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Bayesian XSA model for the 3M cod

by

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Abstract

Different runs of a Bayesian XSA model were conducted for the 3M cod during the benchmark of this stock, that took place in April 2018. The data inputs used in the last approved assessment in June 2017 were reviewed for the benchmark, resulting in some revisions; the revised data are used in this work. A comparison of the results of the scenarios with those from the last approved assessment (from June 2017) is performed.

Introduction

A Bayesian XSA model has been used in the assessment of the 3M cod since 2009. The settings and the results of the last approved assessment can be seen in González-Troncoso, 2017. In the last June Scientific Council meeting concerns were raised about the appropriateness of the settings used in these assessments, because it was observed that model results were quite sensitive to changes in some of the settings. Moreover, since the last approved assessment, the input data of the 3M cod assessment have been reviewed, resulting in some revisions.

Different scenarios of this model were run for the 3M cod benchmark that took place in April 2018. After examining the results, the NAFO SC concluded (NAFO, 2018a) to set R6 as the base case for the Bayesian XSA model. Due to the lack of time, the analyses of this model could not be completed during the benchmark, so a recommendation for running the retrospective analysis of this scenario was pointed out. This document contains the runs conducted at the benchmark (R1 to R6). The retrospective analysis of R6 is also presented in this document, as well as two more runs to explore the sensitivity of results obtained from R6 to changes in some of the settings.

Material and Methods

Used data

The data used in the last approved assessment was revised and updated during a SC meeting held by WebEx in March 2018 (NAFO, 2018b). The final data approved in this meeting for use in the Benchmark is the same data used in this document. The SC meeting also approved a shorter assessment period (1988-2016). The assessment period was shortened relative to the previous assessment, which started in 1972, due to the quality of available data. The final approved data for the benchmark was the following:

-<u>Commercial catch data</u>:
- Total catch: 1988-2016. Presented in Table 1.
- Catch numbers-at-age: 1988-2001, 2006-2016, ages 1-8+. Presented in Table 2.
- Mean weight-at-age in catch (wcatch): 1988-2016, ages 1-8+. Presented in Table 3.

-<u>Survey data</u>: EU Flemish Cap survey data
- Index of stock abundance (in numbers) at age: 1988-2016, ages 1-8+. Presented in Table 4.
- Mean weight-at-age in the stock (wstock): 1988-2016, ages 1-8+. Presented in Table 5.
- Maturity-at-age: 1988-2016, ages 1-8+. Presented in Table 6.

In the mean weights, both for catch and stock, there are some gaps (missing values) in the data that were filled with the mean of the previous and the following year.

Assessment methodology

A Bayesian XSA model was applied to the data. Ages are from 1 to A=8+ and years are from y=1 (1988) to Y=29 (2016). The cohorts are modelled backwards in time, starting from survivors of the last true age (age 7) in each year and survivors from each true age (1 to 7) in the last assessment year, taking into account the natural and fishing mortality. The model equations can be seen in González-Troncoso, 2017.

Different scenarios with this model changing some of the settings and/or input data were run. The scenarios run are listed in Table 7. Runs 1 to 6 took place during the benchmark, whereas the remaining runs were conducted after the benchmark in order to further explore sensitivities. The rationale of these parameters is:

-*medrec*: recruitment value used to set the prior median on survivors.
-*qs*: catchabilities of the surveys by age. They can be all different or can be grouped by groups of ages.
-*psi.EU*: this parameter controls the variability (CV) of the observation equation for the survey abundance index at age. It can be estimated including a prior distribution, it can be different for each age or grouped by groups of ages, or it could be fixed.
-*cv(surv)*: this parameter controls the variability (CV) of the prior distribution on survivors.
-*M*: it can be one value, a vector or a matrix, and it can have a prior or be fixed.
-*adep*: this setting indicates the ages for which the survey catchability depends on population abundance
-*Zeros*: If the zeros in the catch at age and in the survey index are included or not.
-*Years*: years used in the input data of the assessment,

All the runs were made in WinBugs called from R via the package r2winbugs.

Results

All the models reach the convergence after 50,000 iterations, from which 5000 are taken for the results.

The method followed to run the different scenarios was to start running the approved assessment but with the revised data. In the first run, the settings are those from the approved assessment, starting the assessment in 1988 instead of 1972 (and using the revised data). In order to check the influence of the revised data approved by the SC input data meeting, R2 is the same as the approved assessment, starting in 1972, and using the revised data. Then, based on the first run, R3 was run with M fixed as a vector, and R4 with M fixed as a matrix. In R5 we change the CV of the priors of the survivors and priors over M (one by age) were set. In R6 the median of the prior of the recruitment was changed, and the variability of the observation equation for the survey abundance index was fixed. R7 and R8 are variations of R6 in order to examine the impact of changing some parameters. In these last three runs, the way the zeros are treated also changed.

The recruitment value used to set the prior median for survivors was 15000 in the approved assessment. Looking at historical recruitments, and taking into account that M is now centred at larger values than done in previous assessments, a value of 45000 was considered by the benchmark to be more appropriate and was tried in R6.

With regards to **catchability** in the survey, we tried two different settings. In R1-R4 we have catchability different for all ages, but looking to the posterior distribution of the catchabilities of R1 (Figure 1), it can be observed that some of the ages have similar catchabilities. These results are robust with the EU survey and fishery information available. Based on the biological and survey gear information we have chosen to group the ages in catchability as follows: 1, 2, 3 and 4-8+. This is applied starting from R5.

The variability (CV) of the observation equations for the **EU survey indices**, can be controlled by a prior or can be fixed. In R1-R5, priors over this parameter were set, allowing different parameters for each age. Due to the variability of the posterior estimates of this CV (Figure 2), it was decided to fix this CV to be 30% in R6. A CV of 30% is reasonable for the survey abundance index of this stock taking into account their variability.

In the case of the CV of the prior distribution on **survivors**, we start with a CV of 1, as in the last approved assessment, but a value of 10 was tried in all runs starting from R5.

In the case of **M**, four different approaches were tried: to have a prior over the M (constant over years and ages), as in the last approved assessment (R1 and R2); to have a vector of Ms as input (constant through years but different by age) (R3); to have a matrix of Ms as input (varying over ages and years) (R4), and to have 8 priors, one for each age, with the median of the prior equal to the vector used as input in R3 (R5 and R6). The values used for the vector and the matrix are in Table 8 and comes from González-Costas and González-Troncoso (2018) and the results of the GADGET (SCR 18/XX). The posterior median of the scenarios with prior (R1, R2, R5-R8) are presented in Table 9. It can be seen that, when we allow the M to be different between ages, the value for age 1 is much higher than for the rest of the ages. For ages 2 and 3 it is still high, and then it decreases.

With regards to the **first age** in which the catchability is independent of population abundance (so, the exponent gama=1), we have tried two different approaches: catchabilities of ages 1 and 2 dependent on abundance (R1-R4) and only age 1 dependent on abundance (starting from R5). It seems more logical to use only age 1 as dependent on abundance, as when we use ages 1 and 2, the posterior median of the distribution of the exponent (gama) at age 2 is almost equal to 1 (Figure 3).

