SCRS/2018/181 Collect. Vol. Sci. Pap. ICCAT, 75(6): 1552-1575 (2019)

FURTHER INVESTIGATIONS OF SIMPLE "FIXED PROPORTION" CANDIDATE MANAGEMENT PROCEDURES FOR NORTH ATLANTIC BLUEFIN TUNA USING OPERATING MODEL PACKAGE VERSION 3.3.0

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SUMMARY

Simple constant (intended) proportion CMPs are applied to the 16 conditioned Operating Models in version 3.3.0 of the Package. Ranges of the two control parameters for west and east proportions are selected to give reasonable trade-offs between catch and stock recovery (where needed). For most of the OMs this is readily achieved. However, problems arise for some of the abundance factor B OMs (with lower west stock abundances matching those in the most recent assessment) coupled to an unchanging Beverton-Holt stock-recruitment function for the west stock (recruitment factor 2). For one of these scenarios, even with no catch from the west area, an already depleted west stock decline under catches in the east that are well below present levels, because sufficient bluefin of western origin migrate to the east area and can be harvested there. The key immediate question then becomes whether such OM scenarios are sufficiently plausible that they need to be taken into account in MP selection, though it may be that these instances reflect unreliability in OM conditionings developed under heavy pressure of time.

RÉSUMÉ

Une simple proportion constante (visée) de procédures de gestion potentielles est appliquée aux 16 modèles opérationnels conditionnés de la version 3.3.0 du package. Des gammes des deux paramètres de contrôle pour les proportions ouest et est ont été sélectionnées afin de permettre un compromis raisonnable entre la capture et la reconstitution des stocks (le cas échéant). Ceci est facilement réalisable pour la plupart des modèles opérationnels. Cependant, des problèmes se posent pour certains modèles opérationnels du facteur d'abondance B (l'abondance inférieure des stocks de l'Ouest correspondant à celle de l'évaluation la plus récente), associée à une fonction de stock-recrutement de Beverton-Holt inchangée pour le stock de l'Ouest (facteur de recrutement 2). Dans l'un de ces scénarios, même en l'absence de captures dans la zone de l'Ouest, un stock déjà épuisé dans l'ouest décroît avec des captures dans l'Est largement inférieures aux niveaux actuels, car un nombre suffisant de thons rouges d'origine occidentale migre vers l'Est et peuvent y être capturés. La question qui se pose dans l'immédiat est alors de savoir si de tels scénarios de modèles opérationnels sont suffisamment plausibles pour qu'ils soient pris en compte dans la sélection de la procédure de gestion, bien que ces situations pourraient être le reflet du manque de fiabilité des conditionnements des modèles opérationnels élaborés sous une très forte pression temporelle.

RESUMEN

Se aplica una proporción constante simple (intencionada) de posibles procedimientos de ordenación a los 16 modelos operativos condicionados en la versión 3.3.0 del paquete. Se seleccionan rangos de los dos parámetros de control para las proporciones del este y del oeste para facilitar una solución de compromiso razonable entre la captura y la recuperación del stock (cuando es necesario). Para la mayoría de los modelos operativos esto se logra fácilmente. Sin embargo, los problemas surgen para alguno de los modelos operativos del factor B de abundancia (con menores abundancias del stock occidental que se corresponden con las de la evaluación más reciente) asociados a una función stock reclutamiento de Beverton-Holt inalterable para el stock occidental (factor de reclutamiento 2). Para uno de estos escenarios, incluso sin captura de la zona occidental, un stock occidental ya mermado desciende con

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capturas en el este que están muy por debajo de los niveles presentes, porque suficiente atún rojo de origen occidental migra a la zona del este y puede ser capturado ahí. La pregunta clave inmediata es entonces si dichos escenarios de los modelos operativos son lo suficientemente plausibles para que necesiten tenerse en cuenta en la selección del procedimiento de ordenación, aunque podría ser que estos supuestos reflejen poca fiabilidad de los condicionamientos de los modelos operativos desarrollados bajo una intensa presión temporal.

KEYWORDS

Management Strategy Evaluation, Candidate Management Procedure, Operating Model, Atlantic bluefin tuna, Trade-off, Plausibility

Introduction

This paper extends the initial explorations of Butterworth et al. (2018) which aimed ultimately at developing Candidate Management Procedures (CMPs) for the (two mixing stocks of the) North Atlantic Bluefin tuna resource. Little change has been made to the CMPs introduced in that document to the April 2018 ICCAT Bluefin MSE meeting. The important update is that these are now applied to the updated conditioned Operating Models (OMs) in the revised Package version 3.3.0.

Because that Package, following corrections, became available only quite late, the work reported in this document is somewhat limited. It focuses on establishing ranges for control parameters of the CMPs that reflect reasonable trade-offs between resource conservation (securing resource recovery where needed) and taking large catches in both the east and west Atlantic across the range of 16 conditioned OMs available in the Package. The performances of the three OMs for which such a trade-off proves rather difficult to obtain are examined in some more detail.

Methods

The methods applied here are very similar to those introduced in Butterworth *et al.* (2018), though there are some changes and one addition to the future abundance indices that are taken into account in the TAC formulae.

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[2], and then taking a weighted average of the results for each index, where the weight is inversely proportional to the variance (σ^2) shown by that standardised index over the chosen years. The mathematical details are as follows:

J_y is an average index over *n* series (*n*=4 for the East area and *n*=4 for the West area)[3]:

$$J_y = \frac{\sum_i^n w_i \times I_y^{i*}}{\sum_i^n w_i} \qquad (1)$$

where

$$w_i = \frac{1}{(\sigma^i)^2}$$

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

[2] These years commence from 2011 (JPN_LL_NEAtl2), 2009 for FR_AER_SUV, 2012 for MED_LAR_SUV, 2010 for GBYP_AER_SUV, 2011 for JPN_LL_West2, 2007 forUS_RR_66_114, 1979 for GOM_LAR_SUV and 2006 for CAN_ACO_SUV.

[3] For the French and Mediterranean aerial survey, there is no value for 2013 and 2015 respectively. For GBYP aerial survey there is no value for 2012, 2014 and 2016. For Mediterranean survey, Canadian acoustic survey, there is no value for 2016. These years were omitted from this averaging where relevant.

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

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

$$J_{av,y} = \frac{1}{3}\left(J_y + J_{y-1} + J_{y-2}\right) \tag{2}$$

where the J applies to either to the East or to the West area.

CMP specifications

The Fixed Proportion (FXP) CMPs tested set the TAC every second year simply as a multiple of the J_{av} value for the area at the time, 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:

$$TAC_{E,y} = \left(\frac{TAC_{E,2018}}{J_{E,2016}}\right) \cdot \alpha \cdot J_{av,y-2}^{E} \tag{3a}$$

If $TAC_{E,y} \geq 1.2 * TAC_{E,y-1}$ then $TAC_{E,y} = 1.2 * TAC_{E,y-1}$

If $TAC_{E,y} \leq 0.8 * TAC_{E,y-1}$ then $TAC_{E,y} = 0.8 * TAC_{E,y-1}$

For the West area:

$$TAC_{W,y} = \left(\frac{TAC_{W,2018}}{J_{W,2016}}\right) \cdot \beta \cdot J_{av,y-2}^{W} \tag{3b}$$

If $TAC_{W,y} \geq 1.2 * TAC_{W,y-1}$ then $TAC_{W,y} = 1.2 * TAC_{W,y-1}$

If $TAC_{W,y} \leq 0.8 * TAC_{W,y-1}$ then $TAC_{W,y} = 0.8 * TAC_{W,y-1}$

Note that in equation (3a), setting $\alpha = 1$ will amount to keeping the TAC the same as for 2018 until the abundance indices change. If α or $\beta > 1$ harvesting will be more intensive then at present and for α or $\beta < 1$ it will be less intensive.

For the deterministic case, CMPs were run under selections from the Package for deterministic OMs with *Perfect observation* and with no implementation error. For the stochastic case, CMPs were run under selections from the Package for normal OMs with *Good observation* and with no implementation error.

Because of late availability of the Package and the time needed for local installation, only limited investigations have been possible, with many of these having been based on deterministic projections.

Results

Initial efforts were targeted at determining ranges of values of the control parameters α and β that provided both reasonable final resource status and reasonable average annual catches over the next 30 years, and for as many of the 16 conditioned Operating Models (OMs) in the most recent Package circulated as possible. Given the Commission's objective of MSY, achievement of the first of these criteria was determined by considering the Br30 statistic (SSB after 30 years divided by dynamic SSBmsy; the latter needs to be used because some OMs incorporate regime shifts in their stock-recruitment relationships). Ideally Br30 should be in the vicinity of 1, though taking into account the corresponding starting value Br0 because if this is low it would not be realistic to require that much resource growth. Catch performance was assessed by considering AvC30 (the average annual catch over the first 30 years of projection).

These efforts were based on deterministic runs (for computational speed). They suggested that all four combinations of α and β equal to 0.5 and 1.0 reflected an appropriate part of management control parameter space to consider. [These selections were compromised somewhat by errors being found in the projection code after the choices had been made, but subsequent evaluations suggested that they were nevertheless reasonable as starting choices.]

Results for the 16 OMs for this first 30 years projection period are shown in Table 1 and 2 and Figures 1 (deterministic) and 2 (stochastic) for Br30 and AvC30, and in Table 3 for AAV (corresponding to percentage changes at two year intervals). Note that for the Br30 plots, one generally finds the Br30 values themselves between the starting value Br0 and the 30-year no catch value for each OM, and also either close to or above 1, as would be desired. The Br30 values are generally somewhat lower for α=1 (corresponding to a higher intended fishing mortality) than for α=0.5 as would be expected, but are little affected for either west or east stock by the value chosen for β. In contrast, catches for the west area are notably higher for the higher β value, and likewise for the east area for the higher α value. AAV median values are generally in the 10-20% range for both west and east areas, being higher in the west for the higher β choice, but higher for the lower α choice in the east (Table 3).

There are some differences between the deterministic and median stochastic results (Table 4 and Figure 3). The stochastic medians tend to be somewhat lower for Br30, but higher for the average annual catch.

The exceptions to the generally acceptable performance summarised above arise for three scenarios: 2BII (OM14), 2BIII (OM23) and 2BIV (OM32). While there are some differences between deterministic and median stochastic results, generally these cases can give rise to Br30 values that are below the corresponding and already low Br0 values, suggesting harvesting is too heavy and has reduced depleted stocks even further.

