC	Br30
ZeroC-ZeroC	0	0.85	0	3.41
TC1-TC1	36.19	0.36	13.56	1.36
TC2-TC2	36.19	0.37	13.52	1.36
TC3-TC3	36.31	0.37	13.59	1.37

Table 4a. Western stock Br30 biomass outcomes among all reference set OMs. The 5th, 50th (median) and 95th percentiles are shown for each CMP. The median Br30 scores confirm the tunings.

	Br30 5%	Br30 50%	Br30 95%
ZeroC-ZeroC	1.49	2.78	3.31
TC1-TC1	0.35	1.06	1.98
TC2-TC2	0.54	1.25	2.1
TC3-TC3	0.76	1.51	2.5

Table 4b. As **Table 4a** but for the Eastern stock.

	Br30 5%	Br30 50%	Br30 95%
ZeroC-ZeroC	2.1	3.41	4.13
TC1-TC1	0.55	1.36	2.35
TC2-TC2	0.57	1.36	2.36
TC3-TC3	0.58	1.37	2.37

Table 5. Exceptional circumstances based on GOM_LAR_SUV index and fraction of western stock numbers in the West Atlantic. Result are presented for simulations for TC3 given the first 30 years of observations for the stochastic OMs #1 – 12. Number of simulations refers to simulated index observations per projection year and simulation. These points are plotted in **Figure 11**.

True simulated western stock status	**By number of simulations**		**By proportion**	
	EC triggered	**EC not triggered**	**EC triggered**	**EC not triggered**
1 < B/BMSY	887	10988	0.075	0.925
0.5 < B/BMSY < 1	2122	5108	0.293	0.707
0.25 < B/BMSY < 0.5	2591	967	0.728	0.272
0 < B/BMSY < 0.25	6111	26	0.996	0.004

Table 6. As **Table 5** but using the slope and smoothed values of the GOM_LAR_SUV. See **Figure 12**.

True simulated western stock status	By number of simulations		By proportion	
	EC triggered	EC not triggered	EC triggered	EC not triggered
1 < B/BMSY	402	11439	0.034	0.966
0.5 < B/BMSY < 1	1451	4765	0.233	0.767
0.25 < B/BMSY < 0.5	2211	133	0.943	0.057
0 < B/BMSY < 0.25	3556	0	1	0

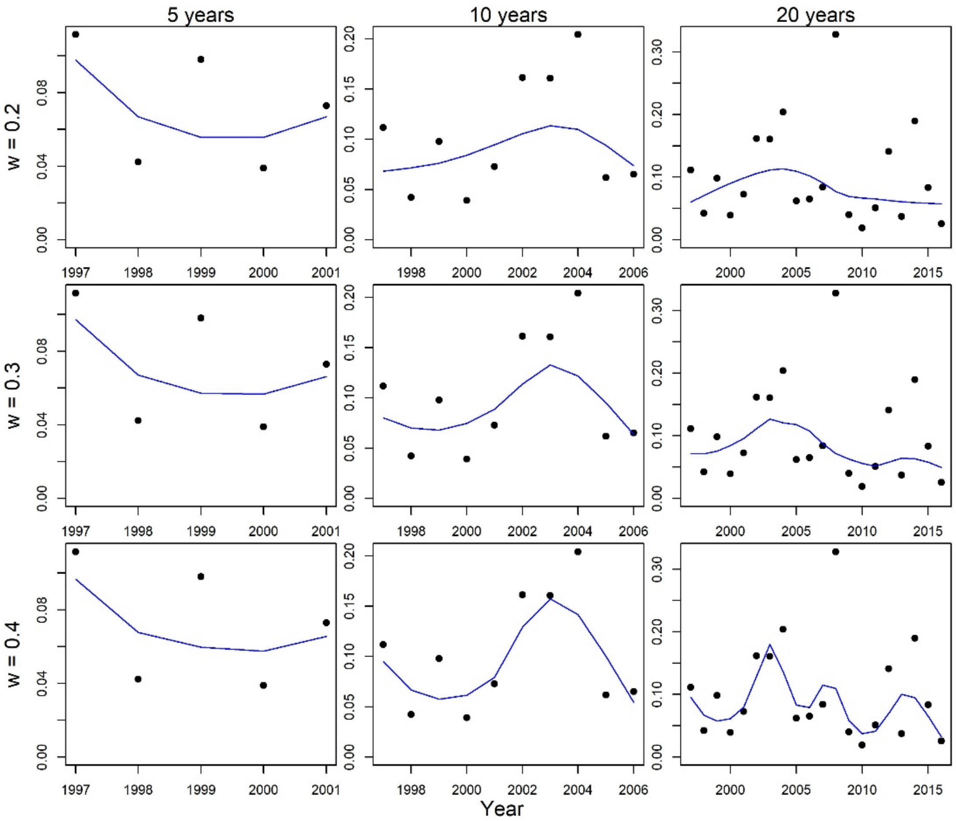

Figure 1. Effect of the smoothing parameter ω given time series of varying length.

