SUMMARY OF A REFERENCE SET OF CONDITIONED OPERATING MODELS FOR ATLANTIC BLUEFIN TUNA

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SUMMARY

A total of 36 reference case operating models for Atlantic bluefin tuna are described that span a range of scenarios for future recruitment dynamics, current abundance levels / recent trajectory, natural mortality rate and age at maturity[3]. Of these operating models 12 required fitting to historical data. The fits of these models to data are presented in this paper. The various operating models fitted similarly well to the indices and none appeared to warrant rejection from the reference set. The fitted reference operating models span a reasonably wide range of estimates for stock status and productivity. A number of fishery-independent and assessment CPUE indices had acceptable fitting diagnostics. These indices span younger and older life stages in both eastern and western areas and could index-based MPs of varying complexity.

RÉSUMÉ

Au total, 36 modèles opérationnels de cas de référence pour le thon rouge de l'Atlantique sont décrits, s'étendant sur une gamme de scénarios portant sur la dynamique du futur recrutement, les niveaux actuels de l'abondance / la récente trajectoire, le taux de mortalité naturelle et l'âge à la maturité[4]. Sur ces modèles opérationnels, 12 ont nécessité un ajustement aux données historiques. Les ajustements de ces modèles aux données sont présentés dans ce document. Les différents modèles opérationnels se sont pareillement bien ajustés aux indices et aucun n'a semblé justifier un rejet du jeu de référence. Les modèles opérationnels de référence qui ont été ajustés couvrent une gamme assez large d'estimations de l'état du stock et de la productivité. Un certain nombre d'indices de CPUE indépendants des pêcheries et d'évaluation présentaient des diagnostics d'ajustement acceptables. Ces indices couvrent des stades du cycle vital plus jeunes et plus âgés dans les zones orientales et occidentales et il pourrait s'agir de procédures de gestion indicielles de complexité variable.

RESUMEN

Se describe un total de 36 modelos operativos de caso de referencia para el atún rojo del Atlántico que se extienden por una gama de escenarios para futuras dinámicas de reclutamiento, niveles de abundancia/trayectoria reciente, tasa de moralidad natural y edad de madurez[5]. De estos 12 modelos operativos, 12 requirieron un ajuste a los datos históricos. Los ajustes de estos modelos a los datos están presentes en este documento. Los diferentes modelos operativos se ajustaron similarmente bien a los índices y ninguno parecía justificar su desestimación del conjunto de referencia. Los modelos operativos de referencia ajustados se extienden por una gama razonablemente amplia de estimaciones del estado y productividad del stock. Varios

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[3] The development of the MSE for North Atlantic bluefin tuna remains an ongoing process at this time. This document is therefore not final, but relates to the extent of development of the work immediately prior to the September 2017 bluefin session which preceded the ICCAT SCRS meeting. However during that bluefin session, certain changes to the specifications of the Operating Models (OMs) were agreed; in that respect the results in this document pertain to refits of those OMs taking these changes into account.

[4] Le développement de la MSE pour le thon rouge de l'Atlantique Nord reste à ce stade un processus en cours. Ce document n'est donc pas définitif, mais se rapporte à l'ampleur du développement des travaux immédiatement avant la session sur le thon rouge de septembre 2017 qui a précédé la réunion du SCRS de l'ICCAT. Toutefois, au cours de la session sur le thon rouge, certains changements aux spécifications des modèles opérationnels ont été approuvés ; à cet égard, les résultats présentés dans ce document ont trait aux réajustements des modèles opérationnels qui tiennent compte de ces changements.

[5] En este momento prosigue el proceso de desarrollo de la MSE para el atún rojo del Atlántico norte. Por tanto, este documento no es final, sino que está relacionado con la medida de desarrollo de este trabajo inmediatamente antes de la sesión de atún rojo de septiembre de 2017, que precedió a la reunión del SCRS de ICCAT. Sin embargo, durante la sesión de atún rojo, se acordaron algunos cambios a las especificaciones de los modelos operativos (OM), en este sentido, los resultados de este documento están relacionados con los reajustes de dichos OM realizados teniendo en cuenta dichos cambios.

índices de CPUE de evaluación e independientes de la pesquería presentaron diagnósticos de ajuste adecuados. Estos índices se extienden por fases de vida más jóvenes y mayores en zonas orientales y occidentales y podrían desarrollar MP basados en los índices con una complejidad variable.

KEYWORDS

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

1 Introduction

A Management Strategy Evaluation (MSE, Butterworth and Punt 1999, Cochrane 1998) approach has been proposed for Atlantic bluefin tuna as a suitable framework for providing robust management advice consistent with the precautionary approach (GBYP 2017a). A principal task in the construction of an MSE framework is the development of operating models which represent credible hypotheses for population and fishery dynamics. Operating models are typically fishery stock assessment models which are fitted to data to ensure that model assumptions and estimated parameters are empirically credible (Punt *et al.* 2014, e.g. CCSBT 2011).

A general approach for testing MPs using MSE established two sets of operating models. The reference set of trials are considered to reflect the most plausible hypotheses which also have a marked impact on stock dynamics, and are the primary basis for identifying the best performing management procedure. Robustness trials are used to determine whether the management procedure behaves as intended in scenarios that are less likely.

In this paper the design of the reference set of operating models is described including the fit of these models to data (their "conditioning"). The operating models will be used to test a range of MPs that use indices of abundance to calculate TAC advice. The fit of the operating model to abundance indices informs which indices might best be used in MPs, and hence need to be included in MSE testing (i.e. what indices need to be simulated for this process).

2 Methods

Seasonal, spatial, multi-stock, age structured operating models were fitted to a wide variety of fishery dependent and independent data (see Carruthers *et al.* 2016a and CMG 2017). Such data included electronic tags, Task II catch rate data and micro-constituent data informing stock of origin (for a summary of these data see Carruthers *et al*. 2016b and GBYP 2017b).

A reference set of operating models was identified that spanned three main axes of uncertainty for Atlantic bluefin tuna: (1) future recruitment, (2) abundance and its trends, and (3) age-at-maturity (spawning fraction) / natural mortality rate (see **Tables 1** and **2** for the reference operating model set design). Although this leads to 36 reference operating models in total, future recruitment scenarios do not impact model fitting. Consequently 12 unique model fits are presented here that cover factors 2 and 3 relating to abundance and trends, and to maturity and natural mortality rate (the grey rows of **Table 2**).

3 Results

Model estimates for the base-case reference model #1

Operating model #1 consists of the first levels of all factors, namely MPD 'best' estimate of abundance from the operating model (with no additional priors), low age at maturity and high natural mortality rate. For this reference case OM the model provides estimates of eastern area biomass that are similar to those from the VPA and Stock Synthesis (SS) assessments (**Figure 1a**). The trend however is more positive than for those assessments and follows an upward trajectory over 1988-2015. However, the very recent 3-fold increases in spawning biomass for the eastern stock that are estimated by the VPA assessment are not matched by the fitted OM #1.

OM #1 estimates of western spawning biomass are substantially higher on average than those from the VPA and SS assessments (around 39 000 tonnes from 1983-2015 compared to 28 000 t and 21 000t for the VPA and SS assessments respectively) (**Figure 1a**). The trend in spawning biomass is also different showing maximum biomass around 2003 rather than 2015 for the two assessments.

Mimicking assessments: Factor 2, abundance

OMs #4 and #7 are departures from OM #1 in that they use priors which intend to obtain similar mean abundance to the VPA assessments (OM #4, Factor 2 level 2) and an increase in the Eastern SSB similar to the Eastern VPA assessment (OM #7, Factor 2 level 3). **Figures 1b** and **1c** illustrate that these prior specifications were largely successful in attaining their objectives.

