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An exploration of the impact of natural mortality assumptions in a Virtual Population Analysis for Divisions 3LNO American Plaice

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Abstract

American plaice on the Grand Bank (Div. 3LNO) is assessed using a Virtual Population Analysis (VPA) which is carried out using the ADAPTive framework. Natural mortality (M) in this model is fixed and has been assumed at M=0.2 since 1997. A large retrospective in Fishing mortality (F) in the 2021 base run of the assessment model (see SCR 21/035) has a significant impact on the impression of relative impacts of F on this stock. There is reason to believe that the assumption of M=0.2 is an underestimate of actual levels of natural mortality in this stock for at least portions of the time series. This is not the first time that there has been an exploration of M in this stock and model (see Morgan and Brodie 2001; Dwyer et al. 2008).

Introduction

American plaice on the Grand Bank (NAFO Divs. 3LNO) is assessed using a Virtual Population Analysis (VPA) which is carried out using the ADAPTive framework (hereafter referred to as "ADAPT"). Retrospective patterns have been identified as a cause of concern in this model during previous assessments indicating that abundance and spawning stock biomass (SSB) have been overestimated and fishing mortality (F) has been underestimated year over year. The 2021 update of the base formulation of this model showed a notable increase in the retrospective on fishing mortality (see SCR 21/035) changing the impression of fishing mortality from being at a very low level, to one that has been above Flim in a number of years. The base formulation of ADAPT assumes recent natural morality (M) is fixed at 0.2 (since 1997). Based on population patterns in this stock inferred from an independent assessment model (Perreault et al 2020) and reduced productivity state of the Grand Bank (SCS Doc. 19/25), there is reason to believe that the current assumption for M is likely to be an underestimate and the model may therefore be over-estimating the level of F.

Methods

Sensitivity of ADAPT to recent M assumptions (M=0.2 since 1997) was tested by implementing a series of changes to M values within the base formulation of the ADAPT VPA for this stock. The base formulation of ADAPT used here is described in Wheeland et al. (2018) and references therein.

Ongoing research suggests M=0.2 for this stock is likely to be an underestimate since at least 2005 (A. Perreault, p. com 2021), and environmental and ecosystem indicators suggest low productivity and poor ecosystem conditions on the Grand Bank (SCS Doc 19/25 and references therein). Two model runs were therefore completed where the model was set to estimate M from 2005 onwards. The first run ("*M-est 2005-2020*") estimated a single M parameter for all years and all ages from 2005 to 2020. The second run ("*M-est blocks*") allowed the model to estimate three M parameters, one for each of the periods of 2005-2009, 2010-2014, 2015-2020, with M held constant across all ages within a period.

Informed by these estimation runs, the base formulation of ADAPT for this stock, and results from Morgan and Brodie (2001), two additional runs were completed with fixed M values. In "*M0.53*", natural mortality was fixed for all ages at M=0.53 from 2005-2020. This was chosen to examine the results of an M pattern consistent with the M-est 2005-2020 but at a higher M magnitude. M=0.53 was chosen to be consistent with a previously observed period of high M in this stock.

For "*M0.4*", natural mortality was fixed M=0.4 since 2010. This time period was selected by *M-est blocks* as having increased M, however a lower M magnitude then that estimated was selected as the high M used in *M0.53* and higher M values tested in Morgan and Brodie (2001) resulted in stock trajectories that were not considered to be realistic.

Results & Discussion

All M-case scenarios examined here resulted in model fit with a lower MSE (Table 1) and less pronounced residual patterns (Figure 1) when compared to the Baserun, indicating improved model fit. Model parameter estimates are provided in Tables 2-6.

Predictably, increasing levels of M resulted in decreased estimates of F. All M-cases showed SSB values after 1995 (M0.53) or 2000 (all others) that were greater than the Baserun. In *M0.53* a substantial peak in SSB is apparent around 2005, reaching levels similar to the early 1980s – this is inconsistent with the current understanding of stock history and are not considered to be an accurate representation of the stock.

A retrospective analysis is shown for *M0.53* (Figure 6) and *M0.4* (Figure 4). Retrospective analyses are not shown for runs with estimated M.

The *M0.53* M-case resulted in the largest difference in SSB, F, abundance, and recruitment estimates. While retrospective patterns on F were reduced relative to the Baserun, there is still a consistent, directional year over year revision in F. In addition, a large and unpredictable change in recruitment is apparent.

M0.4 showed an improved retrospective pattern in abundance and SSB relative to the Basecase, with decreased magnitude of the retro and less directionality. A notable directional retrospective pattern remains for recent fishing mortality, but at a reduced magnitude. The retrospective on recruitment is significantly larger in *M0.4* than in the Basecase.

Conclusion

The results shown here support the hypothesis that the current base formulation of ADAPT is underestimating natural mortality in this stock in recent years. However, the separation of relative changes in natural mortality, fishing mortality, and catchability remains an important but difficult aspect of modelling this – and other – stocks. At low stock size, even low levels of catch can result in high fishing mortality. Given the uncertainties around estimates of M and the risks associated with model misspecification, research into this problem should continue.