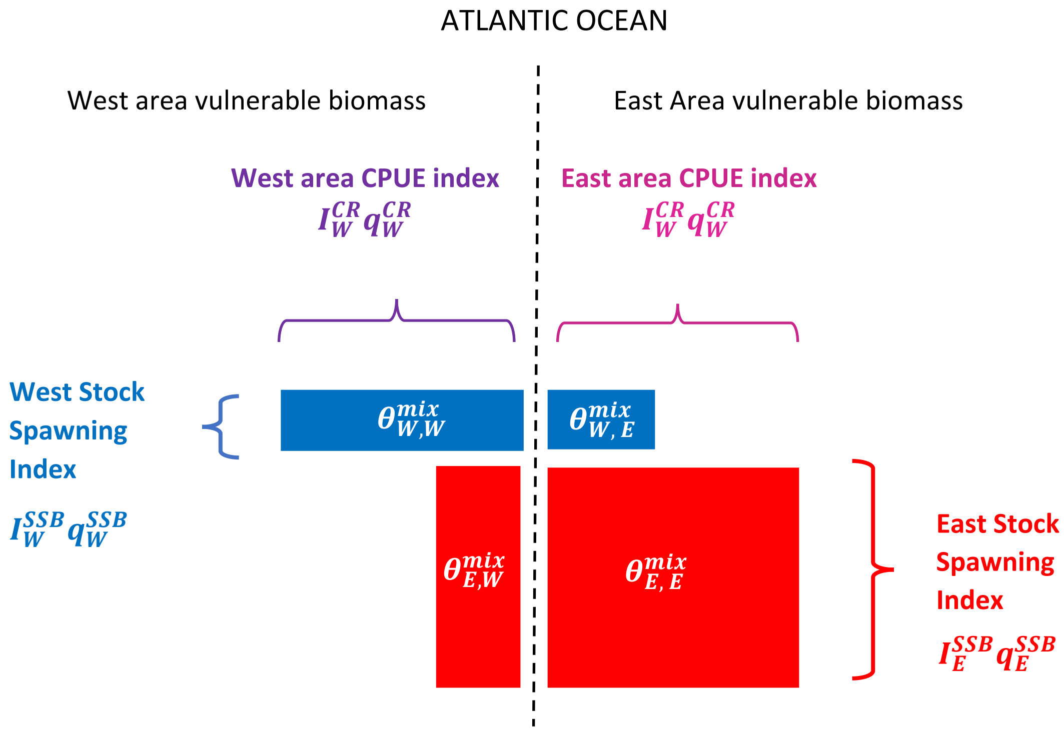

Figure 2. Regional vulnerable biomass estimation according to stock specific spawning indices and area-specific CPUE indices.

