REFERENCE SET OPERATING MODELS (VERSION 6.5) FOR ATLANTIC BLUEFIN TUNA ASSUMING PRIORS FOR AREA-SPECIFIC SCALE AND WESTERN STOCK MIXING

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SUMMARY

In this paper a relatively large reference set of operating models (version 6.5) are presented that have been conditioned on various data as well as informative "priors" for scale and western mixing. The derivation of these "priors" (actually sets of a few alternative values considered to span the plausible range) is described, and the results of the reference operating models fitted are presented. The purpose of this document is to provide sufficient information to begin a process of narrowing operating model specifications into a smaller (than the current 48 member), more manageable reference set for use in CMP development and testing. A central objective of these operating model runs is to facilitate the choice of a suitable lower bound for western mixing. Previously 5% was presented as a suitable lower bound, but a lower level still might be desirable to provide a more rigorous test of CMP performance.

RÉSUMÉ

Ce document présente un ensemble de référence relativement important de modèles opérationnels (version 6.5) qui ont été conditionnés sur diverses données ainsi que des « distributions a priori » informatives pour la mise à échelle et le mélange occidental. Le calcul de ces « distributions a priori » (des ensembles de quelques valeurs alternatives considérées comme couvrant la gamme plausible) est décrit et les résultats des modèles opérationnels de référence ajustés sont présentés. L'objectif de ce document est de fournir suffisamment d'informations pour entamer un processus de réduction des spécifications du modèle opérationnel en un ensemble de référence plus petit (au lieu des 48 actuels) et plus facile à gérer, pouvant être utilisé pour le développement et les tests des CMP. L'un des objectifs principaux de ces scénarios du modèle opérationnel est de faciliter le choix d'une limite inférieure appropriée pour le mélange occidental. Auparavant, 5 % était présenté comme une limite inférieure appropriée, mais un niveau inférieur pourrait être plus approprié pour permettre un test plus rigoureux des performances des CMP.

RESUMEN

En este documento se presenta un conjunto de referencia relativamente amplio de modelos operativos (versión 6.5) que han sido condicionados por varios datos, así como distribuciones a priori informativas para la escala y mezcla occidental. Se describe la derivación de estas distribuciones previas (realmente conjuntos de unos pocos valores alternativos considerados para abarcar la gama plausible) y se presentan los modelos operativos de referencia ajustados. La finalidad de este documento es proporcionar información suficiente para comenzar el proceso de reducción de las especificaciones del modelo operativo a un conjunto de referencia más pequeño (que el actual de 48 miembros) y más gestionable para su uso en el desarrollo y prueba del CMP. Uno de los principales objetivos de estos ensayos de modelos operativos es facilitar la elección de un límite inferior adecuado para la mezcla occidental. Anteriormente, se presentó el 5 % como un límite inferior adecuado para proporcionar una prueba más rigurosa del desempeño del CMP.

KEYWORDS

Atlantic bluefin tuna, MSE, mixing, Operating Model

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1. Introduction

The current operating model for Atlantic bluefin tuna (M3 v6.5) is both relatively complex (i.e. seven spatial strata, four quarters, two distinct spawning stocks) and includes considerable flexibility (age-based movement, recruitment regime changes). Nonetheless it has proven difficult to condition an operating model for Atlantic bluefin tuna that provides adequate fits to all of the various data types whilst obtaining plausible estimates of the fraction of western spawning biomass found in eastern areas (western mixing) and the magnitude of spawning stock biomass in each area (scale) (see Appendix A for an overview of the current reference case operating model). The principal reason for these difficulties can be attributed to conflicts between data types. For example, the electronic tagging data does not document a western stock fish moving into eastern areas, in contrast to the microchemistry stock of origin data that infers that 5-15% of eastern area catches are of western origin fish (a very large fraction of western stock given it is around an order of magnitude smaller than the east stock).

This would be problematic for a stock assessment process that typically derives management advice directly from a small set of fitted models and a relatively narrow interpretation of the data. A core advantage of the management strategy evaluation (MSE) approach is that it does not rely on establishing a single 'base case' model that represents best available interpretation of the data. Rather, multiple operating models are established that span the plausible range of uncertainties, including varying inferences due to data conflicts, in order to test the performance of simple candidate management procedures (CMPs). The emphasis of the MSE approach is CMP robustness to these uncertainties and consequent confidence in an adopted MP, rather than extreme scientific accuracy in Operating Model specification. It follows that the difficulties in achieving plausible scale and western mixing can be formally recognized in the ABT-MSE framework by specifying alternative operating models for these specific model features.

In this paper a relatively large reference set of operating models are presented that have been conditioned on various data as well as informative "priors" for scale and western mixing. The derivation of these "priors" (actually sets of a few alternative values considered to span the plausible range) is described, and the results of the reference operating models fitted are presented. The purpose of this document is to provide sufficient information to begin a process of narrowing operating model specifications into a smaller (than the current 48 member), more manageable reference set for use in CMP development and testing. A central objective of these operating model runs is to facilitate the choice of a suitable lower bound for western mixing. Previously 5% was presented as a suitable lower bound, but a lower level still might be desirable to provide a more rigorous test of CMP performance.

2. Methods

2.1 Establishing factor levels for scale

The 2017 stock assessments for the west area and east areas provide guidelines for the possible range of scale (**Figure 1**). The assessments differed by around a factor of two for both assessments. In the east the assessment with the larger scale was used for advice (the VPA – the SS was not considered particularly reliable); in the west both of the two assessments (SS and VPA) that were taken into account in developing advice. Consequently, a (rounded) lower bound value for both stocks was assumed near the lowest assessed level (15kt West, 200kt East). Intermediate-high levels were selected at somewhat above the scale used to provide advice (50kt West, 400kt East) and more extreme upper bounds were placed at roughly twice the highest assessed scale (90kt West, 700kt East).

