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FINAL DATA, EXPLORATIONS, MODEL SET-UP AND DIAGNOSTICS FOR THE 2022 VPA STOCK ASSESSMENT OF THE EASTERN AND MEDITERRANEAN ATLANTIC BLUEFIN TUNA STOCK

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SUMMARY

This document presents the modeling work done for the 2022 stock assessment for the Eastern and Mediterranean Bluefin tuna stock, during informal modeling subgroup meetings in June 2022. This document presents various runs built upon the base case for the 2017 stock assessment. These runs aim at addressing issues identified in the 2020 update assessment and aspects discussed during the informal meetings held in June 2022, regarding the inclusion of updated catch at age data, improvement of model stability in relation to F_{RATIO} *estimates, the selection of the age for the plus group, inclusion of the WMED_GBYP_AER index. Following several explorations, the present work contains two runs that displayed improved diagnostics compared to previous runs. These models have improved retrospective patterns and no problematic issue was found through jittering the random number generator, jittering the starting values for the terminal F estimate, bootstrapping or through jackknife analysis.*

RÉSUMÉ

Ce document présente les travaux de modélisation réalisés pour l'évaluation du stock de 2022 pour le stock de thon rouge de l'Atlantique Est et de la Méditerranée, au cours des réunions informelles du sous-groupe de modélisation en juin 2022. Ce document présente divers scénarios reposant sur le cas de base de l'évaluation du stock de 2017. Ces scénarios visent à résoudre les questions identifiées lors de l'évaluation mise à jour de 2020 et les aspects discutés aux réunions informelles tenues en juin 2022, concernant l'inclusion des données actualisées de prise par âge, l'amélioration de la stabilité du modèle par rapport aux estimations de FRATIO, la sélection de l'âge pour le groupe plus et l'inclusion de l'indice WMED_GBYP_AER. Faisant suite à plusieurs études approfondies, les travaux actuels comportent deux scénarios présentant une amélioration des diagnostics par rapport aux scénarios précédents. Ces modèles ont amélioré les schémas rétrospectifs et aucune question problématique n'a été constatée par l'analyse de jittering du générateur de nombres aléatoires, l'analyse de jittering des valeurs de départ pour l'estimation de la F terminale, par bootstrap ou par l'analyse de jackknife.

RESUMEN

Este documento presenta el trabajo de modelación realizado para la evaluación de stock de 2022 para el stock de atún rojo del Atlántico este y Mediterráneo durante las reuniones informarles de junio de 2022 del Subgrupo de modelación. Este documento presenta varios ensayos elaborados a partir del caso base para la evaluación de stock de 2017. Estos ensayos tienen como objetivo abordar cuestiones identificadas en la evaluación actualizada de 2020 y los aspectos debatidos durante las reuniones informales de junio de 2022 acerca de la inclusión de datos actualizados de captura por edad, la mejora de la estabilidad del modelo en relación con las estimaciones de FRATIO, la selección de la edad para el grupo plus y la inclusión del índice WMED_GBYP_AER. Tras varias exploraciones, el trabajo presente contiene dos ensayos que mostraron un diagnóstico mejorado en comparación con los ensayos previos. Estos modelos han

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mejorado los patrones retrospectivos y no se encontró ningún problema mediante la ligera variación del generador de números aleatorios, la ligera variación de los valores iniciales para la estimación de F terminal, el bootstrap o mediante el análisis jackknife.

KEYWORDS

Atlantic bluefin tuna; stock assessment

1. Introduction

VPA modeling work to produce an assessment for the East and Mediterranean stock of Atlantic bluefin Tuna (EBFT) has been conducted during informal meetings in June 2022 and building on previous work done with the modeling subgroup since the attempt of an update assessment in 2020 (Rouyer et al. 2020 SCRS/2020/069). For initial runs, the model specifications were kept nearly identical to the 2017 assessment (**Run 0**), as no other model has been agreed on since then. This allowed us to build a continuity run that formed the base to carry out several explorations with the objective to improve several problematic aspects of the model such as the strong retrospective pattern and the instability in recruitment estimates. This work builds upon decisions made during the 2017 data preparatory meeting (March 6-11 2017, Madrid), as well as upon decisions made during the 2017 stock assessment meeting (July 20-28 2017, Madrid) and BFT Species Group (SCRS/2017/188). The data and initial model-set up were detailed in another manuscript (Rouyer et al. SCRS/2022/067). The document presents runs that aimed at addressing feedback from previous discussions during the data-preparatory meeting and informal modeling meetings. The different aspects tackled are (i) the 10+ vs 16+ age Group selection, (ii) testing whether data had enough information to appropriately estimate Fratio, (iii) exploring options to provide more stability to the VPA and (iv) other runs among which trying to include the WMED_GBYP_AER index. The continuity run (run 288) has similar specifications as the 2017 assessment base case but following discussions from the data-preparatory meeting it used:

- CAAv2b that has an updated size structure for the inflated catch (Ortiz et al. 2022 SCRS/2022/101)
- the updated WMED_LARV index
- Fratio estimates for 3 time blocks (1968-1980; 1981-1995; 1996-2007) and Fratio fixed to 1 for the last time block (2008-2020).

A shiny app has been developed and made available to the Group in which all the runs presented and almost the results can be looked at.

2. Materials and method

2.1 Age 10+ vs age 16+

The first series of runs aimed at informing the selection of 10+ vs 16+ age Group:

- **Run 289** was similar to run 288 with expanded age structure to 16+
- **Run 290** similar to run 289 but included in addition the Fratio set to 1 for all years. Fratio=1 for age group 16+ is a more intuitive assumption than for age group 10+
- **Run 291** similar to run 289 but used the Richards Curve
- **Run 292** similar to run 290 (Fratio=1) but used the Richards curve
- **Run 293** similar to run 290, but use additive variance for the indices instead of multiplicative variance

- **Run 294** does not estimate the selectivity of the WMED_LARV index, but uses a fixed selectivity. (Since for the PCAA the maturity ogive, constant over time, is used this can lead to some doming in selectivity).

2.2 Fratio test and exploring to improve stability

The second series of runs were set-up to test whether the Fratio could be properly estimated with the VPA. To do so the runs 305-310 were defined with the Fratio for the first year was set to 0.25 / 0.5 / 0.75 / 1 / 1.25 /1.5, then the Fratio for the three time blocks was estimated as a deviation from that value. The objective function for these runs is then inspected to check whether a minimum can be obtained. If the profile is flat, i.e. no statistically significant difference in objective function between runs, then the model is unable to properly estimate Fratio.

Following this test, several explorations were made:

- **Run 295** was proposed with Fratio for the two first time blocks set to 1 (merged 1968-1995 time block) and the third one (1996-2007) freely estimated. The reason is that Fratio estimates are a major source of instability for the VPA and setting it to a value, as it was before the 2017 assessment, may be a way to solve this. An Fratio of 1 is the default value for Fratio advised by the VPA manual (unless there is a strong biological rationale to do otherwise). The 1996-2007 time block was left to be estimated as it corresponds to the most uncertain time-period for the catch, whose size structure is also poorly known. Some search settings were also modified: allowing for more restarts for the function optimizer and also providing lower starting values for Fterminal ages 1 and 2 for which very little catch has been made since 2007.
- **Run 287** was proposed with constraints for the vulnerability set to 0.5 (instead of 0.4 for the 2017 VPA) for ages 5-9 (instead of ages 1-9 for the 2017 VPA) applied over 6 years (instead of 3 years for the 2017 VPA). The rationale was that ages 1-4 only represent a small fraction of the catch since the late 2000s and that an extended constraint is compatible with what we know from the recent years of the fishery. A recruitment constraint of the same strength was also applied over the same number of years.
- The Fratio of the 1968-1995 time block was profiled
- The Fratio for the 2007-2020 time block was profiled
- The Fratio of the 1968-1995 and 2007-2020 time blocks were profiled assuming they were equal

2.3 Other runs

Several other runs were made to address other aspects:

- Using additive variance for indices
- Fixing the selectivity for the WMED_LARV index
- Using the 10+ age Group and the Richards curve
- Including the WMED_GBYP_AER. The index was included similarly as the WMED_LARV index, but with the selectivity fixed.

2.4 Sensitivity analysis and diagnostics

The models were subjected to different diagnostics (Zarrad et al. SCRS/2017/037):

- Jackknife for indices: investigate the stability of the models selected by removing each index

- Starting values for the random number generator: 100 different seed numbers for the random number generator used by VPA2box were run for each model to investigate whether a global or local solution was found.
- Jitter F terminal: the stability of the model is tested by picking the starting values for terminal F from a uniform distribution
- Fit to indices
- Retrospectives: peels of a successive year of data and estimates the model. Look for retrospective bias, i.e., the model estimates of SSB, recruitment or F for the completed years changing in a directional manner as years of data are added to the model. For instance, one might look at the recruitment to see if adding a year of data changes the recruitment estimates for the overlapping years. This analysis was completed by the computation of Mohn's Rho statistic.
- Likelihood profiling for different values of Fratio

These diagnostics were fully developed for potential base cases, whereas for others runs the focus was put on the retrospectives and fit to indices.

3. Results

3.1 Continuity run over 1968-2020 (Run 288)

The trend in spawning stock biomass (SSB), recruitment (R), in fishing mortality for ages 2-5 (F2-5) and in fishing mortality (Fageplusgroup) for the plus group (age above 10) of Run 288 showed several differences compared to Run 0 (**Figure 1**). The most noticeable difference was the change in scale for the SSB and for the Fplusgroup. Run 288 showed substantially lower SSB and Fplusgroup over the 1996-2007 time period. The recruitment estimates after the 2000s are also noticeably different, probably reflecting changes in the CAA. Looking at the retrospective for run 288 confirmed problems that have been discussed for some years, such as the instability in SSB and in the recent recruitment. Such instability was also apparent in the Fratio estimates for the different time blocks, which varied strongly when years of data were successively removed (**Figure 2**). The fit to the indices was found problematic for the MOR_POR_TP, the JPN_LL_NEA, the SP_BB2, the FR_AER2 and the WMED_LARV (**Figure 3**).

3.2 Age 10+ vs 16+

Comparing run 289 to run 288 showed completely different trends in all the variables (**Figure 4**). Looking at the logLikelihood for the fit to the indices did not suggest any general improvement, whereas retrospective patterns were strong (**Table 1**, **Figure 4**). Setting Fratio to 1 for all years (run 290) changed even more the trends in the different variables, displaying an increasing SSB from the late 1960s to the 2000s and a steep increase from the late 2000s onwards (**Figure 4**). It has to be noted that the terminal fishing mortality estimates showed a doming pattern peaking at age 9 (**Figure 5**). A main aspect was that when assuming Fratio=1 for all years, the fit to key indices (i.e. JPN_LL_EastAtlMed, both MOR_POR_TP and MOR_SP_TP) was lost, whereas the fit noticeably improved for WMED_LARV (**Table 2, Figure 6**). Using the Richards curve (Runs 291 and 292) did not seem to generally solve these issues, retrospectives patterns remained strong but it has also to be noted that the terminal Fishing mortality also showed some doming at age 9. Using additive variance and using a fixed value for the WMED_LARV selectivity (runs 293 and 294) did not solve these aspects (**Table 2**).

3.3 Fratio test and explorations to improve stability

Comparing the objective function for the runs of the Fratio test did not show changes by more than two points around the lowest value, which was reached for a Fratio=1 for the first year (**Table 3, Figure 7**). This indicated that the Fratio could probably not be properly estimated from the information available in the VPA.