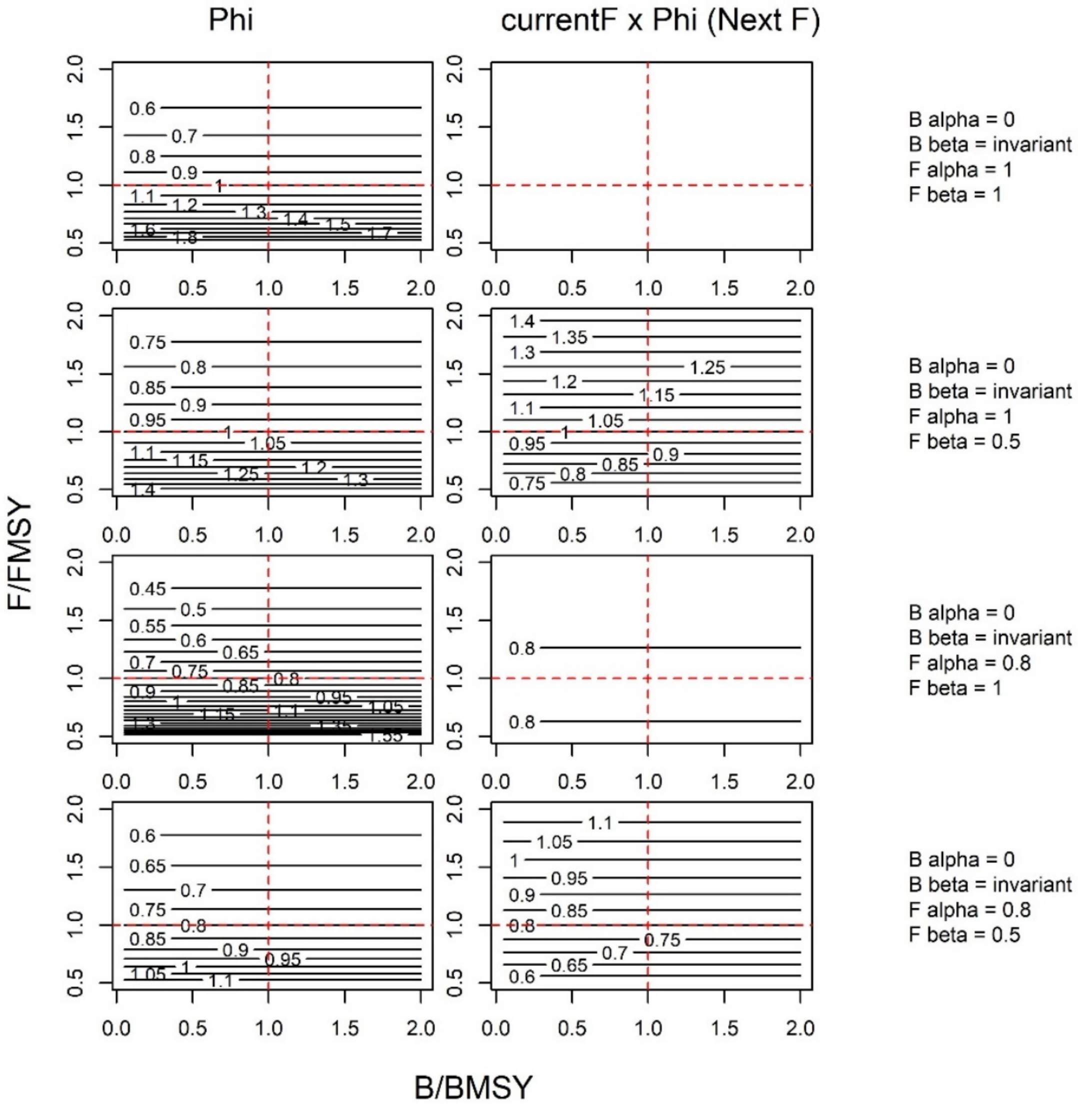

Figure 3. MP TAC adjustment based only on current fishing rate relative to FMSY ($\Delta_{a,t}^{F}$ only).

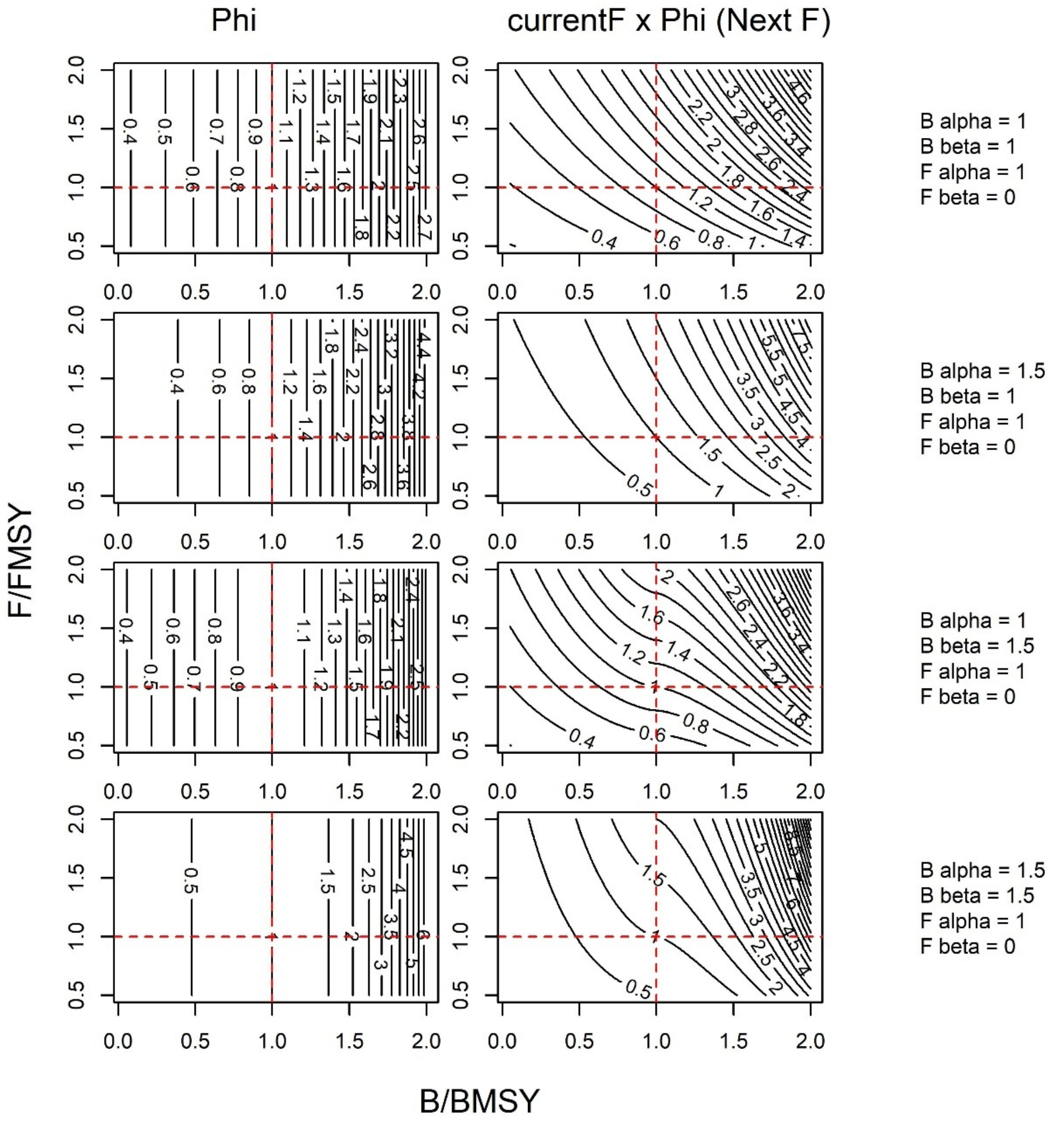

Figure 4. MP TAC adjustment based only on current biomass rate relative to BMSY ($\Delta^{B}_{a,t}$ only).