2.2 Establishing factor levels for western mixing

Model fit was investigated at alternative west stock mixing levels from 1% to 60% (**Table 1**). Western stock mixing was defined as the asymptotic unfished fraction of west spawning stock biomass found in the East area. Spawning stock biomass was used to determine mixing scenarios as the electronic tagging data for the west stock are principally for mature fish, and it is in this aspect that data conflicts arise (there are very few electronic tag data to conflict with stock of origin data for immature fish). Using asymptotic unfished conditions to define mixing has the advantage of disentangling mixing from time-dependent estimates such as fishing mortality rates and recruitment strength. Specifying mixing over a given time period would allow the model to achieve specified mixing rates with implausible estimates of recruitment and fishing mortality rates that could be hard to diagnose.
The conflicts among the data are evident in **Table 1** in which the electronic tagging data imply low mixing levels (e.g. 2.5%, 'Wfracs: 0.025'), but some of the best fits to the stock of origin data (e.g. the microchemistry data SOOm) occur at mixing levels as high as 60%. Upper and lower bounds for western mixing are proposed at 1% and 20% respectively. The lower bound of 1% is very close to zero (implied by the electronic tagging data for

western fish), the upper value of 20% is less credible than the 1% data in terms of the electronic tagging data but is the lowest mixing that still provides close to the best fit to the combined stock of origin data (SOOm and SOOg). An intermediate mixing level of 5% has also been included since this was previously suggested as a lower bound.

2.3 Implementing scenarios for scale and western stock mixing

The alternative plausible values for scale and western spawning stock mixing were implemented as penalties in the global negative log-likelihood, in both cases assuming log normal distribution with a coefficient of variation of 2.5%.

2.4 Constructing a grid of operating models

A grid of 48 operating models were run over four factors, crossing two recruitment scenarios (with and without historical regime shift), two levels for natural mortality rate and maturity, three levels for western mixing and four levels for scale (crossing low and intermediate-high for both areas) (**Table 2**).

In principle, a full cross of all three east and west scales could be carried out including the highest values of 90kt (west area) and 700kt (east area). However preliminary analyses revealed that these scenarios may be best explored in robustness operating models since they provide western stock levels that have never dropped substantially below twice B_{MSY} levels and East stock trends that are essentially flat to 2005 after which very rapid increases in spawning biomass to more than 1500kt are estimated (see Appendix G).

3. Results

A detailed breakdown of result can be found in Appendices B-F.

- Appendix B provides the summary of the 1% and 20% western mixing operating models (32 fitted OMs).
- Appendix C is similar, keeps the 20% mixing scenario but includes the 5% western mixing scenarios.
- Appendix D provides a summary of ranges in key estimates for the 1% and 20% western mixing OMs
- Appendix E is the same as Appendix D but for the 5% and 20% western mixing OMs
- Appendix F contains the M3 input and output files and individual fitting reports for all 48 Oms

3.1 Bracketing scale

Across the scenarios for scale and mixing, the models estimate ranges for spawning stock biomass (SSB) by area that span those for the 2017 stock assessments (**Figures 3.1 and 3.2**). The estimates of SSB by area are essentially identical for the 1% mixing scenario (I*, the dashed lines of **Figure 3.1**) and the 5% mixing scenario (I, the dashed lines of **Figure 3.2**).

Recruitment factor level 1 (regime shift) scenarios were all associated with rapid recent increases (all 'superman' lines seen in **Figure 3.3**). The most extreme of these occur for the eastern stock in scenarios where the eastern scale is set to a mean of 400kt (the '-+' and '++' OMs, denoted by the rapidly increasing blue and orange lines seen in panel D of **Figure 3.3**).

There was relatively little impact of 5% and 20% mixing on stock SSB levels and trends (dashed and solid lines, respectively). As before by area, the SSB results by stock were very similar in the case of the 1% and 5% western mixing levels (see Appendix C for 5% mixing results).

3.2 Bracketing stock status

Stock status estimates for both west and east stocks varied substantially from below half BMSY levels to above BMSY levels (**Figure 3.4**). No surprisingly, stock status was related to the specified scale with the west area 50kt ('+-' and '++') OMs providing the least exploited estimates of west stock status and the east area 400kt ('-+' and '++') OMs providing the least exploited estimates of east stock status.

3.3 Bracketing mixing

As expected, the 1% asymptotic western mixing scenario (dashed lines, **Figure 3.5**) spans a somewhat larger range of mixing than the 5% level (dashed lines, **Figure 3.6**) but perhaps importantly the 1% level includes scenarios where west stock mixing remains low throughout the recent time period (**Figure 3.5** panel B).

3.4 Fits to data

When examining operating model fits to data for the regime shift recruitment scenarios (recruitment factor level 1, **Table 3.1**) a number of patterns can be observed in the negative log likelihood components for various data types:

- composition data (Comp) are fitted more poorly in operating models where both stocks have low scale (15kt and 200kt respectively, '--').
- Fishery independent surveys (Surv) have worse fits with the higher western area scale of 50kt.
- Under the least productive scenario (low M / high age at maturity, B) catches (Cat) are fitted worse for operating models where both scales are low (15kt and 200kt, '--').
- Microchemistry stock of origin data (SOOm) generally favor larger western area scale of 50kt.

Operating models with a single recruitment phase showed similarly clear patterns in fit to various data (**Table 3.2**):

- Fit to catches (Cat) and CPUE indices (CR, and to a lesser extent fishery-independent surveys, Surv) was substantially worse for low productivity (B) operating models.
- Similarly to the regime shift recruitment OMs, composition data were fitted worse in OMs where both stocks have low scale, and microchemistry data were fitted best with high west area scale.

3.5 Passing central 'red face' tests

A primary objective of the MSE framework for Atlantic bluefin tuna is the development and testing of index-based CMPs. Two primary candidate indices are the Gulf of Mexico larval survey (GOM_LAR_SUV) and the Mediterranean larval survey (MED_LAR_SUV) that are 'fishery independent' and are stock specific (exist in exclusive spawning areas). In general, all operating models obtained acceptable to good fit to these indices (**Figure 3.7**). The exception were two operating models with a single recruitment phase (2) of low productivity (B) and high western scale combined with low eastern scale (+-): 2BI*+- and 2BII+- (OMs #39 and #47 respectively).

Most operating models could fit the prior on seasonal biomass for the Gulf of Mexico (**Figure 3.8 A**) but did not reach the value prescribed for the second quarter in the Mediterranean (**Figure 3.8 B**).