The two first time blocks of run 295 were set equal to one and therefore merged as one block (1968-1995). This improved the retrospective patterns, which reflected in the Mohn's Rho statistics (**Table 4, Figure 8**). Run 287 assumed several changes in constraints for the vulnerability and the recruitment. These changes further improved the retrospectives with the Mohn's Rho statistics getting closer to 0 (**Table 4, Figure 8**). Successive peels were much more close to each other, in fact only removing a 4th year created a different pattern (**Figure 8**). Run 287 also displayed a significantly lower objective function (**Table 4**).

Profiling the first time block (1968-1995) of run 287 showed that the lowest objective function value was reached for Fratios of 0.75 and 1, but without being statistically different from each other (**Table 5**). Profiling the second time block (2007-2020) showed a similar result (**Table 6**). Profiling both time blocks showed that the minimum objective function was reached for a Fratio value of 0.75 (**Table 7**). That run, run 286, displayed improved retrospective patterns, displaying Mohn's Rho statistics whose absolute value was very low and below 0.1 for each variable (**Table 7, Figure 9**). Run 286 displayed a comparable scale as the continuity run (run 288) and run 287 (same run but with Fratio=1), but estimated higher recruitments from 2010 onwards (**Figure 9**). These runs displayed a substantial increase in SSB for recent years, but this increase was not found as strong as for other runs and suggested a SSB at comparable levels as in the 1970s (**Figure 9**).

Jittering the starting values for the random number generator for runs 286 and 287 showed that these runs were well determined (**Figures 10 and 11**). The maximum likelihood runs were within the bins with the highest counts and within that bin, the trends were tight. The seeds for which different trends were found, but not the maximum likelihood, were associated with different terminal F peaking at ages 4 and 5, not consistent with what is known from the fishery that mostly exploits larger age classes. The Jackknife diagnostic, removing one index at a time, showed an effect of the JPN_LL_EastAtlMed on the overall scale and the Fratio estimate for the second block for both runs 286 and 287 (**Figures 12 and 13**). Other indices influenced the recruitment, but generally the trends were mostly preserved. Jittering the terminal F starting values showed that run 286 and run 287 displayed consistent trends in SSB until 2017, whereas recruitment trends showed three different trajectories starting in 2012 onwards (**Figures 14 and 15**). These trajectories seemed to correspond to different estimates of terminal F for which higher values of F were estimated for ages 4-5, as illustrated by the results obtained when jittering the seed of the random number generator. The terminal F profile across ages of the MLE seemed the most likely given the current exploitation diagram focused on larger/older individuals.

Looking at results from 500 bootstraps for fishing mortality and abundance at age and the objective function showed that for run 286, the deterministic run was not far from the median of the bootstraps or nearly equal to it (**Figure 16**). The same results were found when looking at bootstrap results for run 287 (**Figure 17**).

3.4 Other runs

Using additive variance for the indices or fixing the selectivity of the WMED_LARV did not seem to improve the objective function or the retrospective statistics for run 286 (runs 296 and 297, **Table 9**) and for run 287 (run 298 and 299, Table 9).

Interestingly, using the Richards curve for the continuity run 288 (run 301) substantially improved the retrospective patterns, with Fratio estimates being more stable across retrospective peels (**Figure 18**). This run also yielded a much smaller and flatter SSB, much higher fishing mortality and low Fratio values for the historical time blocks (**Figure 18**). This interesting run would require more investigations than time was allowed for the purpose of the 2022 assessment.

The WMED_GBYP_AER was added to run 286 (run 303). This did not affect the objective function, but the retrospective patterns got worse (**Table 10**). That index was given relatively little weight by the VPA (**Table 10**). Removing the WMED_LARV from this run (run 304), so that only WMED_GBYP_AER was included to represent the recent trend in spawners in the Western Mediterranean, did not seem to improve the model diagnostics. It was associated with a different pattern in SSB and recruitment and with a terminal F peaking at age 5 (**Figure 19**).

An attempt to use a dummy index to control the general scale of the VPA was made, by introducing an index for one year and with a strong weight to run 288 (then called run 84) was initially presented during the June informal modeling meeting. That run showed a slight improvement in retrospective patterns, but within the time available no success was encountered in trying to obtain a change in scale with a variation in the index. More efforts would be required to achieve this.

4. Discussion

The present work showed that the continuity model still displayed the problematic characteristics that have been highlighted in the past. Attempts to use a 16+ age group did not show that it made it easier to assume Fratio=1 for all years as fit to the indices was found problematic and as it produced SSB trends *a priori* not very plausible (e.g. increasing SSB from the late 1960s to the 2000s). Attempts to improve the stability of the continuity run led to two runs (runs 286 and run 287) displaying improved diagnostics. These runs also showed not as strong increases in SSB than previous ones, even though some strong recent recruitments were estimated. These runs seemed relatively well determined regarding the various diagnostics that were run. The estimated Fratio for the 1996-2007 time block was above 2 for both runs, consistent with the focus on larger fish during that exploitation period. Assuming Fratio=1 is the default VPA assumption and in that respect run 287 could be preferred to run 286. However, noting that the difference in objective function was small between the two runs, that the test performed in the present work showed that Fratio could not be estimated appropriately and that some doming was found in the 16+ runs, using a Fratio=0.75 as used in run 286 could be discussed. Run 286 has the best statistical properties of all the runs tried here. It has also to be noted that using the Richards curve seemed to solve stability related problems.

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Table 1. Statistics of runs 288-292 and log-Likelihood for the fit to indices in runs 288-292, which are runs investigating the age group 16+.

run	FR_AER1	FR_AER2	JPN_LL_EastMed	JPN_LL1_NEA	JPN_LL2_NEA	MOR_POR_TP	MOR_SP_TP	SP_BB1	SP_BB2	WMED_LARV
RUN_288	4.00	-3.15	20.34	11.10	5.37	5.30	8.11	5.53	-1.50	-6.74
RUN_289	4.30	1.23	7.64	5.54	6.87	3.02	-5.71	9.24	1.17	-14.31
RUN_290	3.92	0.34	-6.70	9.11	5.31	-4.56	0.55	8.07	1.68	-1.49
RUN_291	3.66	1.49	21.00	12.15	10.62	-0.33	3.91	11.34	0.79	0.50
RUN_292	3.81	1.36	-6.16	9.13	6.22	0.03	3.43	9.87	1.08	-1.22

run	obj_func	obj_func_with_cte	nb_param	nb_data	AIC	AICc	BIC	chi_square	mohnSSB	mohnRec	mohnF25	mohnFplus
RUN_288	-56.57	111.59	28	183	279.18	289.73	369.05	160.65	0.51	-0.25	0.69	-0.52
RUN_289	-41.9	126.27	34	183	320.53	336.61	429.66	174.9	5.08	1.43	-0.47	-0.98
RUN_290	-33.84	134.33	31	183	330.65	343.79	430.15	161.79	-0.14	-0.36	1.50	-0.48
RUN_291	-75.32	92.85	34	183	253.7	269.78	362.82	177.78	-0.06	0.17	0.19	-0.19
RUN_292	-37.36	130.81	31	183	323.61	336.75	423.11	162.84	0.07	0.51	0.87	-0.20

Table 2. Log-Likelihood for the fit to indices and statistics of runs 290, 293 and 294, exploring the effect of additive variance for indices and fixed selectivity for WMED_LARV.

run	FR_AER1	FR_AER2	JPN_LL_EastMed	JPN_LL1_NEA	JPN_LL2_NEA	MOR_POR_TP	MOR_SP_TP	SP_BB1	SP_BB2	WMED_LARV
RUN_290	3.92	0.34	-6.70	9.11	5.31	-4.56	0.55	8.07	1.68	-1.49
RUN_293	3.20	0.56	-6.68	9.61	5.24	-4.74	0.88	8.39	1.53	-0.94
RUN_294	3.94	0.99	-6.63	9.02	5.03	-5.06	0.40	8.12	1.26	-0.75

run	obj_func	obj_func_with_cte	nb_param	nb_data	AIC	AICc	BIC	chi_square	mohnSSB	mohnRec	mohnF25	mohnFplus
RUN_290	-33.84	134.33	31	183	330.65	343.79	430.15	161.79	-0.14	-0.36	1.50	-0.48
RUN_293	-34.78	133.38	31	183	328.76	341.9	428.26	162.12	-0.54	0.30	1.38	22.78
RUN_294	-34.75	133.41	31	183	328.82	341.96	428.32	158.81	-0.09	0.62	-0.02	3.45

Table 3. Results of the Fratio test, profiling different starting values for the Fratio from which Fratios for the three time blocks were estimated as deviations.

Fratio	obj_func	obj_func_with_cte	nb_param	nb_data	AIC	AICc	BIC	chi_square	mohnSSB	mohnRec	mohnF25	mohnFplus
0.25	-54.33	113.83	28	183	283.67	294.21	373.53	143.56	-0.07	55.34	0.46	-0.18
0.5	-56.71	111.46	28	183	278.91	289.46	368.78	139.62	0.17	43.26	1.03	-0.37
0.75	-57.03	111.13	28	183	278.27	288.81	368.13	141.62	0.18	0.25	0.53	-0.33
1	-58.22	109.95	28	183	275.9	286.44	365.76	142.54	0.23	-0.13	0.45	-0.37
1.25	-57.71	110.46	28	183	276.92	287.47	366.79	142.92	0.22	-0.27	0.48	-0.39
1.5	-56.47	111.69	28	183	279.39	289.93	369.25	139.82	0.81	0.24	-0.14	-0.58

Table 4. Statistics for runs 287, 288 and 295 exploring potential stability improvements

run	obj_func	obj_func_with_cte	nb_param	nb_data	AIC	AICc	BIC	chi_square	mohnSSB	mohnRec	mohnF25	mohnFplus
RUN_287	-67.28	100.88	26	183	253.77	262.77	337.22	153.3	0.14	-0.10	0.47	-0.29
RUN_288	-56.57	111.59	28	183	279.18	289.73	369.05	160.65	0.51	-0.25	0.69	-0.52
RUN_295	-60.54	107.63	26	183	267.26	276.26	350.7	155.19	0.16	0.31	0.50	-0.25

Table 5. Profiling the 1968-1995 Fratio time block for run 287.