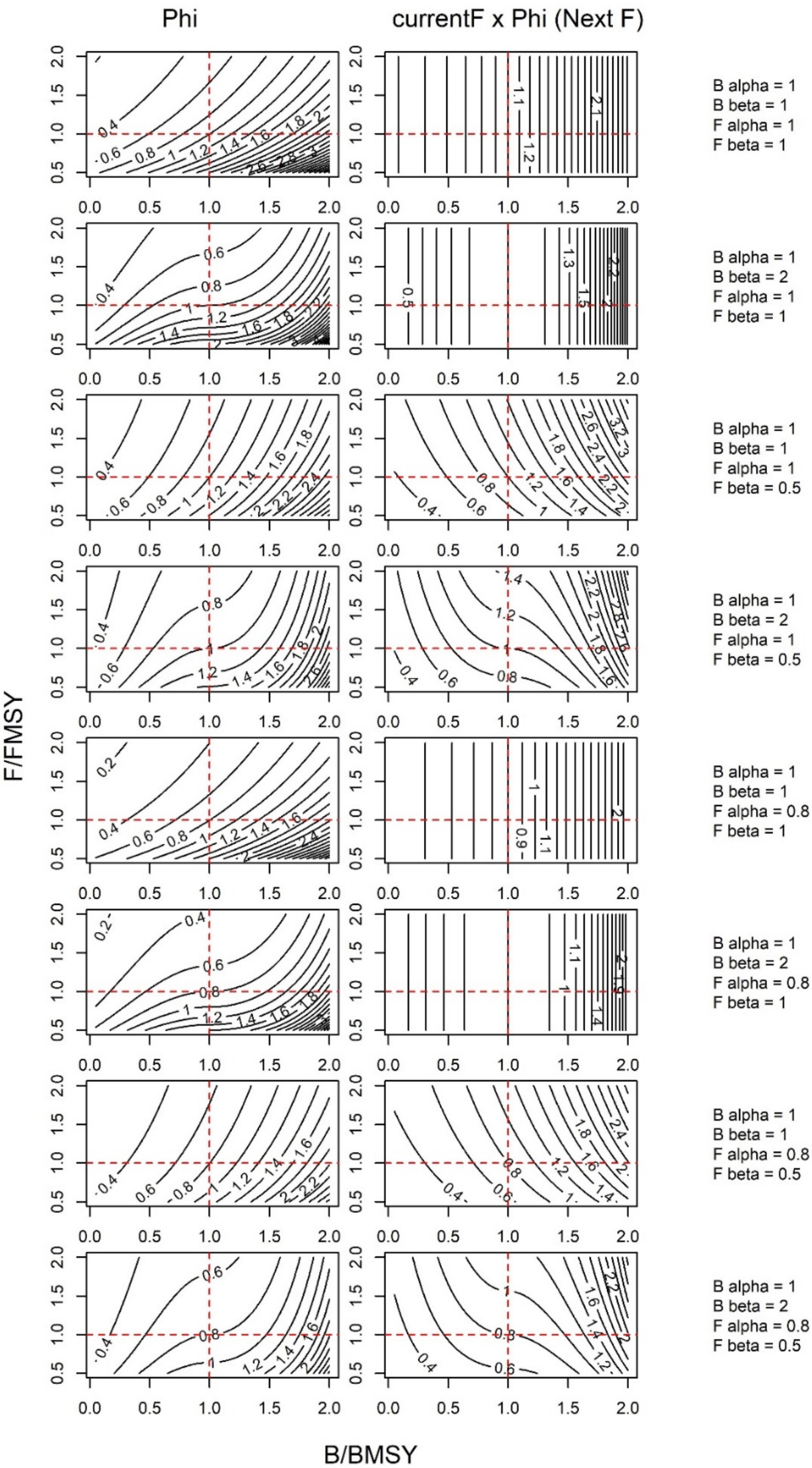

Figure 5. MP TAC adjustment using current estimates of biomass and fishing mortality rate relative to MSY levels ($\Delta^B_{a,t}$ and $\Delta^B_{a,t}$, respectively).

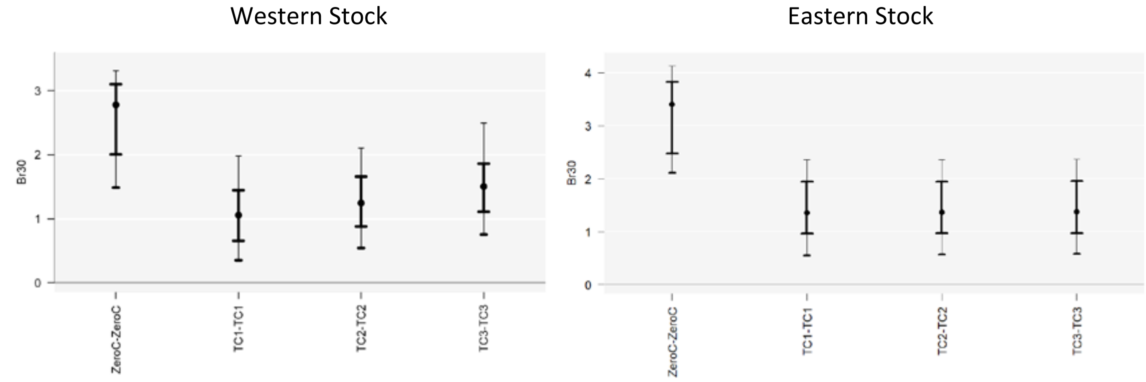

Figure 6a. Stock biomass performance (Br30 is the fraction of dynamic BMSY after 30 projected year) of CMPs for all deterministic reference set OMs combined. Points are medians, inner bars are the interquartile range, thin bars denote the 95% interval.