The relatively poor fit to the catch data for operating models with no regime shift (2) low productivity (B) and low east biomass (-- and +-) (indicated by the log-likelihood **Table 3.2** – operating models #37, #39, #45 and #47) can be seen to occur in the period from 1995 to 2007 where catches were imputed under the assumption of under reporting (**Figure 3.9**). The catch misfits occur in two historical Mediterranean purse seine fleets: PSMEDold and PSMEDoldQ2 (**Figure 3.10**).

3.6 Comparing outcomes of 1% and 5% OMs as a lower bound on Western stock mixing

When considering the option of a lower west stock mixing scenario of 1% versus 5% it is instructive to compare the range of model estimates across the proposed sets (I* and II vs I and II). The range of estimates in stock status, magnitude and SSB trajectory are very similar among these two sets of operating models (**Figure 3.11 and Tables 3.3 and 3.4**).

4. Discussion

A total of 48 operating models are presented in this report. As demonstrated here it is difficult to digest such a large quantity of results from so many model fits. It follows that a priority for the technical team is identifying approaches for reducing the reference set of operating models. For example, the set of 48 models can be reduced to 32 by removing the intermediate 5% mixing scenario (noting that even when reduced this would still increase back to 48 operating models when the future recruitment regime shift scenario is included).

In cases where the reference set is reduced but there is interest in testing CMP performance over a subset of the removed OMs, these can be added to the proposed robustness set of operating models (see Appendix H for a summary of robustness operating models that have been previously suggested).

It may be possible to investigate use of the negative log likelihood values as a basis for OM model rejection. However, some caution is necessary. For example, the inability of some operating models to fit catches may or may not be critical since this occurs over a time period in the late 90s and early 2000s when catch values are heavily influenced by estimates of the size of the illegal catches.

It is common in MSEs for various aspects of operating model specification to be inconsequential in determining CMP performance. The ABT-MSE process will benefit from a transition to the next phase in which CMP performance can be evaluated in order to choose ‘consequential’ uncertainties as priorities for robustness tests outside the reference operating model grid.

There are a number of additional priorities at this stage including a review of indices for use in CMPs, and statistical approaches for generating future index data and recruitments.

Acknowledgements

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Table 2.1 Negative log-likelihood components (lower values in green are better fit) for various data types given the 'Base' OM (Appendix A) and varying prior on the asymptotic fraction of western spawning stock biomass found in Eastern areas (e.g. Wfracs: 0.01 refers to 1% of western stock biomass found in eastern areas under unfished conditions). The columns denote data types: Cat = catch data by fleet, quarter and area. CR = the fishery dependent catch rate (CPUE) indices, Surv = fishery-independent survey indices, Comp = length composition data, SOOm = stock of origin microchemistry data, SOOg = stock of origin genetics, Tag = Electronic tagging data.

Code	Cat	CR	Surv	Comp	SOOm	SOOg	Tag
Wfracs: 0.01	594	693	1157	378	393	93	2523
Wfracs: 0.025	589	666	1090	431	353	87	2453
Wfracs: 0.05	349	690	1005	421	373	92	2477
Wfracs: 0.1	625	683	1102	394	403	86	2519
Wfracs: 0.2	615	702	1087	391	369	80	2593
Wfracs: 0.3	633	694	1084	378	369	80	2638
Wfracs: 0.4	609	685	1087	386	366	80	2670
Wfracs: 0.5	578	640	1051	414	386	80	2722
Wfracs: 0.6	746	648	1093	350	352	82	2774

Table 2.2. The grid of operating models presented here. Note that recruitment level 3 has been proposed for reference set operating models for Atlantic bluefin tuna but only differs from level 1 in future recruitment regime.

	Western stock	Eastern stock
Recruitment		
1	B-H with h=0.6 (“high R0”) switches to h = 0.9 (“low R0”) starting from 1975	50-87 B-H h=0.98 switches to 88+ B-H *h*=0.98
2	B-H with h=0.6 fixed, high R0	B-H with h=0.7 fixed, high R0
3	Historically as in Level 1. In projections, “low R0” switches back to “high R0” after 10 years	Historically as in Level 1. In projections, 88+ B-H with *h*=0.98 switches back to 50-87 B-H with *h*=0.98 after 10 years.
Spawning fraction both stocks		Natural Mortality rate both stocks
A	Younger (E+W same)	High
B	Older (E+W older but different for the 2 stocks)	Low
Western stock mixing into East area		
I*	1% unfished asymptotic biomass	
I	5% unfished asymptotic biomass	
II	20% unfished asymptotic biomass on average	
Scale	Western area	Eastern area
--	15kt	200kt
-+	15kt	400kt
+-	50kt	200kt
++	50kt	400kt

Table 3.1. Negative log-likelihood components for operating models given the historical regime shift (recruitment factor level 1). Lower (green) numbers represent better fit. Cat = catch data by fleet, quarter and area. CR = the fishery dependent catch rate (CPUE) indices, Surv = fishery-independent survey indices, Comp = length composition data, SOOm = stock of origin microchemistry data, SOOg = stock of origin genetics, Tag = Electronic tagging data, Rec = prior on recruitment deviations, Mov = prior on movement parameters, Sel = prior on size selectivity parameters, SRA = penalty incurred when catches exceed F=1 catches in the stock reduction analysis phase (1864-1964), MI = a prior on similarity to the 'Master Index' that predicts F by year, area, season and fleet, R0diff = a prior on the difference in R0 estimated in two-phase recruitment models (recruitment level 1 and 3), SPr = seasonal distribution prior, TOT_nP = total global objective function without priors, TOT = total global objective function.