Fratio	obj_func	obj_func_with_cte	nb_param	nb_data	AIC	AICc	BIC	chi_square	mohnSSB	mohnRec	mohnF25	mohnFplus
0.5	-66.46	101.71	26	183	255.42	264.42	338.86	146.65	-0.06	-0.42	1.47	-0.25
0.75	-67.67	100.49	26	183	252.98	261.98	336.43	150.23	0.05	-0.28	0.72	-0.31
1	-67.28	100.88	26	183	253.77	262.77	337.22	153.3	0.14	-0.10	0.47	-0.29
1.25	-65.89	102.28	26	183	256.56	265.56	340.01	155.46	0.14	-0.08	0.48	-0.27

Table 6. Profiling the 2007-2020 Fratio time block for run 287

Fratio	obj_func	obj_func_with_cte	nb_param	nb_data	AIC	AICc	BIC	chi_square	mohnSSB	mohnRec	mohnF25	mohnFplus
0.5	-53.92	114.24	26	183	280.48	289.48	363.93	141.14	-0.26	-0.12	0.28	0.40
0.75	-66.13	102.04	26	183	256.08	265.08	339.52	151.95	-0.07	-0.15	0.35	-0.03
1	-67.28	100.88	26	183	253.77	262.77	337.22	153.3	0.14	-0.10	0.47	-0.29
1.25	-60.68	107.49	26	183	266.98	275.98	350.43	151.06	0.82	0.08	0.30	-0.63

Table 7. Profiling both 1968-1995 and 2007-2020 time blocks for run 287, assuming they are equal

Fratio	obj_func	obj_func_with_cte	nb_param	nb_data	AIC	AICc	BIC	chi_square	mohnSSB	mohnRec	mohnF25	mohnFplus
0.5	-66.91	101.26	26	183	254.51	263.51	337.96	137.03	-0.07	-0.33	0.91	-0.08
0.625	-67.84	100.33	26	183	252.66	261.66	336.1	141.05	0.02	-0.14	0.42	-0.11
0.75	-68.97	99.19	26	183	250.38	259.38	333.83	147.78	0.04	-0.00	0.07	-0.09
0.875	-68.87	99.3	26	183	250.59	259.59	334.04	152.05	0.05	-0.10	0.30	-0.20
1	-67.28	100.88	26	183	253.77	262.77	337.22	153.3	0.14	-0.10	0.47	-0.29
1.125	-64.54	103.62	26	183	259.25	268.25	342.7	153.01	0.39	0.04	0.35	-0.44
1.25	-57.37	110.79	26	183	273.59	282.59	357.04	151.83	0.30	1.08	-0.17	-0.41

Table 8. General statistics, log-Likelihood of fit to the indices and estimated weight of indices for runs 286, 287 and 288.

run	obj_func	obj_func_with_cte	nb_param	nb_data	AIC	AICc	BIC	chi_square	mohnSSB	mohnRec	mohnF25	mohnFplus
RUN_286	-68.97	99.19	26	183	250.38	259.38	333.83	147.78	0.04	-0.00	0.07	-0.09
RUN_287	-67.28	100.88	26	183	253.77	262.77	337.22	153.3	0.14	-0.10	0.47	-0.29
RUN_288	-56.57	111.59	28	183	279.18	289.73	369.05	160.65	0.51	-0.25	0.69	-0.52

run	FR_AER1	FR_AER2	JPN_LL_EastMed	JPN_LL1_NEA	JPN_LL2_NEA	MOR_POR_TP	MOR_SP_TP	SP_BB1	SP_BB2	WMED_LARV
RUN_286	4.11	2.93	17.66	10.75	6.09	7.06	10.15	4.58	0.07	-9.00
RUN_287	4.20	3.13	20.27	10.05	5.93	5.84	6.71	5.13	-0.68	-7.58
RUN_288	4.00	-3.15	20.34	11.10	5.37	5.30	8.11	5.53	-1.50	-6.74

run	FR_AER1	FR_AER2	JPN_LL_EastMed	JPN_LL1_NEA	JPN_LL2_NEA	MOR_POR_TP	MOR_SP_TP	SP_BB1	SP_BB2	WMED_LARV
RUN_286	0.26	0.56	0.43	0.43	0.43	0.47	0.47	0.66	0.66	1.33
RUN_287	0.26	0.55	0.42	0.42	0.42	0.53	0.53	0.66	0.66	1.21
RUN_288	0.27	0.97	0.42	0.42	0.42	0.52	0.52	0.67	0.67	1.14

Table 9. General statistics for runs investigating using additive variance for the indices or fixing the selectivity of the WMED_LARV.

run	obj_func	obj_func_with_cte	nb_param	nb_data	AIC	AICc	BIC	chi_square	mohnSSB	mohnRec	mohnF25	mohnFplus
RUN_286	-68.97	99.19	26	183	250.38	259.38	333.83	147.78	0.04	-0.00	0.07	-0.09
RUN_287	-67.28	100.88	26	183	253.77	262.77	337.22	153.3	0.14	-0.10	0.47	-0.29
RUN_296	-66.92	101.24	26	183	254.49	263.49	337.94	141.88	-0.11	-0.38	1.04	-0.11
RUN_297	-69.53	98.63	26	183	249.27	258.27	332.71	148.1	-0.03	-0.17	0.63	-0.11
RUN_298	-65.61	102.56	26	183	257.12	266.12	340.57	149.59	0.14	-0.12	0.48	-0.30
RUN_299	-63.36	104.8	26	183	261.6	270.6	345.05	154.01	0.03	0.77	0.21	-0.17

Table 10. Statistics, log-Likelihood for the fit to the indices and estimated weight for the indices for runs addressing the WMED_GBYP_AER.

run	obj_func	obj_func_with_cte	nb_param	nb_data	AIC	AICc	BIC	chi_square	mohnSSB	mohnRec	mohnF25	mohnFplus
RUN_286	-68.97	99.19	26	183	250.38	259.38	333.83	147.78	0.04	-0.00	0.07	-0.09
RUN_303	-68.85	105.75	28	190	267.49	277.58	358.41	150.89	-0.08	-0.27	0.92	-0.03
RUN_304	-72.67	88.14	26	175	228.29	237.77	310.57	147.35	0.13	1.37	-0.40	-0.08

run	FR_AER1	FR_AER2	JPN_LL_EastMed	JPN_LL1_NEA	JPN_LL2_NEA	MOR_POR_TP	MOR_SP_TP	SP_BB1	SP_BB2	WMED_GBYP_AER	WMED_LARV
RUN_286	4.11	2.93	17.66	10.75	6.09	7.06	10.15	4.58	0.07	NA	-9.00
RUN_303	4.06	3.01	16.74	10.95	5.91	7.08	10.61	4.64	-0.10	0.07	-8.49
RUN_304	4.11	-0.55	17.68	10.79	6.40	7.06	10.06	4.65	0.12	-1.23	NA

run	FR_AER1	FR_AER2	JPN_LL_EastMed	JPN_LL1_NEA	JPN_LL2_NEA	MOR_POR_TP	MOR_SP_TP	SP_BB1	SP_BB2	WMED_GBYP_AER	WMED_LARV
RUN_286	0.26	0.56	0.43	0.43	0.43	0.47	0.47	0.66	0.66	NA	1.33
RUN_303	0.26	0.56	0.44	0.44	0.44	0.47	0.47	0.66	0.66	0.72	1.28
RUN_304	0.26	0.77	0.43	0.43	0.43	0.47	0.47	0.66	0.66	0.87	NA

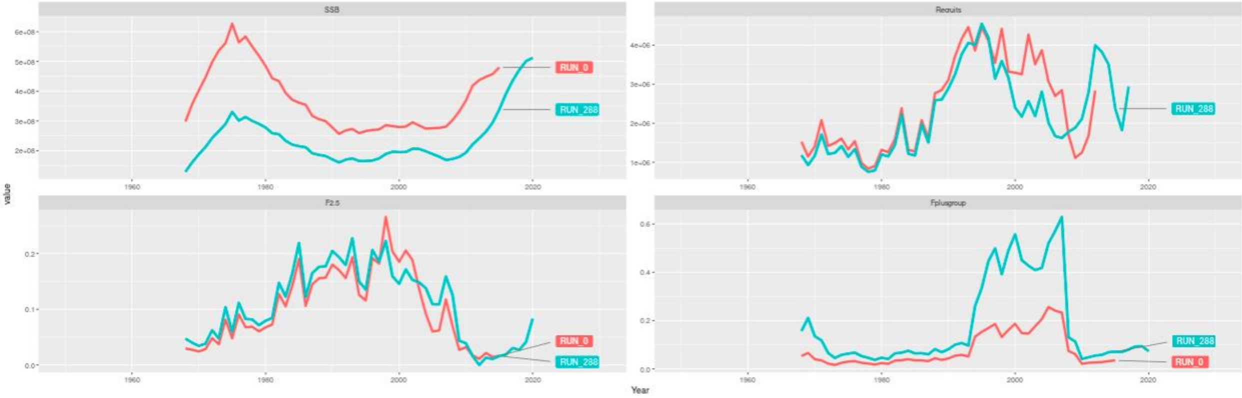
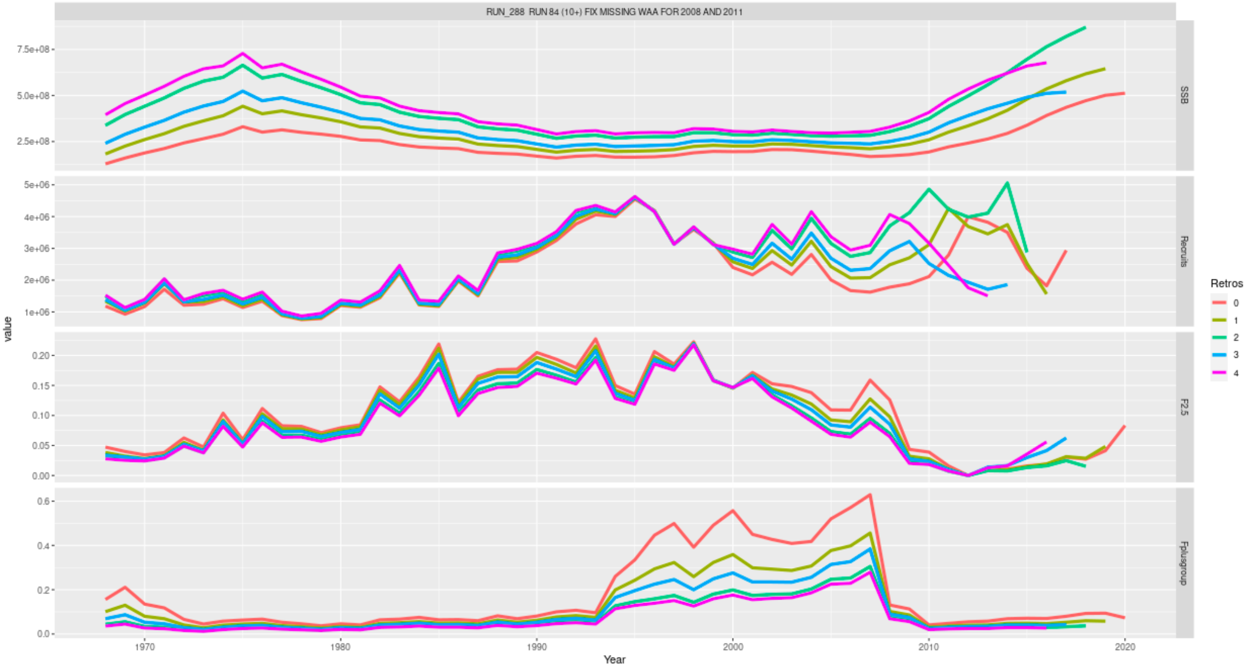


Figure 1. Trends in spawning stock biomass (SSB), Recruitment (Recruits), fishing mortality for ages 2 to 5 (F2.5) and for the plus group (Fplusgroup) for Run 0 (2017 base case in red) and run 288 (update over 1968-2020 in blue). The 3 last years of recruitment are not shown here, as it is common practice to discard the last years that are badly estimated in VPA.