For the deterministic 2BII (OM14) scenario, there is an apparent problem for the east stock, but Figure 5 suggests that this is misleading: SSB is increasing but dynamic SSBmsy is increasing faster, so that this is not necessarily a problem.

However, the situation for the west stock is more serious for scenario 2BII (OM23), and more so for 2BIV (OM32) (see Figure 6 and Table 5). To focus on the latter scenario, Fig 6(b) shows that even with no catch permitted in the west area, the west stock continues to decline unless the exploitation rate in the east is reduced from α=0.5 to the vicinity of 0.25, which would mean sharply reducing the current TACs in the east

Discussion

For most of the OMs, adequate recovery (where needed) together with fairly large catches can be readily achieved. This is the case for all eight type-A OMs, though bear in mind that those tend to have appreciably higher west stock abundances than for the conventional non-mixing assessments.

The problem arises for the abundance factor B OMs (with lower west stock abundances) coupled to an unchanging Beverton-Holt stock-recruitment function for the west stock (recruitment factor 2). There even with no catch from the west area, the west stock can decline under catches in the east because sufficient bluefin of western origin migrate to the east area and can be harvested there.

The key immediate question then becomes whether OM scenarios such as 2BIV are sufficiently plausible that they need to be taken into account when seeking an MP which evidences robustness over a range of reasonably plausible levels of uncertainty.

Further analyses

Further refinement of the CMPs put forward here, given that these need to provide evidence of robustness to plausible uncertainties, would first seem to need to await resolution of issues raised above relating to OM plausibility. Accordingly, the results presented here should be seen as illustrative, rather than definitive.

[Note that Tom Carruthers subsequently reported that conditioning of some OMs (conducted under considerable time pressures) was not completely reliable, so that it may be that some of the issues raised above are not fundamental problems, but rather reflections of that lack of reliability.]

Reference

Butterworth DS, Miyagawa M. and Jacobs MRA. 2018. Results for initial explorations of simple candidate "fixed proportion" MPs for Atlantic bluefin tuna based on the operating models package circulated. SCRS/2018/047.

Acknowledgments

We thank Tom Carruthers for assistance with various aspects of the Operating Model Package. Computations were performed using facilities provided by the University of Cape Town's ICTS High Performance Computing team: http://hpc.uct.ac.za.

Table 1a. Stochastic results for **dynamic depletion (Br)** of CMPs to 16 OMs for $\mathrm{Br} = \mathrm{SSB}/SSB_{MSY}$ for $\boldsymbol{\alpha}$ **= 0.5**. Medians (bold) and 90% percentage interval (PI) are shown. Values under 0.5 shown in italics.

α = 0.5																							
Br30				Br0	**WEST**									Br0	**EAST**								
α					0			0.5							0			0.5					
β					0			0.5			1				0			0.5			1		
					0.05	**Median**	0.95	0.05	**Median**	0.95	0.05	**Median**	0.95		0.05	**Median**	0.95	0.05	**Median**	0.95	0.05	**Median**	0.95
A-group	OM	1.00	1 A I	1.11	1.87	**2.20**	2.49	1.17	**1.42**	1.69	1.03	**1.23**	1.51	0.89	2.31	**2.73**	3.39	1.54	**1.95**	2.51	1.50	**1.90**	2.45
		10.00	1 A II	0.70	1.88	**2.20**	2.47	1.12	**1.34**	1.59	0.97	**1.18**	1.40	0.66	2.09	**2.43**	2.99	1.35	**1.73**	2.21	1.31	**1.68**	2.15
		19.00	1 A III	1.15	1.97	**2.35**	2.60	1.34	**1.59**	1.86	1.15	**1.41**	1.66	0.90	2.51	**2.98**	3.73	1.66	**2.09**	2.72	1.61	**2.03**	2.65
		28.00	1 A IV	0.66	2.07	**2.46**	2.72	1.33	**1.57**	1.83	1.14	**1.38**	1.63	0.67	2.21	**2.58**	3.15	1.40	**1.78**	2.26	1.35	**1.73**	2.19
		2.00	2 A I	0.86	1.70	**2.03**	2.36	1.00	**1.32**	1.72	0.93	**1.23**	1.61	0.23	1.32	**1.58**	2.03	0.94	**1.23**	1.58	0.93	**1.21**	1.56
		11.00	2 A II	0.83	1.48	**1.77**	2.06	0.85	**1.14**	1.44	0.77	**1.06**	1.35	0.26	0.84	**1.02**	1.30	*0.38*	**0.57**	0.83	*0.37*	**0.56**	0.81
		20.00	2 A III	0.70	1.77	**2.18**	2.56	1.07	**1.42**	1.84	1.00	**1.34**	1.74	0.14	1.24	**1.53**	1.94	0.96	**1.26**	1.67	0.95	**1.24**	1.65
		29.00	2 A IV	0.35	1.31	**1.62**	1.91	0.59	**0.77**	1.01	*0.49*	**0.66**	0.88	0.24	0.89	**1.09**	1.39	*0.47*	**0.66**	0.83	*0.45*	**0.63**	0.80
B-group		4.00	1-B-I	1.11	1.82	**2.08**	2.36	1.02	**1.26**	1.53	0.84	**1.13**	1.40	1.07	2.20	**2.57**	3.20	1.62	**2.01**	2.55	1.58	**1.97**	2.49
		13.00	1-B-II	0.84	2.35	**2.66**	2.95	1.62	**1.78**	2.09	1.39	**1.56**	1.85	0.81	2.11	**2.44**	2.97	1.42	**1.77**	2.24	1.37	**1.73**	2.18
		22.00	1-B-III	1.18	1.87	**2.18**	2.41	1.18	**1.40**	1.64	1.04	**1.27**	1.49	1.16	2.42	**2.85**	3.48	1.77	**2.18**	2.78	1.72	**2.14**	2.71
		31.00	1-B-IV	0.57	2.54	**3.00**	3.28	1.50	**1.77**	2.12	1.23	**1.50**	1.78	0.87	2.21	**2.57**	3.14	1.53	**1.92**	2.40	1.48	**1.86**	2.33
		5.00	2-B-I	0.52	1.61	**1.92**	2.26	0.85	**1.22**	1.56	0.75	**1.10**	1.42	0.21	1.20	**1.44**	1.83	0.95	**1.22**	1.53	0.94	**1.20**	1.52
		14.00	2-B-II	0.59	1.51	**1.79**	2.08	0.96	**1.22**	1.48	0.87	**1.10**	1.36	0.13	*0.30*	***0.37***	*0.52*	*0.03*	***0.09***	*0.19*	*0.03*	***0.08***	*0.18*
		23.00	2-B-III	0.24	1.35	**1.67**	2.01	*0.21*	***0.35***	0.53	*0.12*	***0.25***	*0.42*	0.35	*0.00*	***0.00***	*0.00*	*0.00*	***0.00***	*0.00*	*0.00*	***0.00***	*0.00*
		32.00	2-B-IV	0.25	1.13	**1.39**	1.70	*0.05*	***0.19***	*0.44*	*0.00*	***0.08***	*0.31*	0.47	*0.00*	***0.00***	*0.00*	*0.00*	***0.00***	*0.00*	*0.00*	***0.00***	*0.00*

Table 1b. Stochastic results for **dynamic depletion(Br)** of CMPs to 16 OMs for Br $= \mathrm{SSB}/SSB_{MSY}$ for $\boldsymbol{\alpha}$ **= 1**. Medians (bold) and 90% percentage interval (PI) are shown. Values under 0.5 shown in italics.

α = 1																							
Br30				Br0	**WEST**									Br0	**EAST**								
α					0			1							0			1					
β					0			0.5			1				0			0.5			1		
					0.05	**Median**	0.95	0.05	**Median**	0.95	0.05	**Median**	0.95		0.05	**Median**	0.95	0.05	**Median**	0.95	0.05	**Median**	0.95
A-group	OM	1	1 A I	1.11	1.87	**2.20**	2.49	0.95	**1.22**	1.47	0.80	**1.03**	1.31	0.89	2.31	**2.73**	3.39	1.10	**1.46**	1.95	1.07	**1.43**	1.90
		10	1 A II	0.70	1.88	**2.20**	2.47	0.87	**1.07**	1.31	0.74	**0.95**	1.15	0.66	2.09	**2.43**	2.99	0.96	**1.25**	1.73	0.93	**1.21**	1.68
		19	1 A III	1.15	1.97	**2.35**	2.60	1.13	**1.37**	1.64	0.97	**1.21**	1.45	0.90	2.51	**2.98**	3.73	1.44	**1.52**	2.13	1.11	**1.48**	2.08
		28	1 A IV	0.66	2.07	**2.46**	2.72	1.08	**1.30**	1.57	0.92	**1.13**	1.39	0.67	2.21	**2.58**	3.15	0.97	**1.31**	1.74	0.94	**1.26**	1.70
		2	2 A I	0.86	1.70	**2.03**	2.36	0.74	**0.98**	1.36	0.69	**0.91**	1.28	0.23	1.32	**1.58**	2.03	0.64	**0.93**	1.29	0.63	**0.92**	1.27
		11	2 A II	0.83	1.48	**1.77**	2.06	0.61	**0.87**	1.20	0.55	**0.79**	1.13	0.26	0.84	**1.02**	1.30	0.16	**0.29**	0.53	*0.15*	**0.28**	0.51
		20	2 A III	0.70	1.77	**2.18**	2.56	0.77	**1.01**	1.41	0.71	**0.96**	1.32	0.14	1.24	**1.53**	1.94	0.76	**1.05**	1.43	0.75	**1.03**	1.42
		29	2 A IV	0.35	1.31	**1.62**	1.91	*0.39*	**0.54**	0.72	*0.31*	***0.45***	0.61	0.24	0.89	**1.09**	1.39	*0.22*	***0.37***	0.52	*0.21*	***0.35***	*0.49*
B-group		4	1-B-I	1.11	1.82	**2.08**	2.36	0.75	**1.03**	1.31	0.56	**0.84**	1.17	1.07	2.20	**2.57**	3.20	1.22	**1.56**	2.06	1.19	**1.53**	2.01
		13	1-B-II	0.84	2.35	**2.66**	2.95	1.38	**1.54**	1.84	1.20	**1.35**	1.61	0.81	2.11	**2.44**	2.97	0.99	**1.30**	1.76	0.96	**1.27**	1.71
		22	1-B-III	1.18	1.87	**2.18**	2.41	1.00	**1.20**	1.41	0.85	**1.09**	1.28	1.16	2.42	**2.85**	3.48	1.29	**1.64**	2.23	1.26	**1.61**	2.17
		31	1-B-IV	0.57	2.54	**3.00**	3.28	1.18	**1.42**	1.73	0.96	**1.20**	1.46	0.87	2.21	**2.57**	3.14	1.12	**1.47**	1.90	1.08	**1.42**	1.85
		5	2-B-I	0.52	1.61	**1.92**	2.26	0.57	**0.82**	1.24	0.51	**0.73**	1.08	0.21	1.20	**1.44**	1.83	0.74	**1.03**	1.37	0.72	**1.02**	1.36
		14	2-B-II	0.59	1.51	**1.79**	2.08	0.76	**1.04**	1.32	0.66	**0.92**	1.20	0.13	*0.30*	***0.37***	0.52	*0.00*	***0.00***	*0.03*	*0.00*	***0.00***	*0.02*
		23	2-B-III	0.24	1.35	**1.67**	2.01	*0.00*	***0.03***	*0.16*	*0.00*	***0.00***	*0.10*	0.35	*0.00*	***0.00***	*0.00*	*0.00*	***0.00***	*0.00*	*0.00*	***0.00***	*0.00*
		32	2-B-IV	0.25	1.13	**1.39**	1.70	*0.00*	***0.00***	*0.07*	*0.00*	***0.00***	*0.02*	0.47	*0.00*	***0.00***	*0.00*	*0.00*	***0.00***	*0.00*	*0.00*	***0.00***	*0.00*