OM	Code	Cat	CR	Surv	Comp	SOOm	SOOg	Tag	Rec	Mov	Sel	SRA	R0diff	MI	SPr	TOT_nP	TOT
1	1 A I* –	289	626	941	584	392	114	2492	29	314	128	1	17	51	24	5463	6004
2	1 A I* -+	132	640	894	345	463	141	2476	26	315	127	0	16	64	-9	5082	5630
3	1 A I* +-	105	691	1222	340	371	109	2422	32	311	128	1	23	42	-5	5254	5791
4	1 A I* ++	85	664	1212	325	347	111	2377	30	314	128	0	18	44	-20	5103	5638
9	1 A II –	259	617	972	607	299	84	2651	22	310	128	0	17	50	2	5491	6018
10	1 A II -+	112	636	924	340	410	109	2599	26	312	127	0	17	63	-11	5119	5663
11	1 A II +-	104	728	1234	344	374	84	2503	23	307	127	0	21	46	8	5381	5904
12	1 A II ++	63	659	1249	316	331	87	2505	27	309	128	0	19	46	-20	5189	5719
13	1 B I* –	483	640	969	639	427	118	2636	33	321	127	3	28	50	44	5956	6519
14	1 B I* -+	287	677	907	390	490	146	2570	48	321	128	3	19	63	-10	5457	6039
15	1 B I* +-	256	603	1581	349	276	97	2551	10	311	128	1	33	41	4	5717	6241
16	1 B I* ++	201	687	1291	349	359	112	2459	35	314	129	2	24	44	-16	5442	5990
21	1 B II –	441	634	991	637	378	92	2757	32	314	127	1	29	50	34	5964	6517
22	1 B II -+	268	664	951	378	435	109	2698	39	318	128	1	20	65	-11	5493	6063
23	1 B II +-	234	618	1595	342	256	74	2663	10	307	128	0	34	42	3	5785	6306
24	1 B II ++	172	684	1320	338	339	87	2585	33	312	129	1	25	46	-16	5508	6053

Table 3.2. As table 3.1 but for the single regime historical recruitment (factor level 2).

OM	Code	Cat	CR	Surv	Comp	SOOm	SOOg	Tag	Rec	Mov	Sel	SRA	R0diff	MI	SPr	TOT_nP	TOT
25	2 A I* –	277	721	953	426	332	119	2711	83	315	127	0	0	48	19	5558	6132
26	2 A I* -+	148	694	945	413	369	127	2631	66	315	128	0	0	55	12	5338	5902
27	2 A I* +-	246	700	1041	412	331	108	2599	86	306	128	0	0	41	15	5452	6012
28	2 A I* ++	121	658	966	396	381	124	2593	65	310	127	0	0	48	5	5243	5793
33	2 A II –	255	717	958	425	280	92	2829	84	310	127	0	0	51	18	5573	6144
34	2 A II -+	139	682	918	412	333	98	2768	65	310	127	0	0	57	11	5360	5919
35	2 A II +-	210	683	970	422	319	88	2779	83	306	127	0	0	44	12	5483	6043
36	2 A II ++	108	659	958	406	345	95	2720	66	308	127	0	0	49	3	5293	5843
37	2 B I* –	697	816	1140	478	356	124	2851	89	317	129	0	0	48	38	6498	7081
38	2 B I* -+	553	769	1100	459	383	126	2762	79	320	128	0	0	52	27	6179	6758
39	2 B I* +-	637	765	1224	453	334	111	2697	83	306	129	0	0	40	43	6265	6823
40	2 B I* ++	377	741	1145	415	355	117	2658	72	306	129	0	0	43	17	5825	6375
45	2 B II –	547	786	1112	467	324	98	2969	90	309	128	0	0	50	49	6351	6929
46	2 B II -+	354	721	1051	465	380	100	2927	78	313	127	0	0	56	35	6033	6609
47	2 B II +-	581	764	1219	457	281	84	2881	81	303	129	0	0	42	41	6308	6862
48	2 B II ++	309	734	1127	432	316	93	2817	76	309	128	0	0	47	18	5846	6406

Table 3.3. Ranges of stock specific estimates for operating models with 1% and 20% west stock mixing.

	West range	West interquartile	East range	East interquartile
SSB2016 relative to dyn SSBMSY	0.23 - 1.77	0.34 - 0.85	0.45 - 1.65	0.58 - 1.12
2016 SSB (kt)	6.5 - 44.1	9.4 - 22.3	177 - 1181.3	298.6 - 833.3
SSB trajectory 2007-2016 (% per year)	-0.37 - 13.47	2.42 - 7.63	-0.61 - 32.06	1.23 - 20.42

Table 3.4. Ranges of stock specific estimates for operating models with 5% and 20% west stock mixing.

	West range	West interquartile	East range	East interquartile
SSB2016 relative to dyn SSBMSY	0.24 - 1.77	0.34 - 0.85	0.44 - 1.63	0.58 - 1.12
2016 SSB (kt)	6.5 - 44.1	9.5 - 22.7	179.6 - 1213.9	297.7 - 837.3
SSB trajectory 2007-2016 (% per year)	-0.34 - 13.47	2.45 - 7.63	-0.51 - 31.79	1.33 - 20.38

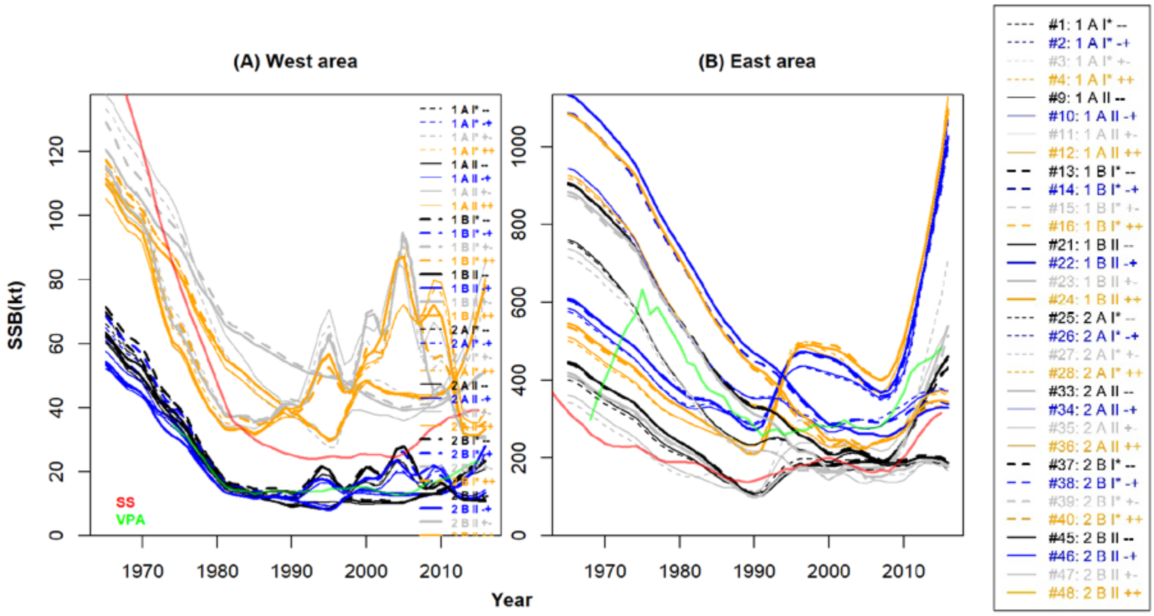

Figure 3.1. The ranges in the scale of OMs presented for the 1% and 20% Western mixing OMs (Appendix B). Although the legend is the same for recruitment levels, those showing recent increases are all recruitment factor 1 (with historical regime shift).