There are some zeros in the observed catch-at-age in numbers and in the observed EU index. In the case of the catch-at-age the XSA model allows us to have 0, but not in the case of survey numbers at age. A first approach with a value of 0.0005 instead of 0 in both inputs was taken. Differences between the results are not evident. So, we leave the 0 in the catch at age and two more attempts were made in the EU survey index: 0.0005 and the mean of the minimum value in that age for all the years. This last approach, tried in R6-R8, seems to be the most reasonable.

Table 10 shows the median posterior SSB for all the scenarios run (R1-R8) as well as for the approved assessment. Figures 4-7 show the SSB, the R, the F_{bar} and the number at age for each of the scenarios and for the approved assessment, respectively.

In the results, we have three different groups: R3 and R4 show the lowest SSB and R6, R7 and R8 the highest. The difference between R6-7-8 and the rest of the models is remarkable. The differences come mainly from the numbers at age in ages 5+. R1 and R2 are very similar, which means that the revised data and shortened assessment period do not affect the results of the assessment. R5 is fairly similar to R1 and R2, except for the recruitment estimates, so changing settings as having M variable over ages, the CV of the prior of the survivors or to have age 2 independent of abundance have not a great impact affect the results. Instead of that, fixing the value of M has a great impact in the subsequent numbers, mainly in ages 5 and 6, that are much lower that for the rest of the scenarios. The main difference arises when we change the value of the median of the prior over the recruitment and when we fix the CV of the EU survey index. In that case, the SSB is much higher than in the rest of the models. Running R6 with the median over the recruitment as 15000 instead of 45000 (R8), the results are very similar to those of R6, so it seems that the difference comes mainly from fixing the CV of the EU survey index. Setting this CV as 20% instead of 30% (R7), the SSB increases slightly.

The SSB of the last approved assessment is the lowest in the last years if we take out R3 and R4. SSB result in the SSB of 2016 is more than three times the SSB in 2016 of the last approved assessment.

One of the outputs that probably make the difference in the level of SSB between both models is the survey catchability. Figure 9 show the catchabilities by age for both models. Take into account that the XSA estimates the catchabilities to be different for all ages (1-8+), while the SCAA groups the ages (1, 2, 3 and 4-8+). We can see that while the median catchability in the SCAA is around 1 for ages older than 3, in the case of the XSA they range between 1.19 at age 7 and 1.83 at age 5. For that, the abundance in the last year are bigger for the SCAA that for the XSA, giving bigger SSB.

Retrospective pattern

A 5-years retrospective analysis was made for Run 5 and 6. Results of R6 are shown in Figure 7. No evident patterns can be seen.

References

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Table 1. Total commercial cod catch in Division 3M. Reported nominal catches since 1960 and estimated total catch from 1988 to 2016 in tons.

Year	Estimated[2]	Portugal	Russia	Spain	France	Faroes	UK	Poland	Norway	Germany	Cuba	Others	Total[1]
1960		9	11595	607					46	86		10	12353
1961		2155	12379	851	2626		600	336		1394		0	20341
1962		2032	11282	1234			93	888	25	4		349	15907
1963		7028	8528	4005	9501		2476	1875				0	33413
1964		3668	26643	862	3966		2185	718	660	83		12	38797
1965		1480	37047	1530	2039		6104	5073	11	313		458	54055
1966		7336	5138	4268	4603		7259	93		259		0	28956
1967		10728	5886	3012	6757		5732	4152		756		46	37069
1968		10917	3872	4045	13321		1466	71				458	34150
1969		7276	283	2681	11831					20		52	22143
1970		9847	494	1324	6239		3	53				35	17995
1971		7272	5536	1063	9006			19		1628		25	24549
1972		32052	5030	5020	2693	6902	4126	35	261	506		187	56812
1973		11129	1145	620	132	7754	1183	481	417	21		18	22900
1974		10015	5998	2619		1872	3093	700	383	195		63	24938
1975		10430	5446	2022		3288	265	677	111	28		108	22375
1976		10120	4831	2502	229	2139		898	1188	225		134	22266
1977		6652	2982	1315	5827	5664	1269	843	867	45	1002	553	27019
1978		10157	3779	2510	5096	7922	207	615	1584	410	562	289	33131
1979		9636	4743	4907	1525	7484		5	1310		24	76	29710
1980		3615	1056	706	301	3248		33	1080	355	1	62	10457
1981		3727	927	4100	79	3874			1154			12	13873
1982		3316	1262	4513	119	3121	33		375			14	12753
1983		2930	1264	4407		1489			111	3		1	10205
1984		3474	910	4745		3058			47	454	5	9	12702
1985		4376	1271	4914		2266			405	429	9	5	13675
1986		6350	1231	4384		2192				345	3	13	14518
1987		2802	706	3639	2300	916						269	10632
1988	28899	421	39	141		1100					3	14	1718
1989	48373	170	10	378								359	917
1990	40827	551	22	87		1262						840	2762
1991	16229	2838	1	1416		2472	26		897		5	1334	8989
1992	25089	2201	1	4215		747	5				6	51	7226
1993	15958	3132	0	2249		2931						4	8316
1994	29916	2590	0	1952		2249			1			93	6885
1995	10372	1641	0	564		1016						0	3221
1996	2601	1284	0	176		700	129			16		0	2305
1997	2933	1433	0	1			23					0	1457
1998	705	456	0									0	456
1999	353	2	0									0	2
2000	55	30	6									0	36
2001	37	56	0									0	56
2002	33	32	1									0	33
2003	16	7	0									9	16
2004	5	18	2									3	23
2005	19	16	0			7						3	26
2006	339	51	1	16								55	123
2007	345	58	6	33								28	125
2008	889	219	74	42	3	0						63	401
2009	1161	856	87	85		22						122	1172
2010	9291	1345	374	921		1183	761		514			147	5245
2011	12836	2412	655	1610	200	2211	1063		1301		185	340	9977
2012	12836	2593	745	1597	131	2045	868		809		172	108	9068
2013	13985	4427	896	2380		2723	1328		1322			445	13521
2014	14290	5345	950	2099		3370		393	1344			855	14356
2015	13785	4680	893	1999		3319			1296			641	12828
2016	14023	5958	893	1232		3124	1198		1318			72	13795

[1] Recalculated from NAFO Statistical data base using the NAFO 21A Extraction Tool
[2] STACFIS estimates

Table 2. Catch-at-age (thousands).

	1	2	3	4	5	6	7	8+
1988	1	3500	25593	11161	1399	414	315	162
1989	0	52	15399	23233	9373	943	220	205
1990	7	254	2180	15740	10824	2286	378	117
1991	1	561	5196	1960	3151	1688	368	76
1992	0	15517	10180	4865	3399	2483	1106	472
1993	0	2657	14530	3547	931	284	426	213
1994	0	1358	28303	9218	430	206	16	203
1995	0	0	192	4773	2003	474	98	169
1996	0	81	714	311	1072	88	0	0
1997	0	0	1016	956	179	359	60	0
1998	0	0	8	170	286	30	19	2
1999	0	0	15	15	96	60	3	1
2000	0	0	54	1	1	4	1	0
2001	0	9	0	4	2	0	2	2
2002								
2003								
2004								
2005								
2006	0	22	19	81	2	10	2	0
2007	0	2	30	1	27	1	14	5
2008	1	89	136	133	3	40	1	3
2009	0	23	51	210	108	0	32	7
2010	34	452	1145	1498	808	388	4	103
2011[1]	18	537	1608	701	1144	961	354	275
2012[1]	39	389	1443	834	1013	739	357	344
2013	22	646	4169	962	1124	755	521	388
2014	7	13	730	4131	1464	871	556	405
2015	0	94	402	1548	1457	2596	602	480
2016	0	40	883	731	1822	1167	939	757

Table 3. Weight-at-age (kg) in catch. In red, the filled gaps.