References

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Table 1. Description of M-case scenarios used for testing sensitivity to M assumptions

Run name	Description	MSE	M levels where they differ from the Baserun
Baserun	M=0.2, except M=0.53 from 1989-1996	0.613	N/A
M-est 2005-2020	Within the model, estimate a single value of M for 2005-2020 within the model	0.521	0.391 (2005-2020)
M-est Blocks	Within the model, estimate three values of M, one for each of the periods of 2005-2009, 2010-2014, 2015-2020,	0.417	0.169 (2005-9) 0.551 (2010-14) 0.566 (2015-20)
M0.53	Fix M at an increased level since 2005, level based on previous period of high M currently used in the Baserun model	0.596	0.53 (fixed since 2005)
M0.4	Fix M at an increased level since 2010, level and period based on M-est Blocks run	0.325	0.4 (fixed since 2010)

Table 2. Model parameters for ADAPT Baserun

Parameter	Estimate	Standard Error	Bias
N[2021 6]	19166.46	15276.08	6103.273
N[2021 7]	8023.242	3216.248	649.3367
N[2021 8]	8544.806	2628.536	404.3096
N[2021 9]	4314.091	1259.206	171.8512
N[2021 10]	1988.122	549.1698	65.66579
N[2021 11]	1345.818	378.7646	42.48037
N[2021 12]	1140.11	330.5589	35.51942
N[2021 13]	1117.73	302.5666	30.21398
N[2021 14]	644.2301	183.2498	18.24822
N[2021 15]	985.7532	192.2697	13.87667
q ID#[1]	0.015945	0.002392	0.000166
q ID#[2]	0.017949	0.002647	0.000182
q ID#[3]	0.016458	0.002418	0.00017
q ID#[4]	0.013884	0.002036	0.000146
q ID#[5]	0.011603	0.001701	0.000125
q ID#[6]	0.009568	0.001402	0.000105
q ID#[7]	0.009103	0.001333	0.000102
q ID#[8]	0.009716	0.001423	0.000108
q ID#[9]	0.008372	0.001227	9.25E-05
q ID#[10]	0.009684	0.001423	0.000105
q ID#[11]	0.005839	0.000816	5.28E-05
q ID#[12]	0.008192	0.001141	7.46E-05
q ID#[13]	0.009552	0.001328	8.8E-05
q ID#[14]	0.008771	0.001219	8.27E-05
q ID#[15]	0.007943	0.001103	7.52E-05
q ID#[16]	0.006442	0.000894	6.2E-05
q ID#[17]	0.006369	0.000884	6.13E-05
q ID#[18]	0.006545	0.000908	6.37E-05
q ID#[19]	0.006034	0.000837	5.81E-05
q ID#[20]	0.00627	0.00087	6E-05
q ID#[21]	0.002999	0.00051	3.94E-05
q ID#[22]	0.005464	0.000924	7.16E-05
q ID#[23]	0.007668	0.001293	0.000102
q ID#[24]	0.006847	0.001152	9.26E-05
q ID#[25]	0.006602	0.00111	9.07E-05
q ID#[26]	0.006104	0.001025	8.5E-05
q ID#[27]	0.005681	0.000954	7.98E-05
q ID#[28]	0.005997	0.001006	8.44E-05
q ID#[29]	0.004711	0.000791	6.57E-05
q ID#[30]	0.005019	0.000842	6.96E-05

Table 3. Model parameters for M-est 2005-2020 run

Parameter	Estimate	Standard Error	Bias
N[2021 6]	34905.14	25757.27	9522.118
N[2021 7]	12468.32	4644.195	873.5099
N[2021 8]	11569.25	3288.314	474.2679
N[2021 9]	5391.964	1417.506	182.0258
N[2021 10]	2220.342	539.8352	61.03073
N[2021 11]	1392.196	339.9715	36.1014
N[2021 12]	1099.478	273.8033	27.76359
N[2021 13]	999.7988	232.3442	22.15199
N[2021 14]	569.0425	135.349	12.49562
N[2021 15]	1088.684	167.5298	11.86678
M[2005 5]	0.390525	0.016857	-0.00034
q ID#[1]	0.008591	0.001316	9.62E-05
q ID#[2]	0.010634	0.001567	0.000109
q ID#[3]	0.010466	0.00151	0.000103
q ID#[4]	0.009383	0.001334	9.06E-05
q ID#[5]	0.007982	0.001128	7.74E-05
q ID#[6]	0.00675	0.000948	6.54E-05
q ID#[7]	0.006473	0.000907	6.28E-05
q ID#[8]	0.006891	0.000964	6.66E-05
q ID#[9]	0.005907	0.000827	5.68E-05
q ID#[10]	0.006783	0.000952	6.43E-05
q ID#[11]	0.003373	0.000477	3.23E-05
q ID#[12]	0.005132	0.000708	4.65E-05
q ID#[13]	0.006392	0.000867	5.58E-05
q ID#[14]	0.006162	0.000825	5.3E-05
q ID#[15]	0.005789	0.000769	4.89E-05
q ID#[16]	0.004737	0.000627	4.03E-05
q ID#[17]	0.004764	0.000629	4.02E-05
q ID#[18]	0.004858	0.000641	4.13E-05
q ID#[19]	0.00444	0.000587	3.75E-05
q ID#[20]	0.00461	0.000609	3.89E-05
q ID#[21]	0.001259	0.000227	1.99E-05
q ID#[22]	0.002594	0.000452	3.79E-05
q ID#[23]	0.00402	0.000683	5.56E-05
q ID#[24]	0.003858	0.000644	5.17E-05
q ID#[25]	0.003913	0.000645	5.14E-05
q ID#[26]	0.00374	0.000611	4.87E-05
q ID#[27]	0.003557	0.000578	4.59E-05
q ID#[28]	0.003778	0.000612	4.87E-05
q ID#[29]	0.002957	0.000479	3.79E-05
q ID#[30]	0.003162	0.000512	4.03E-05