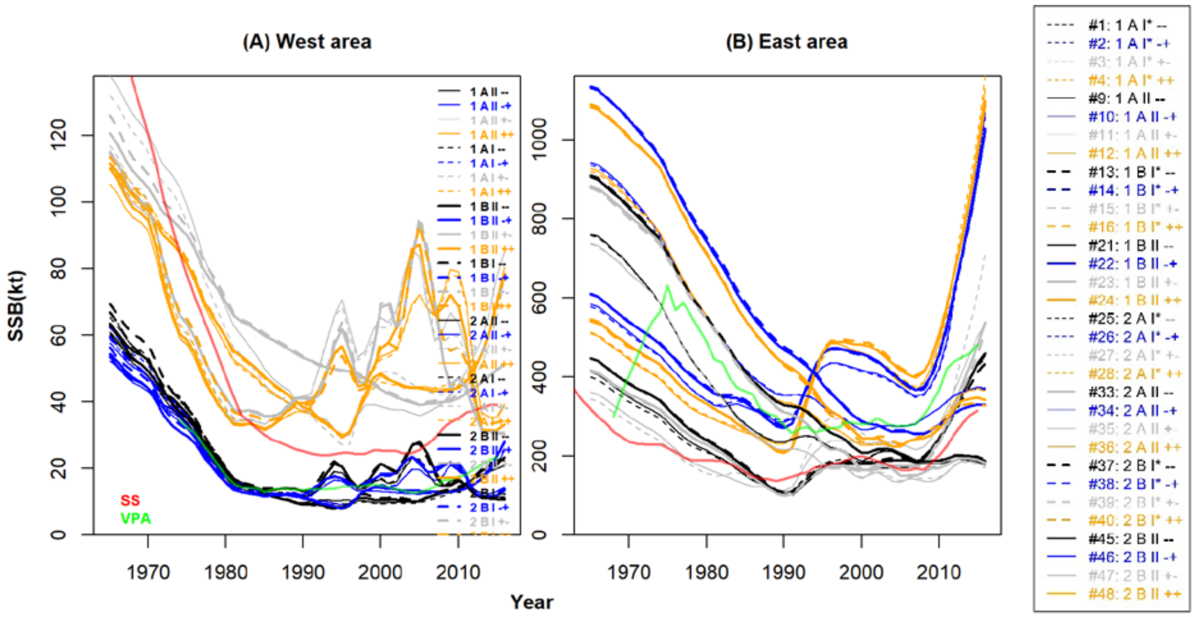

Figure 3.2. As Figure 3.1 but for the 5% and 20% western mixing OMs.

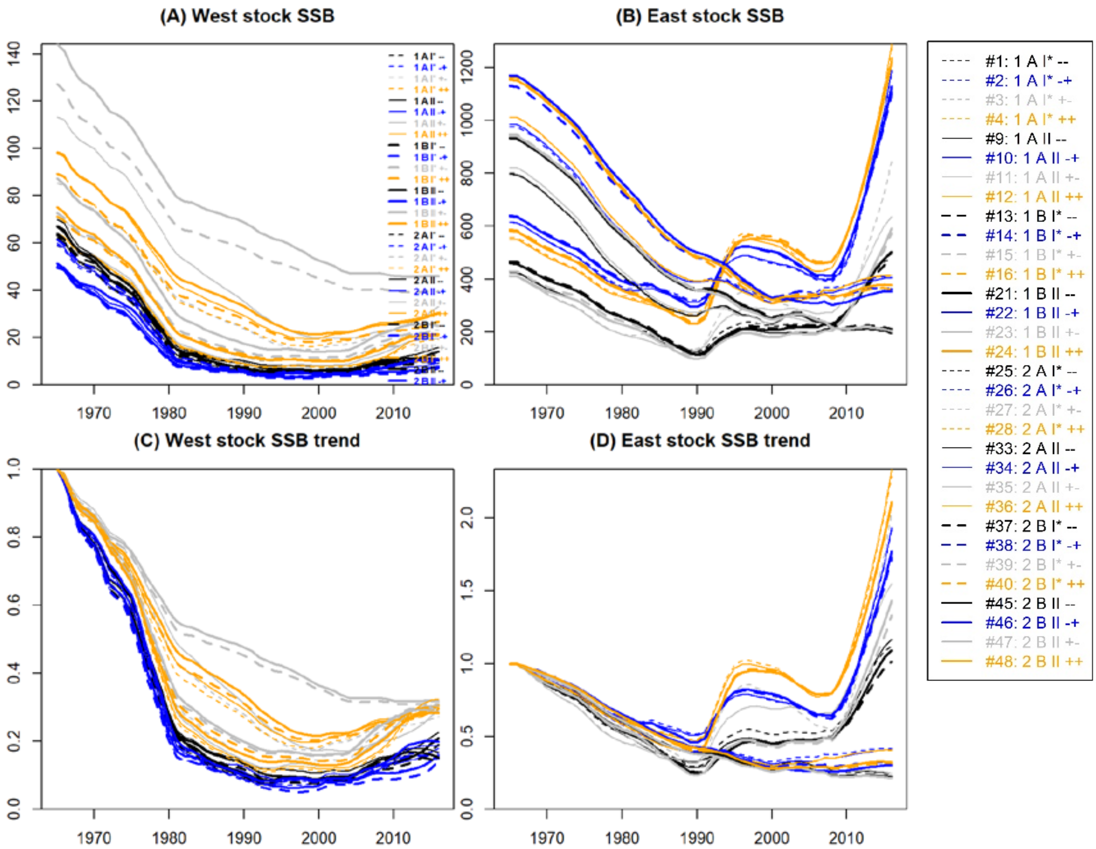

Figure 3.3. Stock-specific spawning stock biomass for the 1% and 20% mixing levels. The top row (A, B) are in absolute magnitude, the bottom row (C, D) are expressed relative to the spawning biomass in 1965.