	1	2	3	4	5	6	7	8+
1988	0.058	0.198	0.442	0.821	2.190	3.386	5.274	7.969
1989	0.069	0.209	0.576	0.918	1.434	2.293	4.721	7.648
1990	0.080	0.153	0.500	0.890	1.606	2.518	3.554	7.166
1991	0.118	0.229	0.496	0.785	1.738	2.622	3.474	6.818
1992	0.115	0.298	0.414	0.592	1.093	1.704	2.619	3.865
1993	0.115	0.210	0.509	0.894	1.829	2.233	3.367	4.841
1994	0.112	0.248	0.649	0.973	1.686	2.331	3.008	4.898
1995	0.112	0.248	0.649	0.973	1.686	2.331	3.008	4.898
1996	0.110	0.286	0.789	1.051	1.543	2.429	2.730	4.653
1997	0.107	0.360	0.754	1.038	1.506	2.115	2.451	4.408
1998	0.098	0.472	0.719	1.024	1.468	1.800	2.252	3.862
1999	0.098	0.472	0.920	1.298	1.848	2.436	3.513	4.893
2000	0.098	0.583	0.672	1.749	2.054	2.836	3.618	5.055
2001	0.098	0.481	0.998	1.696	2.560	3.303	3.905	5.217
2002	0.098	0.588	1.323	1.388	2.572	3.770	5.158	5.603
2003	0.098	0.462	1.063	1.455	2.978	3.696	5.859	6.120
2004	0.098	0.839	1.677	2.009	3.353	5.576	6.241	8.273
2005	0.098	0.895	1.618	2.368	3.259	4.767	6.177	6.553
2006	0.098	1.081	1.462	2.283	3.966	5.035	6.332	7.997
2007	0.098	0.974	1.858	3.388	4.062	6.128	6.809	9.440
2008	0.088	0.448	1.364	3.037	3.498	5.248	6.643	8.251
2009	0.172	0.507	1.026	2.087	3.727	4.810	5.900	9.534
2010	0.162	0.700	1.279	1.829	2.764	4.372	4.199	8.575
2011	0.086	0.396	0.939	1.522	2.228	3.560	5.980	8.753
2012	0.086	0.374	0.990	1.491	2.136	3.583	6.183	9.183
2013	0.007	0.284	0.762	1.305	2.112	2.990	4.530	8.564
2014	0.108	0.203	0.538	1.108	1.809	2.874	4.087	7.671
2015	0.085	0.261	0.531	0.857	1.370	1.938	3.570	6.252
2016	0.085	0.191	0.550	0.787	1.237	2.157	3.439	6.719

Table 4. EU bottom trawl survey abundance at age and total (thousands) and total biomass (tons).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total Abundance	Total Biomass
1988	4868	79905	49496	13448	1457	211	225	72	0	0	0	0	0	0	0	0	149683	40839
1989	19604	10800	91303	54613	20424	1336	143	126	6	7	0	0	0	0	0	0	198363	114050
1990	2303	12348	5121	16952	15834	4492	340	146	77	25	0	0	0	0	0	0	57637	59362
1991	129032	26220	16903	2125	6757	1731	299	68	32	4	10	0	0	0	0	0	183181	40248
1992	71533	41923	5578	2385	385	1398	244	14	0	0	8	0	0	0	0	0	123468	26719
1993	4075	138357	31096	1099	1317	173	489	87	0	0	0	0	0	0	0	0	176693	60963
1994	3017	4130	27756	5097	130	67	7	111	0	5	0	0	0	0	0	0	40319	26463
1995	1425	11901	1338	3892	928	33	23	0	21	5	0	0	0	0	0	0	19567	9695
1996	36	3121	6659	892	2407	192	8	5	0	0	0	0	0	0	0	0	13320	9013
1997	37	150	3478	4803	391	952	21	0	0	0	0	4	0	0	0	0	9837	9966
1998	23	83	95	1256	1572	78	146	0	6	0	0	0	0	0	0	0	3259	4986
1999	5	84	116	117	717	444	19	5	0	0	0	0	0	0	0	0	1507	2854
2000	178	16	327	198	96	446	172	11	17	0	0	5	0	5	0	0	1470	3062
2001	473	1990	13	122	79	15	142	99	6	6	6	0	0	0	0	0	2951	2695
2002	0	1330	641	29	70	33	26	96	30	0	5	0	0	0	0	0	2261	2496
2003	684	54	628	134	22	42	7	8	39	24	0	0	0	0	0	0	1642	1593
2004	14	3380	25	600	168	5	10	3	5	15	0	0	0	0	0	0	4226	4071
2005	8069	16	1118	78	709	136		17	16	8	0	0	0	0	0	0	10166	5242
2006	19709	3886	62	1481	85	592	115	7	0	7	14	0	7	0	0	0	25965	12505
2007	3917	11620	5022	21	1138	58	425	74	13	20	0	0	0	0	0	0	22308	23886
2008	6096	16671	12433	4530	72	946	56	231	76	0	14	0	0	0	0	0	41124	43676
2009	5139	7479	16150	14310	4154	26	1091	0	335	0	0	14	0	0	0	0	48697	75228
2010	66370	27689	8654	7633	4911	1780	8	442	46	251	26	0	0	0	0	0	117810	69295
2011	347674	142999	16993	6309	7739	3089	1191	0	215	0	89	0	0	0	0	0	526300	106151
2012	103494	128087	10942	11721	4967	4781	1630	832	24	93	30	101	0	17	0	0	266720	113227
2013	5525	67521	32339	4776	4185	2782	1807	963	278	40	29	32	5	0	0	0	120280	72289
2014	7282	2372	48564	43168	17861	6842	3447	1931	1551	600	79	54	8	0	0	0	133760	159939
2015	1141	12952	7250	25614	14107	21854	3434	1426	762	366	194	14	21	21	0	7	89164	114807
2016	56	4485	14356	2230	14540	12375	4814	1157	522	303	145	28	20	0	0	0	55032	80583

Table 5. Weight-at-age (kg) in stock. In red, the filled gaps.