Table 4. Model parameters for M-est Blocks run

Parameter	Estimate	Standard Error	Bias
N[2021 6]	36201.67	23892.24	7902.694
N[2021 7]	10976.82	3662.647	626.1235
N[2021 8]	9125.02	2349.881	318.8213
N[2021 9]	3926.332	954.3044	119.2966
N[2021 10]	1423.791	335.9105	39.4372
N[2021 11]	802.7424	201.9491	23.45739
N[2021 12]	565.4967	154.5961	18.04906
N[2021 13]	450.7221	121.9043	14.13953
N[2021 14]	227.477	66.24183	7.702814
N[2021 15]	340.092	72.23693	7.644371
M[2005 5]	0.169439	0.025555	-0.00052
M[2010 5]	0.550666	0.022664	0.000116
M[2015 5]	0.566128	0.031748	-0.00106
q ID#[1]	0.008139	0.001094	7E-05
q ID#[2]	0.010376	0.001346	8.1E-05
q ID#[3]	0.01046	0.001333	7.82E-05
q ID#[4]	0.009523	0.001199	6.9E-05
q ID#[5]	0.008353	0.001048	6.05E-05
q ID#[6]	0.007186	0.000898	5.23E-05
q ID#[7]	0.007021	0.000877	5.19E-05
q ID#[8]	0.00757	0.000946	5.61E-05
q ID#[9]	0.006564	0.000821	4.88E-05
q ID#[10]	0.007602	0.000953	5.47E-05
q ID#[11]	0.003263	0.000406	2.41E-05
q ID#[12]	0.005034	0.000613	3.51E-05
q ID#[13]	0.006357	0.000762	4.26E-05
q ID#[14]	0.006226	0.000739	4.09E-05
q ID#[15]	0.005872	0.000693	3.77E-05
q ID#[16]	0.004906	0.000578	3.16E-05
q ID#[17]	0.004945	0.000581	3.16E-05
q ID#[18]	0.005133	0.000603	3.31E-05
q ID#[19]	0.004724	0.000556	3.03E-05
q ID#[20]	0.004899	0.000576	3.12E-05
q ID#[21]	0.001122	0.000178	1.39E-05
q ID#[22]	0.002404	0.000369	2.72E-05
q ID#[23]	0.00385	0.000577	4.09E-05
q ID#[24]	0.003808	0.000562	3.88E-05
q ID#[25]	0.003953	0.000577	3.94E-05
q ID#[26]	0.003853	0.000558	3.79E-05
q ID#[27]	0.003725	0.000538	3.65E-05
q ID#[28]	0.004005	0.000577	3.93E-05

Table 5. Model parameters for M0.53 run

Parameter	Estimate	Standard Error	Bias
N[2021 6]	66856.62	52547.26	20686.39
N[2021 7]	21138.27	8337.893	1654.948
N[2021 8]	17652.73	5297.216	799.9132
N[2021 9]	7737.079	2112.515	282.5139
N[2021 10]	2928.824	726.6091	84.62742
N[2021 11]	1738.99	425.8142	46.13674
N[2021 12]	1296.869	319.0867	32.57107
N[2021 13]	1094.557	252.0387	23.72467
N[2021 14]	594.4239	137.6488	12.24763
N[2021 15]	1337.139	193.3995	11.28273
q ID#[1]	0.004423	0.000657	4.63E-05
q ID#[2]	0.005931	0.000866	6.01E-05
q ID#[3]	0.006212	0.000903	6.3E-05
q ID#[4]	0.005889	0.000853	5.96E-05
q ID#[5]	0.005106	0.000739	5.25E-05
q ID#[6]	0.004425	0.00064	4.59E-05
q ID#[7]	0.00427	0.000618	4.47E-05
q ID#[8]	0.004546	0.000658	4.75E-05
q ID#[9]	0.003877	0.000562	4.05E-05
q ID#[10]	0.004428	0.000643	4.59E-05
q ID#[11]	0.001878	0.00026	1.71E-05
q ID#[12]	0.003059	0.000422	2.77E-05
q ID#[13]	0.004039	0.000555	3.67E-05
q ID#[14]	0.004069	0.000559	3.72E-05
q ID#[15]	0.003956	0.000542	3.6E-05
q ID#[16]	0.003274	0.000449	3.02E-05
q ID#[17]	0.003348	0.000458	3.07E-05
q ID#[18]	0.003396	0.000465	3.14E-05
q ID#[19]	0.003081	0.000422	2.84E-05
q ID#[20]	0.003193	0.000437	2.93E-05
q ID#[21]	0.000532	8.99E-05	7.16E-06
q ID#[22]	0.001202	0.000202	1.6E-05
q ID#[23]	0.002019	0.000337	2.68E-05
q ID#[24]	0.00206	0.000343	2.75E-05
q ID#[25]	0.00219	0.000364	2.93E-05
q ID#[26]	0.002164	0.00036	2.91E-05
q ID#[27]	0.002104	0.00035	2.84E-05
q ID#[28]	0.002257	0.000375	3.05E-05
q ID#[29]	0.001761	0.000293	2.37E-05
q ID#[30]	0.001889	0.000314	2.53E-05