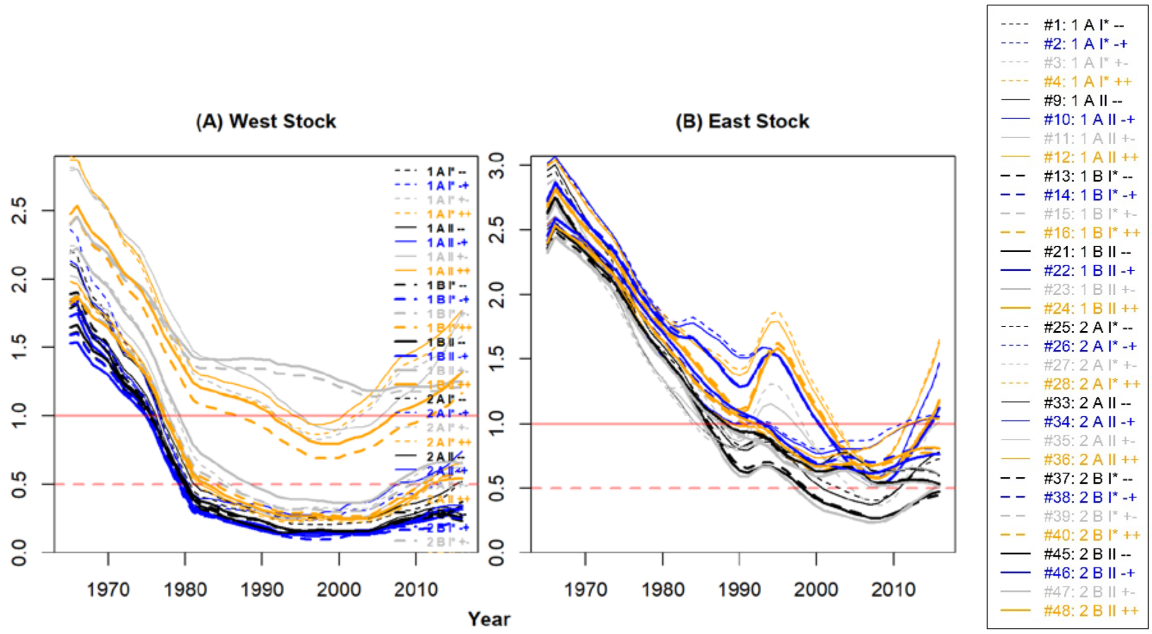

Figure 3.4. Variability in stock status estimates (stock SSB relative to dynamic SSBMSY) among operating model runs for the 1% and 20% mixing scenarios.

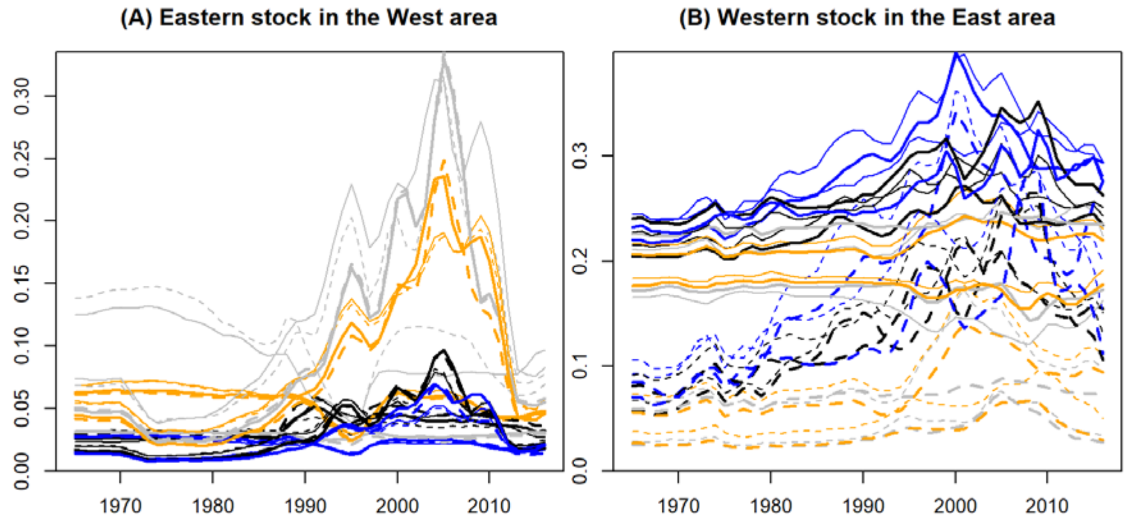

Figure 3.5. Stock mixing expressed here as the fraction of stock biomass found in the opposite area. The legend is the same as for previous figures. The dashed lines are for the 1% western mixing scenario (asymptotic fraction of mature west stock biomass in the opposing area), the solid lines are for the 20% mixing scenario.