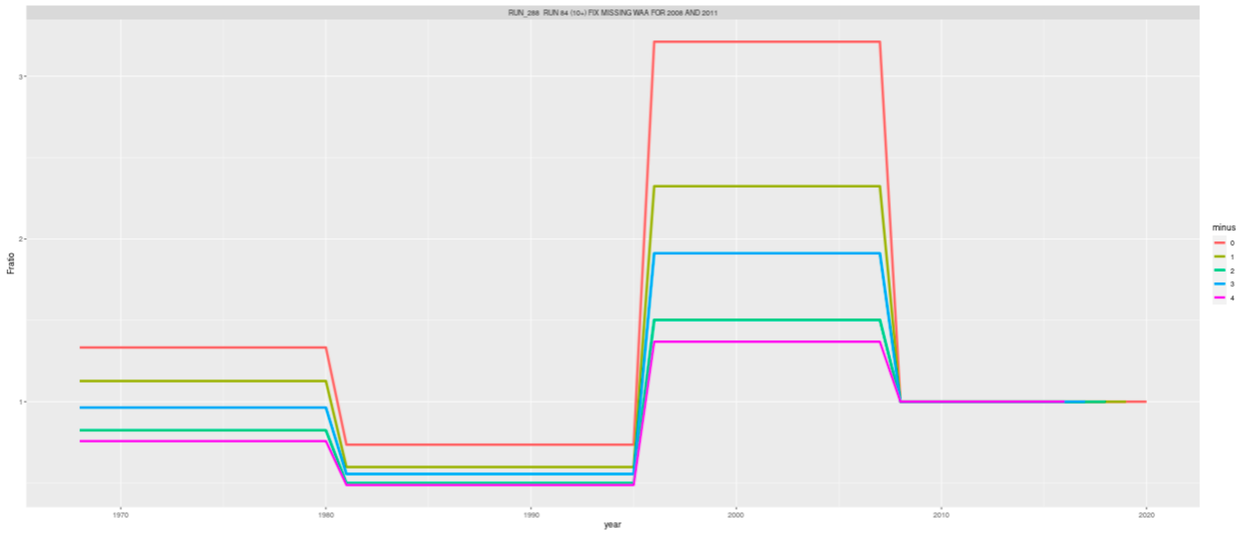


Figure 2. Retrospective analysis for SSB, recruitment, F for ages 2-5, F for the plus group and Fratios for run 288. The different colors represent successive peels: 0 (red), 1 (dirty green), 2 (bright green), 3 (blue) and 4 (purple).

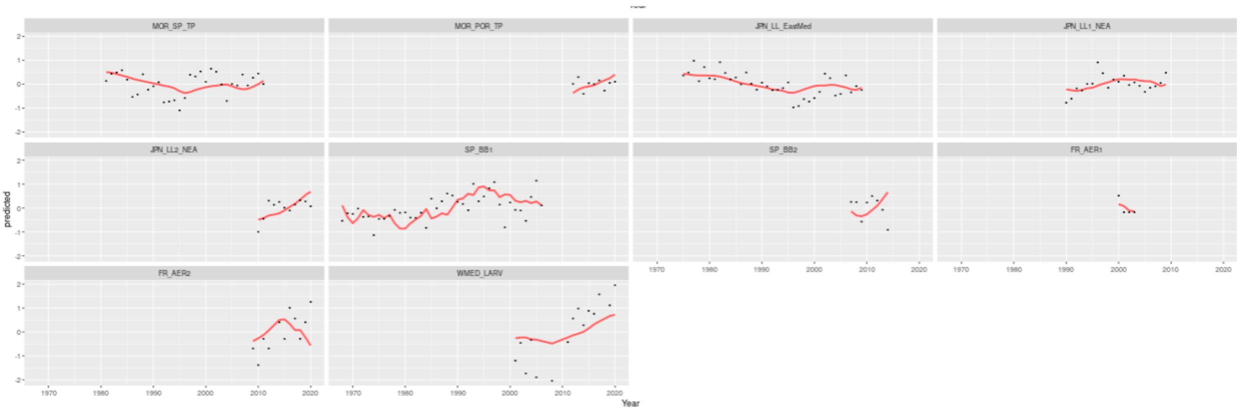


Figure 3. Fit to the indices for run 288. From top left to bottom right, indices are the Moroccan and Spanish trap (MOR_SP_TP), the Moroccan and Portuguese trap (MOR_POR_TP), the Japanese Longline Eastern Atlantic and Mediterranean (JPN_LL_EastMed), the Japanese Longline Northeast Atlantic 1 (JPN_LL_NEA1), Japanese Longline Northeast Atlantic 2 (JPN_LL_NEA2), the Spanish baitboats in the Bay of Biscay 1 (SP_BB1) and the spanish baitboats in the Bay of Biscay 2 (SP_BB2), the french aerial survey in the Gulf of Lion 1 (FR_AER1) and the french aerial survey in the Gulf of Lion 2 (FR_AER2), the Western Mediterranean Larval index (WMED_LARV).

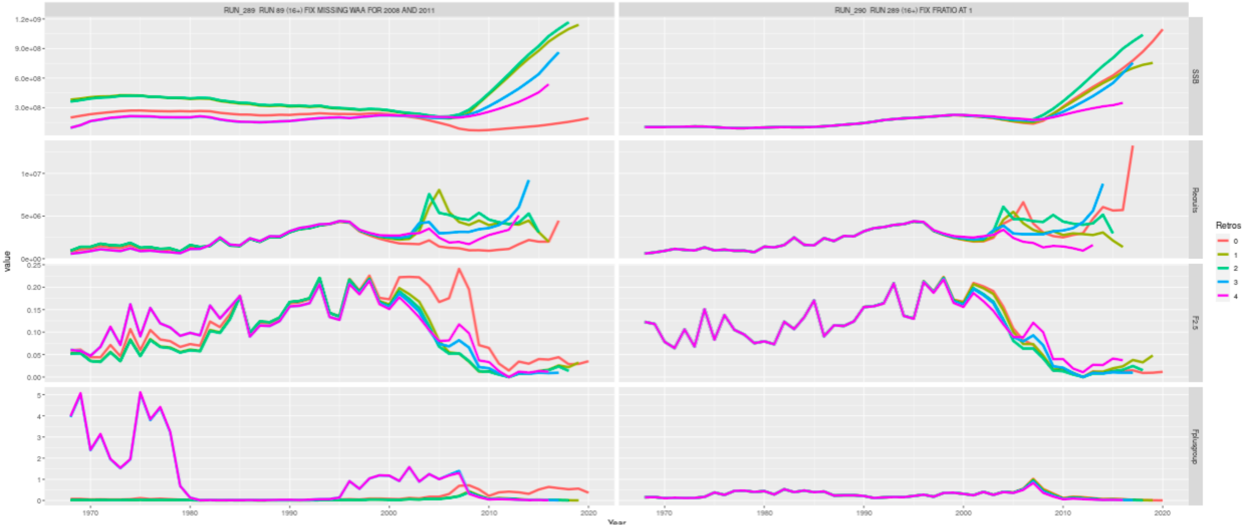


Figure 4. Retrospective analysis for SSB (top), recruitment (2nd row), fishing mortality for ages 2-5 (3rd row) and fishing mortality for the plus group (last row), for run 289 (16+ left panel) and 290 (16+ and Fratio=1, right panel). The different colors represent successive peels: 0 (red), 1 (dirty green), 2 (bright green), 3 (blue) and 4 (purple).

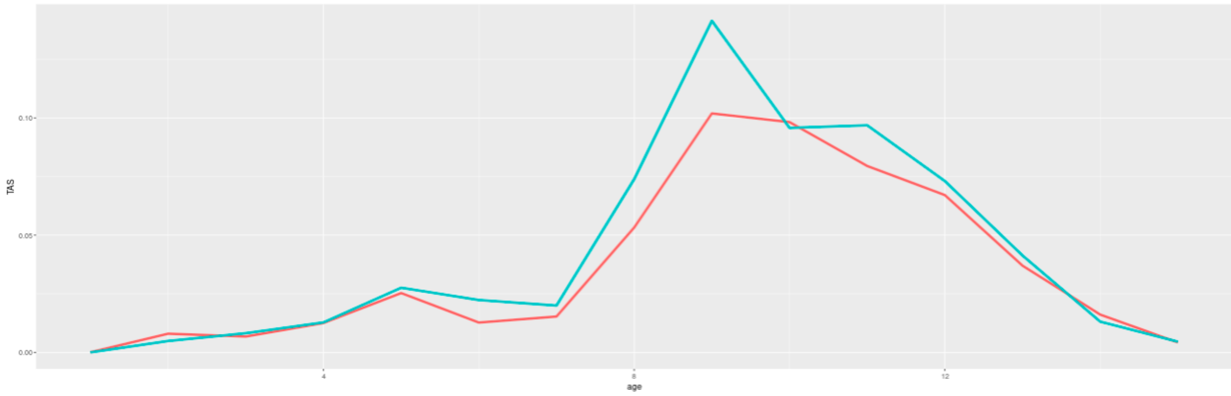


Figure 5. Terminal fishing mortality estimates at age for run 289 (16+, red) and 290 (16+ and Fratio=1, blue).

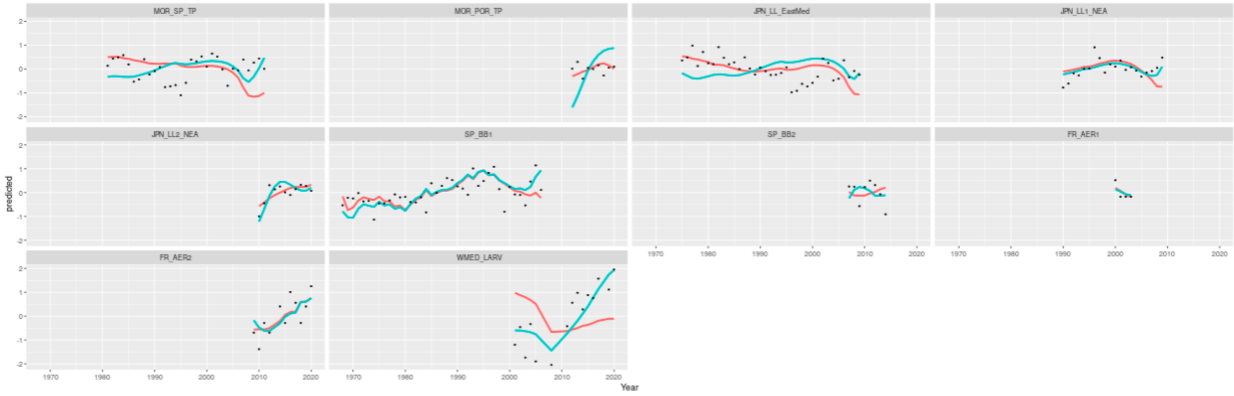


Figure 6. Fit to the indices for run 289 (16+, red) and 290 (16+ and Fratio=1, blue). From top left to bottom right, indices are the Moroccan and Spanish trap (MOR_SP_TP), the Moroccan and Portuguese trap (MOR_POR_TP), the Japanese Longline Eastern Atlantic and Mediterranean (JPN_LL_EastMed), the Japanese Longline Northeast Atlantic 1 (JPN_LL_NEA1), Japanese Longline Northeast Atlantic 2 (JPN_LL_NEA2), the Spanish baitboats in the Bay of Biscay 1 (SP_BB1) and the spanish baitboats in the Bay of Biscay 2 (SP_BB2), the french aerial survey in the Gulf of Lion 1 (FR_AER1) and the french aerial survey in the Gulf of Lion 2 (FR_AER2), the Western Mediterranean Larval index (WMED_LARV).