Table 2a. Stochastic results for average annual catch over 30 years projection (AvC30) of CMPs to 16 OMs for Br $= \mathrm{SSB}/SSB_{MSY}$ for $\boldsymbol{\alpha}$ **= 0.5.** Medians (bold) and 90% percentage interval (PI) are shown.

α = 0.5																	
AvC30				**WEST**							**EAST**						
α				0	0.50						0	0.50					
β				0	0.50			1.00			0	0.50			1.00		
				Median	0.05	**Median**	0.95	0.05	**Median**	0.95	**Median**	0.05	**Median**	0.95	0.05	**Median**	0.95
A-group	OM	1.00	1 A I	**0.13**	1.80	**2.26**	2.77	3.35	**4.21**	5.19	**1.42**	17.39	**21.57**	26.73	17.29	**21.31**	26.39
		10.00	1 A II	**0.13**	1.87	**2.34**	2.93	3.49	**4.38**	5.51	**1.42**	17.82	**22.74**	28.84	17.69	**22.44**	28.48
		19.00	1 A III	**0.13**	1.79	**2.24**	2.77	3.34	**4.19**	5.19	**1.42**	17.05	**21.48**	26.52	16.95	**21.28**	26.17
		28.00	1 A IV	**0.13**	1.88	**2.34**	2.92	3.50	**4.38**	5.53	**1.42**	17.52	**22.50**	28.45	17.39	**22.20**	28.08
		2.00	2 A I	**0.13**	2.02	**2.47**	3.31	3.80	**4.71**	6.33	**1.42**	21.15	**28.86**	39.19	21.03	**28.65**	38.89
		11.00	2 A II	**0.13**	1.51	**1.77**	2.19	2.78	**3.29**	4.12	**1.42**	18.51	**22.97**	31.16	18.31	**22.64**	30.69
		20.00	2 A III	**0.13**	2.12	**2.66**	3.55	4.01	**5.08**	6.85	**1.42**	22.12	**30.66**	42.19	22.02	**30.47**	41.96
		29.00	2 A IV	**0.13**	1.83	**2.18**	2.86	3.37	**4.03**	5.34	**1.42**	18.08	**23.39**	30.02	17.85	**23.03**	29.35
B-group		4.00	1-B-I	**0.13**	1.74	**2.22**	2.83	3.25	**4.20**	5.36	**1.42**	16.38	**19.97**	24.56	16.29	**19.80**	24.33
		13.00	1-B-II	**0.13**	1.81	**2.22**	2.74	3.38	**4.17**	5.15	**1.42**	16.50	**20.89**	26.31	16.39	**20.67**	25.98
		22.00	1-B-III	**0.13**	1.73	**2.28**	2.93	3.25	**4.32**	5.59	**1.42**	16.40	**19.82**	24.61	16.31	**19.65**	24.35
		31.00	1-B-IV	**0.13**	1.87	**2.35**	2.94	3.51	**4.43**	5.53	**1.42**	16.54	**20.85**	26.44	16.45	**20.68**	26.14
		5.00	2-B-I	**0.13**	2.33	**2.96**	4.26	4.42	**5.68**	8.21	**1.42**	18.88	**30.00**	46.07	18.78	**29.81**	45.83
		14.00	2-B-II	**0.13**	1.43	**1.74**	2.41	2.59	**3.19**	4.51	**1.42**	14.42	**18.32**	25.97	14.03	**17.79**	25.53
		23.00	2-B-III	**0.13**	0.90	**1.05**	1.24	1.52	**1.78**	2.18	**1.37**	9.07	**10.40**	12.74	8.52	**9.72**	12.12
		32.00	2-B-IV	**0.13**	0.81	**0.94**	1.11	1.24	**1.54**	1.84	**1.30**	7.52	**8.19**	9.06	6.59	**7.86**	8.68

Table 2b. Stochastic results for average annual catch over 30 years projection (AvC30) of CMPs to 16 OMs for $\mathrm{Br} = \mathrm{SSB}/SSB_{MSY}$ for $\boldsymbol{\alpha}$ **= 1.** Medians (bold) and 90% percentage interval (PI) are shown.

α = 1																							
Br30				Br0	**WEST**									Br0	**EAST**								
α					0			1							0			1					
β					0			0.5			1				0			0.5			1		
					0.05	**Median**	0.95	0.05	**Median**	0.95	0.05	**Median**	0.95		0.05	**Median**	0.95	0.05	**Median**	0.95	0.05	**Median**	0.95
A-group	OM	1	1 A I	1.11	1.87	**2.20**	2.49	0.95	**1.22**	1.47	0.80	**1.03**	1.31	0.89	2.31	**2.73**	3.39	1.10	**1.46**	1.95	1.07	**1.43**	1.90
		10	1 A II	0.70	1.88	**2.20**	2.47	0.87	**1.07**	1.31	0.74	**0.95**	1.15	0.66	2.09	**2.43**	2.99	0.96	**1.25**	1.73	0.93	**1.21**	1.68
		19	1 A III	1.15	1.97	**2.35**	2.60	1.13	**1.37**	1.64	0.97	**1.21**	1.45	0.90	2.51	**2.98**	3.73	1.44	**1.52**	2.13	1.11	**1.48**	2.08
		28	1 A IV	0.66	2.07	**2.46**	2.72	1.08	**1.30**	1.57	0.92	**1.13**	1.39	0.67	2.21	**2.58**	3.15	0.97	**1.31**	1.74	0.94	**1.26**	1.70
		2	2 A I	0.86	1.70	**2.03**	2.36	0.74	**0.98**	1.36	0.69	**0.91**	1.28	0.23	1.32	**1.58**	2.03	0.64	**0.93**	1.29	0.63	**0.92**	1.27
		11	2 A II	0.83	1.48	**1.77**	2.06	0.61	**0.87**	1.20	0.55	**0.79**	1.13	0.26	0.84	**1.02**	1.30	0.16	**0.29**	0.53	*0.15*	**0.28**	0.51
		20	2 A III	0.70	1.77	**2.18**	2.56	0.77	**1.01**	1.41	0.71	**0.96**	1.32	0.14	1.24	**1.53**	1.94	0.76	**1.05**	1.43	0.75	**1.03**	1.42
		29	2 A IV	0.35	1.31	**1.62**	1.91	*0.39*	**0.54**	0.72	*0.31*	***0.45***	0.61	0.24	0.89	**1.09**	1.39	*0.22*	***0.37***	0.52	*0.21*	***0.35***	*0.49*
B-group		4	1-B-I	1.11	1.82	**2.08**	2.36	0.75	**1.03**	1.31	0.56	**0.84**	1.17	1.07	2.20	**2.57**	3.20	1.22	**1.56**	2.06	1.19	**1.53**	2.01
		13	1-B-II	0.84	2.35	**2.66**	2.95	1.38	**1.54**	1.84	1.20	**1.35**	1.61	0.81	2.11	**2.44**	2.97	0.99	**1.30**	1.76	0.96	**1.27**	1.71
		22	1-B-III	1.18	1.87	**2.18**	2.41	1.00	**1.20**	1.41	0.85	**1.09**	1.28	1.16	2.42	**2.85**	3.48	1.29	**1.64**	2.23	1.26	**1.61**	2.17
		31	1-B-IV	0.57	2.54	**3.00**	3.28	1.18	**1.42**	1.73	0.96	**1.20**	1.46	0.87	2.21	**2.57**	3.14	1.12	**1.47**	1.90	1.08	**1.42**	1.85
		5	2-B-I	0.52	1.61	**1.92**	2.26	0.57	**0.82**	1.24	0.51	**0.73**	1.08	0.21	1.20	**1.44**	1.83	0.74	**1.03**	1.37	0.72	**1.02**	1.36
		14	2-B-II	0.59	1.51	**1.79**	2.08	0.76	**1.04**	1.32	0.66	**0.92**	1.20	0.13	*0.30*	***0.37***	0.52	*0.00*	***0.00***	*0.03*	*0.00*	***0.00***	*0.02*
		23	2-B-III	0.24	1.35	**1.67**	2.01	*0.00*	***0.03***	*0.16*	*0.00*	***0.00***	*0.10*	0.35	*0.00*	***0.00***	*0.00*	*0.00*	***0.00***	*0.00*	*0.00*	***0.00***	*0.00*
		32	2-B-IV	0.25	1.13	**1.39**	1.70	*0.00*	***0.00***	*0.07*	*0.00*	***0.00***	*0.02*	0.47	*0.00*	***0.00***	*0.00*	*0.00*	***0.00***	*0.00*	*0.00*	***0.00***	*0.00*

Table 3. Stochastic results for **AAV** of CMPs to 16 OMs for $\mathrm{Br} = \mathrm{SSB}/SSB_{MSY}$. Note that AAV here refers to average percentage over every time the TAC changes, which is every 2 years.