All OM model estimates

In general the 12 fitted operating models span a reasonably wide range of simulated stock parameters and behaviour. MPD model estimates of FMSY ranged from 0.14 – 0.31 for the Eastern stock (**Table 3**) and 0.08-0.23 for the Western stock (**Table 4**). Stock depletion at present (current SSB relative to its unfished level) ranged from 0.32 – 0.8 for the East stock and 0.3 – 0.45 for the Western stock.

With the exception of factor 2 level C, where very recent increases in the East matched the specifications from a prior, there was not a substantial difference in the trajectories for the two stocks among the various operating models (**Figure 4**).

Fit to indices of abundance

The following indices did not show problematic patterns in residuals (**Figure 2a** and **2b**) and are likely to be collected in the future.

Eastern, fishery dependent:	JPN_LL_NEAtl2
Eastern, fishery independent:	FR_AER_SUV, MED_LAR_SUV, MED_AER_SUV
Western, fishery dependent:	JPN_LL2, US_RR_66_114
Western, fishery independent:	GOM_LAR_SUV

These indices may be considered as candidates for simulation in the MSE framework for the calculation of TACs by MPs.

Effect of OM factors

In terms of the harvest rate at maximum sustainable yield (UMSY), the most important Factor was 3, which includes various scenarios for age at maturity and the natural mortality rate. Lower natural mortality rates and older ages at maturity led to lower UMSY values for both stocks. The impact of natural mortality rate (I vs III, II vs IV) was much higher on the UMSY estimates for the western stock however, and made little different to UMSY estimates for the eastern stock.

Depletion estimates were also affected by the maturity and natural mortality rate with the most pessimistic estimates arising from the lower natural mortality rate scenarios II and IV.

Statistical properties of indices

In order to simulate realistic relative abundance indices it is necessary to characterize the properties of operating model fitting to these data. Two principal properties are residual error and auto-correlation in residual errors. These specify the degree of annual error in simulated indices in addition to the propensity to simulate runs of residuals where the index is above or below the true relative biomass for multiple years (**Table 5**).

4 Discussion

In general, the various reference operating models span a reasonably wide range of scenarios for stock status and productivity. While even the best fits to indices showed some residual patterns, the observation model can account for misfit by simulating auto-correlation in residuals and hyper-stability.

The principal purpose of this document is to investigate whether certain operating models do not meet acceptable standards of model fit. The various operating models fitted similarly well to the indices and none appeared to warrant rejection from the reference set.

A number of fishery-independent and assessment CPUE indices may be available that span younger and older life stages in both eastern and western areas. It follows these provide a basis for investigating a range of index-based MPs of varying complexity.

5 Acknowledgements

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Table 1. The factors and associated levels which define the reference set of operating models.

	West	East
Future recruitment		
1	Hockey-stick	83+ B-H with h=0.98
2	B-H with h estimated	83+ B-H with h=0.70
3	Hockey-stick changes to B-H after 10 years	83+ B-H with h=0.98 changes to 50-82 B-H with h=0.98 after 10 years
Abundance		
A	Best estimate	
B	East and West area spawning biomasses match VPA assessment in absolute terms	
C	Recent eastern area SSB increases 3x to match VPA assessment	
Maturity (both stocks)		*Natural Mortality (both stocks)*
I	Younger	High
II	Younger	Low
III	Older	High
IV	Older	Low

Table 2. The design of reference set of operating models. Note that only future recruitment level 1 is presented in this paper (grey shaded rows) since the future recruitment scenario does not impact the fits of the operating models to past data.

OM No.	Future Recruitment	Abundance	Maturity / Mortality
1	1	A	I
2	2	A	I
3	3	A	I
4	1	B	I
5	2	B	I
6	3	B	I
7	1	C	I
8	2	C	I
9	3	C	I
10	1	A	II
11	2	A	II
12	3	A	II
13	1	B	II
14	2	B	II
15	3	B	II
16	1	C	II
17	2	C	II
18	3	C	II
19	1	A	III
20	2	A	III
21	3	A	III
22	1	B	III
23	2	B	III
24	3	B	III
25	1	C	III
26	2	C	III
27	3	C	III
28	1	A	IV
29	2	A	IV
30	3	A	IV
31	1	B	IV
32	2	B	IV
33	3	B	IV
34	1	C	IV
35	2	C	IV
36	3	C	IV

Table 3. Operating model estimates (maximum posterior density) for the Eastern stock. OM refers to the operating model umber (**Table 2**). FMSYa is apical fishing rate corresponding to MSY.UMSY is harvest rate at MSY. SSBrel is SSB at MSY (SSBMSY) relative to unfished (SSB0). recMSY is the fraction of unfished recruitment at MSY. D is current spawning stock depletion, while Dep is biomass depletion. The OFL is the overfishing limit and is the catch corresponding to FMSY fishing of the current vulnerable biomass.

OM	MSY	FMSYa	UMSY	BMSY	SSBMSY	BMSY_B0	SSBrel	recMSY	D	Dep	SSB	OFL
1	32605	0.277	0.118	244111	217423	0.304	0.278	0.963	0.507	0.551	394007	52200
4	34520	0.31	0.116	262779	234704	0.31	0.284	0.962	0.608	0.657	491194	63794
7	27973	0.236	0.121	204002	180902	0.294	0.267	0.968	0.685	0.74	553376	75509
10	35163	0.149	0.1	317989	296088	0.31	0.29	0.98	0.338	0.361	371817	39932
13	36141	0.149	0.098	332212	309793	0.315	0.295	0.974	0.401	0.426	497149	52246
16	30804	0.135	0.1	278117	258494	0.302	0.282	0.98	0.427	0.454	515816	55497
19	32771	0.279	0.118	244228	185949	0.304	0.249	0.968	0.474	0.514	352464	54626
22	34728	0.209	0.117	261131	198600	0.298	0.243	0.955	0.548	0.59	513767	79037
25	27924	0.259	0.12	205109	155434	0.299	0.243	0.972	0.592	0.639	448139	70963
28	35281	0.15	0.1	317545	266656	0.31	0.27	0.983	0.318	0.339	340483	40546
31	32118	0.124	0.096	301929	254350	0.307	0.268	0.968	0.413	0.437	514510	58632
34	30512	0.137	0.1	273697	229068	0.302	0.262	0.983	0.371	0.395	428451	51193

Table 4. As Table 3 but for the Western stock.

OM	MSY	FMSYa	UMSY	BMSY	SSBMSY	BMSY_B0	SSBrel	recMSY	D	Dep	SSB	OFL
1	5049	0.209	0.112	40180	37643	0.325	0.309	0.882	0.347	0.38	57777	6907
4	4722	0.235	0.114	36728	34387	0.324	0.308	0.89	0.323	0.354	49593	6038
7	7567	0.194	0.116	57507	53682	0.313	0.297	0.898	0.524	0.565	117542	14606
10	4800	0.131	0.096	45416	43553	0.327	0.314	0.898	0.291	0.313	58249	5831
13	4578	0.142	0.1	41205	39450	0.32	0.307	0.913	0.296	0.319	53084	5545
16	6766	0.124	0.098	62275	59599	0.317	0.303	0.913	0.457	0.485	118398	12124
19	4717	0.165	0.095	44871	27547	0.363	0.268	0.858	0.332	0.363	46782	7239
22	5237	0.134	0.093	50999	31518	0.359	0.267	0.852	0.417	0.45	66957	10076
25	6824	0.18	0.105	57949	33883	0.343	0.241	0.891	0.49	0.529	84365	15150
28	4644	0.116	0.087	48734	34257	0.352	0.279	0.886	0.278	0.3	50103	6201
31	4981	0.085	0.074	62701	46076	0.372	0.309	0.844	0.352	0.373	83438	8402
34	6459	0.116	0.093	63189	43416	0.333	0.259	0.91	0.418	0.443	93620	12672