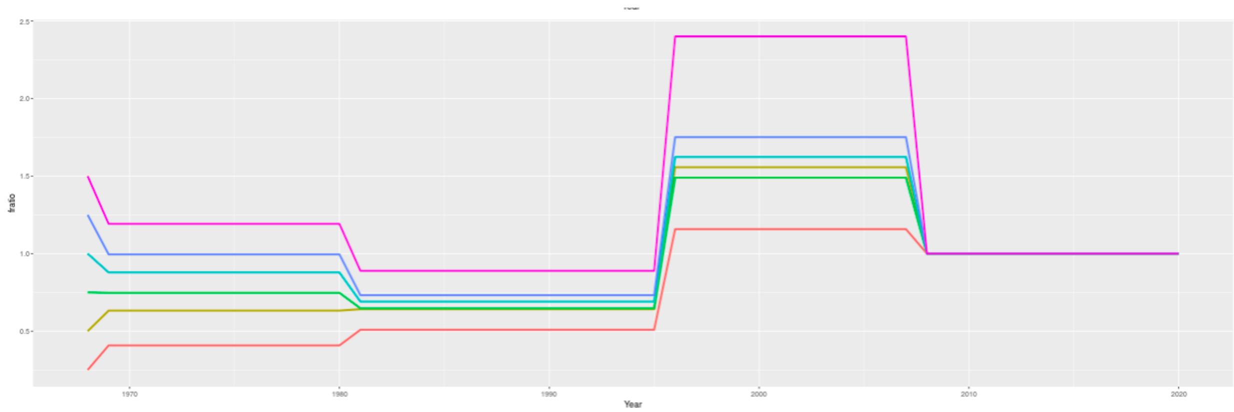


Figure 7. Time series of Fratio obtained through the test to identify whether the Fratio could be estimated appropriately within the VPA. The first year was set to different Fratio values that were then used as a deviation to estimate the Fratio for the other time blocks.

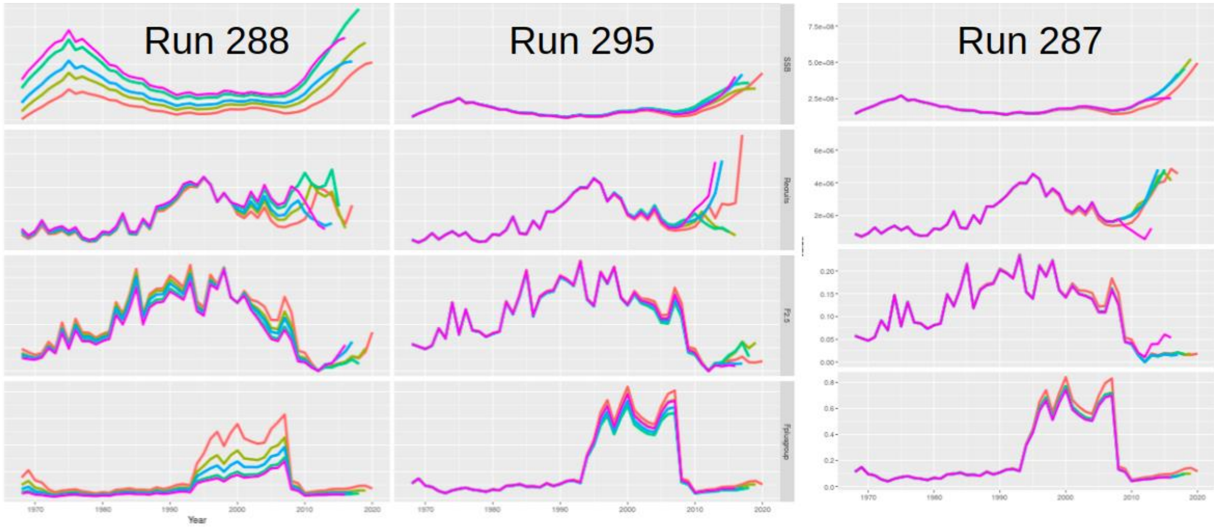


Figure 8. Retrospective analysis for SSB (top), recruitment (2nd row), fishing mortality for ages 2-5 (3rd row) and fishing mortality for the plus group (last row), for run 288 (continuity left panel), run 295 (Fratio=1 for 1968-1995, central panel) and run 287 (Constraints on vulnerability and recruitment, right panel). The different colors represent successive peels: 0 (red), 1 (dirty green), 2 (bright green), 3 (blue) and 4 (purple).

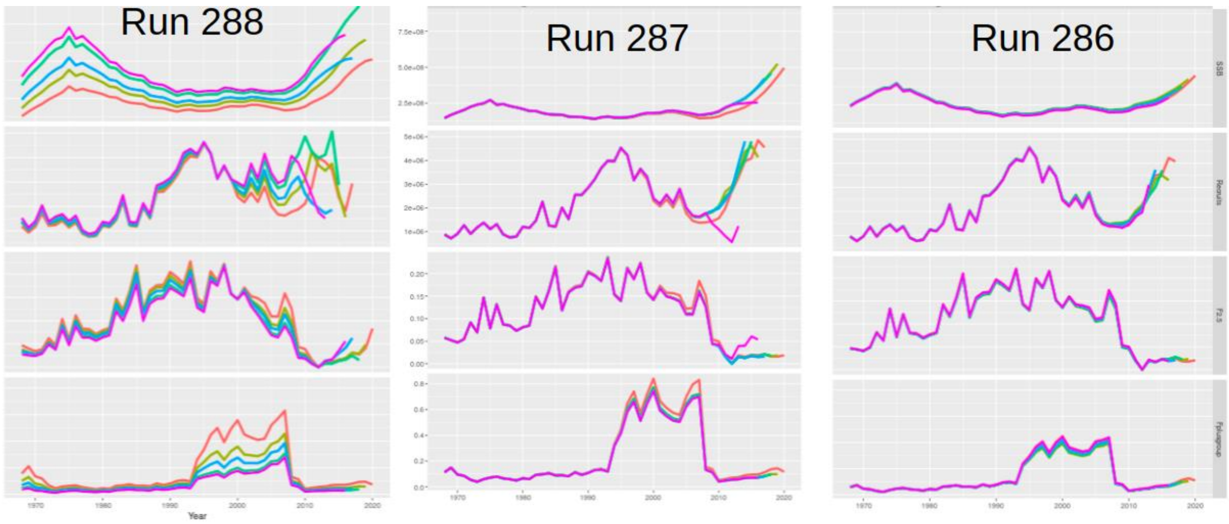


Figure 9. Retrospective analysis for SSB (top), recruitment (2nd row), fishing mortality for ages 2-5 (3rd row) and fishing mortality for the plus group (last row), for run 288 (continuity left panel), run 287 (Fratio=1 for 1968-1995, constraints on vulnerability and recruitment, central panel) and run 286 (Fratio=0.75 for 1968-1995, constraints on vulnerability and recruitment, right panel). The different colors represent successive peels: 0 (red), 1 (dirty green), 2 (bright green), 3 (blue) and 4 (purple).

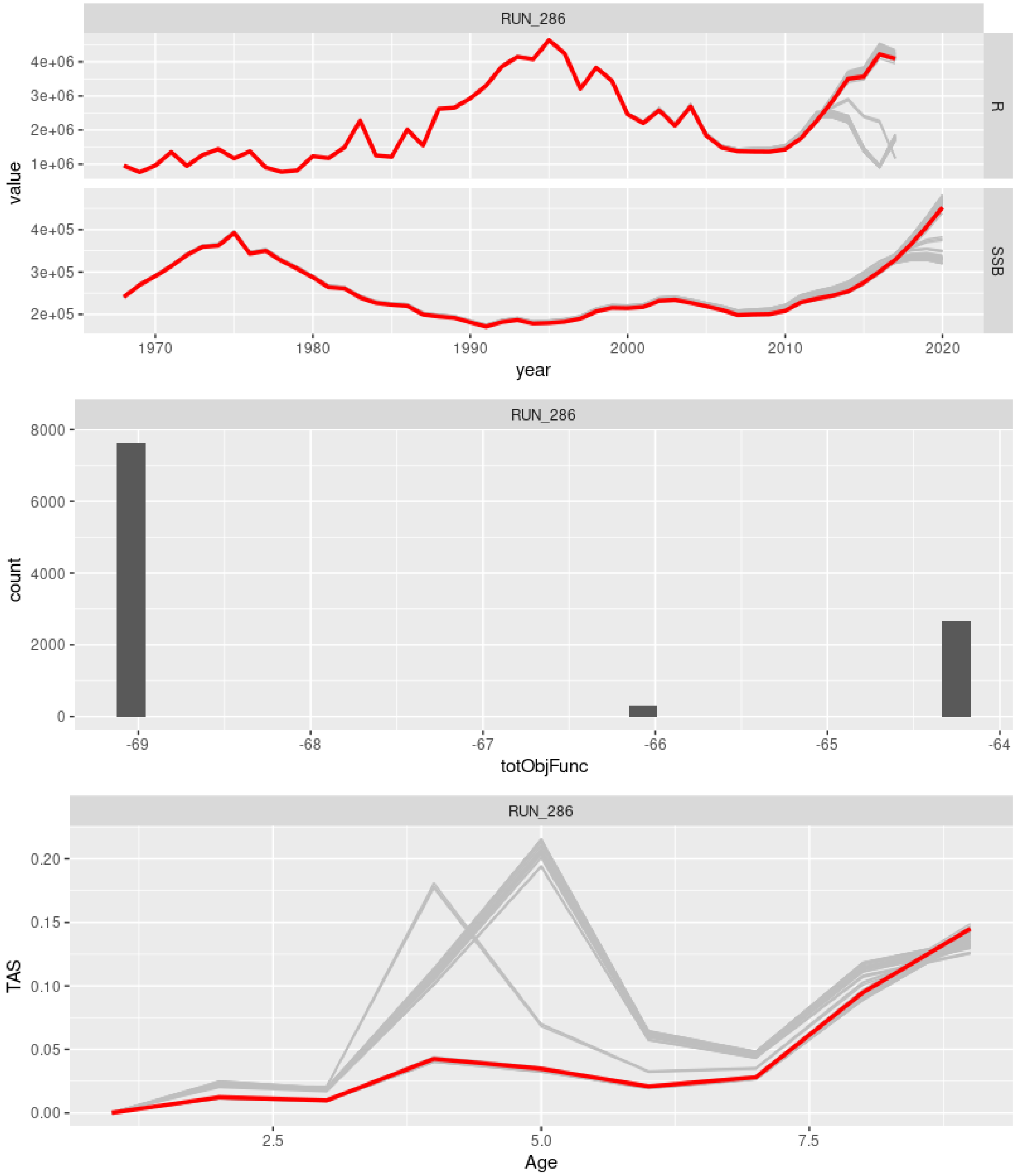


Figure 10. Jittering the starting value for the random number generator with 100 values for run 286. The two top panels show the trends in recruitment and in SSB, the middle panel shows the histogram of objective function values and the bottom panel shows the terminal fishing mortality estimates profile. The maximum likelihood estimator is in red.