AAV				WEST					EAST				
α				0.0	0.5		1.0		0.0	0.5		1.0	
β				0.0	0.5	1.0	0.5	1.0	0.0	0.5	1.0	0.5	1.0
A-group	OM	1	1 A I	4.1	10.9	14.7	11.7	14.4	4.1	11.2	11.0	10.2	10.0
		10	1 A II	4.1	11.7	15.3	10.9	14.4	4.1	13.2	13.2	10.8	10.5
		19	1 A III	4.1	11.6	14.7	11.8	15.0	4.1	11.8	12.0	10.5	10.4
		28	1 A IV	4.1	11.8	14.9	11.2	14.1	4.1	13.6	13.4	10.5	10.6
		2	2 A I	4.1	13.5	17.7	12.7	16.9	4.1	16.9	16.9	13.6	13.5
		11	2 A II	4.1	16.1	17.3	14.9	16.4	4.1	17.0	16.9	12.9	12.0
		20	2 A III	4.1	13.7	19.3	13.3	17.5	4.1	20.0	19.9	17.0	16.5
		29	2 A IV	4.1	12.7	16.6	12.0	15.1	4.1	16.9	16.9	11.8	11.1
B-group		4	1-B-I	4.1	11.6	15.2	11.5	14.5	4.1	12.2	12.2	10.0	10.1
		13	1-B-II	4.1	11.3	14.7	11.1	13.6	4.1	13.3	13.3	11.5	11.2
		22	1-B-III	4.1	11.9	15.7	10.7	14.6	4.1	12.2	12.2	10.2	10.2
		31	1-B-IV	4.1	11.7	15.9	10.9	14.4	4.1	13.2	13.1	11.4	11.3
		5	2-B-I	4.1	14.3	19.9	13.5	19.8	4.1	19.8	19.7	19.3	19.2
		14	2-B-II	4.1	14.6	17.6	13.6	16.8	4.1	20.0	20.0	20.0	20.0
		23	2-B-III	4.1	17.8	18.2	18.1	0.8	4.1	14.0	15.3	17.6	19.0
		32	2-B-IV	4.1	18.7	19.9	0.0	0.0	4.1	18.0	17.1	5.4	5.1

Table 4a. Comparison of Br30 values for Stochastic (median shown) and Deterministic projections of 16 Oms under CMPs. **Result s for West Stock.** Values of Br30 under 0.5 are shown in italics.

Br30				WEST STOCK									
α				0		0.5				1			
β				0		0.5		1		0.5		1	
				Median	Det.	Median	Det.	Median	Det.	Median	Det.	Median	Det.
A-group	OM	1	1 A I	**2.20**	2.19	**1.42**	1.61	**1.23**	1.45	**1.22**	1.42	**1.03**	1.27
		10	1 A II	**2.20**	2.19	**1.34**	1.53	**1.18**	1.39	**1.07**	1.29	**0.95**	1.16
		19	1 A III	**2.35**	2.32	**1.59**	1.74	**1.41**	1.57	**1.37**	1.53	**1.21**	1.38
		28	1 A IV	**2.46**	2.44	**1.57**	1.76	**1.38**	1.59	**1.30**	1.51	**1.13**	1.35
		2	2 A I	**2.03**	2.05	**1.32**	1.47	**1.23**	1.40	**0.98**	1.11	**0.91**	1.05
		11	2 A II	**1.77**	1.79	**1.14**	1.23	**1.06**	1.16	**0.87**	0.96	**0.79**	0.89
		20	2 A III	**2.18**	1.38	**1.42**	1.06	**1.34**	0.99	**1.01**	0.93	**0.96**	0.86
		29	2 A IV	**1.62**	1.63	**0.77**	0.91	**0.66**	0.81	**0.54**	0.62	**0.45**	0.55
B-group		4	1-B-I	**2.08**	2.09	**1.26**	1.44	**1.13**	1.33	**1.03**	1.24	**0.84**	1.14
		13	1-B-II	**2.66**	2.68	**1.78**	2.04	**1.56**	1.83	**1.54**	1.80	**1.35**	1.61
		22	1-B-III	**2.18**	2.17	**1.40**	1.49	**1.27**	1.40	**1.20**	1.34	**1.09**	1.25
		31	1-B-IV	**3.00**	3.00	**1.77**	2.06	**1.50**	1.80	**1.42**	1.73	**1.20**	1.50
		5	2-B-I	**1.92**	1.95	**1.22**	1.42	**1.10**	1.33	**0.82**	1.06	**0.73**	0.98
		14	2-B-II	**1.79**	1.82	**1.22**	1.20	**1.10**	1.09	**1.04**	1.09	**0.92**	1.00
		23	2-B-III	**1.67**	*1.05*	***0.35***	*0.22*	***0.25***	*0.08*	***0.03***	*0.08*	***0.00***	*0.02*
		32	2-B-IV	**1.39**	*0.17*	***0.19***	*0.00*	***0.08***	*0.00*	***0.00***	*0.00*	***0.00***	*0.00*

Table 4b. Comparison of Br30 values for Stochastic (median shown) and Deterministic projections of 16 Oms under CMPs. **Result s for East Stock.** Values of Br30 under 0.5 are shown in italics.

Br30				EAST STOCK									
α				0		0.5				1			
β				0		0.5		1		0.5		1	
				Median	Det.	Median	Det.	Median	Det.	Median	Det.	Median	Det.
A-group	OM	1	1 A I	**2.73**	2.75	**1.95**	2.12	**1.90**	2.08	**1.46**	1.67	**1.43**	1.64
		10	1 A II	**2.43**	2.49	**1.73**	1.88	**1.68**	1.84	**1.25**	1.46	**1.21**	1.43
		19	1 A III	**2.98**	3.02	**2.09**	2.29	**2.03**	2.25	**1.52**	1.78	**1.48**	1.74
		28	1 A IV	**2.58**	2.63	**1.78**	1.96	**1.73**	1.91	**1.31**	1.51	**1.26**	1.47
		2	2 A I	**1.58**	1.65	**1.23**	1.36	**1.21**	1.34	**0.93**	1.14	**0.92**	1.12
		11	2 A II	**1.02**	1.09	**0.57**	0.71	**0.56**	0.70	**0.29**	*0.46*	**0.28**	*0.45*
		20	2 A III	**1.53**	1.57	**1.26**	0.94	**1.24**	0.92	**1.05**	*0.45*	**1.03**	*0.44*
		29	2 A IV	**1.09**	1.14	**0.66**	0.78	**0.63**	0.76	***0.37***	0.54	**0.35**	0.52
B-group		4	1-B-I	**2.57**	2.61	**2.01**	2.10	**1.97**	2.07	**1.56**	1.68	**1.53**	1.65
		13	1-B-II	**2.44**	2.50	**1.77**	1.93	**1.73**	1.89	**1.30**	1.50	**1.27**	1.46
		22	1-B-III	**2.85**	2.88	**2.18**	2.31	**2.14**	2.27	**1.64**	1.82	**1.61**	1.78
		31	1-B-IV	**2.57**	2.65	**1.92**	2.09	**1.86**	2.05	**1.47**	1.67	**1.42**	1.63
		5	2-B-I	**1.44**	1.55	**1.22**	1.38	**1.20**	1.37	**1.03**	1.24	**1.02**	1.23
		14	2-B-II	***0.37***	*0.48*	***0.09***	*0.20*	***0.08***	*0.19*	***0.00***	*0.03*	***0.00***	0.03
		23	2-B-III	***0.00***	2.00	***0.00***	1.79	***0.00***	1.77	***0.00***	1.62	***0.00***	1.60
		32	2-B-IV	***0.00***	1.54	***0.00***	1.15	***0.00***	1.12	***0.00***	*0.86*	***0.00***	0.83

Table 5. Br30 values for different α and β combinations for 2BIII (OM23) and 2BIV (OM32) for the deterministic case.

Br30		OM23		OM32	
α	β	West	East	West	East
0	0	1.04	2.00	0.17	1.54
0.25	0	0.64	1.87	0.03	1.30
0.5	0	0.50	1.79	0.01	1.17
0.5	0.5	0.12	1.77	0.00	1.13
Br0		0.24	0.35	0.25	0.47

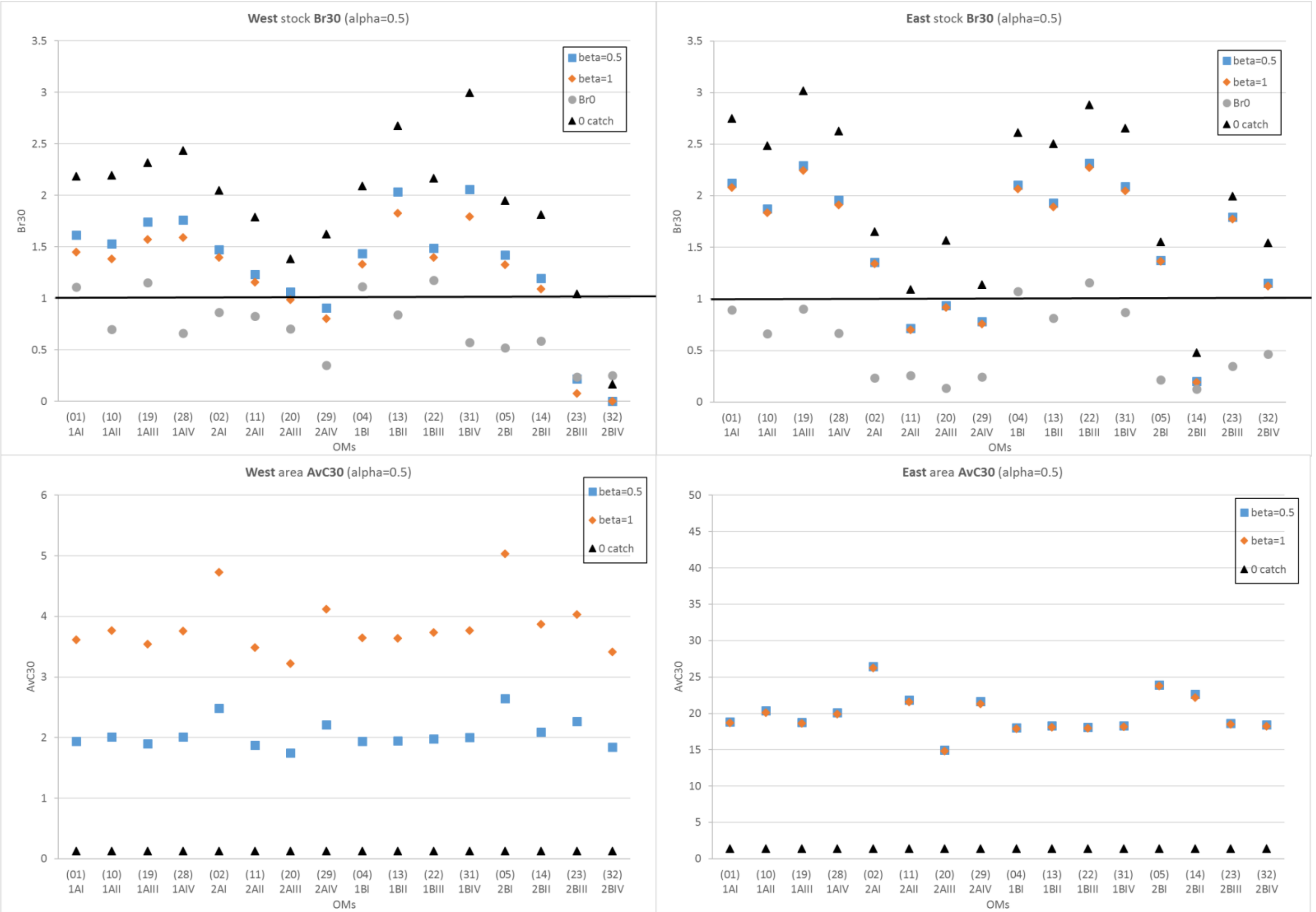

Figure 1a. Br30 and AvC30 for the 16 OMs under three scenarios: (**alpha=0.5,** beta=0.5), (**alpha=0.5**, beta=1) and (alpha=0, beta=0) for the **Deterministic runs**.