Table 5. Statistical properties of fits to indices assuming linearity and non-linearity. Residual error is expressed as a standard deviation of the log-space observed – predicted values. Autocorrelation is lag-1 autocorrelation in log residuals. Residual error and autocorrelation were calculated for each of the 96 simulations. The 5th, median and 95th percentiles of these statistics are reported for each index. The non-linearity is modelled by the beta parameter, I = q SSB ^ beta

No	Name	Residual error (St. Dev)			Autocorrelation			Beta		
		5%	Median	95%	5%	Median	95%			
Linear										
1	JPN_LL_NEAtl2	0.391	**0.409**	0.421	-0.122	**-0.065**	-0.023			
2	FR_AER_SUV	0.717	**0.745**	0.779	0.054	**0.094**	0.146			
3	MED_LAR_SUV	0.578	**0.602**	0.649	-0.131	**-0.086**	-0.025			
4	MED_AER_SUV	0.749	**0.770**	0.793	0.054	**0.069**	0.082			
5	JPN_LL2	0.408	**0.414**	0.422	-0.048	**-0.025**	0.011			
6	US_RR_66_114	0.531	**0.543**	0.560	0.193	**0.222**	0.255			
7	GOM_LAR_SUV	0.527	**0.552**	0.624	-0.298	**-0.262**	-0.169			
Non-linear (with beta hyperstability parameter)										
1	JPN_LL_NEAtl2	0.379	**0.408**	0.422	-0.228	**-0.132**	-0.058	1.0879	**1.4543**	1.8396
2	FR_AER_SUV	0.489	**0.532**	0.637	-0.648	**-0.580**	-0.430	2.84	**3.3233**	3.9538
3	MED_LAR_SUV	0.404	**0.411**	0.421	-0.402	**-0.381**	-0.364	1.9531	**2.1439**	2.5955
4	MED_AER_SUV	0.661	**0.663**	0.665	-0.042	**-0.040**	-0.038	0.1	**0.1001**	0.1001
5	JPN_LL2	0.391	**0.391**	0.392	-0.075	**-0.072**	-0.068	0.1001	**0.1001**	0.1001
6	US_RR_66_114	0.529	**0.544**	0.554	0.179	**0.224**	0.246	0.1001	**1.0583**	1.6417
7	GOM_LAR_SUV	0.525	**0.547**	0.551	-0.300	**-0.263**	-0.250	0.1001	**0.4605**	1.2686

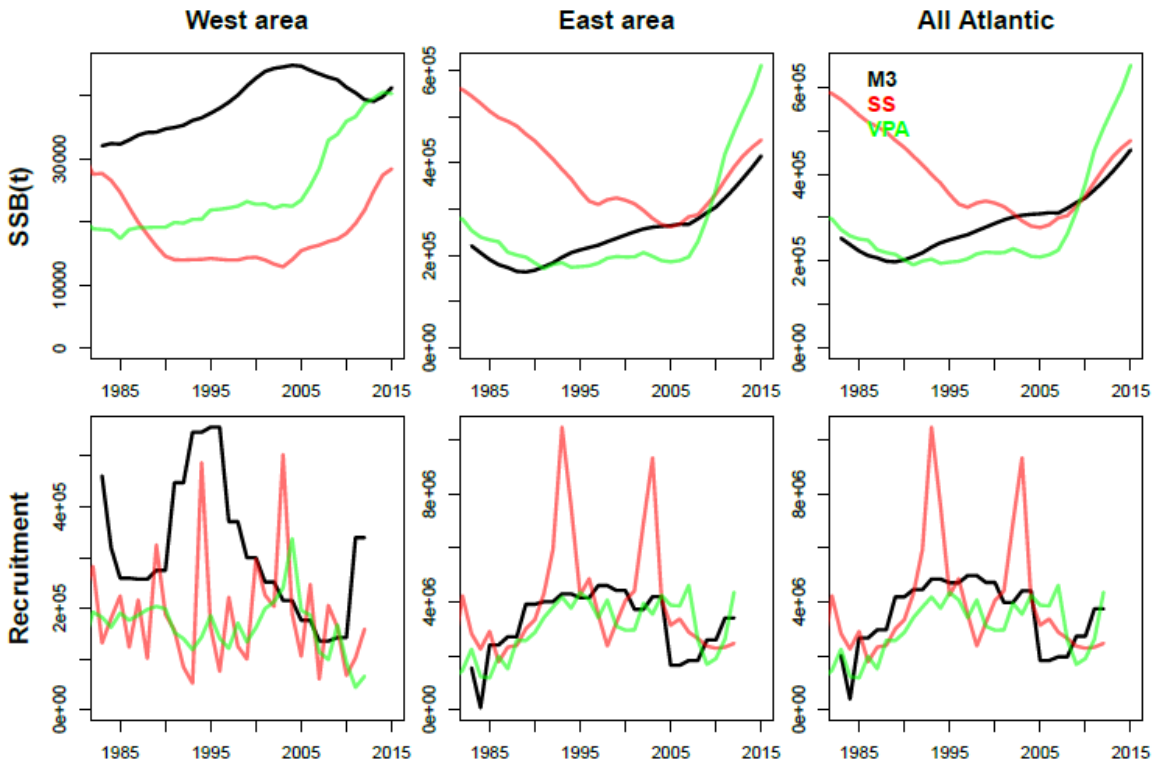

Figure 1a. Similarity of M3 operating model estimates (OM #1) with Western and Eastern assessments (2017).

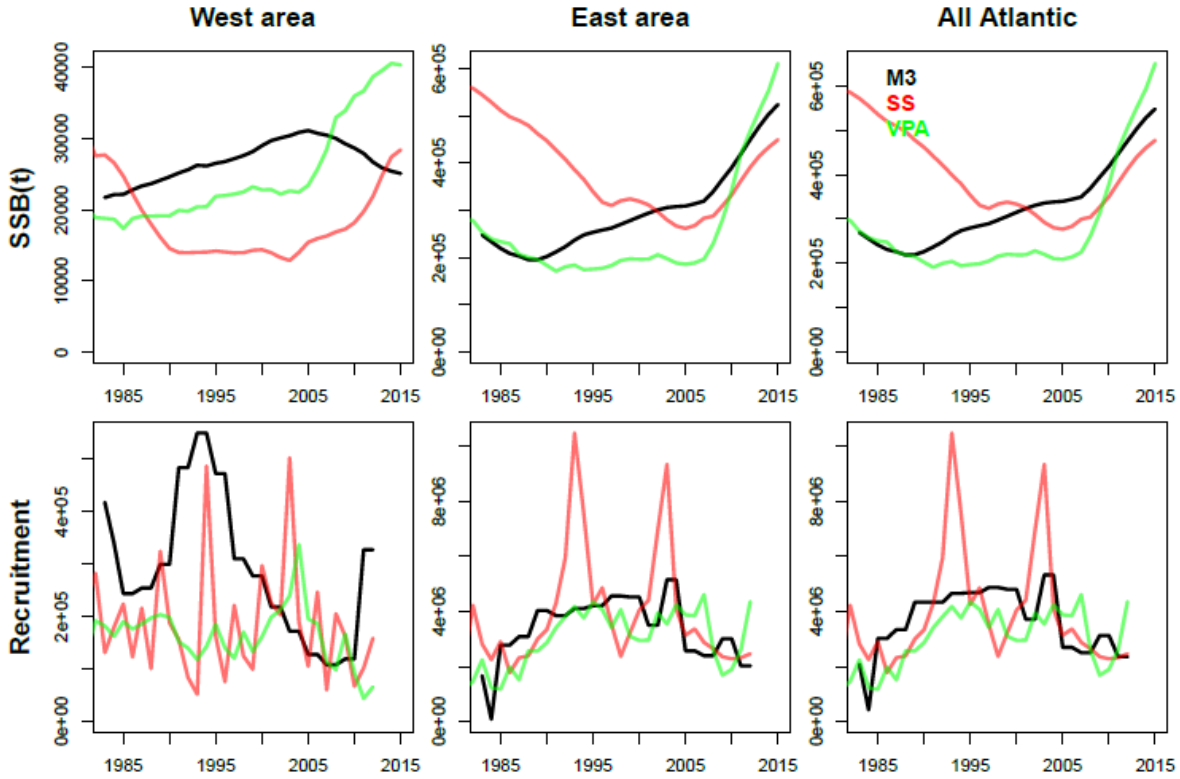

Figure 1b. Similarity of M3 operating model estimates (OM #4) with Western and Eastern assessments (2017). This operating model differs from OM#1 (**Figure 1a** above) in that it corresponds to level B for factor 2 (abundance) and the mean spawning biomass levels in absolute terms in the East and West areas have an informative prior that matches the VPA assessments.