	1	2	3	4	5	6	7	8+
1988	0.032	0.106	0.308	0.664	1.970	3.500	5.742	6.954
1989	0.036	0.101	0.330	0.836	1.293	2.118	4.199	7.360
1990	0.043	0.181	0.354	0.868	1.566	2.507	4.132	6.572
1991	0.056	0.171	0.501	0.865	1.594	2.593	3.423	6.182
1992	0.056	0.247	0.485	1.394	1.723	2.578	3.068	9.406
1993	0.043	0.227	0.657	1.216	2.279	2.381	3.373	5.731
1994	0.063	0.214	0.599	1.321	2.132	4.054	4.119	6.555
1995	0.048	0.243	0.479	0.969	1.851	2.680	5.532	7.309
1996	0.044	0.260	0.544	0.813	1.331	2.252	4.079	5.118
1997	0.081	0.333	0.652	1.020	1.327	2.092	1.997	9.717
1998	0.073	0.371	0.773	1.206	1.684	2.015	3.070	7.525
1999	0.108	0.398	0.946	1.329	1.866	2.444	3.461	4.987
2000	0.106	0.606	0.971	1.638	1.940	2.860	3.461	7.985
2001	0.084	0.493	1.281	1.724	2.588	3.488	3.893	5.137
2002	0.071	0.440	1.191	1.540	2.661	3.916	5.302	5.672
2003	0.058	0.337	0.926	1.566	3.047	3.769	5.721	6.451
2004	0.004	0.620	1.488	2.098	3.332	4.808	6.207	7.886
2005	0.084	0.580	1.256	2.242	2.875	4.187	6.033	8.148
2006	0.096	0.720	1.096	2.549	3.644	4.777	5.858	9.691
2007	0.053	0.609	1.640	3.478	4.097	5.787	6.373	8.315
2008	0.068	0.382	1.344	2.695	3.191	5.015	6.324	7.938
2009	0.078	0.407	0.976	2.072	3.881	6.958	6.583	9.461
2010	0.061	0.384	1.089	1.677	2.956	5.379	7.616	9.144
2011	0.038	0.211	0.913	1.618	2.339	3.594	6.050	9.396
2012	0.074	0.369	0.726	1.349	1.988	2.656	4.933	7.812
2013	0.071	0.175	0.687	1.159	2.004	2.750	4.206	7.614
2014	0.048	0.169	0.354	1.059	1.623	2.536	3.846	8.444
2015	0.049	0.156	0.469	0.747	1.216	1.847	3.434	6.775
2016	0.044	0.169	0.412	0.783	1.304	2.024	2.883	6.905

Table 6. Maturity at age and age of first maturation (median values of ogives).

	1	2	3	4	5	6	7	8+	a50
1972	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1973	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1974	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1975	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1976	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1977	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1978	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1979	0.000	0.000	0.000	0.008	0.154	0.813	0.991	1.000	5.54
1980	0.000	0.000	0.002	0.029	0.302	0.862	0.989	1.000	5.31
1981	0.000	0.000	0.005	0.104	0.716	0.982	0.999	1.000	4.70
1982	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000	4.55
1983	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000	4.55
1984	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000	4.55
1985	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000	4.55
1986	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000	4.55
1987	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000	4.55
1988	0.054	0.099	0.175	0.291	0.441	0.603	0.745	0.879	5.36
1989	0.054	0.099	0.175	0.291	0.441	0.603	0.745	0.879	5.36
1990	0.054	0.099	0.175	0.291	0.441	0.603	0.745	0.879	5.36
1991	0.018	0.045	0.111	0.247	0.463	0.687	0.849	0.951	5.16
1992	0.002	0.011	0.048	0.184	0.503	0.819	0.953	0.993	4.99
1993	0.001	0.007	0.049	0.282	0.751	0.959	0.994	1.000	4.46
1994	0.000	0.001	0.050	0.657	0.986	1.000	1.000	1.000	3.82
1995	0.000	0.000	0.006	0.803	1.000	1.000	1.000	1.000	3.79
1996	0.000	0.000	0.029	0.666	0.993	1.000	1.000	1.000	3.84
1997	0.000	0.008	0.111	0.670	0.971	0.998	1.000	1.000	3.75
1998	0.000	0.002	0.096	0.874	0.998	1.000	1.000	1.000	3.54
1999	0.000	0.001	0.130	0.902	0.999	1.000	1.000	1.000	3.46
2000	0.000	0.001	0.160	0.971	1.000	1.000	1.000	1.000	3.34
2001	0.000	0.001	0.315	0.998	1.000	1.000	1.000	1.000	3.12
2002	0.000	0.010	0.636	0.997	1.000	1.000	1.000	1.000	2.89
2003	0.001	0.024	0.513	0.978	0.999	1.000	1.000	1.000	2.99
2004	0.000	0.000	0.100	0.967	1.000	1.000	1.000	1.000	3.40
2005	0.041	0.171	0.502	0.830	0.959	0.991	0.998	1.000	3.00
2006	0.000	0.014	0.365	0.959	0.999	1.000	1.000	1.000	3.15
2007	0.000	0.012	0.261	0.920	0.997	1.000	1.000	1.000	3.31
2008	0.000	0.012	0.231	0.882	0.995	1.000	1.000	1.000	3.37
2009	0.000	0.010	0.181	0.830	0.991	1.000	1.000	1.000	3.49
2010	0.000	0.009	0.167	0.812	0.989	1.000	1.000	1.000	3.52
2011	0.001	0.008	0.072	0.428	0.878	0.986	0.999	1.000	4.13
2012	0.000	0.000	0.018	0.578	0.990	1.000	1.000	1.000	3.93
2013	0.004	0.037	0.285	0.804	0.977	0.998	1.000	1.000	3.39
2014	0.000	0.003	0.046	0.400	0.902	0.992	0.999	1.000	4.15
2015	0.000	0.000	0.004	0.117	0.794	0.991	1.000	1.000	4.60
2016	0.000	0.000	0.004	0.047	0.393	0.894	0.991	1.000	5.17

Table 7. Settings of Bayesian XSA runs

Run	Base	medrec	Age groups survey catchability	CCV survey observation equation	CV prior on survivors	M	CV prior on M	*adep*	Treatment of zeros	Years	Retro
1	Approved	15000	All different	Prior	1	1 prior	0.3	1,2	0.0005	1988-2016	No
2	Approved	15000	All different	Prior	1	1 prior	0.3	1,2	0.0005	1972-2016	No
3	1	15000	All different	Prior	1	Vector		1,2	0.0005	1988-2016	No
4	1	15000	All different	Prior	1	Matrix		1,2	0.0005	1988-2016	No
5	1	15000	1,2,3,4+	Prior	10	8 priors	0.15	1	0.0005 in survey, 0 in catch	1988-2016	Yes
6	5	45000	1,2,3,4+	Fix (30%)	10	8 priors	0.15	1	Min for EU, 0 in catch	1988-2016	Yes
7	6	45000	1,2,3,4+	Fix (20%)	10	8 priors	0.15	1	Min for EU, 0 in catch	1988-2016	Yes
8	6	15000	1,2,3,4+	Fix (30%)	10	8 priors	0.15	1	Min for EU, 0 in catch	1988-2016	Yes

Table 8. Values used for M: input and prior medians

1. M vector = c(1.26,0.65,0.44,0.35,0.30,0.27,0.24,0.24)
2. M matrix (from the GAGDET model):

	1	2	3	4	5	6	7	8
1988	0.766	0.397	0.358	0.352	0.350	0.350	0.350	0.350
1989	1.125	0.842	0.388	0.356	0.351	0.350	0.350	0.350
1990	0.910	0.656	0.581	0.368	0.353	0.351	0.350	0.350
1991	0.455	0.410	0.367	0.361	0.351	0.350	0.350	0.350
1992	0.479	0.374	0.355	0.352	0.351	0.350	0.350	0.350
1993	0.406	0.389	0.355	0.351	0.350	0.350	0.350	0.350
1994	0.410	0.395	0.360	0.351	0.350	0.350	0.350	0.350
1995	0.471	0.419	0.357	0.351	0.350	0.350	0.350	0.350
1996	0.392	0.385	0.362	0.351	0.350	0.350	0.350	0.350
1997	0.373	0.362	0.358	0.353	0.350	0.350	0.350	0.350
1998	0.362	0.359	0.351	0.351	0.350	0.350	0.350	0.350
1999	0.367	0.363	0.353	0.350	0.350	0.350	0.350	0.350
2000	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350
2001	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350
2002	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350
2003	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350
2004	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350
2005	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350
2006	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350
2007	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350
2008	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350
2009	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350
2010	0.876	0.692	0.412	0.365	0.352	0.350	0.350	0.350
2011	0.822	0.683	0.457	0.370	0.354	0.351	0.350	0.350
2012	0.581	0.622	0.506	0.392	0.356	0.352	0.350	0.350
2013	0.592	0.656	0.497	0.403	0.363	0.353	0.351	0.350
2014	1.441	0.693	0.517	0.384	0.361	0.353	0.351	0.350
2015	1.425	0.894	0.480	0.415	0.364	0.356	0.352	0.350
2016	0.809	0.789	0.527	0.392	0.373	0.356	0.352	0.350