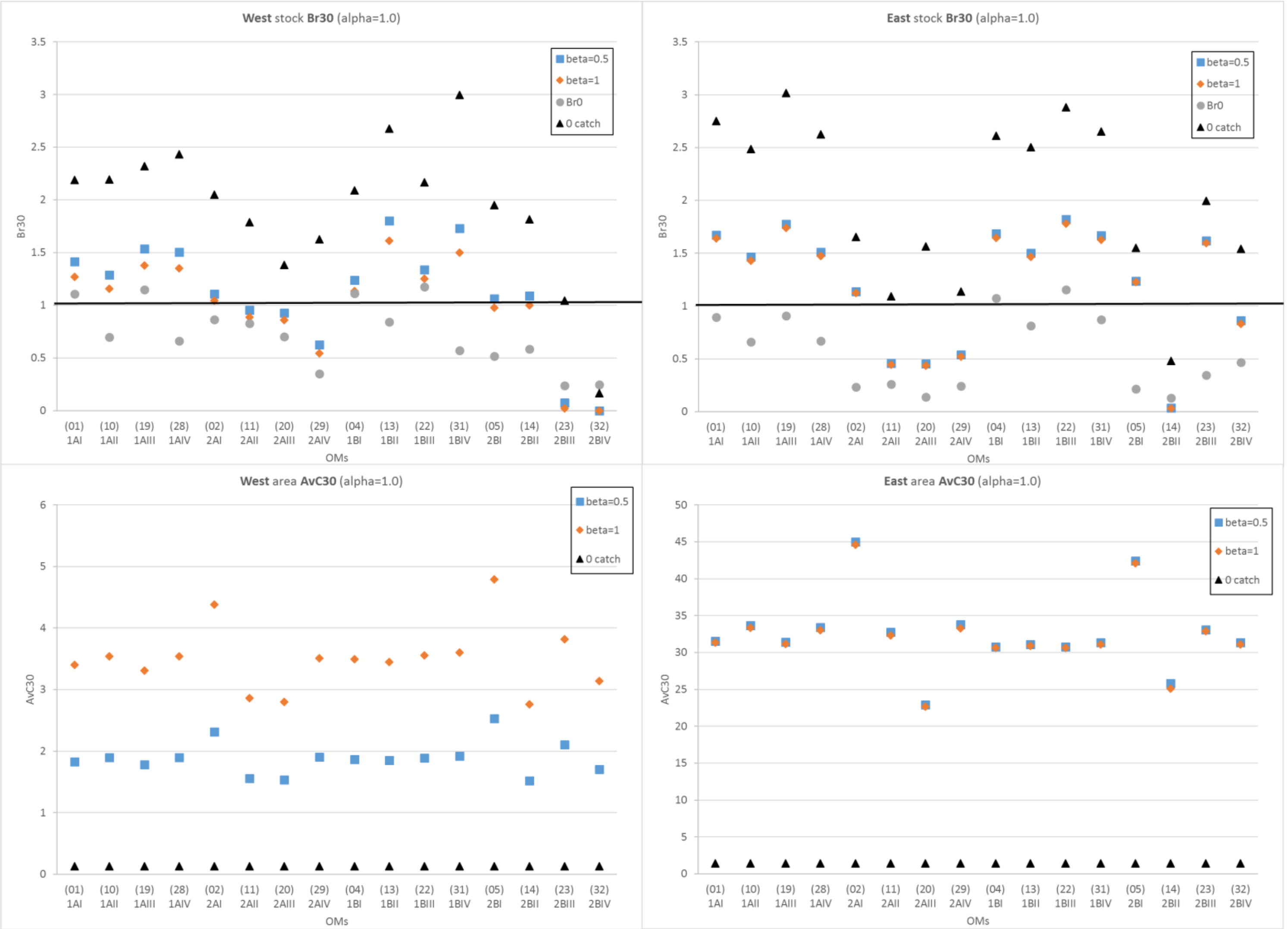

Figure 1b. Br30 and AvC30 for the 16 OMs under three scenarios: (**alpha=1.0,** beta=0.5), (**alpha=1.0**, beta=1) and (alpha=0, beta=0) for the **Deterministic runs**.

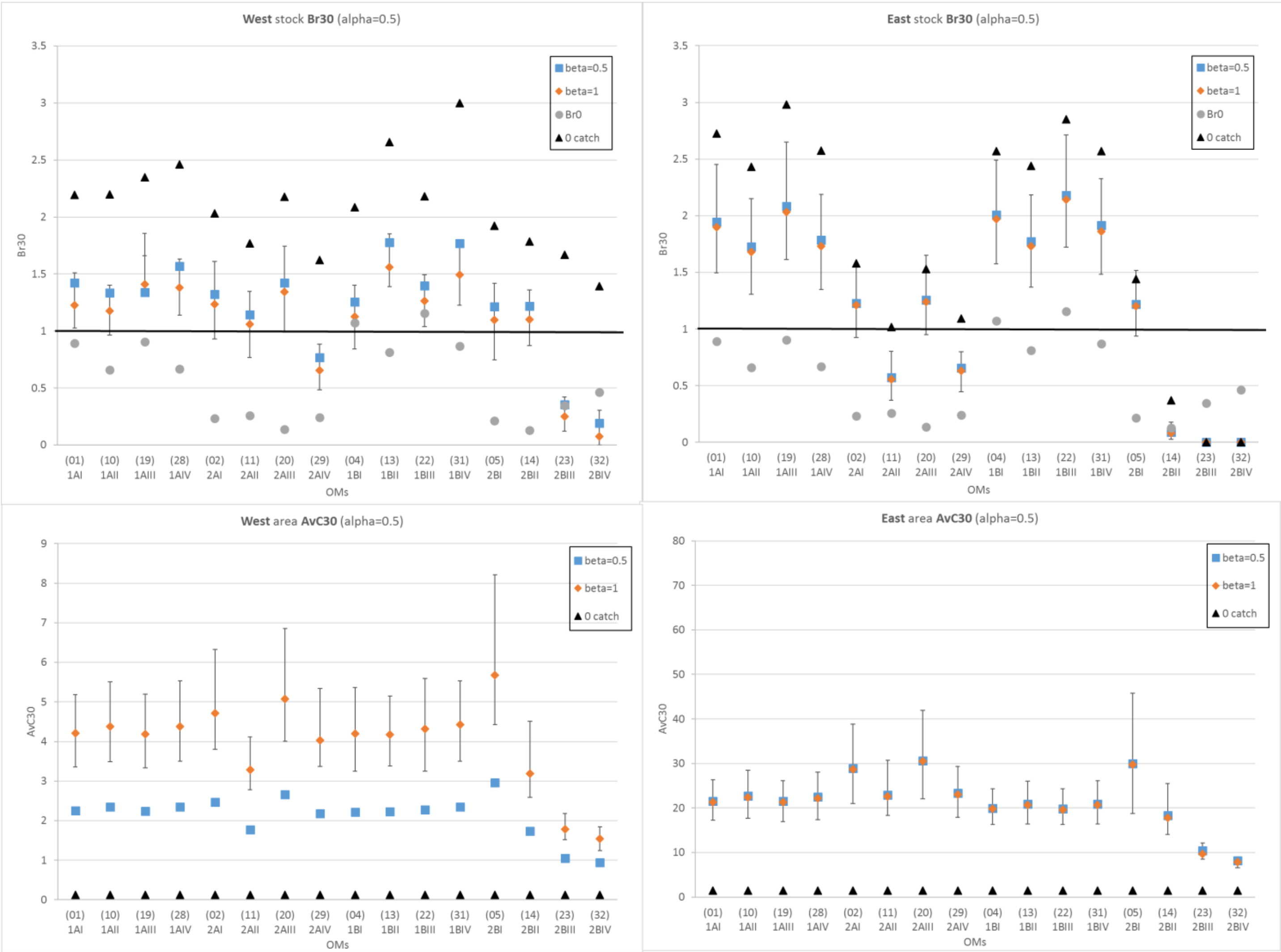

Figure 2a. Br30 and AvC30 for the 16 OMs under three scenarios: (**alpha=0.5**, beta=0.5), (**alpha=0.5**, beta=1) and (alpha=0, beta=0) for the **Stochastic runs**. Medians are shown with 90% PI's for beta=1 case.