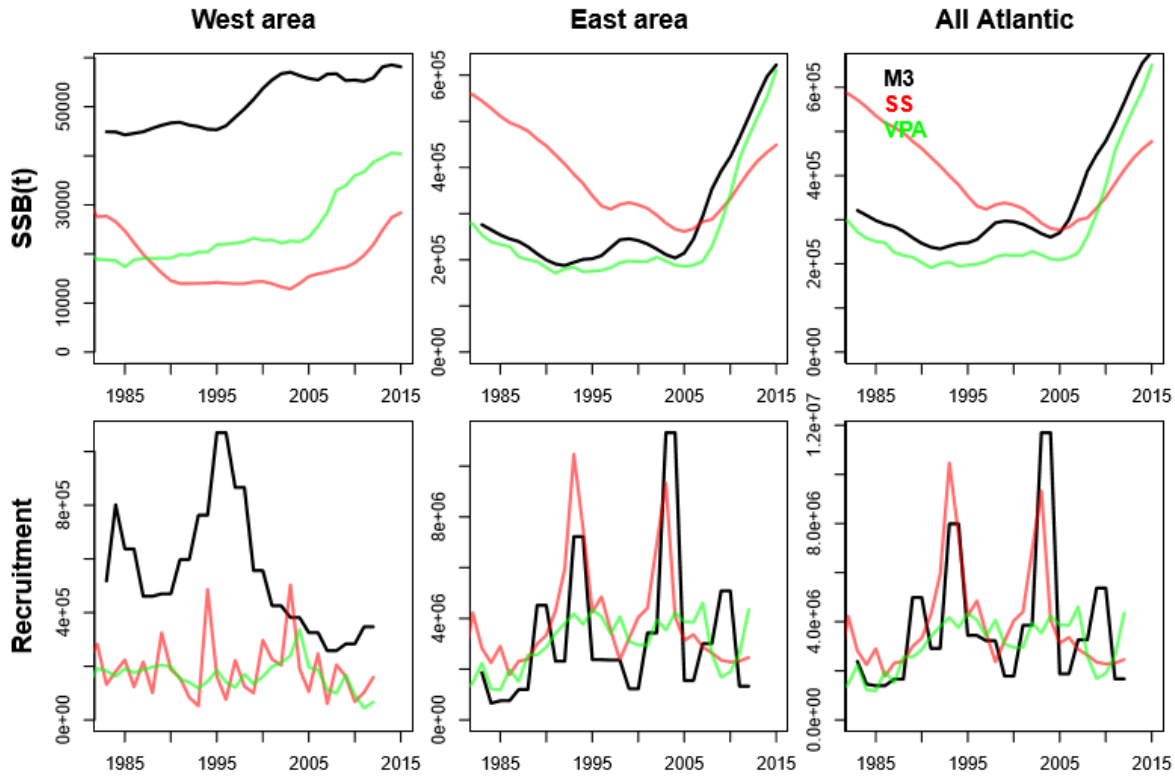

Figure 1c. Similarity of M3 operating model estimates (OM #7) with Western and Eastern assessments (2017). This operating model differs from OM#1 (**Figure 1a** above) in that it corresponds to level C for factor 2 (abundance) and the trend in Eastern areas SSB over the last 9 years has an informative prior for M3 to be able to match the three fold increase in the Eastern VPA assessment.

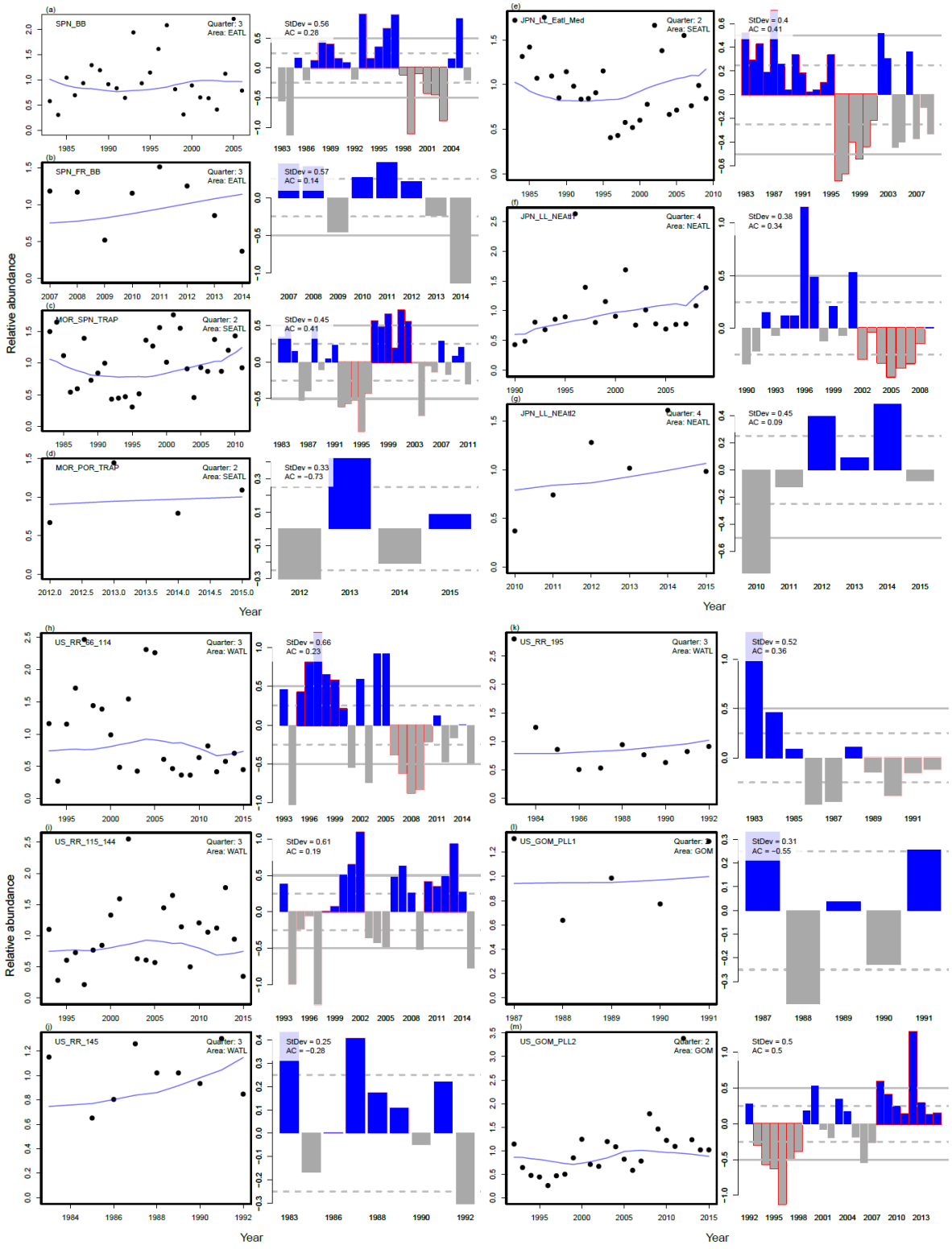

Figure 2a. Fit of OM#1 to CPUE indices used in both the stock assessments and the conditioning of these operating models.