Table 6. Model parameters for M0.4 run

Parameter	Estimate	Standard Error	Bias
N[2021 6]	29478.83	12601.69469	2702.93497
N[2021 7]	19642.83	5191.097046	691.3142501
N[2021 8]	15948.66	3104.67298	304.7565553
N[2021 9]	6957.04	1205.438651	101.9115276
N[2021 10]	2512.96	420.0858224	32.26471211
N[2021 11]	1398.98	244.713305	17.9675263
N[2021 12]	953.92	187.6182115	13.83230847
N[2021 13]	745.18	152.4565149	10.90652487
N[2021 14]	438.24	95.38862665	6.644194901
N[2021 15]	604.67	94.23795282	5.039341727
q ID#[1]	0.0101619	0.000825513	3.01649E-05
q ID#[2]	0.0122548	0.000927908	3.14973E-05
q ID#[3]	0.0121267	0.000862702	2.79841E-05
q ID#[4]	0.0108401	0.000963328	4.10711E-05
q ID#[5]	0.0094282	0.000810904	3.45161E-05
q ID#[6]	0.0080436	0.000738546	3.45863E-05
q ID#[7]	0.0078275	0.000847281	4.75117E-05
q ID#[8]	0.0084327	0.00117792	8.45103E-05
q ID#[9]	0.0072910	0.001144247	9.15088E-05
q ID#[10]	0.0084652	0.001478646	0.000129805
q ID#[11]	0.0040195	0.000463186	2.55206E-05
q ID#[12]	0.0060362	0.00048368	1.78952E-05
q ID#[13]	0.0074405	0.000520286	1.67087E-05
q ID#[14]	0.0071586	0.000597317	2.40305E-05
q ID#[15]	0.0066755	0.000659646	3.18701E-05
q ID#[16]	0.0055394	0.000606913	3.31495E-05
q ID#[17]	0.0055485	0.000690753	4.29924E-05
q ID#[18]	0.0057273	0.000643218	3.65117E-05
q ID#[19]	0.0052871	0.000718473	4.87995E-05
q ID#[20]	0.0054898	0.000704527	4.50066E-05
q ID#[21]	0.0015651	0.000473184	7.07427E-05
q ID#[22]	0.0032281	0.000767013	8.96319E-05
q ID#[23]	0.0049965	0.000898107	7.87541E-05
q ID#[24]	0.0048144	0.000781836	6.20864E-05
q ID#[25]	0.0049047	0.000807968	6.56005E-05
q ID#[26]	0.0047140	0.000757024	6.03355E-05
q ID#[27]	0.0045033	0.000762872	6.4556E-05
q ID#[28]	0.0048031	0.000730514	5.56E-05
q ID#[29]	0.0037991	0.00055865	4.07463E-05
q ID#[30]	0.0040537	0.000538049	3.51934E-05

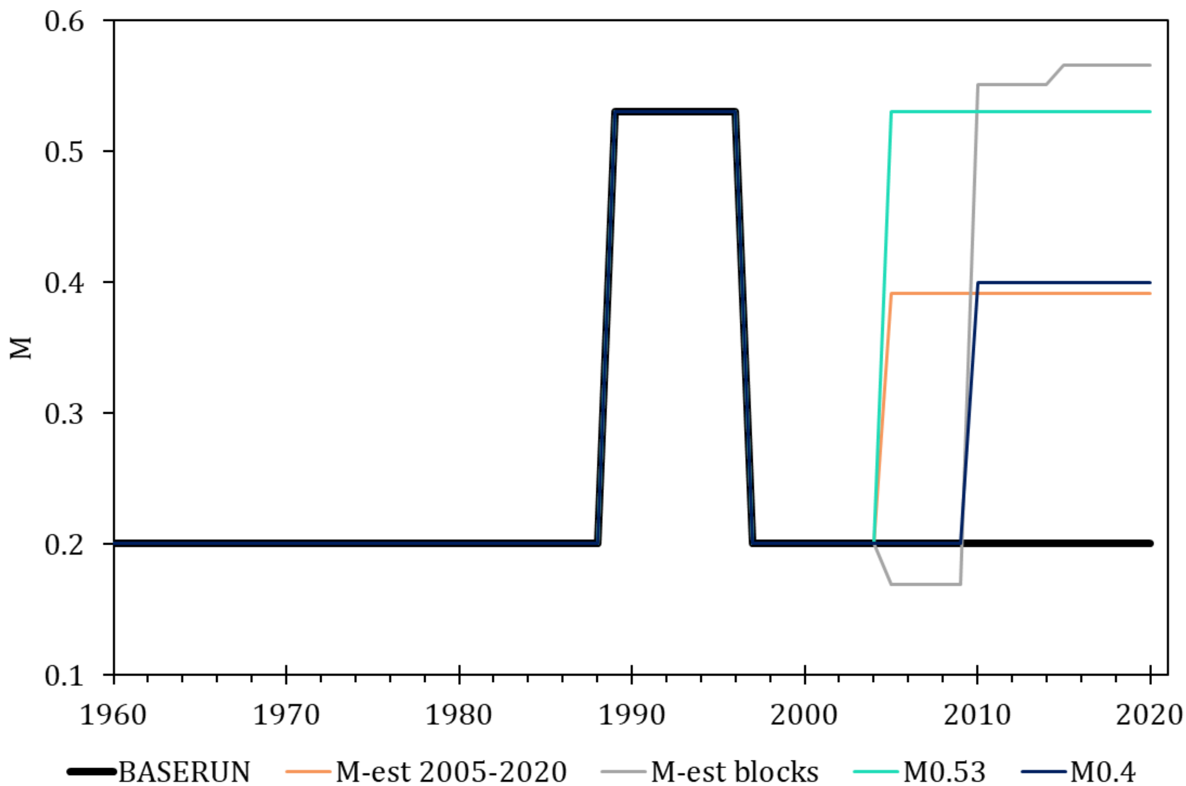
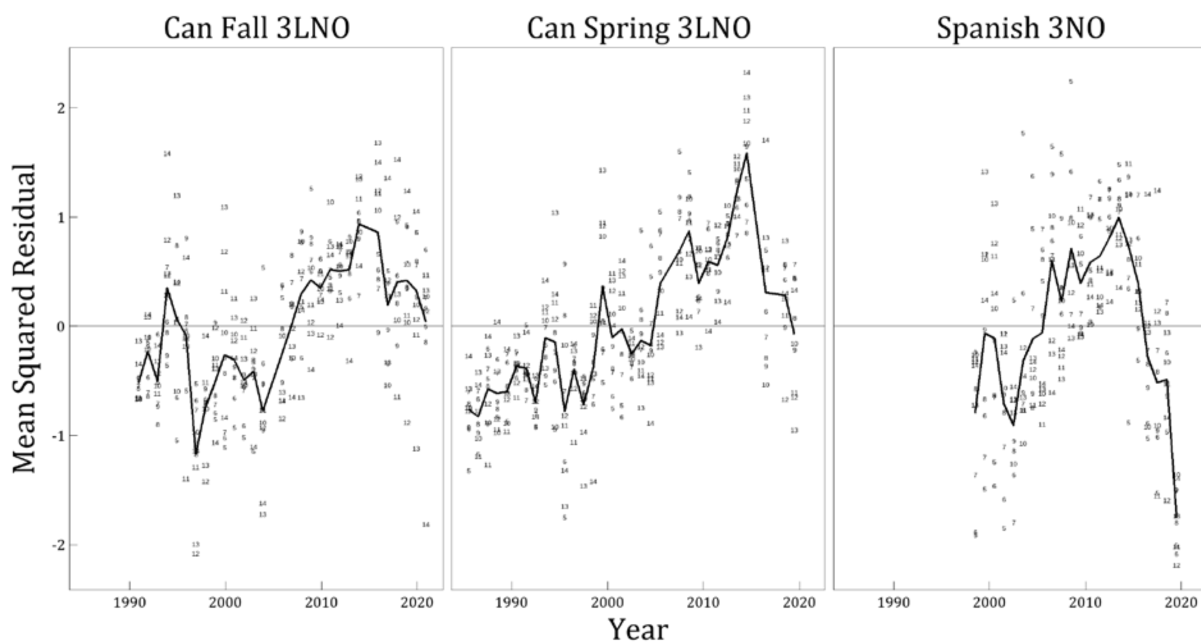