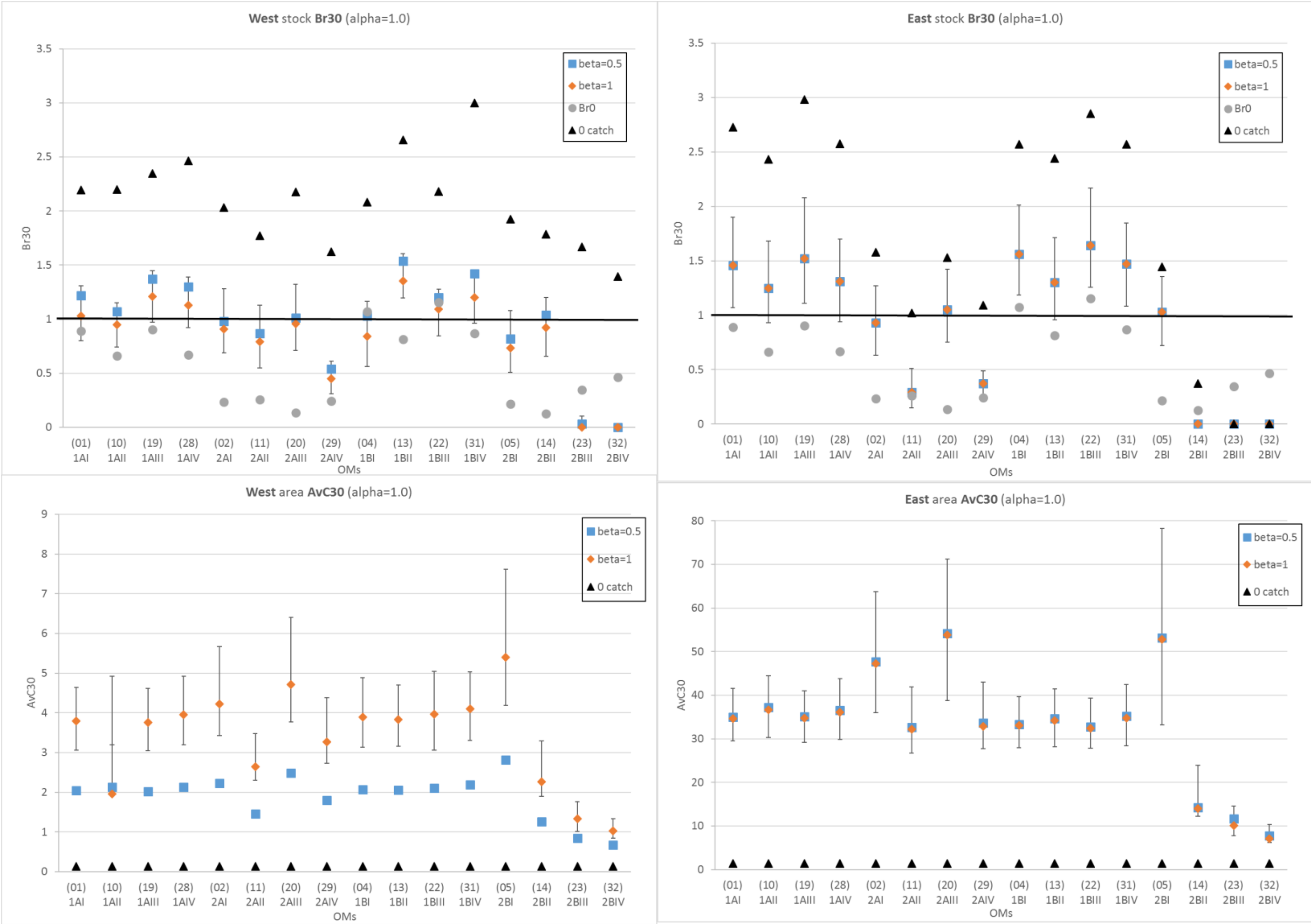

Figure 2b. Br30 and AvC30 for the 16 OMs under three scenarios: (**alpha=1.0**, beta=0.5), (**alpha=1.0**, beta=1) and (alpha=0, beta=0) for the **Stochastic runs**. Medians are shown with 90% PI's for beta=1 case.

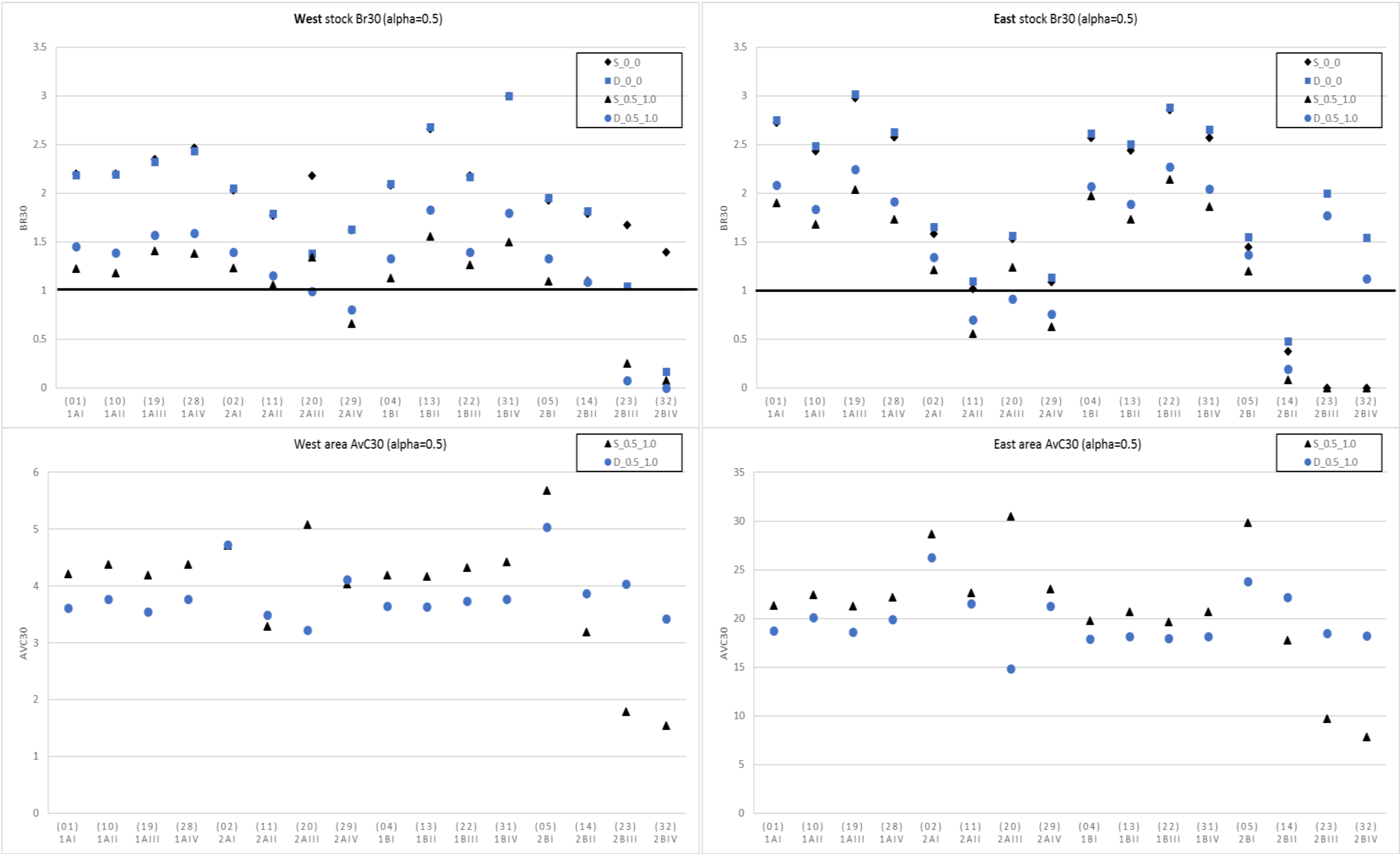

Figure 3a. Br30 and AvC30 showing the difference between D(Deterministic) and S(Stochastic) for (alpha=0, beta=0) and (**alpha=0.5**, beta=1.0) scenarios. Notation in the plots is D or S followed by alpha_beta.

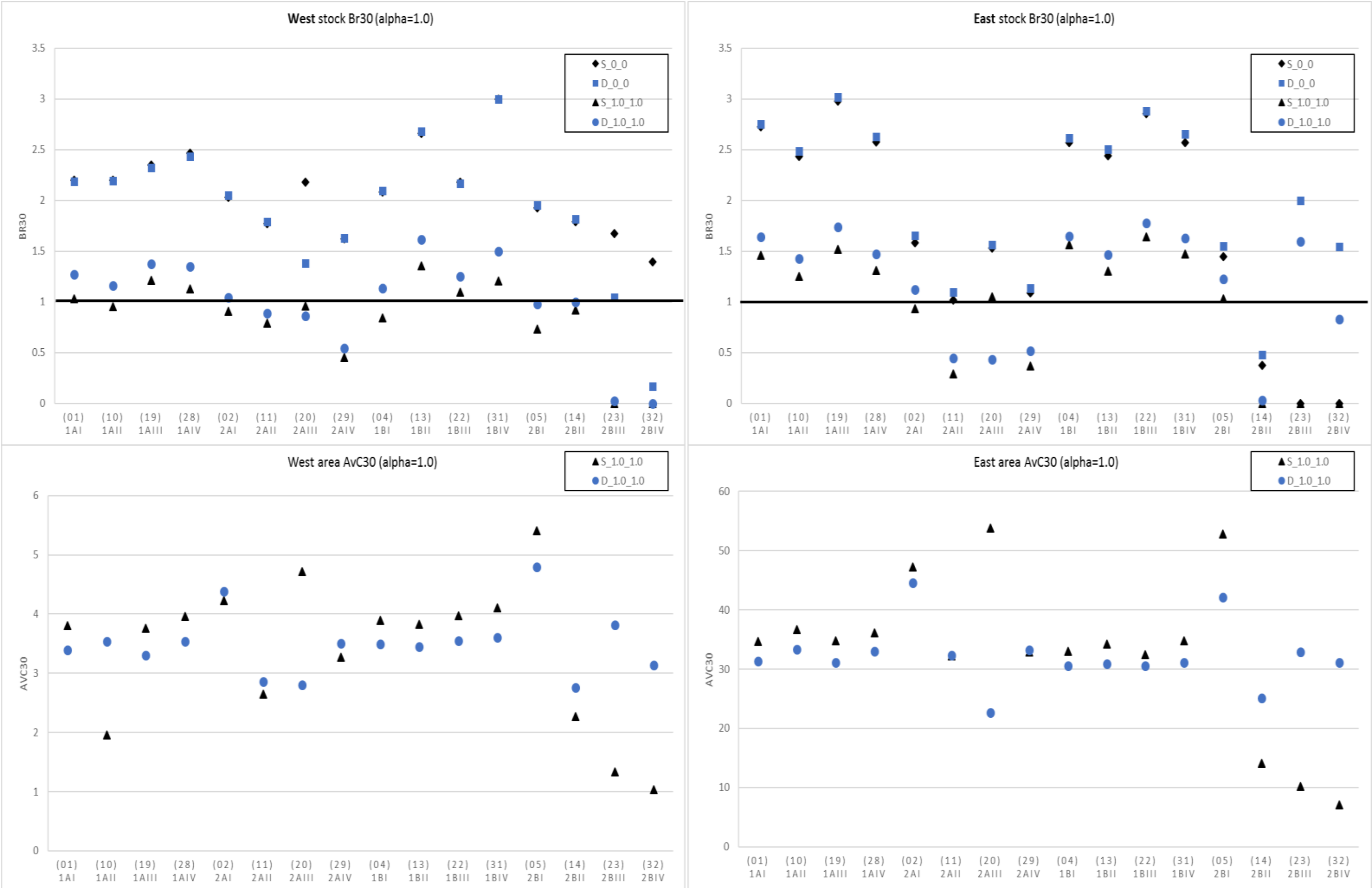

Figure 3b. Br30 and AvC30 showing the difference between D(Deterministic) and S(Stochastic) for (alpha=0, beta=0) and (**alpha=1.0**, beta=1.0) scenarios. Notation in the plots is D or S followed by alpha_beta.