Table 9. Results of the posterior median over M for R1, R2, R5 and R6

	1	2	3	4	5	6	7	8
R1	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
R2	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
R5	1.24	0.62	0.42	0.33	0.28	0.27	0.26	0.24
R6	1.25	0.58	0.40	0.29	0.24	0.26	0.34	0.24
R7	1.24	0.54	0.38	0.26	0.22	0.26	0.41	0.24
R8	1.24	0.58	0.40	0.29	0.24	0.25	0.34	0.24

Table 10. Median SSB (tons) for the different runs of the Bayesian SCAA.

Year	R1	R2	R3	R4	R5	R6	R7	R8	Approved
1988	20138	19868	22285	22440	22438	21895	21590	21861	19651
1989	28209	27894	30339	31516	30407	29844	29444	29771	34403
1990	27455	27124	28810	30213	29290	29252	29130	29191	25789
1991	17750	17540	18530	19217	19088	19050	19126	19011	17916
1992	22752	22592	22582	23351	22712	22755	22928	22712	21133
1993	10437	10311	10159	10425	10284	10454	10497	10417	10456
1994	21455	21293	20647	21084	20393	19512	19280	19482	21795
1995	14988	14896	14912	15345	14895	14494	14379	14478	19598
1996	3882	3745	3498	3681	3631	3530	3512	3512	3513
1997	3710	3639	2973	3090	3578	3452	3484	3422	3225
1998	3188	3078	1667	1792	2833	2659	2778	2609	3122
1999	2252	2186	855	953	1897	1809	1965	1763	2271
2000	1975	1922	514	592	1643	1588	1771	1540	1993
2001	1718	1607	562	643	1326	1129	1303	1107	1596
2002	2028	1937	842	881	1581	1377	1484	1349	1781
2003	2319	2249	1107	1126	1786	1752	1812	1712	2034
2004	3197	3148	1672	1716	2411	2711	2790	2656	3009
2005	3752	3725	2212	2145	3036	4006	4124	3931	3394
2006	3951	3907	2680	2849	3356	5839	6246	5752	3788
2007	5897	5763	4212	4409	5203	8839	9359	8685	5326
2008	10698	10370	9262	10108	10673	15120	15599	14868	9778
2009	19932	19385	17152	18827	20052	27332	28229	26868	18596
2010	33698	32954	28721	31285	32384	40749	41887	40152	31712
2011	31069	30505	24003	26101	29062	41129	43233	40389	30688
2012	30482	29811	22412	24689	29694	46779	49555	45840	27756
2013	40592	39714	34367	38405	45907	67254	69426	65984	36577
2014	35993	35268	27552	30029	38708	64392	67314	63134	32929
2015	31211	30747	18885	20188	34803	61593	65287	60214	27893
2016	31598	30685	14116	14793	34957	76128	81948	74033	26698
2017	32938	32283	4069	4179	36674	88372	93882	85474	27187