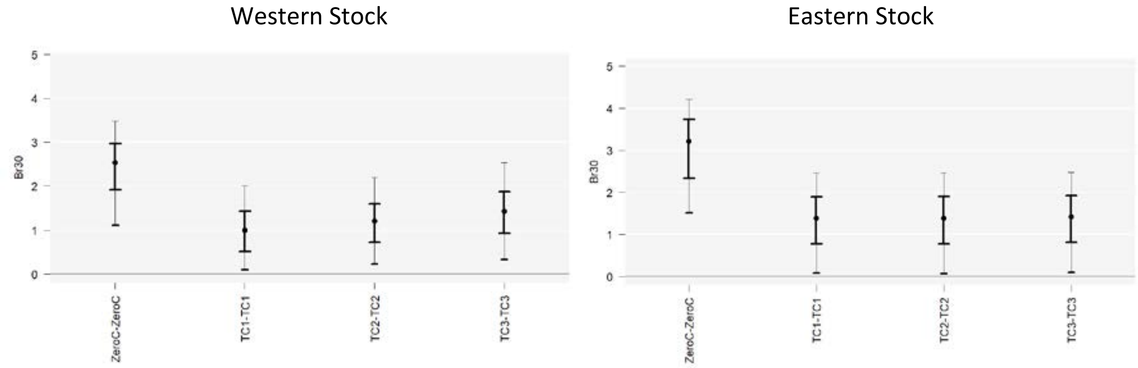

Figure 6b. As **Figure 6a** but for the stochastic operating models.

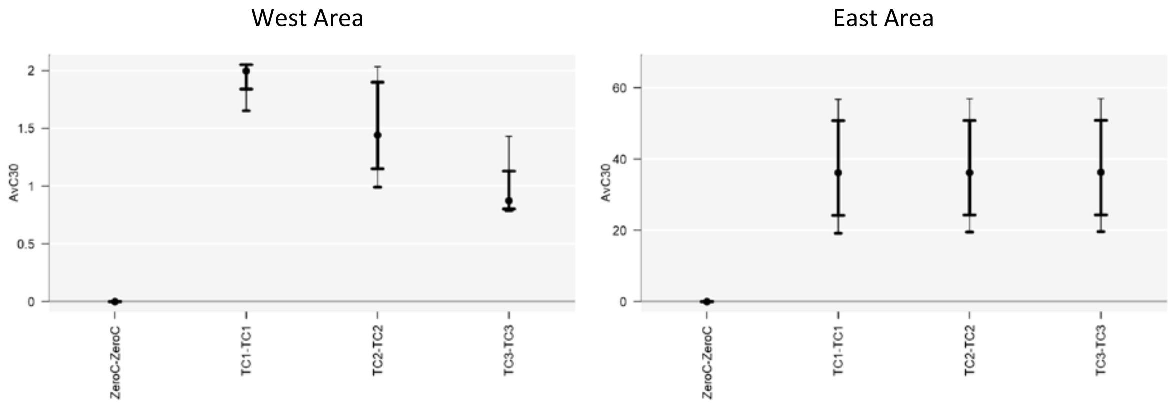

Figure 7. As **Figure 6a** but for area-specific catch performance (AvC30 is the mean yield over the first 30 projection years).

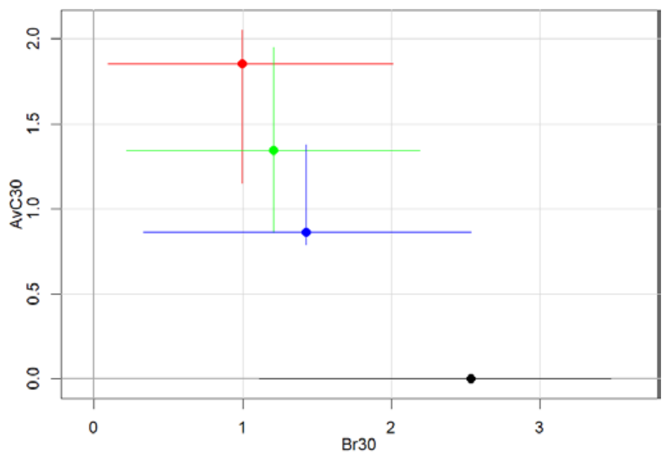

Figure 8. Yield (AvC30 vs Br30) trade-off among tunings for all deterministic reference OMs combined. The points are mean values, the lines denote the 90% interval.