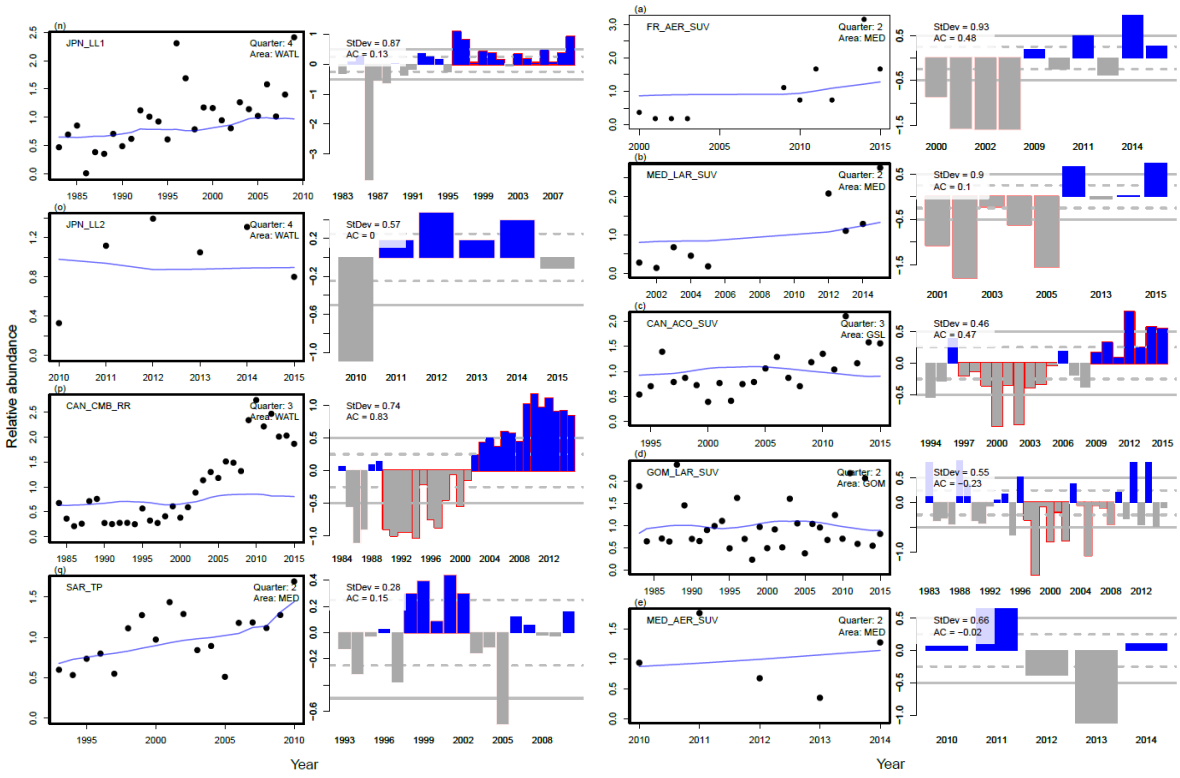

Figure 2b. Fit of OM#1 CPUE indices and fishery independent indices used in the stock assessment and the conditioning of these operating models.

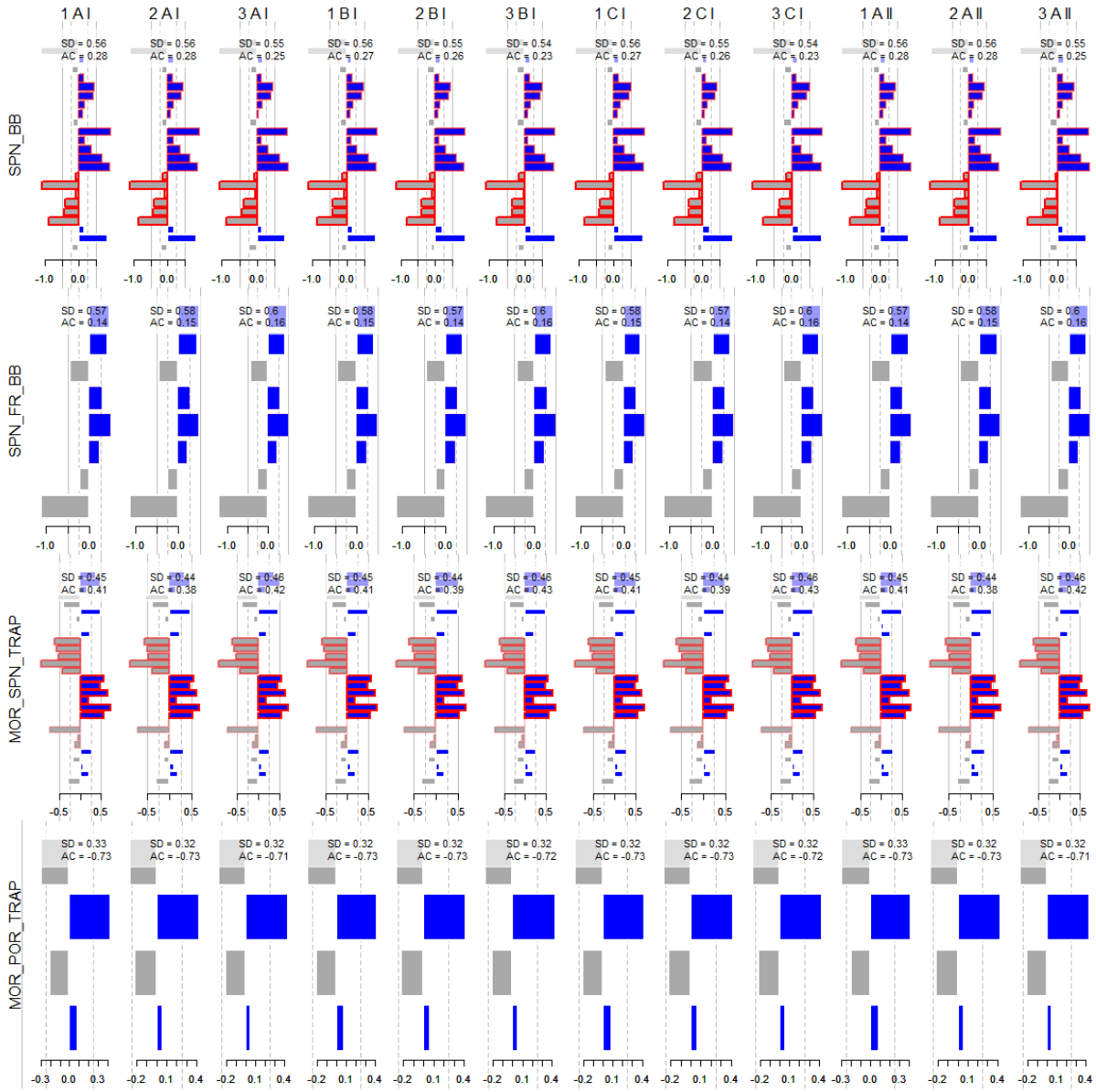

Figure 3a. Residuals for all operating model fits (columns) to various assessment indices (rows).