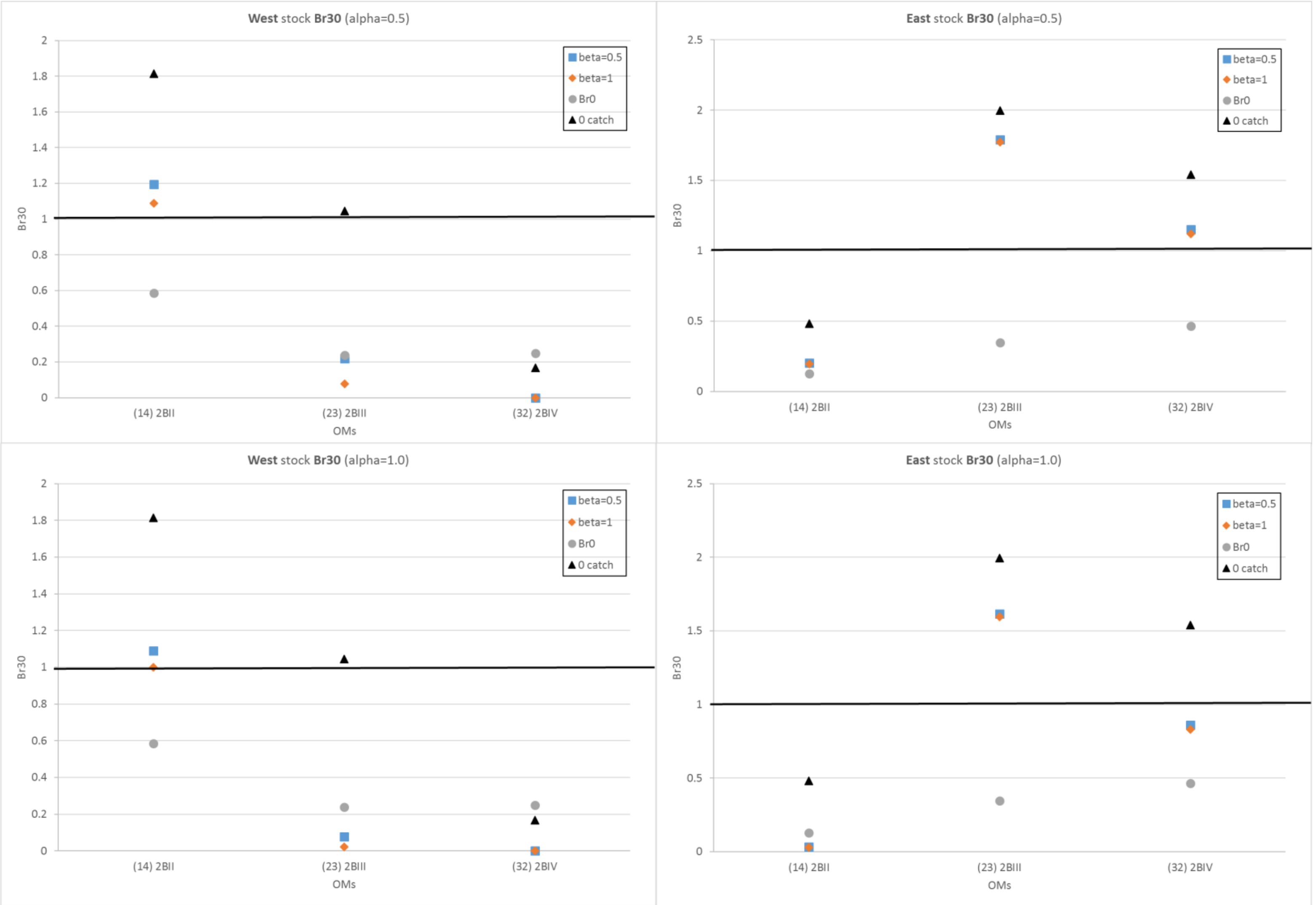

Figure 4a. Br30 and AvC30 for the three problematic OMs (OM14, 23, 32) under three CMP scenarios: (alpha=1.0, beta=0.5), (alpha=1.0, beta=1) and (alpha=0, beta=0) for the **Deterministic** runs.

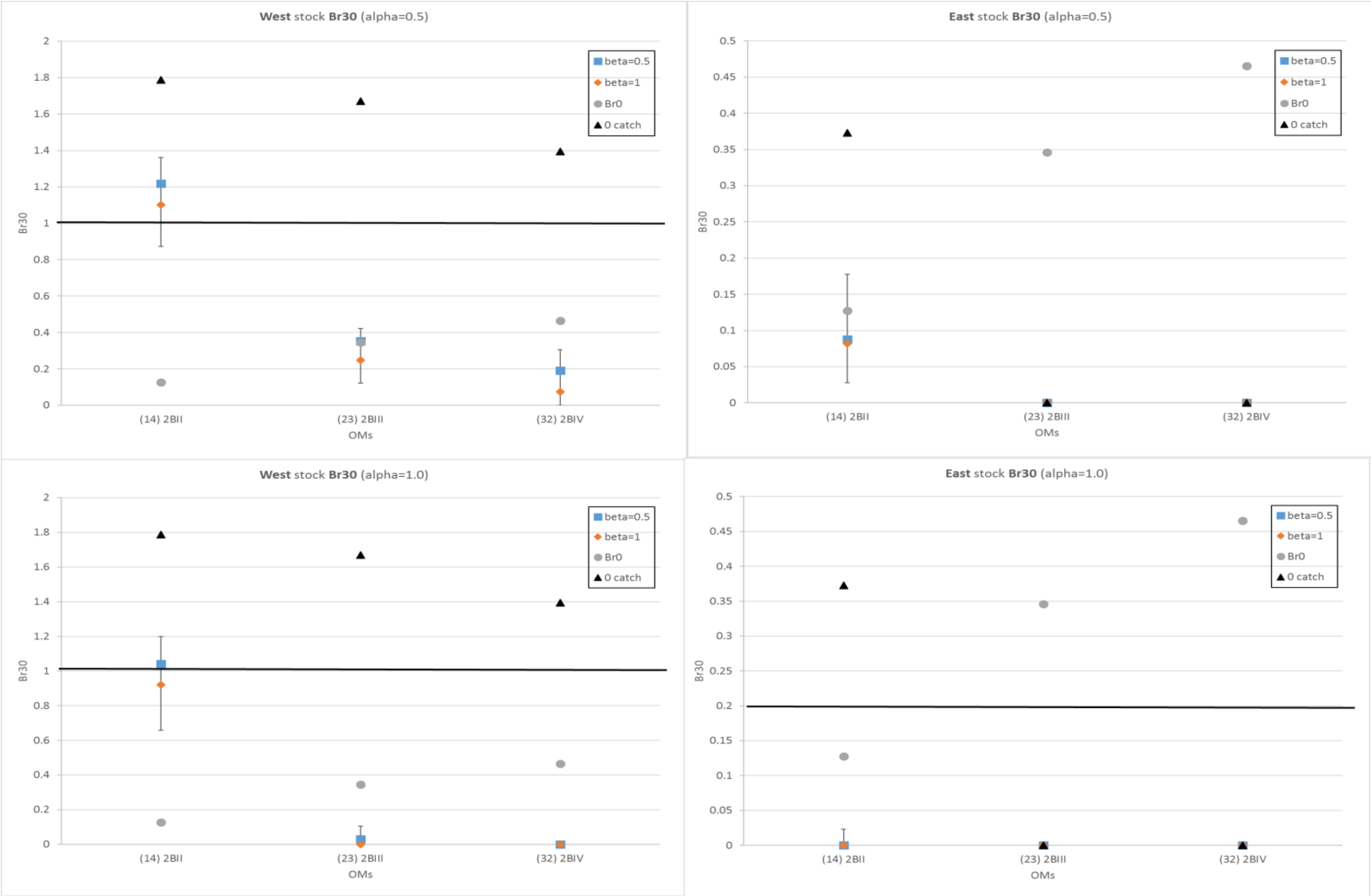

Figure 4b. Br30 and AvC30 for the three problematic OMs (OM14, 23, 32) under three CMP scenarios: (alpha=1.0, beta=0.5), (alpha=1.0, beta=1) and (alpha=0, beta=0) for the **Stochastic** runs.