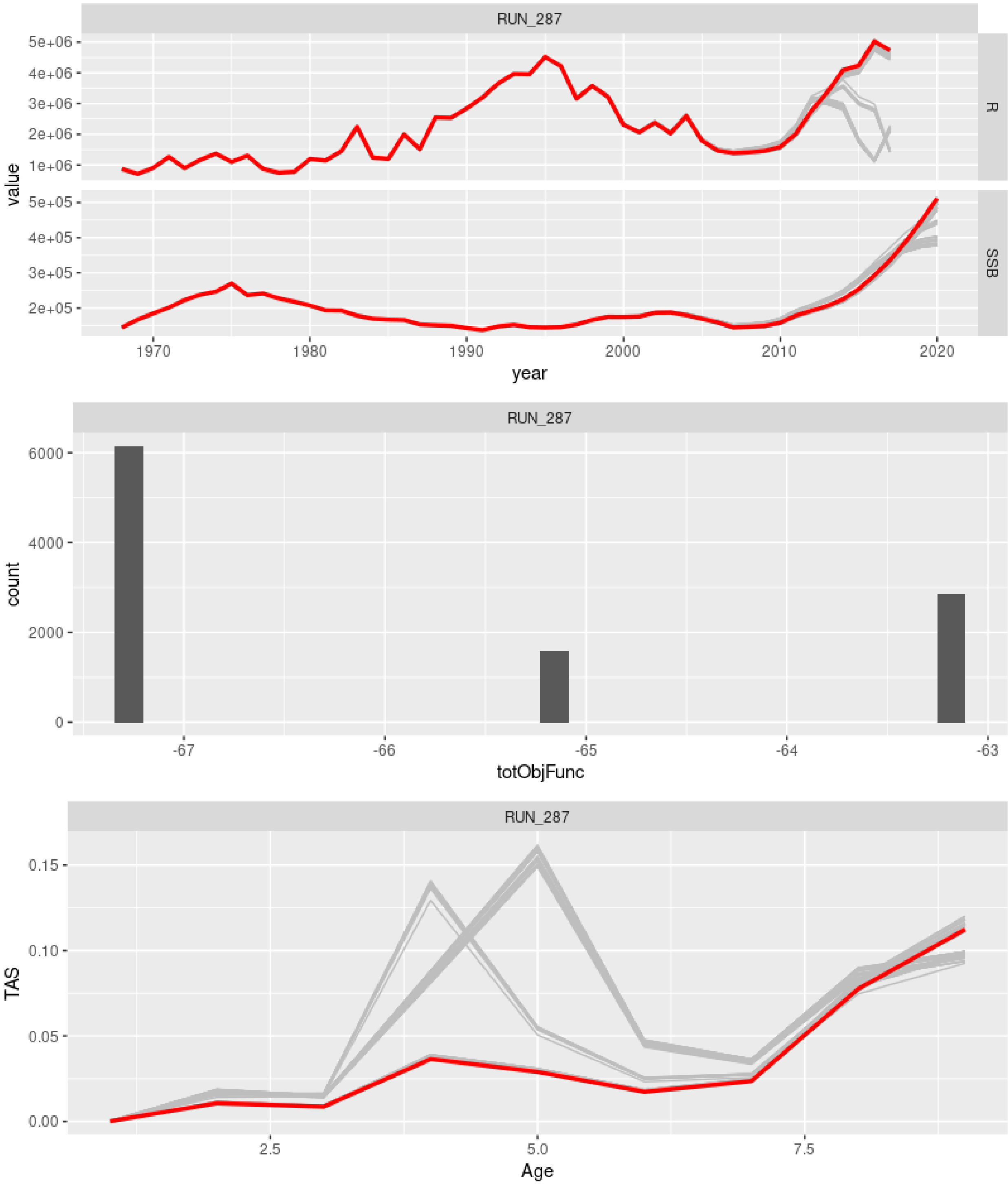


Figure 11. Jittering the starting value for the random number generator with 100 values for run 287. The two top panels show the trends in recruitment and in SSB, the middle panel shows the histogram of objective function values and the bottom panel shows the terminal fishing mortality estimates profile. The maximum likelihood estimator is in red.

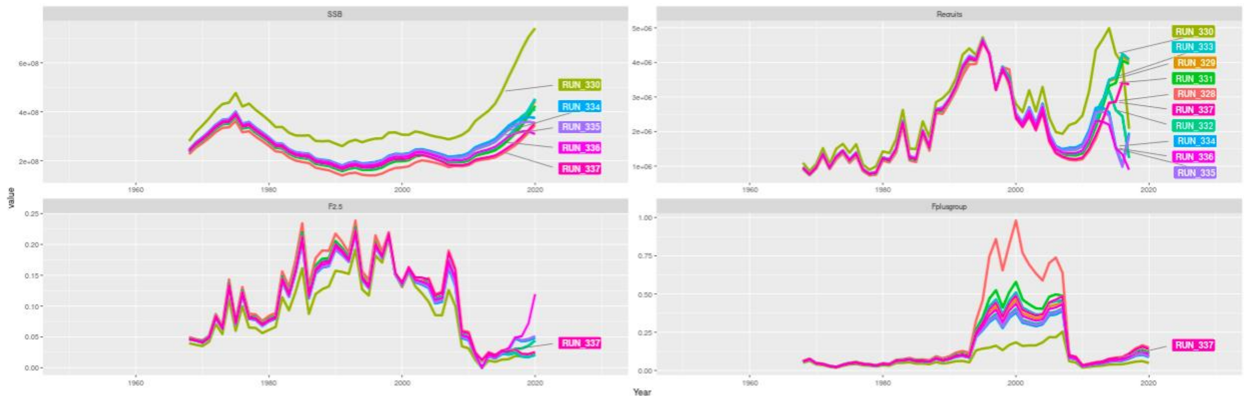


Figure 12. Jackknife analysis for run 286, where indices are sequentially removed. Run 328 represents run 286 minus MOR_SP_TP, run 329 represents run 286 minus MOR_POR_TP, run 330 represents run 286 minus JPN_LL_EastAtlMed, run 331 represents run 286 minus JPN_LL_NEA1, run 332 represents run 286 minus JPN_LL_NEA2, run 333 represents run 286 minus SP_BB1, run 334 represents run 286 minus SP_BB2, run 335 represents run 286 minus FR_AER1, run 336 represents run 286 minus FR_AER2, run 337 represents run 286 minus WMED_LARV.

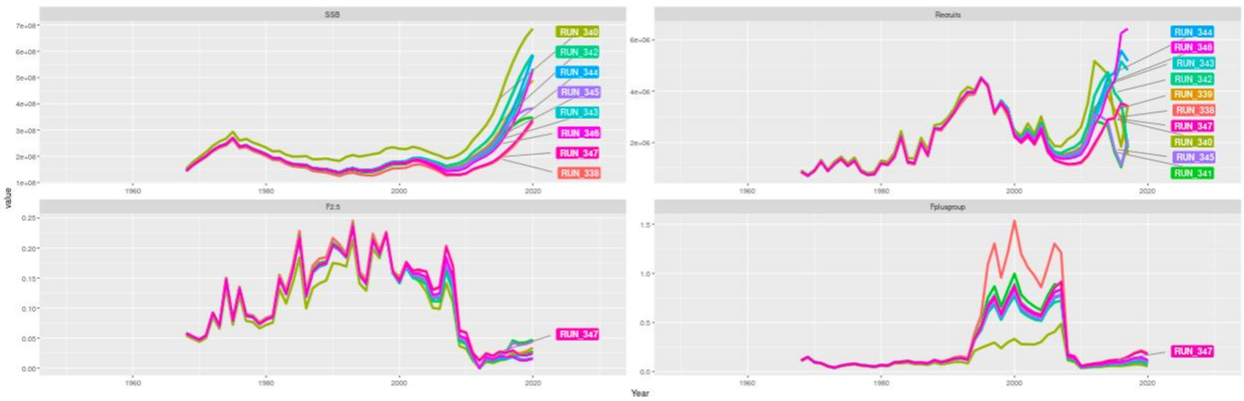


Figure 13. Jackknife analysis for run 287, where indices are sequentially removed. Run 338 represents run 287 minus MOR_SP_TP, run 339 represents run 287 minus MOR_POR_TP, run 340 represents run 287 minus JPN_LL_EastAtlMed, run 341 represents run 287 minus JPN_LL_NEA1, run 342 represents run 287 minus JPN_LL_NEA2, run 343 represents run 287 minus SP_BB1, run 344 represents run 287 minus SP_BB2, run 345 represents run 287 minus FR_AER1, run 346 represents run 287 minus FR_AER2, run 347 represents run 287 minus WMED_LARV.

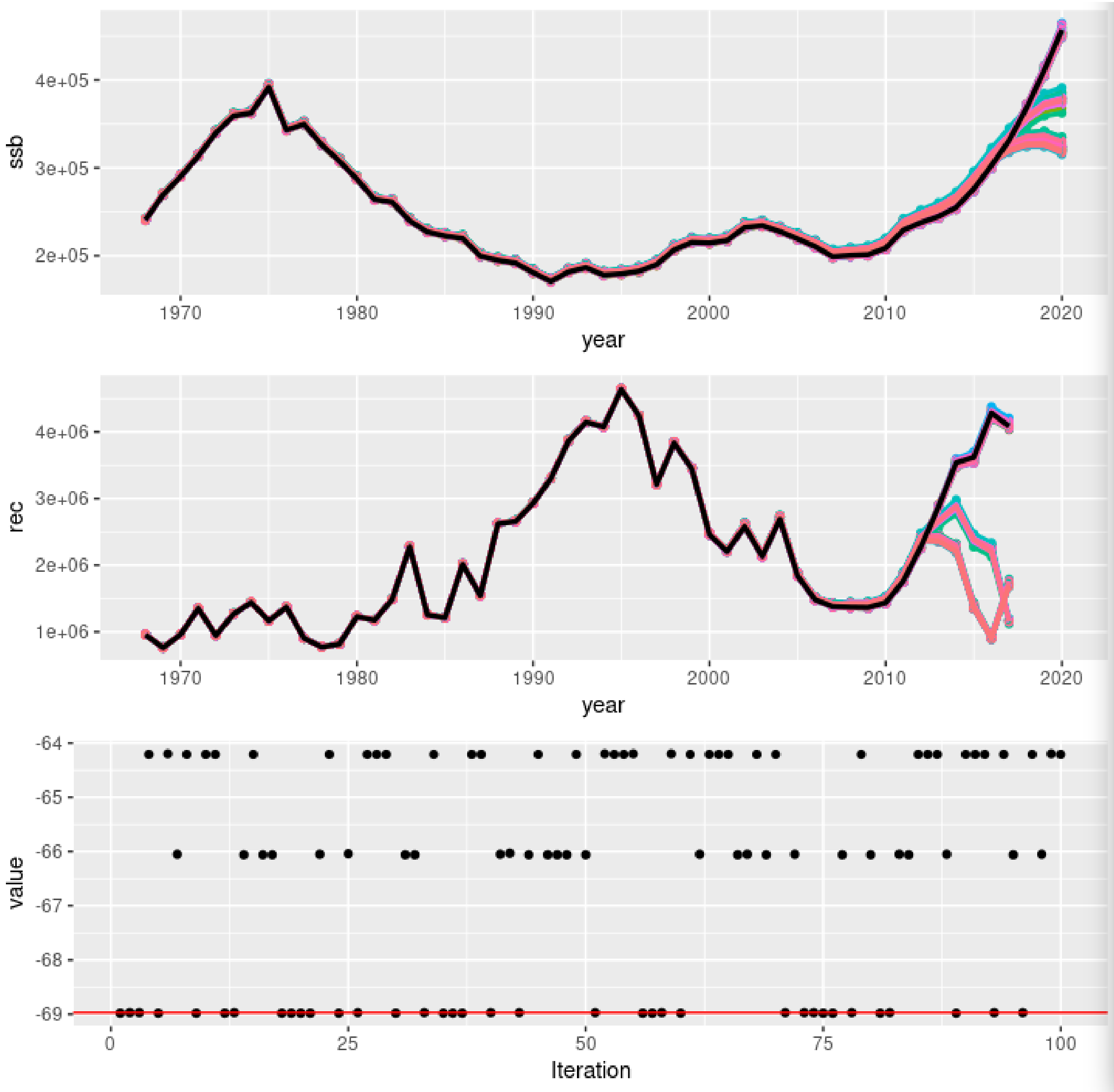


Figure 14. Jittering starting values for terminal F of run 286. The time series of SSB and recruitment for the different jitters are in top and middle panel, respectively. The black line indicates the maximum likelihood estimator (MLE). The bottom panel displays the objective function values for the jitters, the red horizontal line indicate the MLE.