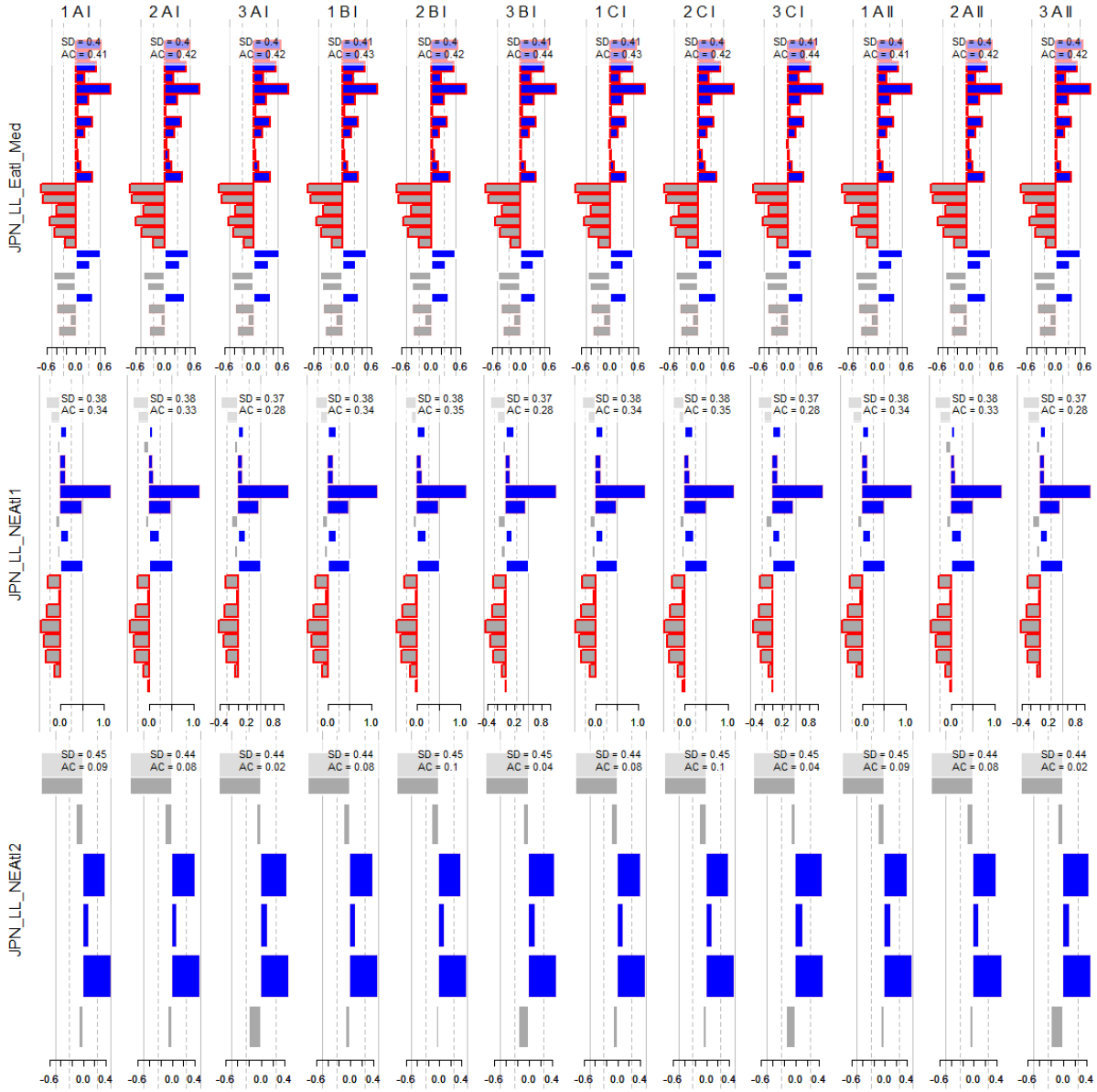

Figure 3b. Residuals for all operating model fits (columns) to further assessment indices (rows).

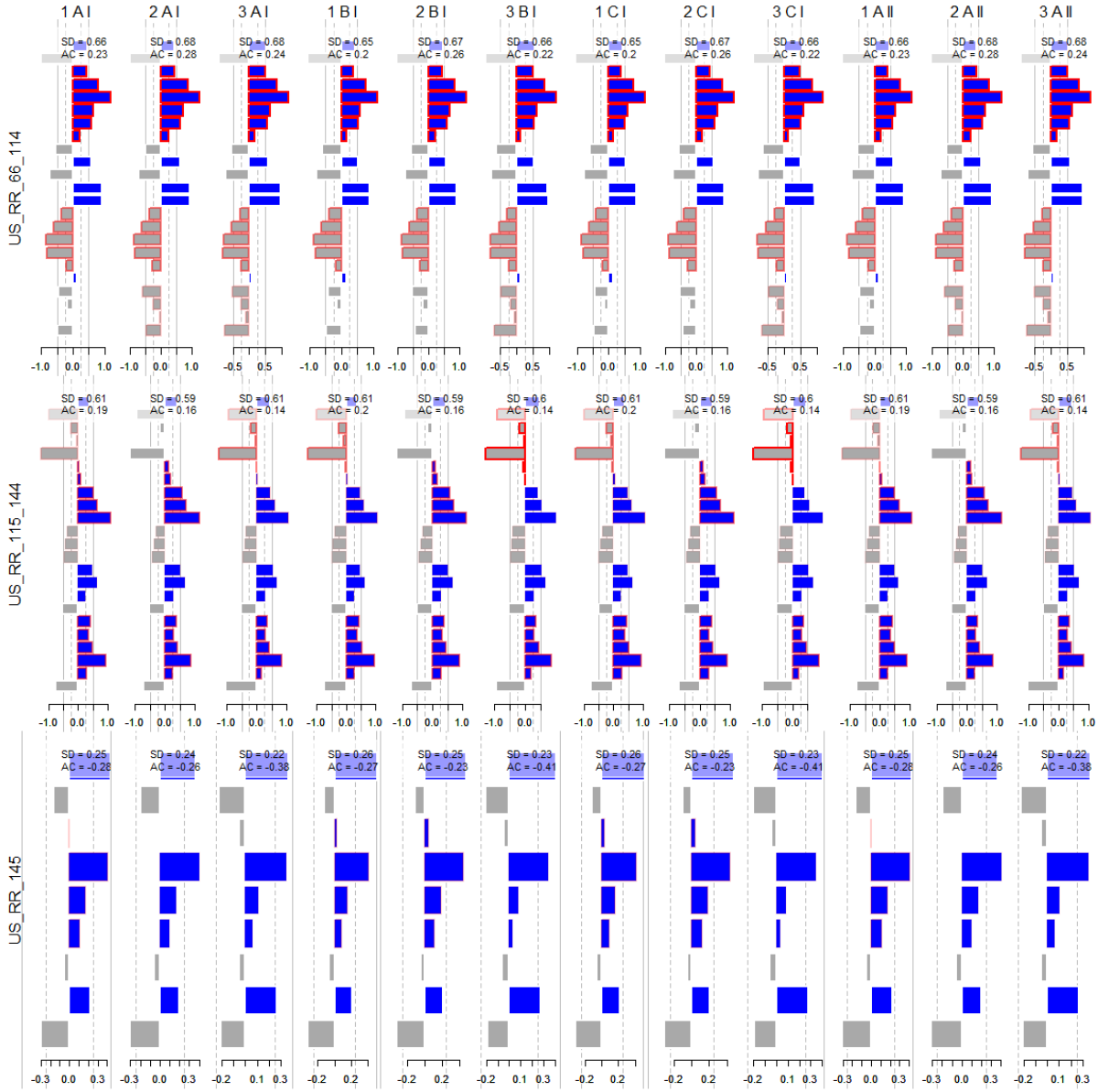

Figure 3c. Residuals for all operating model fits (columns) to yet further assessment indices (rows).