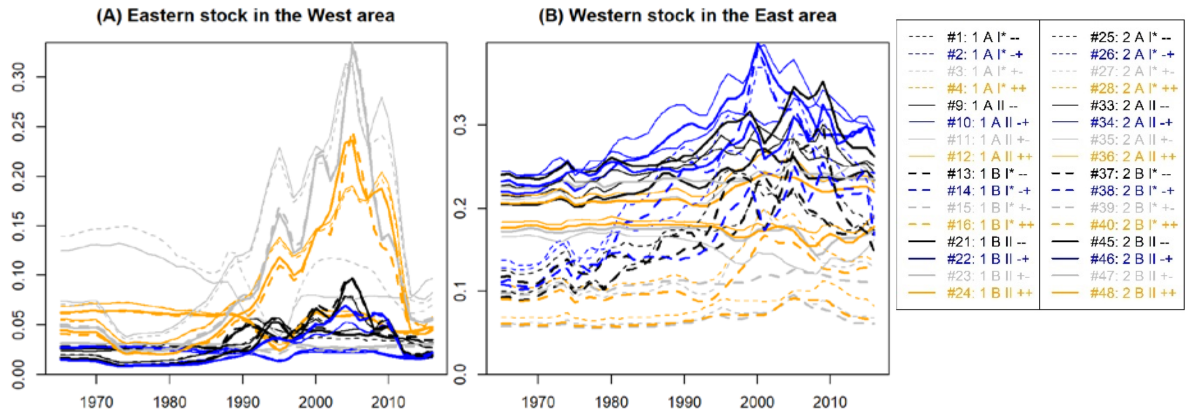

Figure 3.6. As Figure 3.4 but for the 5% (dashed lines) and 20% (solid lines) mixing scenarios.

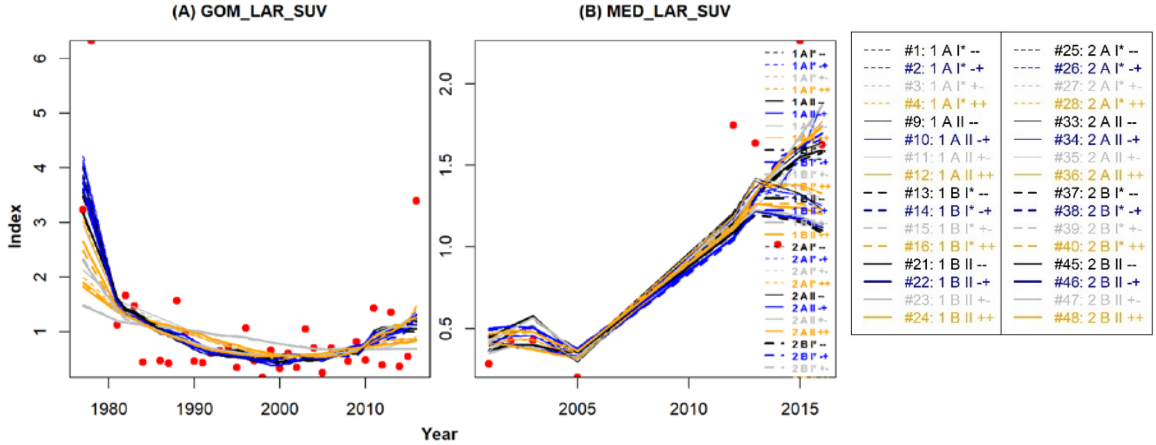

Figure 3.7. Fits to stock-specific fishery-independent abundance indices.

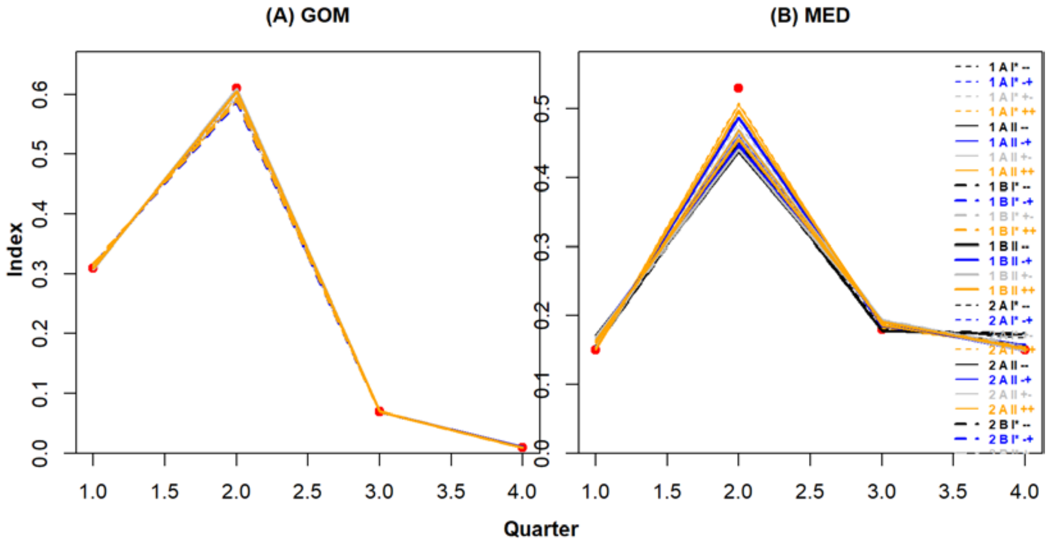

Figure 3.8. Fits to seasonal priors (asymptotic unfished seasonal distribution) for the Gulf of Mexico (A) and Mediterranean (B).