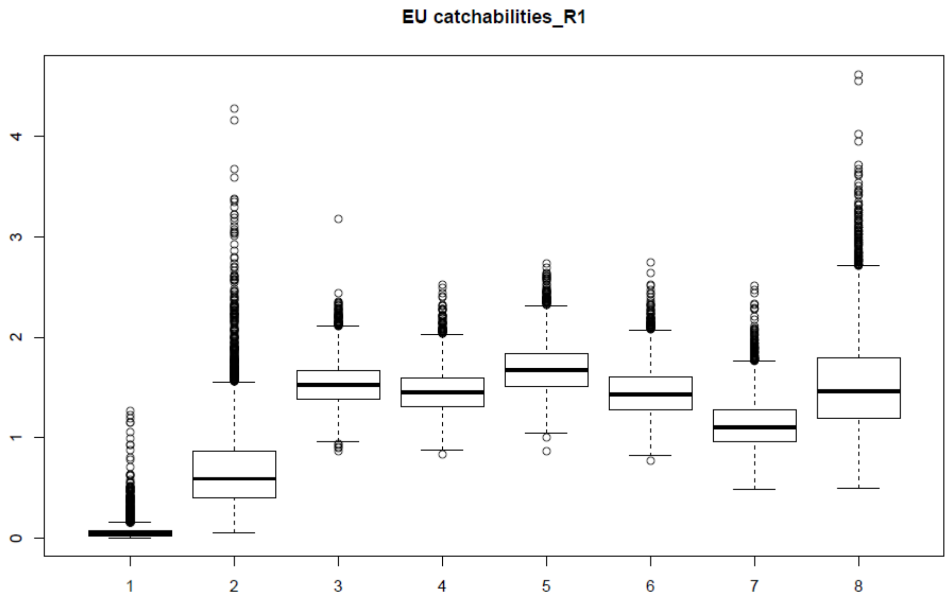

Fig. 1. Posterior EU catchabilities in R1

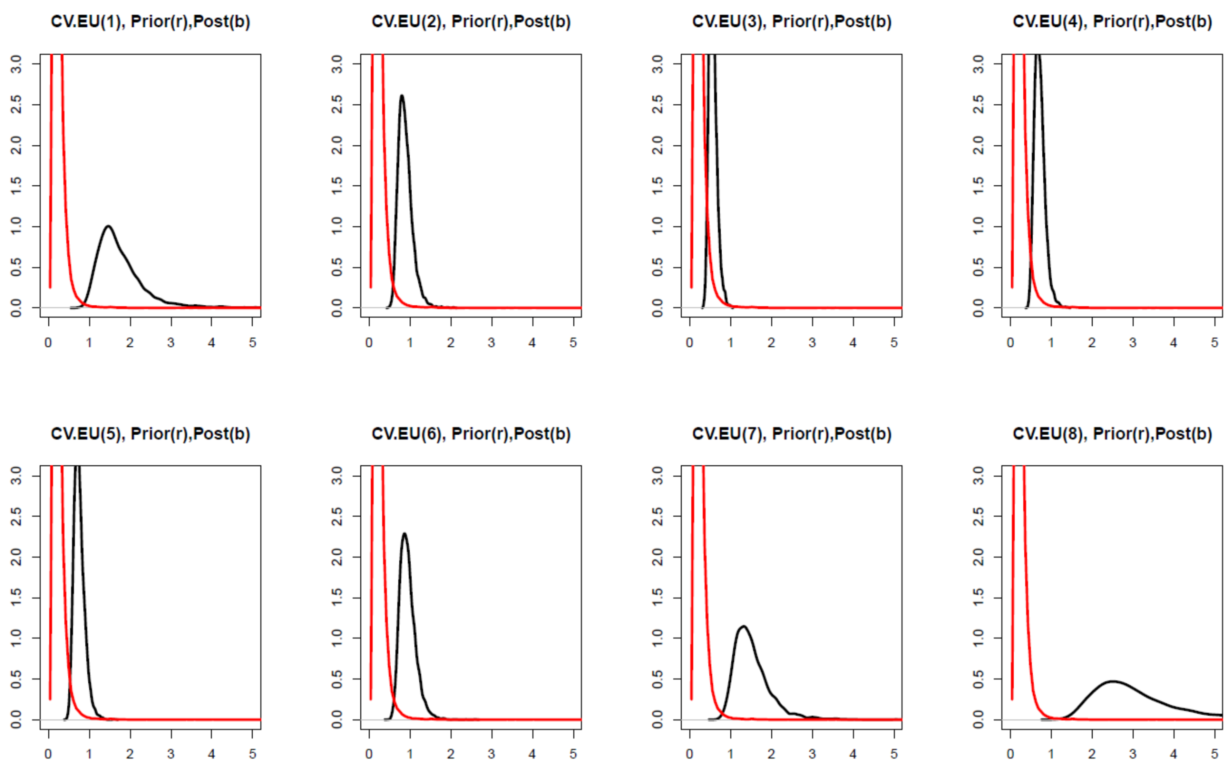

Fig. 2. Prior and posterior of the cv of the abundance EU survey index in R1

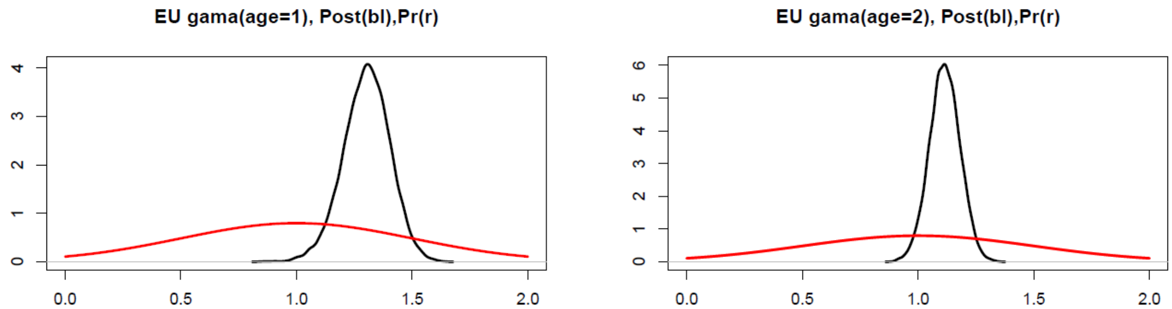

Fig. 3. Prior and posterior of the gama parameter (exponent of catchability for ages dependent on population abundance) in R1.

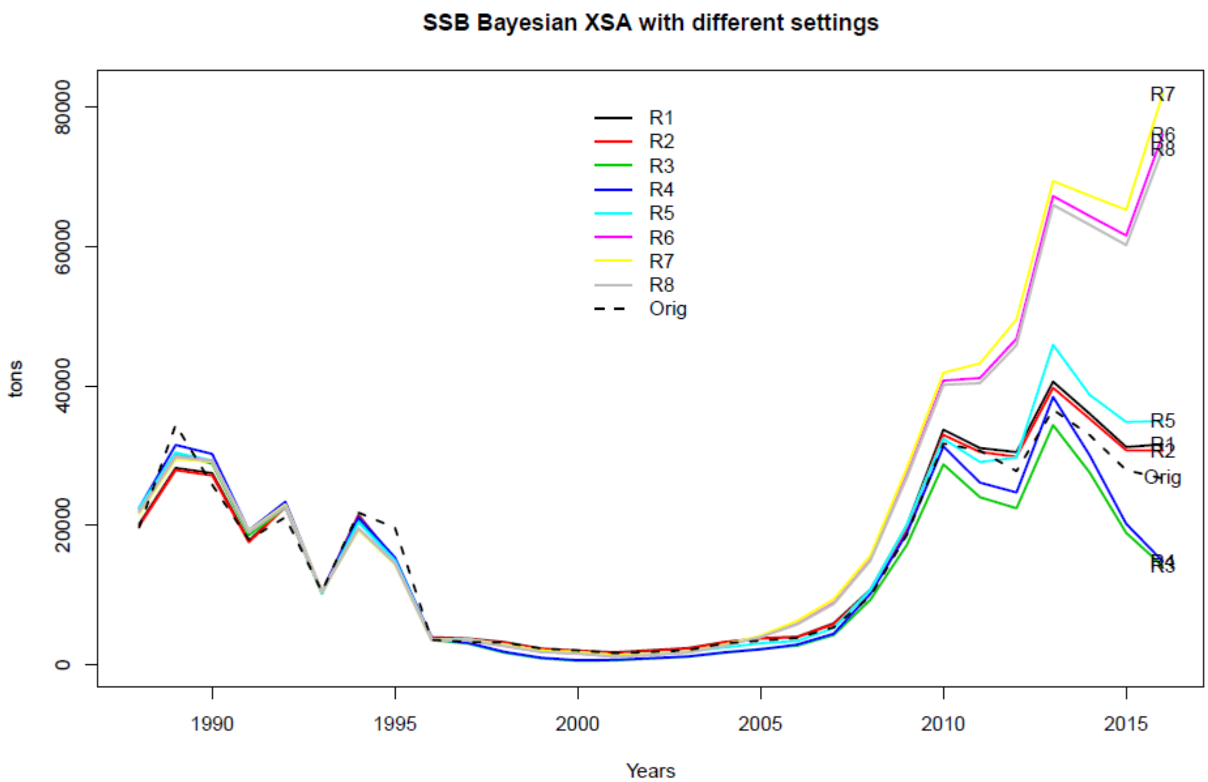

Fig. 4. Results of the posterior median SSB for the different runs of the Bayesian XSA (R1-R8) as well as the approved assessment (labelled as "Orig").