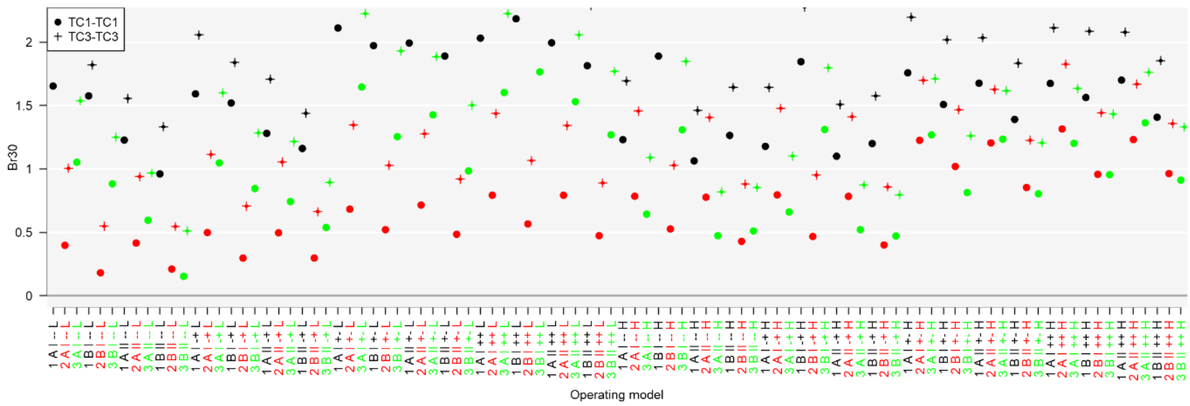

Figure 9a. Western stock Br30 performance for the median Western Br30 =1.06 (TC1) and median Western Br30 = 1.5 (TC3) tunings. Results are essentially identical among CMPs. Results are color coded by the recruitment factor level of the reference grid: (1, black) 2-phase historical recruitment; (2, red) single phase historical recruitment; (3, green) 2-phase historical recruitment with future regime shift after 10 years.

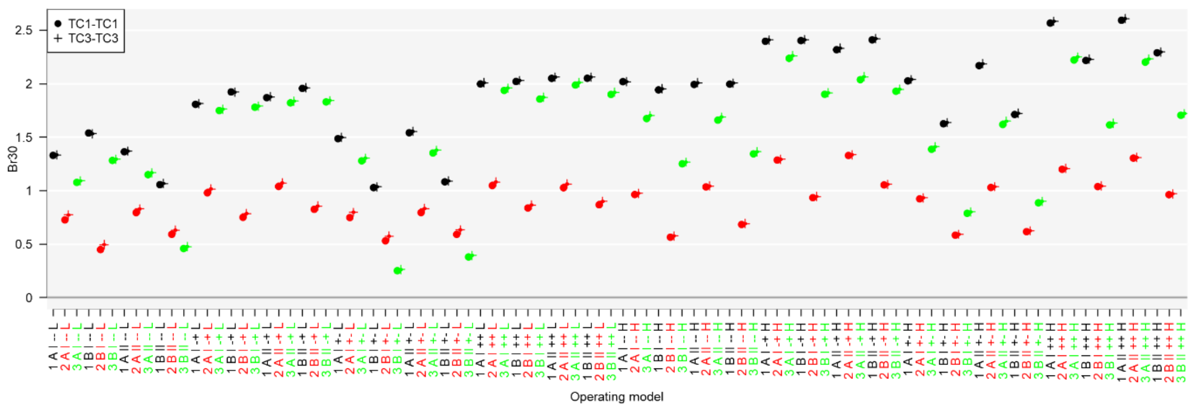

Figure 9b. Eastern stock Br30 performance for the median Western Br30 =1.06 (TC1) and median Western Br30 = 1.5 (TC3) tunings. Results are essentially identical among CMPs.

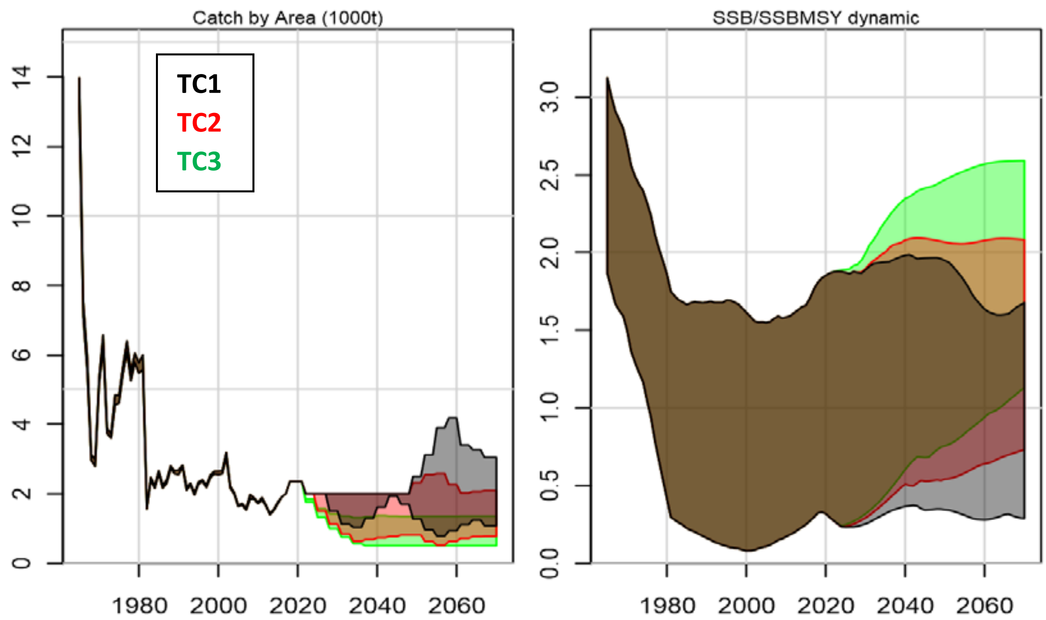

Figure 10a. Catch and Biomass projections for the Western stock / West area for all deterministic reference set OMs. Shaded region is the 90% interval.