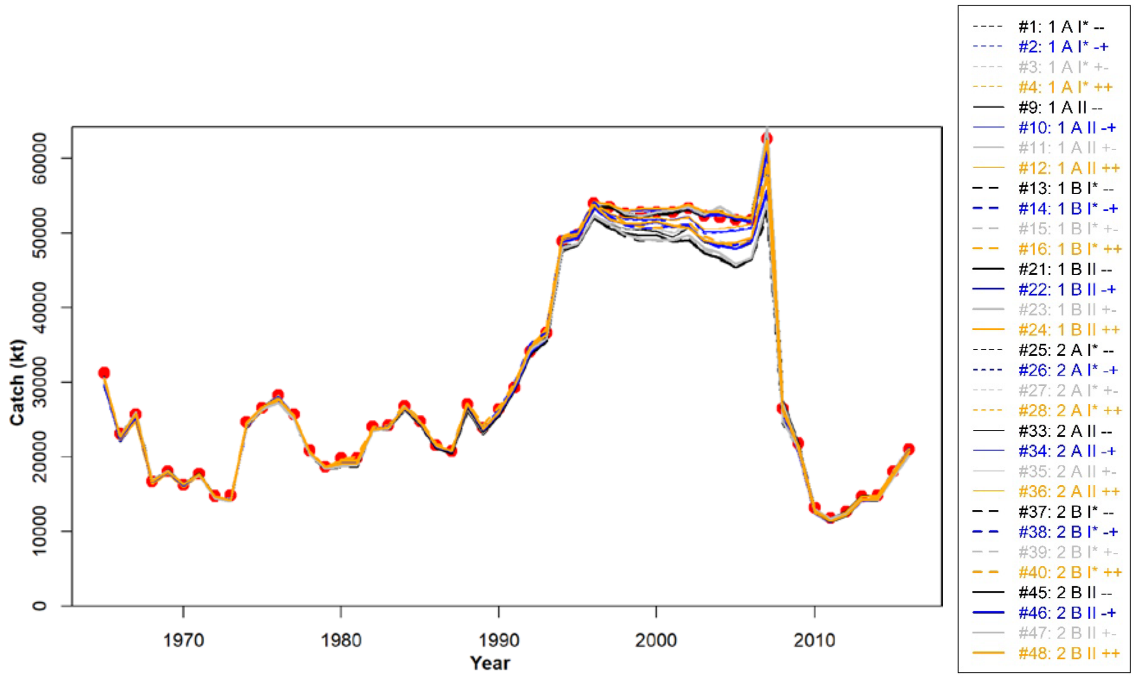

Figure 3.9. Operating model fits to aggregate catches.

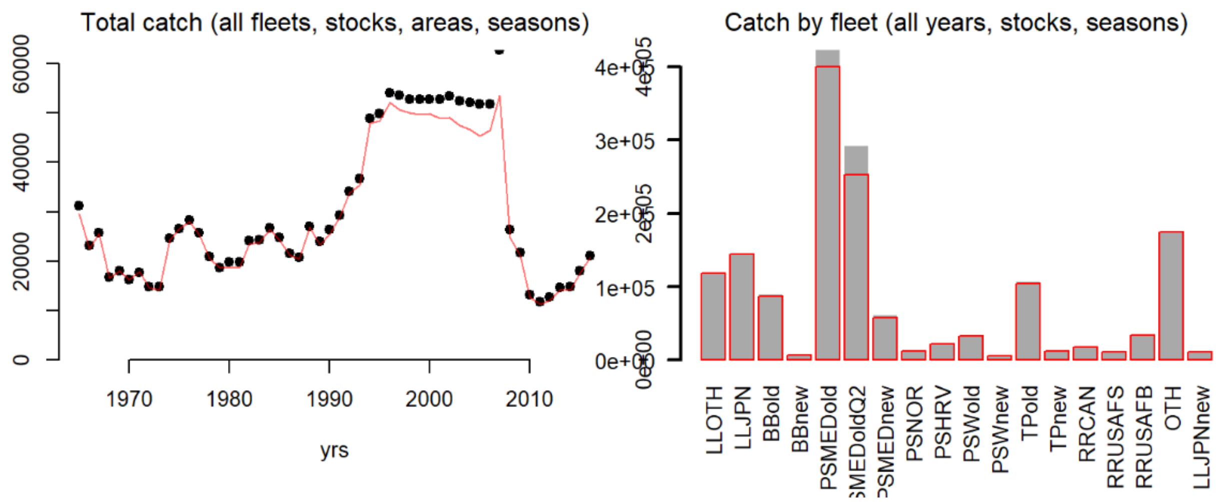

Figure 3.10. Fit to aggregate catches for model #45 (2 B II --).

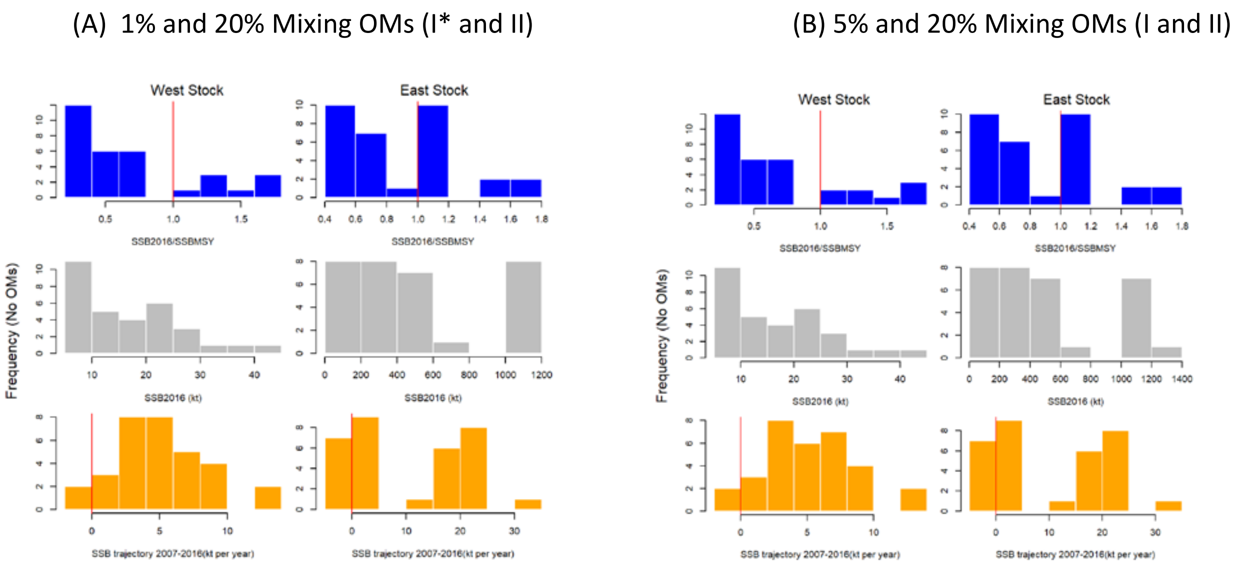

Figure 3.11. The range of operating model outcomes for two possible ranges of mixing (A) the 1% and 20% western mixing levels and (B) the 5% and 20% mixing levels.

Appendix A: Default model weighting from which new scale and mixing OMs are based

Appendix B: OM comparisons for 1% and 20% mixing

Appendix C: OM comparisons for 5% and 20% mixing

Appendix D: OM estimate ranges for 1% and 20% mixing

Appendix E: OM estimate ranges for 5% and 20% mixing

Appendix F: Individual OM input/output and report files

Appendix G: OM highest scale values

Appendix H: Previous robustness operating models considered for investigation