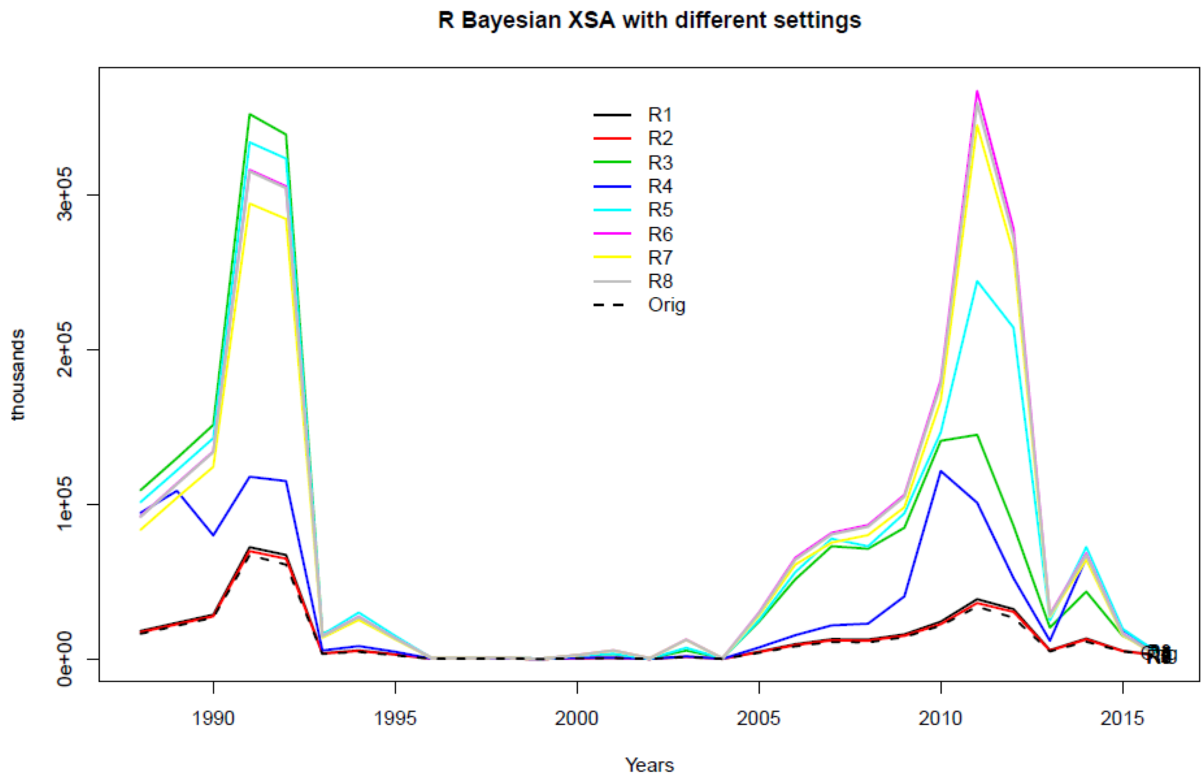

Fig. 5. Results of the posterior median recruitment for the different runs of the Bayesian XSA (R1-R8) as well as the approved assessment (labelled as "Orig").

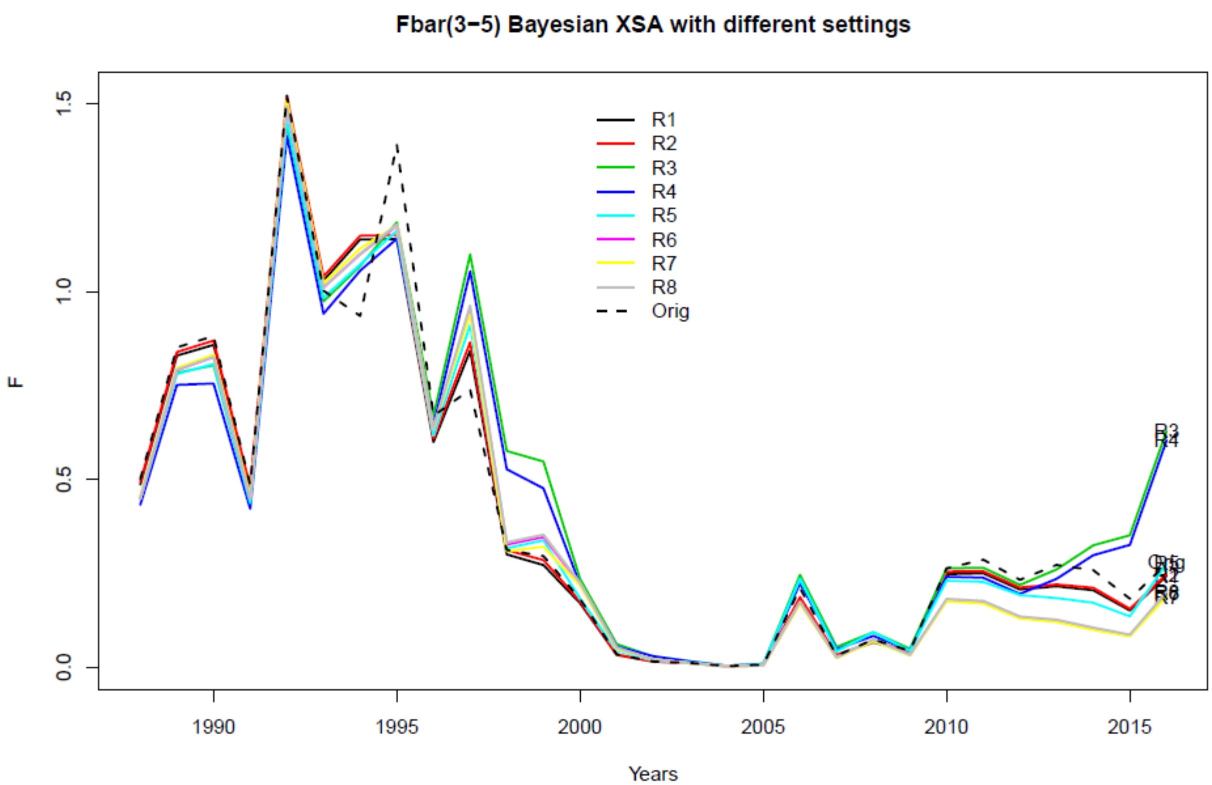

Fig.6. Results of the posterior median Fbar(3-5) for the different runs of the Bayesian XSA (R1-R8) as well as the approved assessment (labelled as "Orig").