Figure 1. Schematic of M-case scenarios

(A) BASERUN



(B) M-est 2005-2020

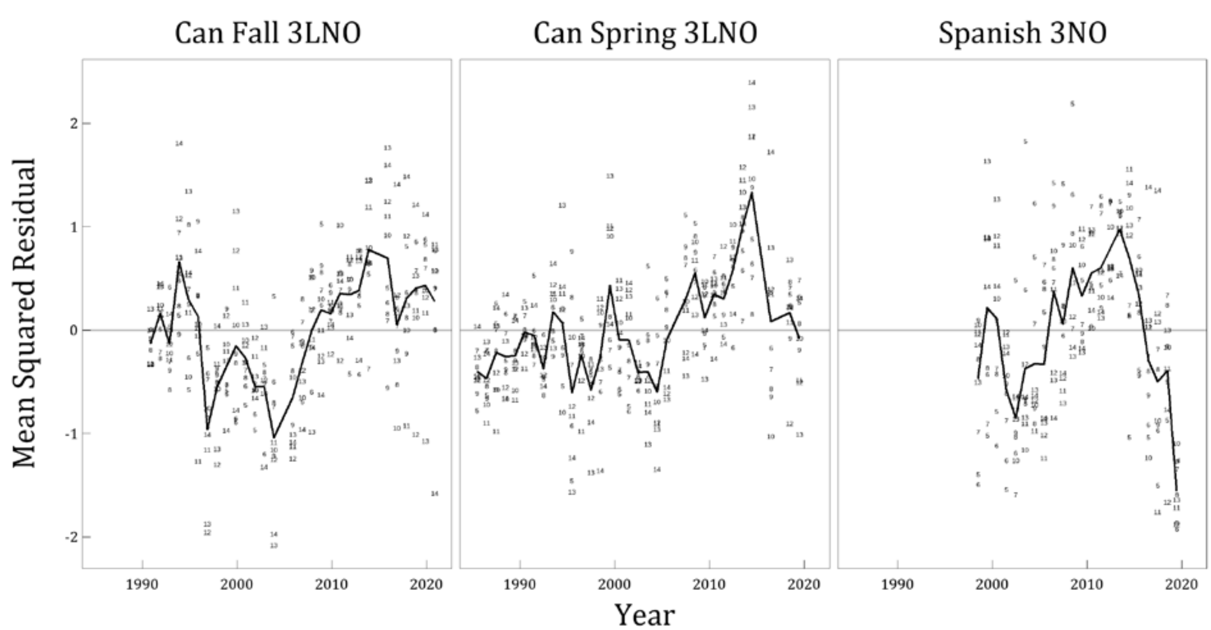
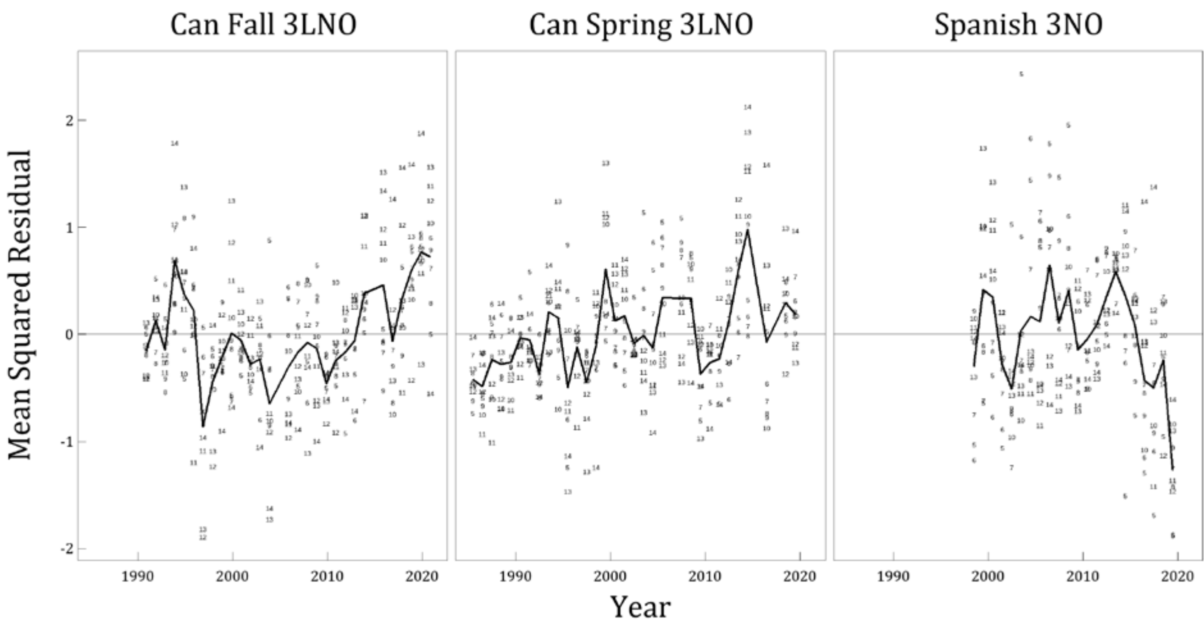