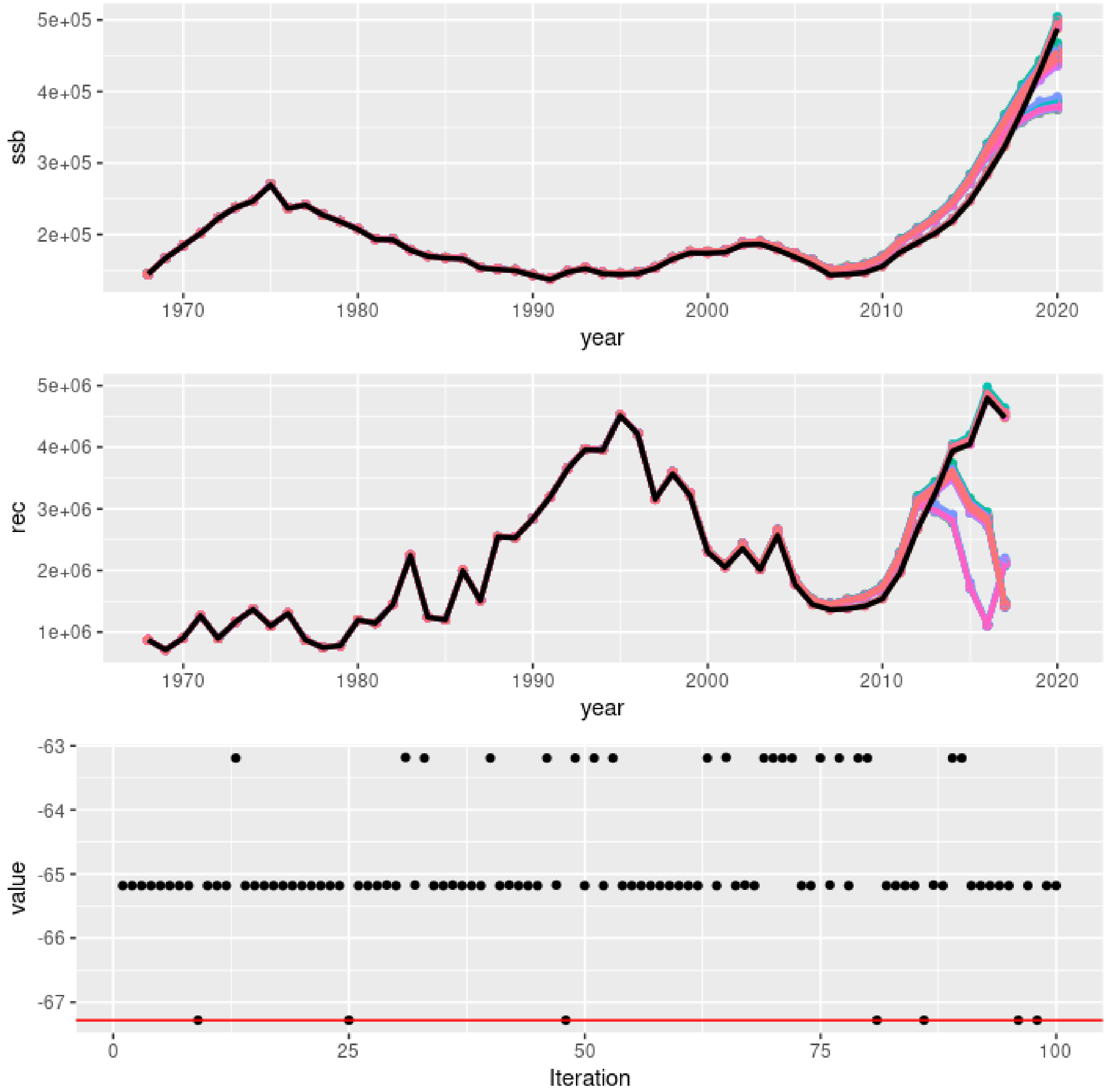


Figure 15. Jittering starting values for terminal F of run 287. The time series of SSB and recruitment for the different jitters are in top and middle panel, respectively. The black line indicates the maximum likelihood estimator (MLE). The bottom panel displays the objective function values for the jitters, the red horizontal line indicate the MLE.

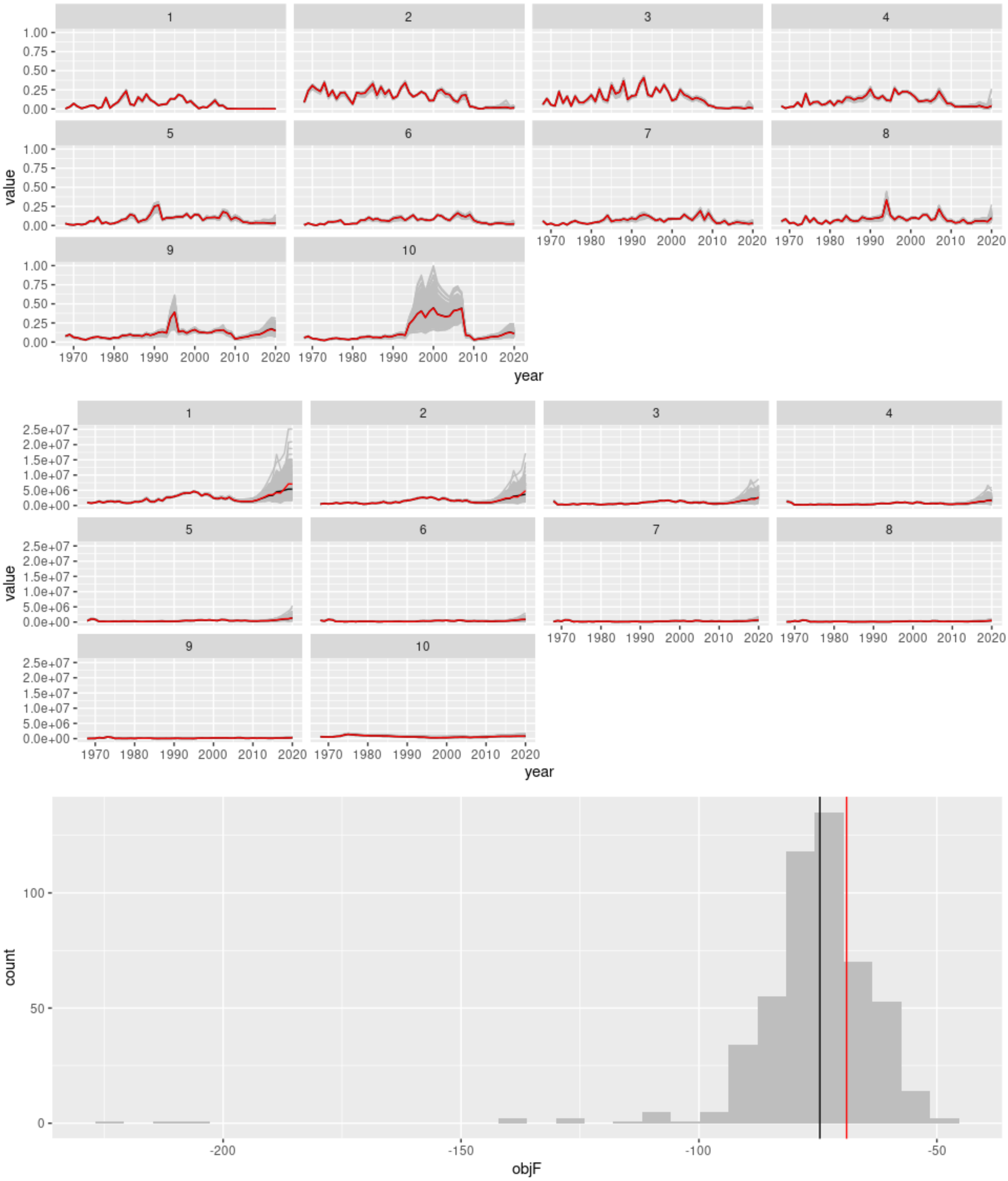


Figure 16. Time series of estimated fishing mortality at age (top panel) and abundance at age (middle panel) through 500 bootstraps. The red line indicates the deterministic run, the black line represents the median of the 500 bootstraps that are in grey. The bottom panel represents the histogram of objective function values obtained through the bootstraps, the black vertical line indicates the median value of the bootstraps and the red vertical line indicates the objective function for the deterministic run.

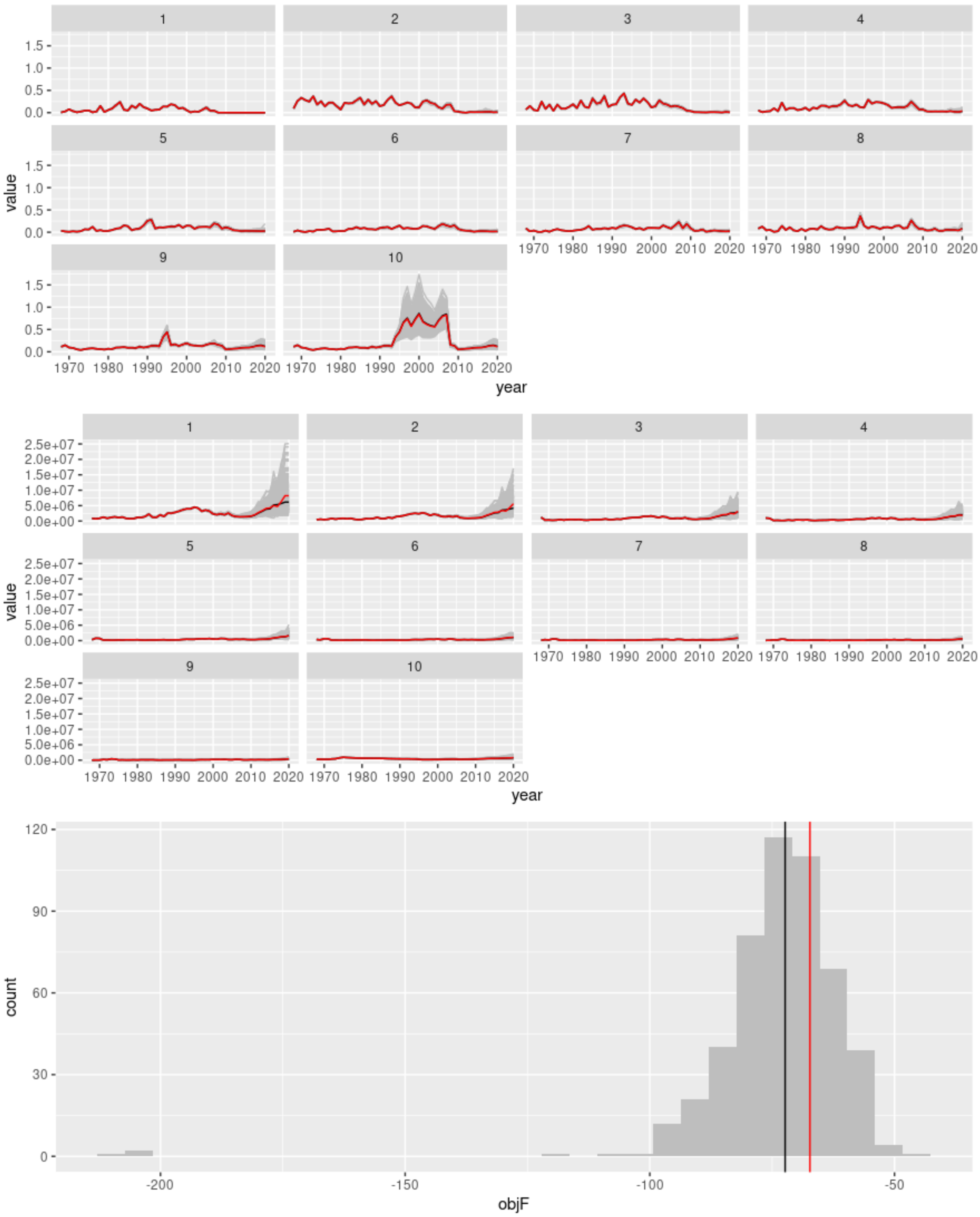


Figure 17. Time series of estimated fishing mortality at age (top panel) and abundance at age (middle panel) through 500 bootstraps. The red line indicates the deterministic run, the black line represents the median of the 500 bootstraps that are in grey. The bottom panel represents the histogram of objective function values obtained through the bootstraps, the black vertical line indicates the median value of the bootstraps and the red vertical line indicates the objective function for the deterministic run.