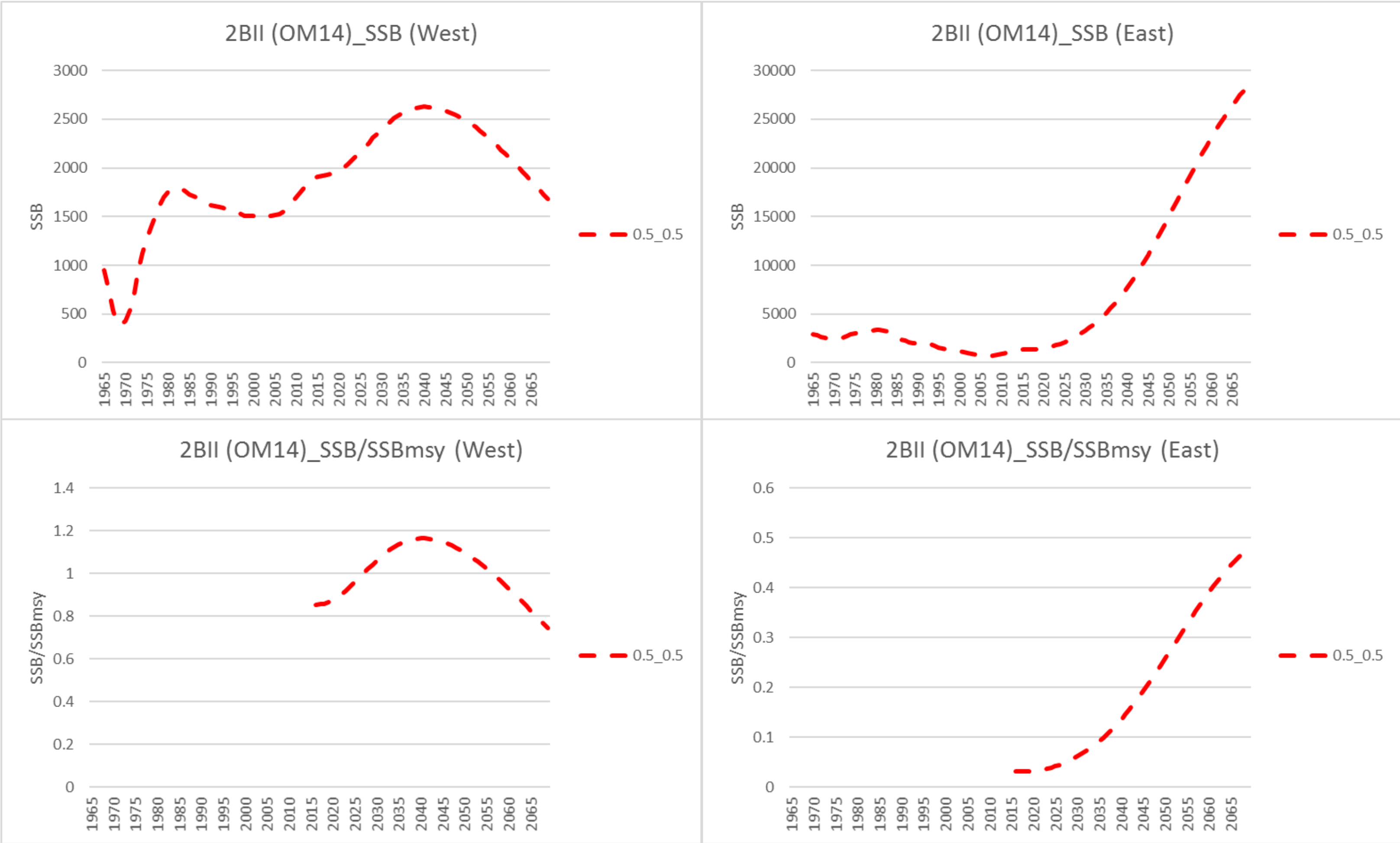

Figure 5. SSB and Br=SSB/SSBmsy for **2BII (OM14)** under the CMP scenario (alpha=0.5, beta=0.5).

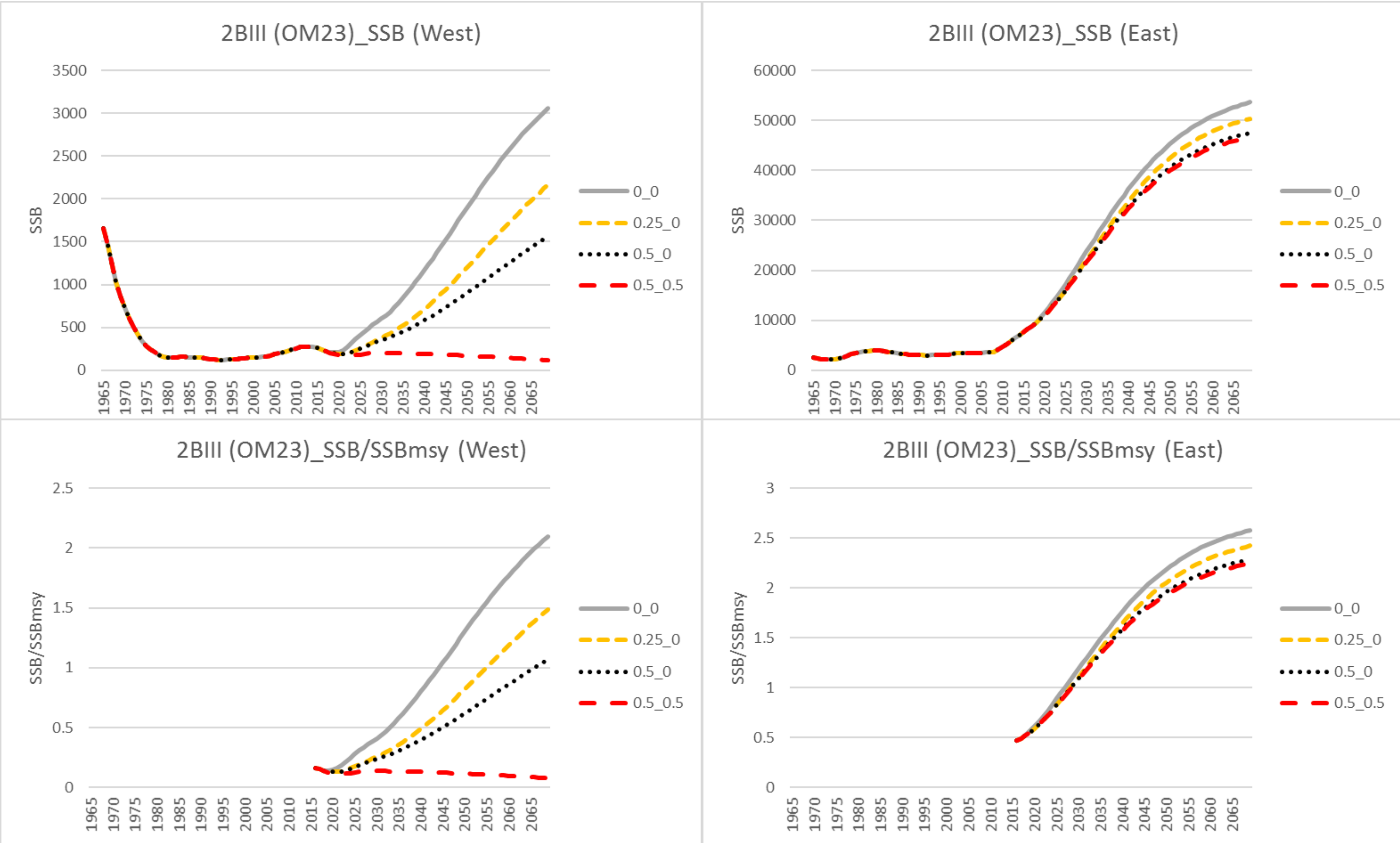

Figure 6a. SSB and Br=SSB/SSBmsy for **2BIII (OM23)** under four different CMP scenarios: (alpha=0, beta=0), (alpha=0.25, beta=0), (alpha=0.5, beta=0) and (alpha=0.5, beta=0.5). Notation in the plots is alpha_beta.

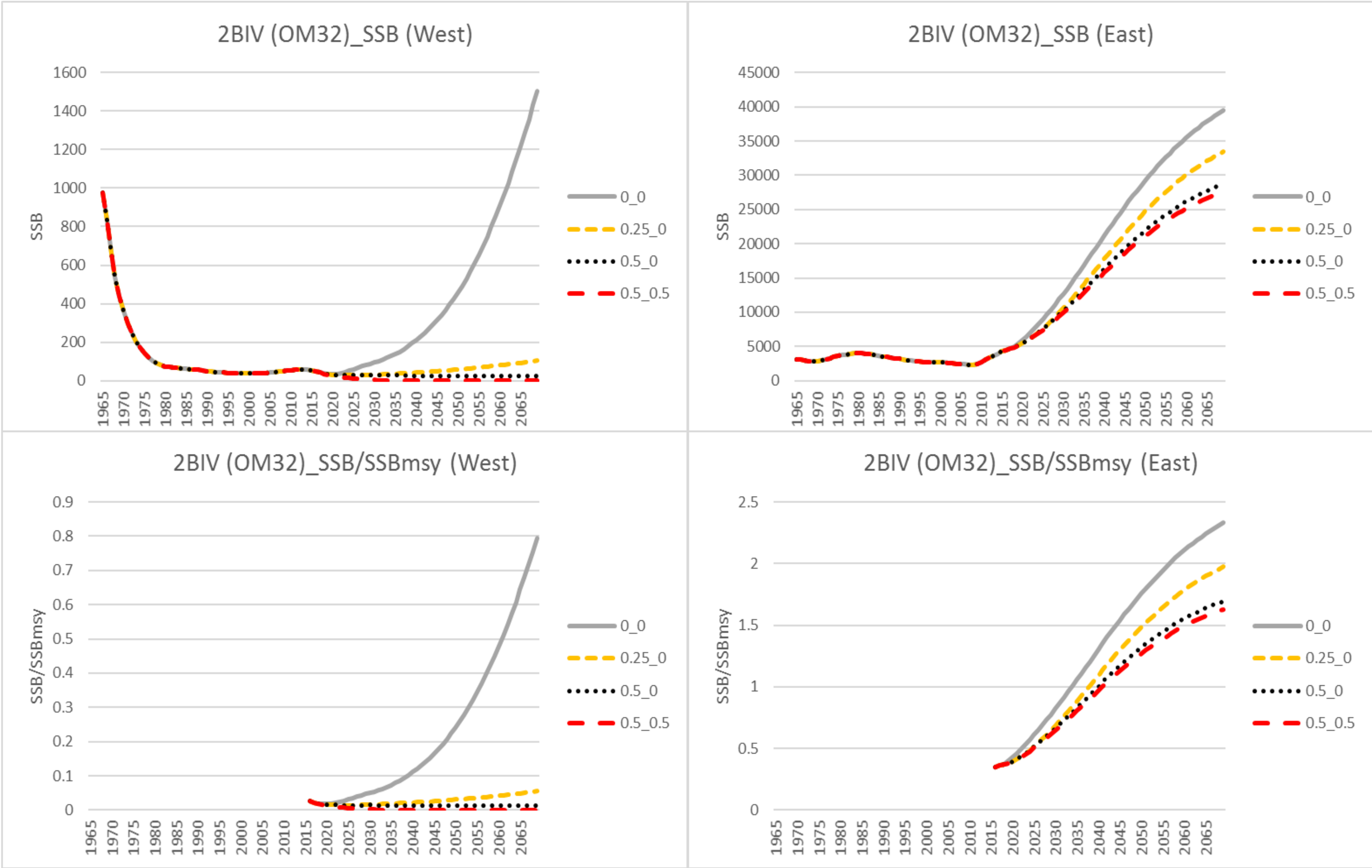

Figure 6b. SSB and Br=SSB/SSBmsy for **2BIV (OM32)** under four different CMP scenario: (alpha=0, beta=0), (alpha=0.25, beta=0), (alpha=0.5, beta=0) and (alpha=0.5, beta=0.5). Notation in the plots is alpha_