Figure 2. Model residuals at age for ADAPT baserun and four M-case scenarios

(C) M-est Blocks



(D) M0.53

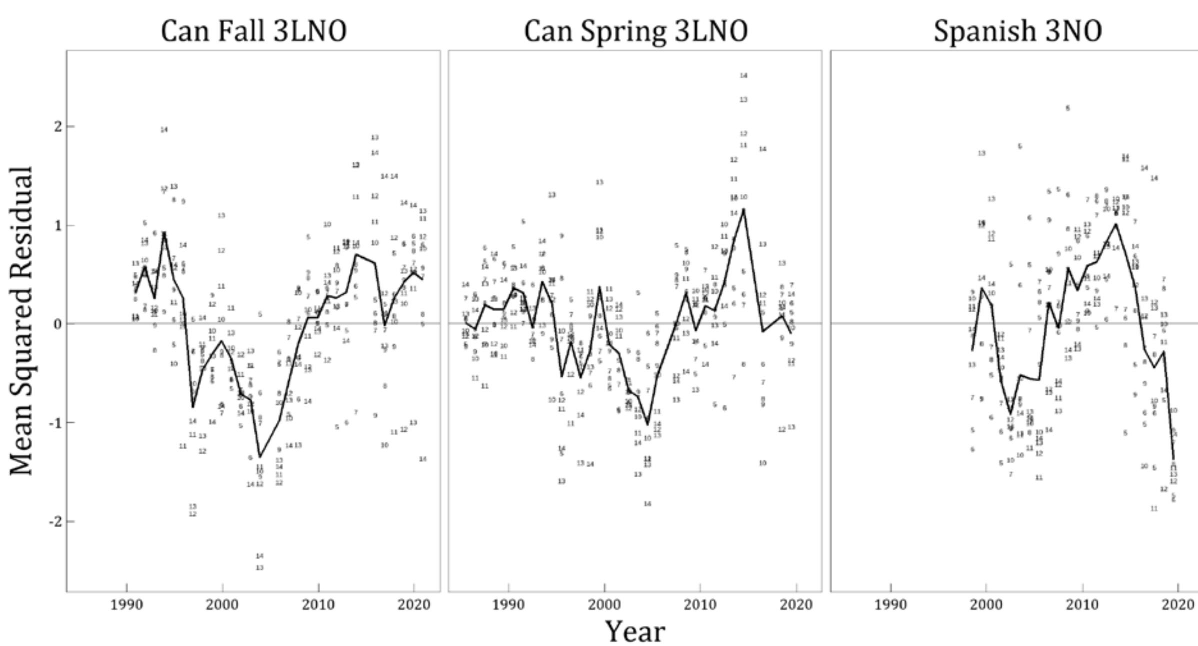


Figure 2. (cont.) Model residuals at age for ADAPT baserun and four M-case scenarios

(E) M=0.4

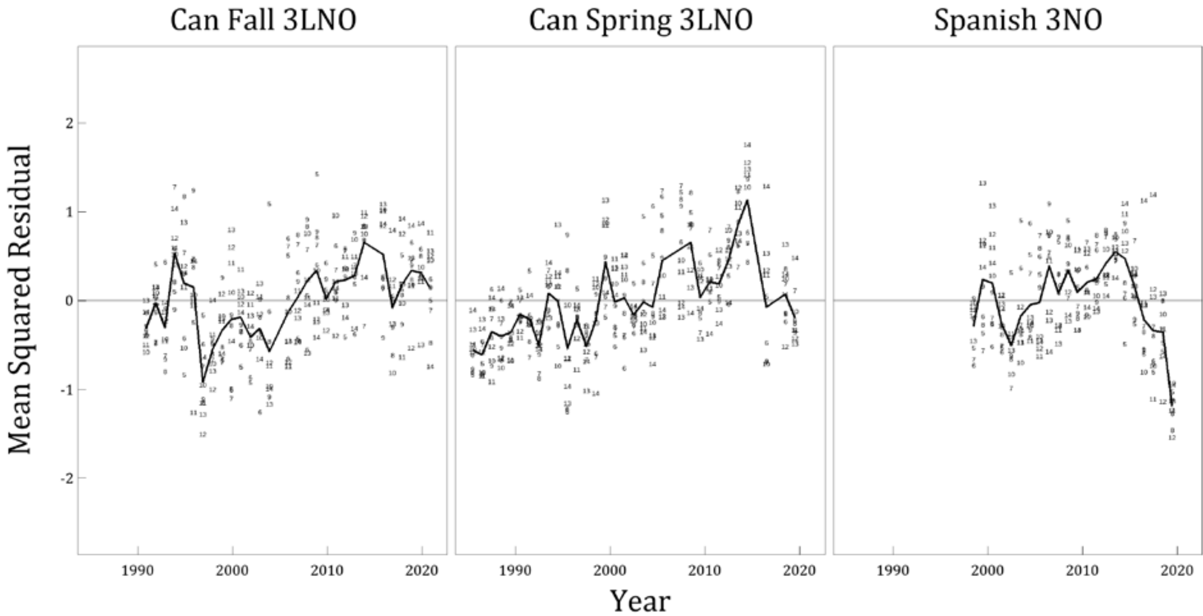


Figure 2. (cont.) Model residuals at age for ADAPT baserun and four M-case scenarios