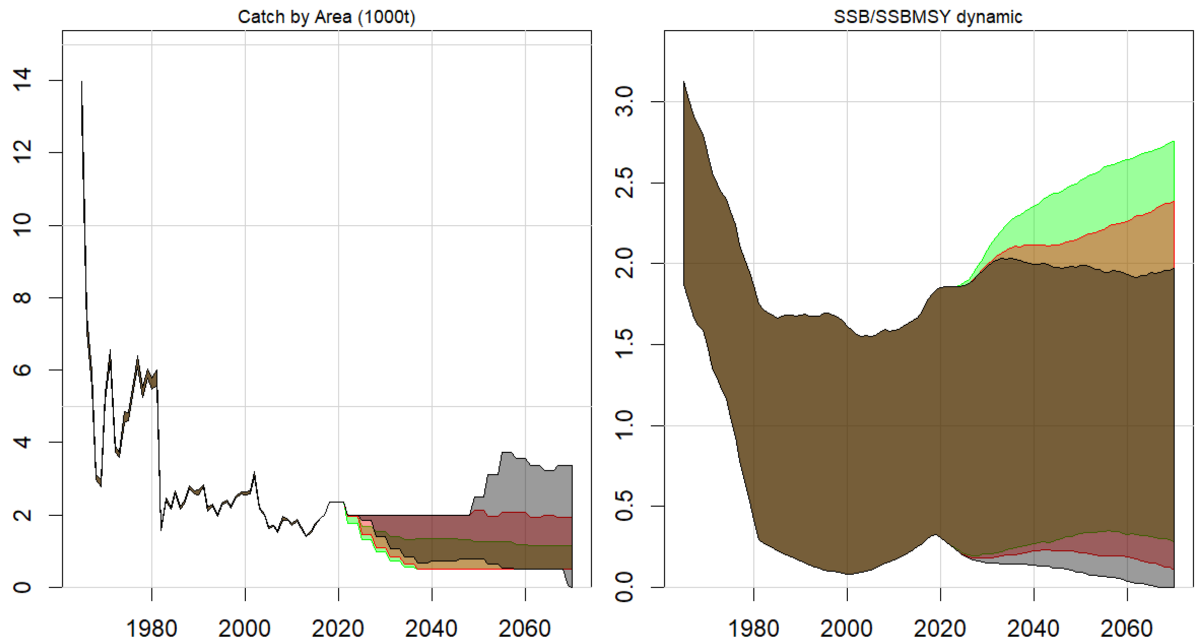

Figure 10b. As **Figure 10a** but for the stochastic OMs.