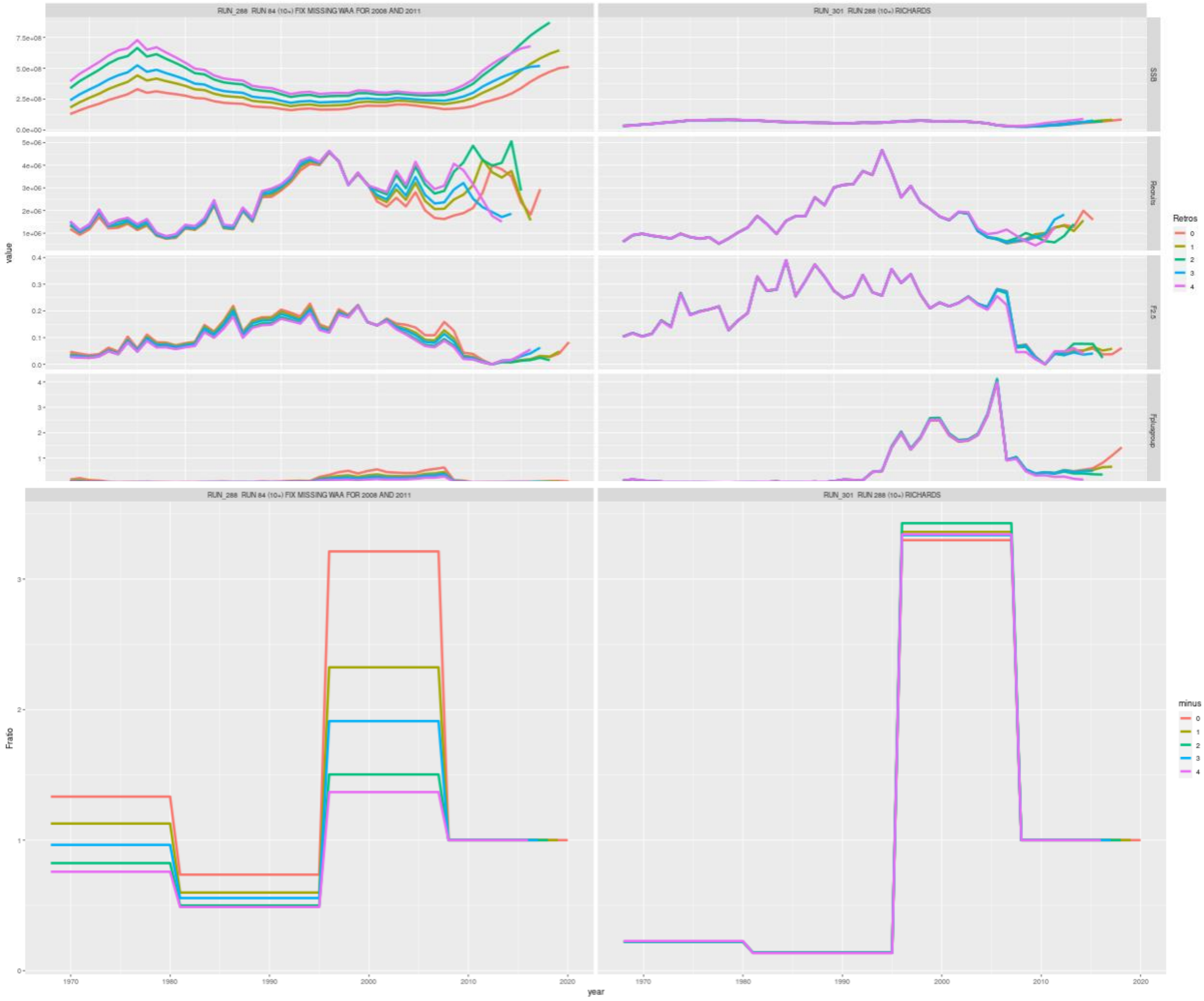


Figure 18. Retrospective analysis for SSB, recruitment, F for ages 2-5, F plus group and Fratio for the continuity run (run 288, left panel) and for run 301 using the Richards growth curve.

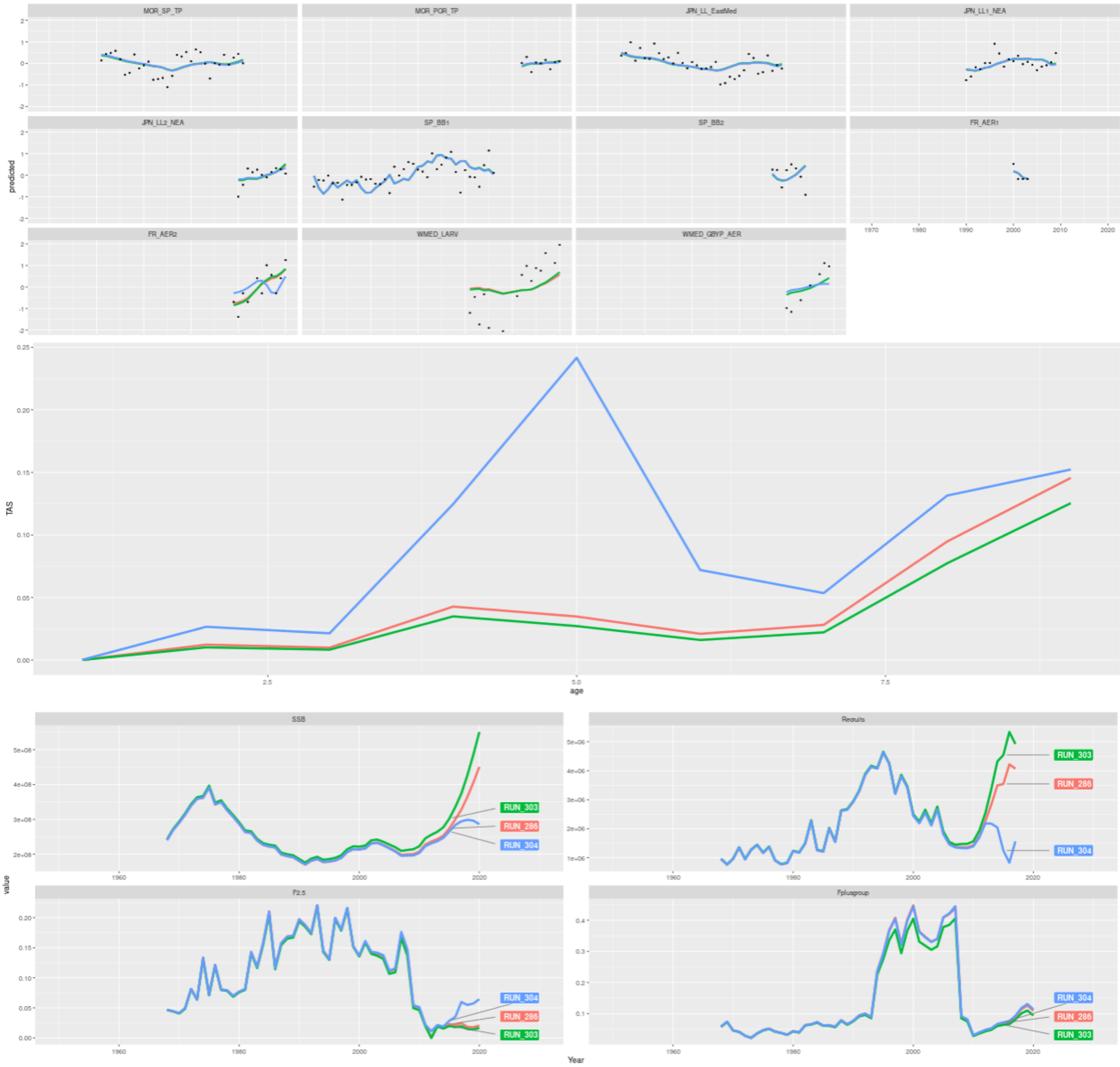


Figure 19. Fit to indices (top panel), profile of terminal F estimate (middle panel) and trends for SSB, recruitment, F for ages 2-5 and F for the plus group for runs 286 (red), run 303 that includes the WMED_GBYP_AER index (green) and run 304 that includes the WMED_GBYP_AER index without the WMED_LARV index (blue).

ANNEX: TABLE SUMMARIZING THE RUNS PRESENTED

Run	Description
0	2017 base case
288	Continuity run using the 1968-2020 data, the updated WMED_LARV, the revised CAA (V2b)
289	Same as run 288, but age group 16+
290	Same as run 289, but Fratio=1 for all years
291	Similar to run 289 but used the Richards Curve
292	Similar to run 290 (Fratio=1) but used the Richards curve
293	Similar to run 290, but use additive variance for the indices instead of multiplicative
294	Similar to run 290, but do not estimate the selectivity of the WMED_LARV index, but use a fixed selectivity. (Since for the PCAA the maturity ogive, constant over time, is used this can lead to some doming in selectivity).
295	Run 288 with Fratio for the two first time blocks set to 1 (merged 1968-1995 time block) and the third one (1996-2007) estimated. The reason is that Fratio estimates are a major source of instability for the VPA and setting it to a value, as it was before the 2017 assessment is a way to solve this. An Fratio of 1 is the default value for Fratio advised by the VPA manual (unless there is a strong biological rationale to do otherwise). The 1996-2007 time block was left to be estimated freely as it corresponds to the most uncertain time-period for the catch, whose size structure is also poorly known. Some search settings were also modified: allowing for more restarts for the function optimizer and also providing lower starting values for Fterminal ages 1 and 2 for which very little catch has been made since 2007.
287	Run 295 with constraints for the vulnerability set to 0.5 (instead of 0.4 for the 2017 VPA) for ages 5-9 (instead of ages 1-9 for the 2017 VPA) applied over 6 years (instead of 3 years for the 2017 VPA). The rationale was that ages 1-4 only represent a small fraction of the catch since the late 2000s and that an extended constraint is compatible with what we know from the recent years of the fishery. A recruitment constraint of the same strength was also applied over the same number of years.
286	Same as run 287, but Fratio = 0.75 for time blocks 1968-1995 and 2007-2020
301	Run 288 using the Richards growth curve
303	Run 286, but includes the WMED_GBYP_AER
304	Run 303, but removes the WMED_LARV index