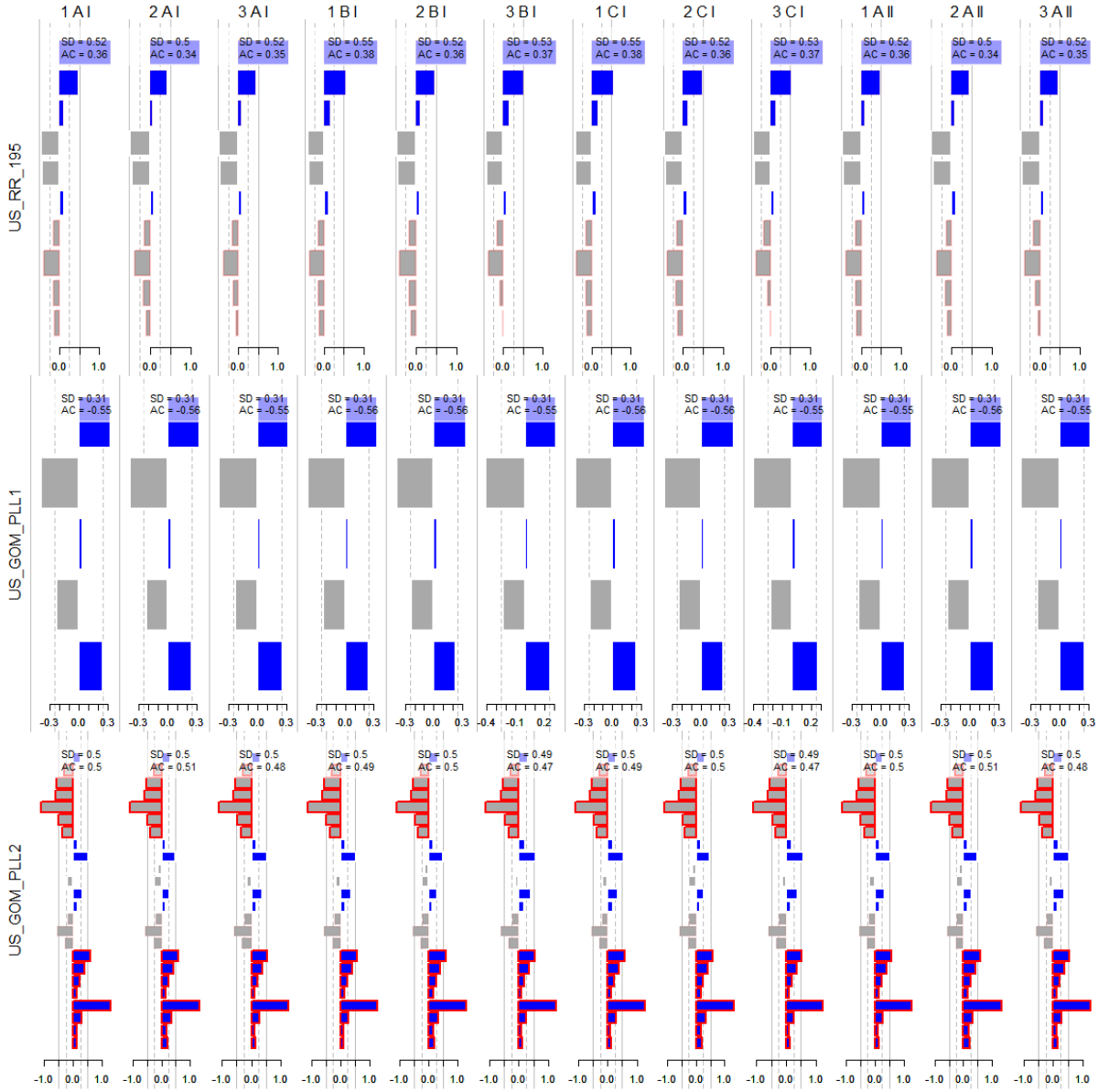

Figure 3d. Residuals for all operating model fits (columns) to still more assessment indices (rows).

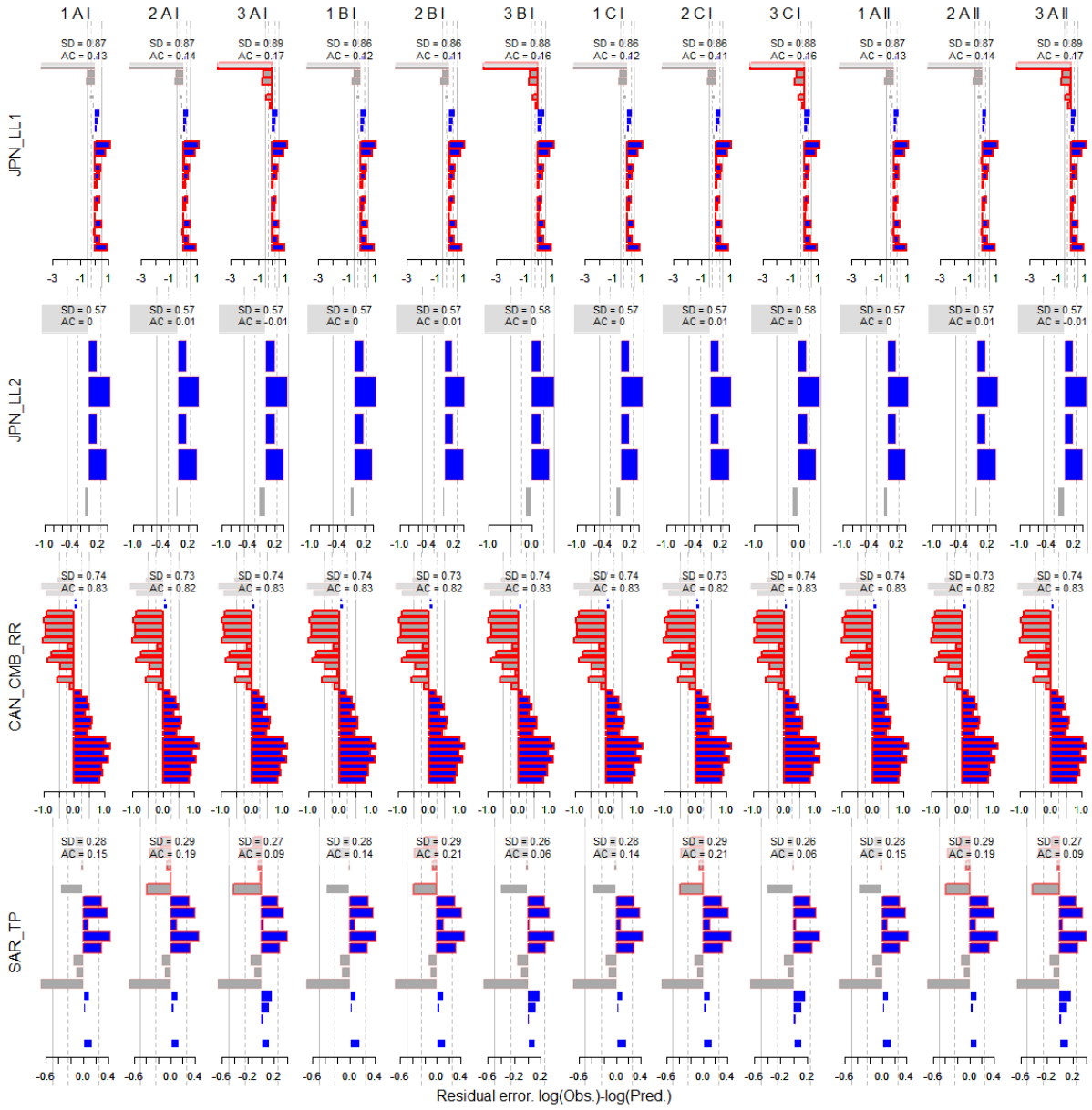

Figure 3e. Residuals for all operating model fits (columns) to the still remaining assessment indices (rows).