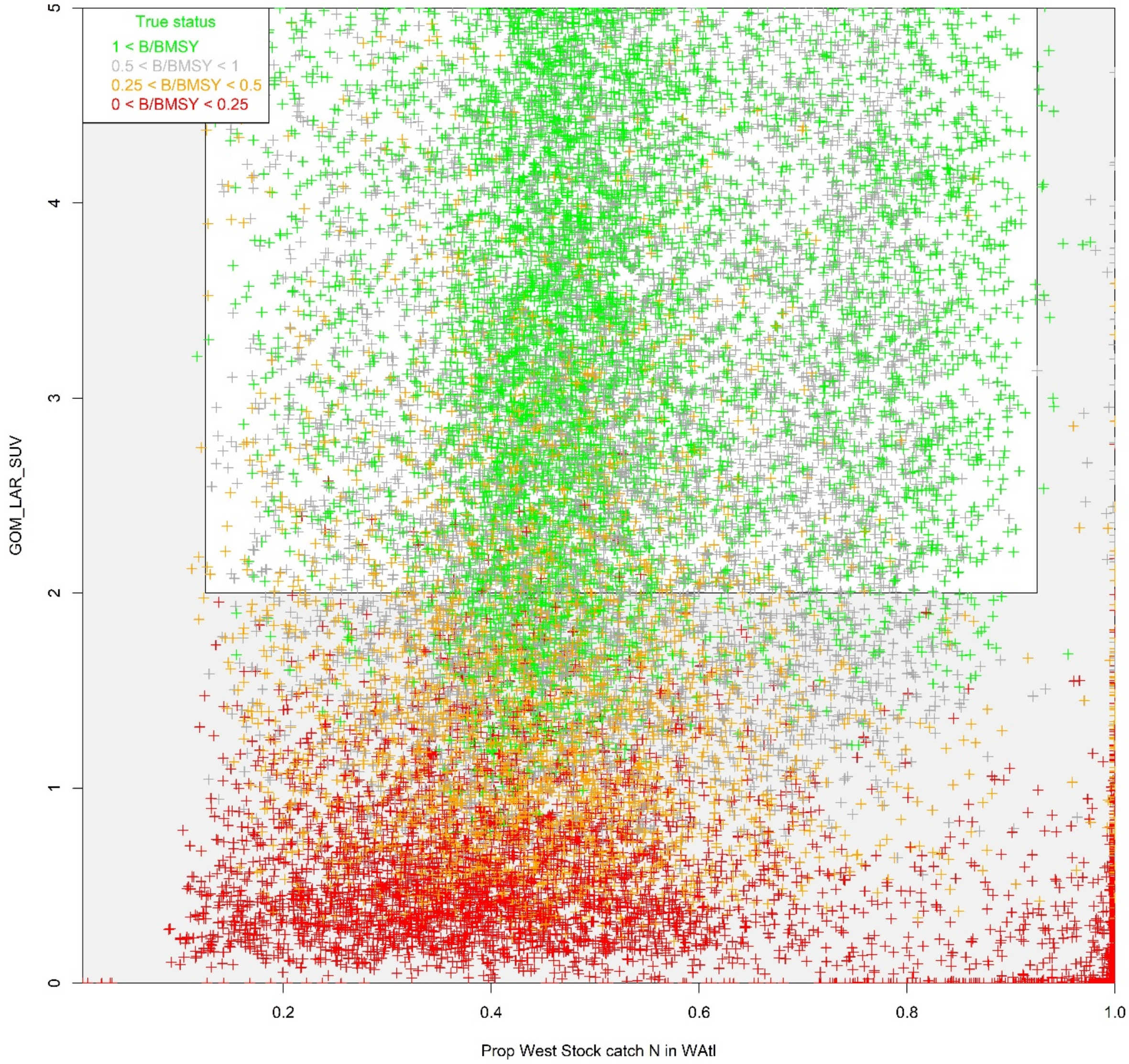

Figure 11. Demonstration exceptional circumstances trigger given observations of the GOM LAR SUV index and the fraction of West stock numbers in the WAtl area. Points are simulated observations by simulation-year for the first 30 projected years of the stochastic operating models #1-12 using CMP TC3. Simulations are colored according to the true simulated western stock status. The shaded region is where exceptional circumstances are triggered. In this case the index (yaxis) is the primary basis for the demonstration exceptional circumstances protocol. **Table 5** provides the numbers and fractions of simulations for which exceptional circumstances are triggered or not for these simulations.

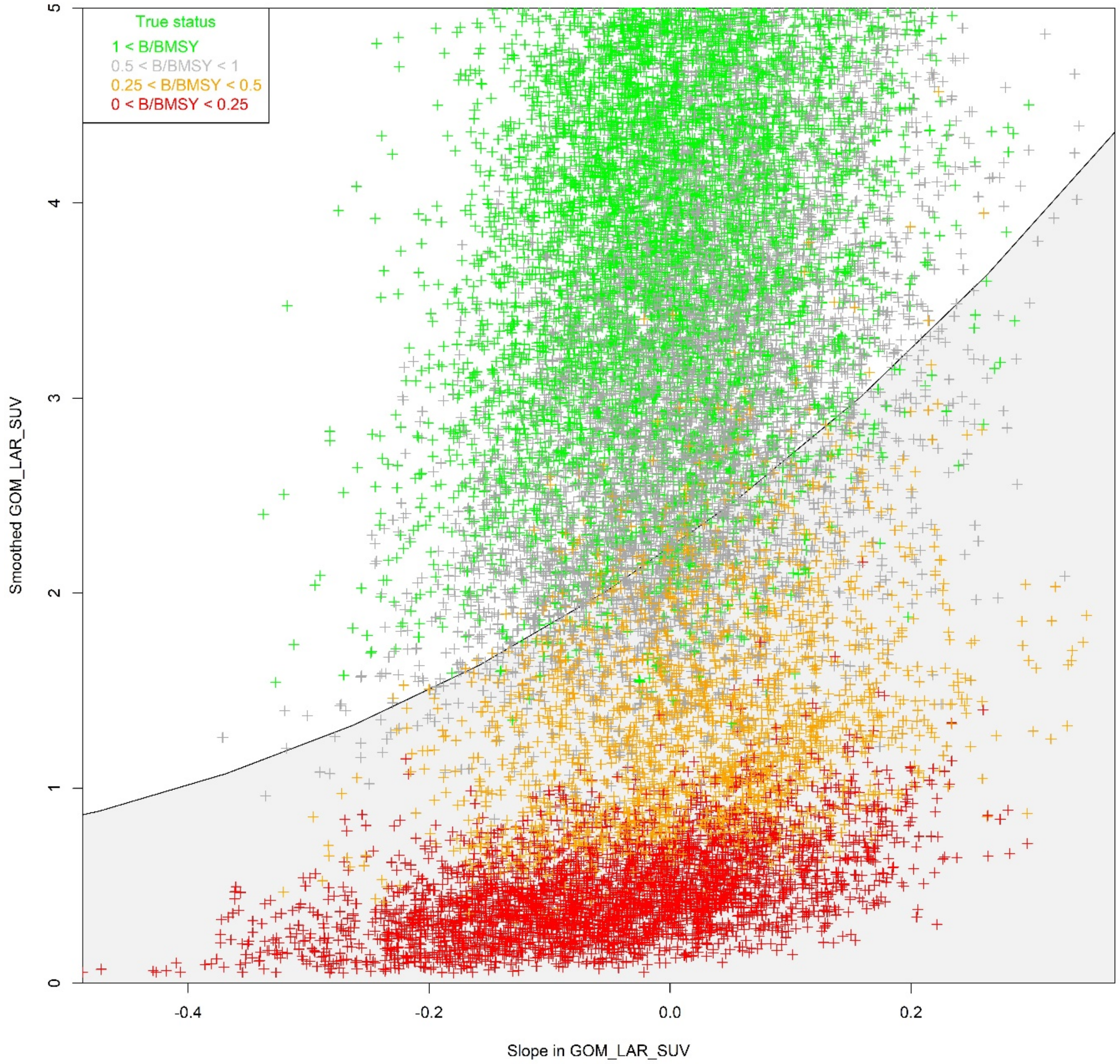

Figure 12. As **Figure 11** but using the slope (6 year calculation) and smoothed values of the GOM_LAR_SUV index.