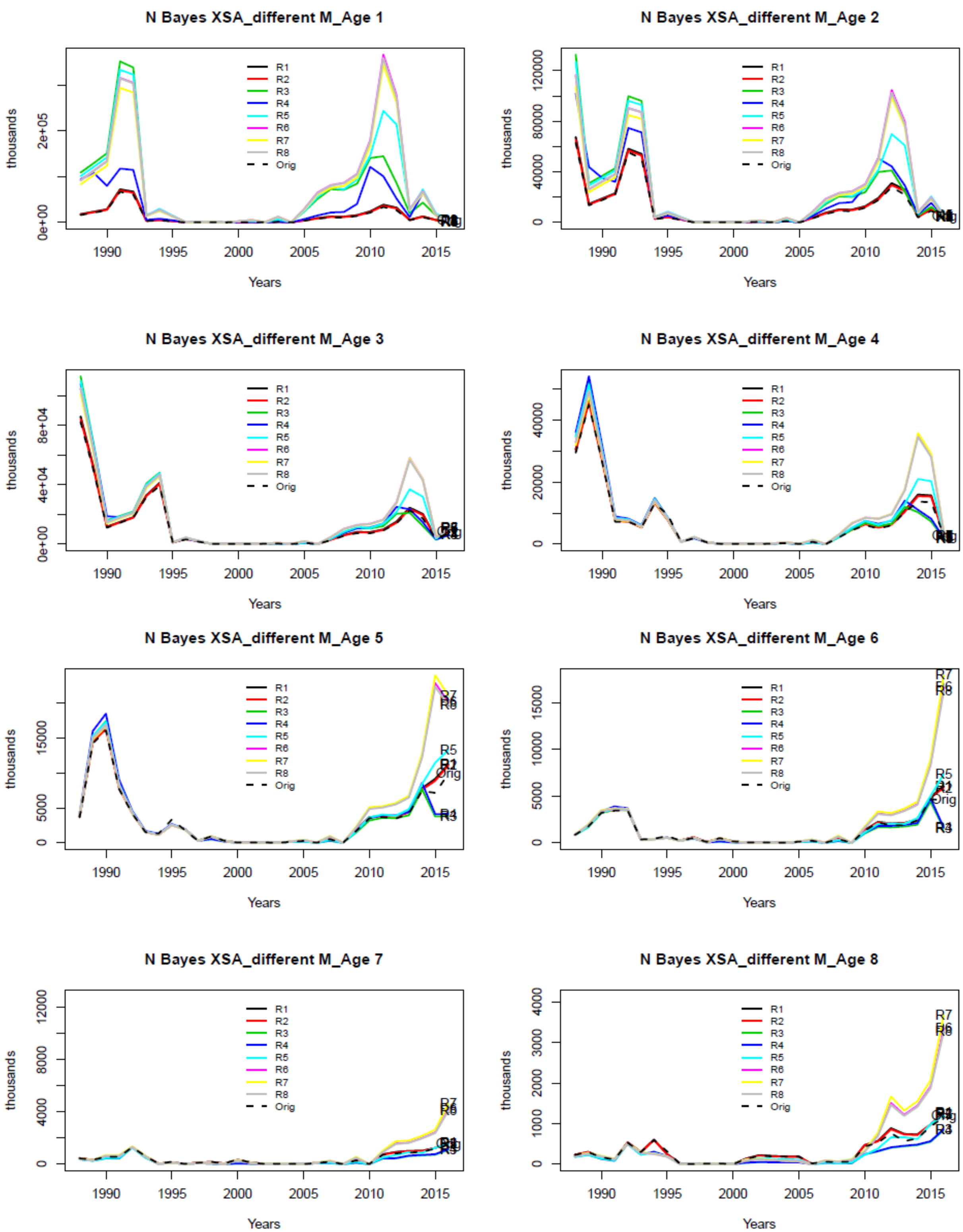

Fig. 7. Results of the posterior median numbers for the different runs of the Bayesian XSA (R1-R8) as well as the approved assessment (labelled as "Orig").

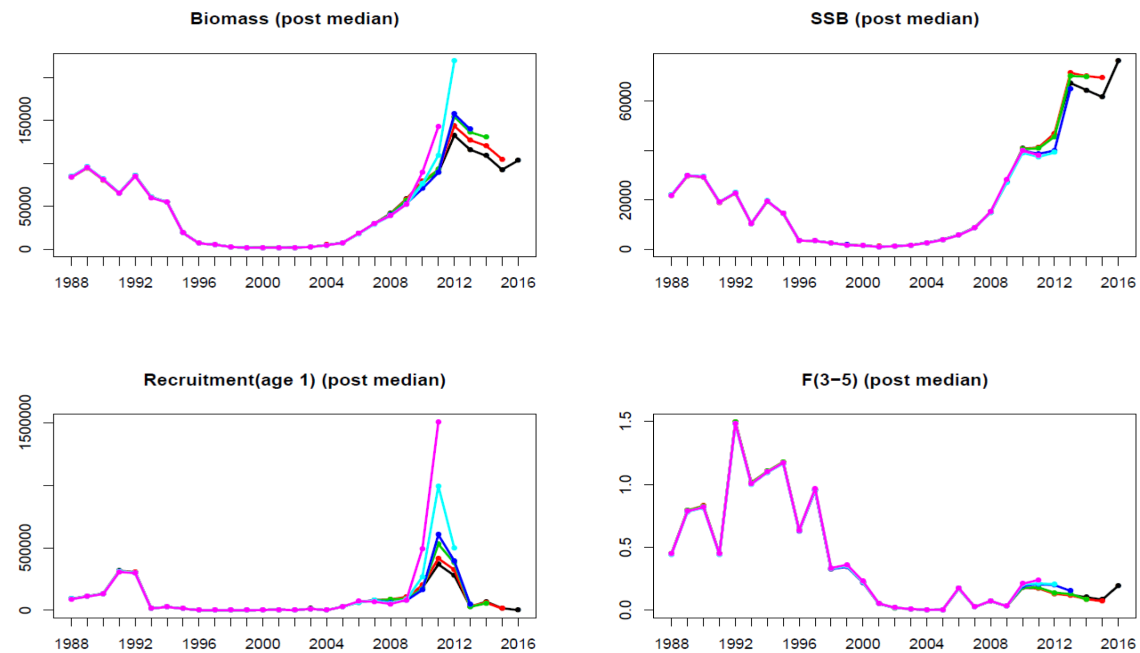

Fig. 8. Retrospective pattern (5 years) for R6.

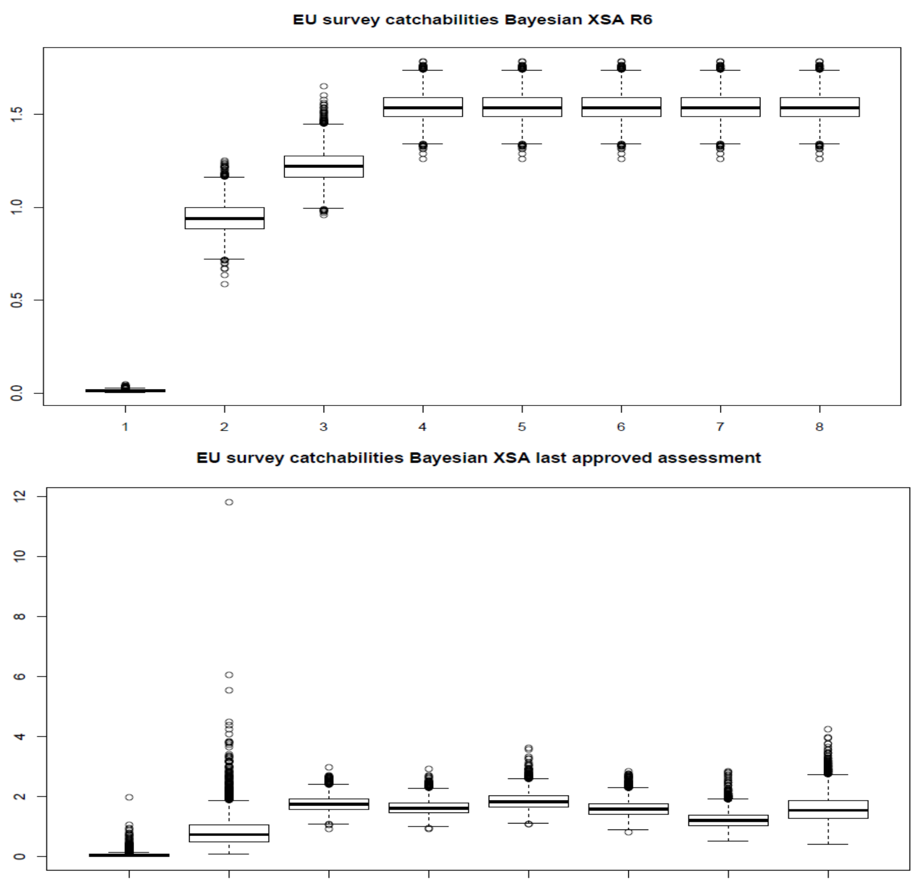

Fig. 9 Survey catchabilities for R6 (up) and for the XSA last approved assessment in 2017 (down).