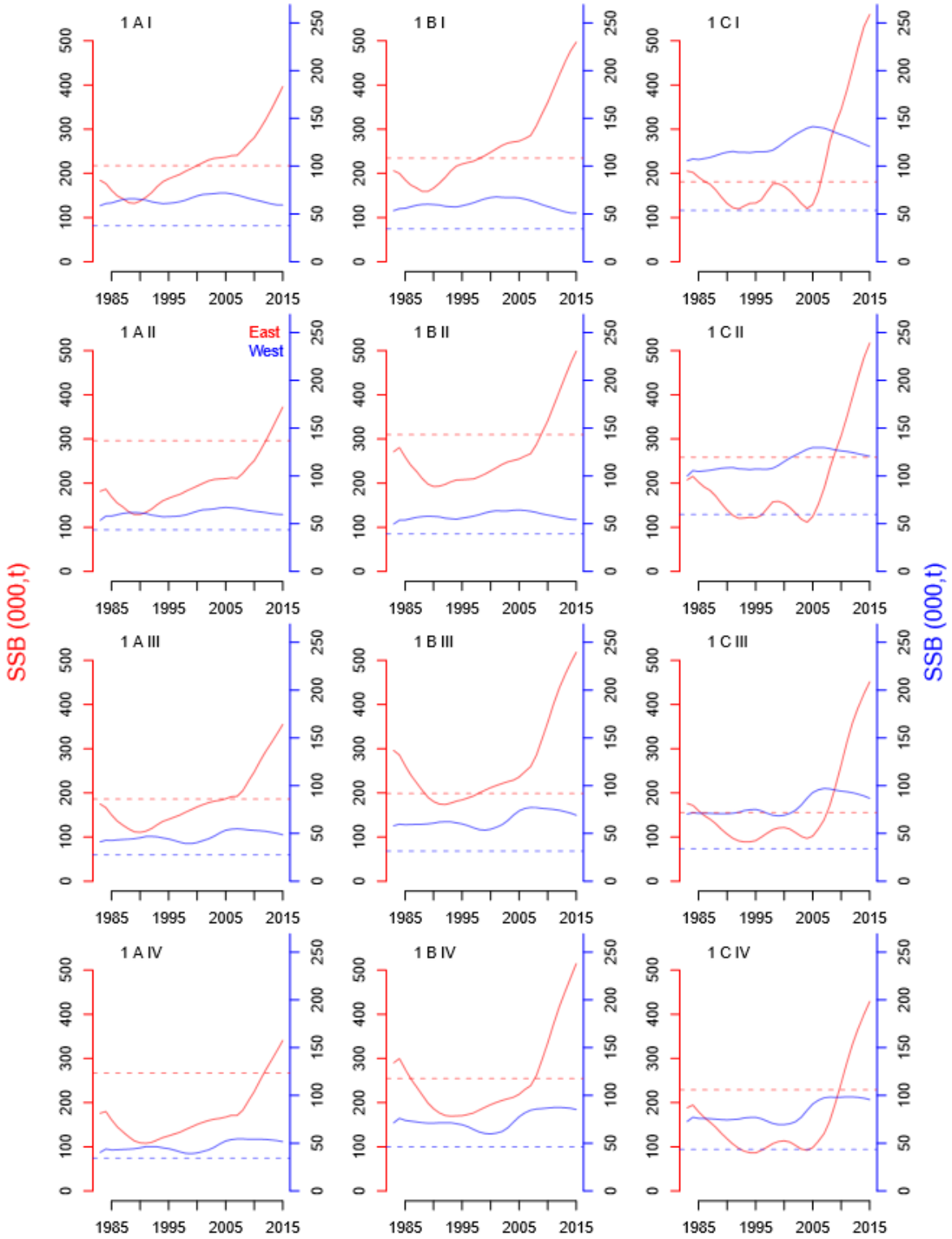

Figure 4. Predicted spawning biomass (East and West stocks) for each operating model (maximum posterior density estimates) (note that these results differ from those for East and West areas because of stock mixing).

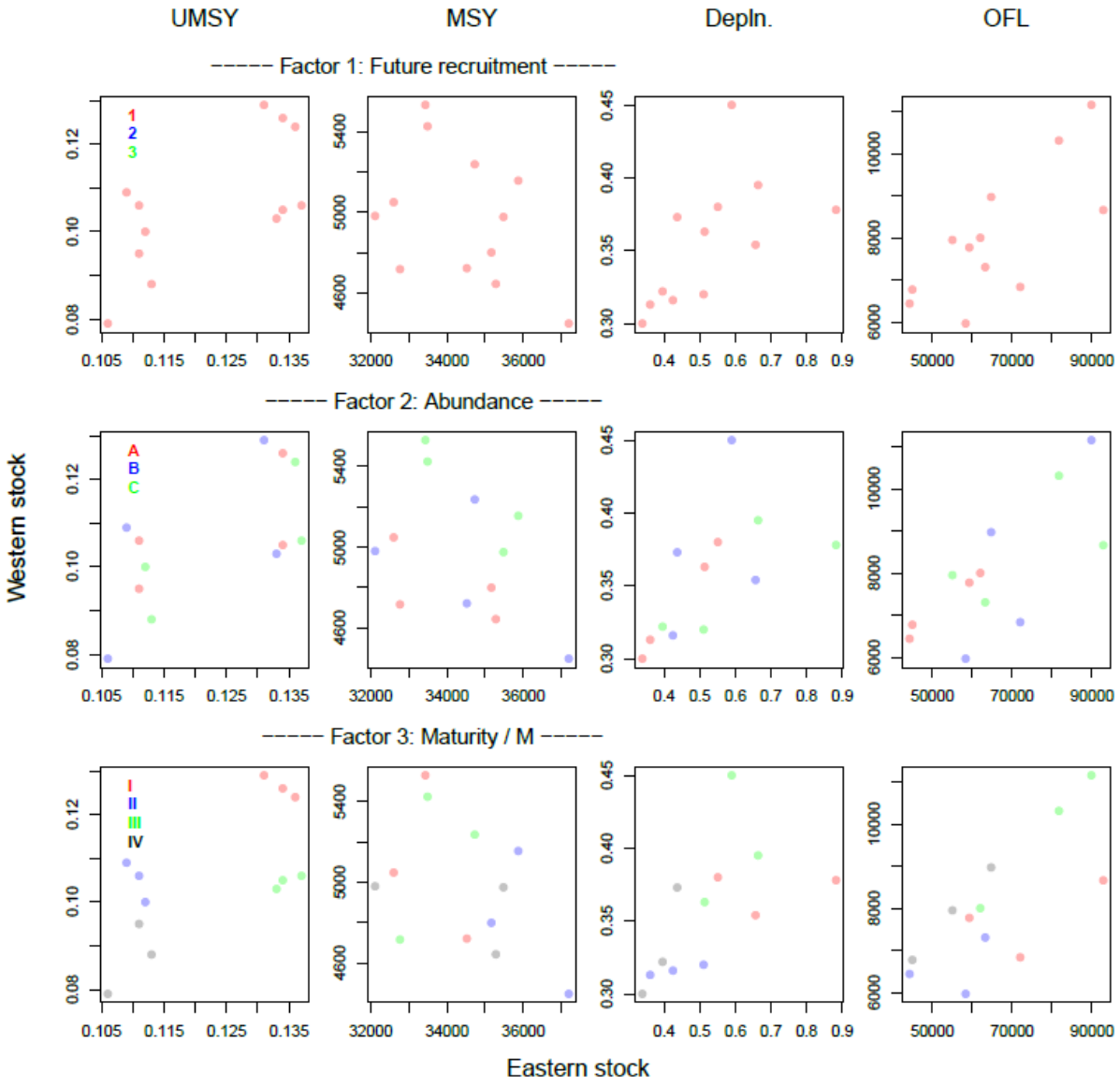

Figure 5. The effect of factors and their levels on OM model estimates. Each panel shows model estimates for the Eastern (horizontal axis) and Western (vertical axis) stocks for four quantities, harvest rate at MSY (UMSY), maximum sustainable yield (MSY), stock depletion (current SSB relative to unfished, 'Depln') and the over fishing limit (UMSY multiplied by current vulnerable biomass). Note that values of these quantities are not affected by whichever of the three levels of factor 1 applies.