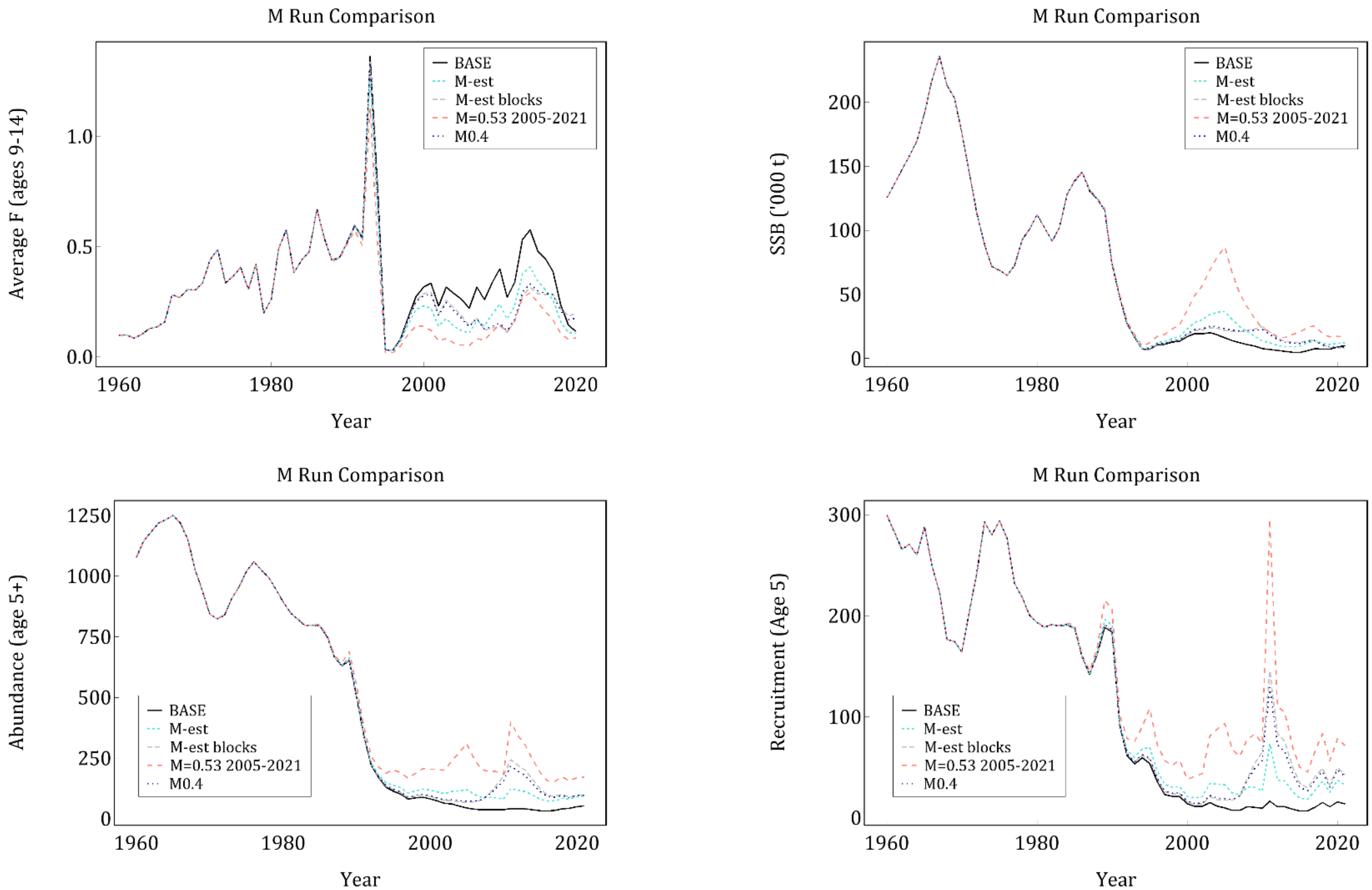


Figure 3. Comparison of model output ADAPT Baserun and four M-case scenarios

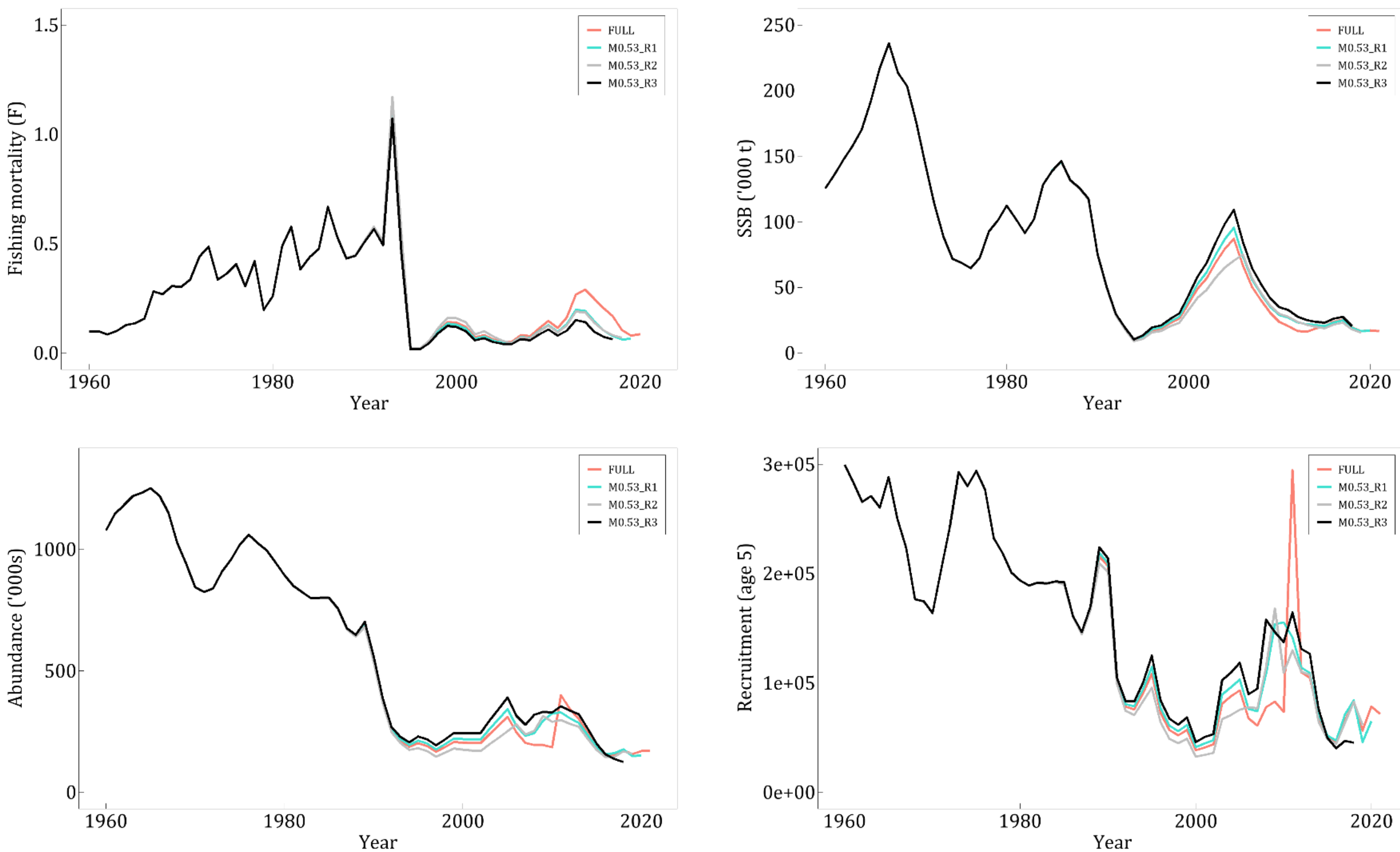


Figure 4. Retrospective pattern for the *M0.53* M-case

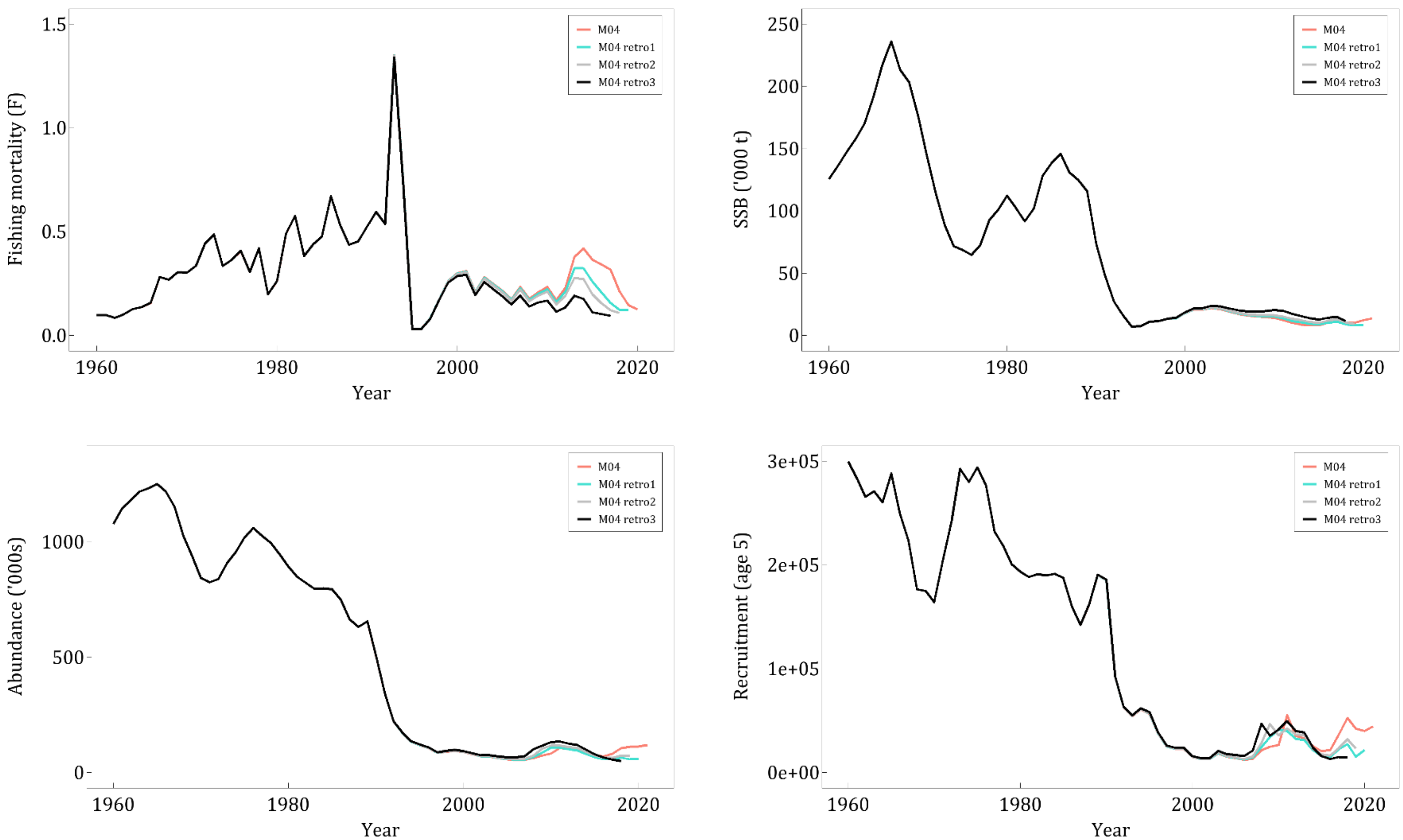


Figure 5. Retrospective pattern for the *M=0.4* M-case