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3M cod assessment for different assumptions over M

by

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Abstract

M is one of the most influential quantities in fisheries stock assessment and in providing management advice. Cod 3M Bayesian XSA model assumes a lognormal prior over M being constant for all ages and years. Using the same data as in the 2013 assessment, four different scenarios over M were tested: the one assumed in the assessment (M constant over ages and time), one with age variable over three classes and constant for time, one with time variable over three periods and constant over ages, and one variable over three age classes and three periods of time. Although the results indicate the forth scenario as the best one, inconsistencies in them make very difficult to choose one of the scenarios based on the information available and further studies are needed. Nevertheless, it would be advisable that this uncertainty on M will be tested in the MSE process. The scenario 4 could be a good starting point to analyse the uncertainty on M in the 3M cod MSE.

Introduction

This stock had been on fishing moratorium since 1999 to 2009 following its collapse. A VPA based assessment of the cod stock in Flemish Cap was approved by NAFO Scientific Council (SC) in 1999 for the first time and was annually updated until 2002. However, catches between 2002 and 2005 were very small undermining the VPA based assessment, as its results are quite sensitive to assumed natural mortality when catches are at low levels. Cerviño and Vázquez (2003) developed a method which combines survey abundance indices at age with catchability at age, the latter estimated from the last reliable accepted XSA. The method was used to assess the stock since 2003. In 2007 results from an alternative Bayesian model were also presented (Fernández *et al.*, 2007) and in 2008 this Bayesian model was further developed and approved by the NAFO SC (Fernández *et al.*, 2008), having been used since then in the assessment of this stock.

Many of the populations of Atlantic cod (*Gadus morhua*) occurring in the Northwest Atlantic collapsed in the early 1990s. These populations have failed to recover despite severe restrictions on fishery removals over the past 15 years. The main factor delaying the recovery of these populations has been a decline in their productivity, in particular an increase in the Natural Mortality (M) of adult cod (Shelton *et al.*, 2006). Causes of the increases in natural mortality in these populations are uncertain. Survival costs to reproduction are expected to increase as age and size at maturity decline.

The Bayesian model assumes priors over a series of parameters. One of these parameters is M, which in the 3M cod assessment was assumed to have a lognormal distribution with median 0.218, being constant for all ages and years and estimated for each of the iterations. In the 2013 approved assessment (González-Troncoso et al., 2013), the posterior median M value estimated was 0.146. This value is quite different from the M value estimated in others cod stocks. Shelton *et al.* (2006) and Swain (2010) estimated M values for different cod stocks quite higher than the estimated in the 3M cod assessments.

M is one of the most influential quantities in fisheries stock assessment and in providing management advice. M relates directly to the productivity of the stock, the yields that can be sustained and the management reference points. Unfortunately, M is highly uncertain for most fish populations. M is commonly assumed to be constant over age, time and gender, an assumption that is likely to be violated (Vetter, 1988). It is therefore important to evaluate the current assumptions about M used in stock assessment. The aim of this study is to try different assumptions about the variability of M over age and time in the Cod 3M assessment Bayesian model.

Material and Methods

The data used is the same used in the 2013 assessment (González-Troncoso *et al.*, 2013): Fishery data from 1972 to 2012, Canadian survey indices from 1978 to 1995 and EU survey indices from 1988 to 2012. The assessment used is a Bayesian XSA with priors over the survivors, F (for the years without catch-at-age), total catch (for years 2011 and 2012), survey indices and M. The assessment applies a lognormal prior over M constant over age and time.

In order to see the influence of the M estimation in the time series, we tried four different scenarios with different variability assumptions over M in the 3M cod assessment:

1. (Assess 1): Approved assessment: M constant over age and time with a lognormal prior. We have just one prior for all the ages (1-8+) and all the period (1972-2012).

2. (Assess 2): M variable over age for three classes (1-2, 3-5, 6-8+) but constant over time: In this case we have three priors over M, one per age class. We chose these age classes because ages 1 and 2 composed the recruitment, 3 to 5 are the main ages in the fishery and after 6 we have the oldest individuals.

3. (Assess 3): M constant over age but variable over time (1972-1995, 1996-2008, 2009-2012): Based on the analysis made by Gonzalez-Costas and Gonzalez-Troncoso (2014) of the variability of the biological parameters in the 3M cod stock and the fishery, we chose three periods:

   1972-1995: Mean weights at age and recruits per spawner were variable and maturity at age was high and constant till 1990 when started to decline. SSB was variable but normally higher than B_{lim}. The fishery was open.

   1996-2008: SSB and abundance were very low, mean weights presented a big increase. The age of 50% maturity significantly decreased. Recruits per spawner were low till 2003 and high between 2004-2008. The SSB was during all period below B_{lim}. The fishery was closed from 1999 to 2009.

   2009-2012: Mean weights at age and recruits per spawner decreased. The age of 50% maturity increased to levels around 4 years old. The SSB was during all period above B_{lim} and the fishery was open in 2010.

   In this case we have three priors over M, one for each period of time.

4. (Assess 4): Based on the results of the scenarios 2 and 3, the next step was to allow M being variable over age class (1-2, 3-5, 6-8+) and time period (1972-1995, 1996-2008, 2009-2012). In this case we have 9 priors over M.

In all cases, the prior over M is the following one (the same used in the assessment):

$$M \sim LN(\text{median} = 0.218, cv = 0.3)$$

In the scenarios in which we have more than one prior they are computed separately.

Results

With regards to Spawning Stock Biomass (SSB), Recruitment (R) and Fishing mortality (F), we present the results of the assessments for the different scenarios analyzed (Table 1 and Figure 1). In all cases the data presented is the median of the posterior given by the corresponding assessment. Results for SSB, R and F from the assessment are very similar for all the scenarios, so the impact of the assumption of M in the final results seems to be very low. Probably the impact is higher in the calculation of the reference points.

Table 2 presents the value estimated for M in the different scenarios. We can see that the value for M in the different scenarios is quite different. The M value estimated in the Assess 1 (M constant for ages and time) is one of the lowest of the all scenarios (0.15).

Assess 2 (M variable by ages and constant in all time series) estimates M values for ages 1-2 and 6-8 around 0.2. This level of M is more similar to the other cod stocks of the area. The M value estimated for ages 3-5 was similar to the estimate in Assess 1 for all ages and time (0.15).

Assess 3 (M constant by age and variable in time) estimates an increasing value of M with time, the lowest of all M values in the first period (0.13), around 0.2 in the interim period and a value of 0.24 in the last time period.

Assess 4 (M variable by age and variable in time), estimates similar values for ages 1-2 in all the time periods (around 0.2), although a bit higher in the last period (0.23). For ages 3-5 the estimate in the first period is very low (0.14) and for the last period is very high (0.25). For the older ages (6-8+) the highest value is in the interim period, reaching the highest of all estimated values (0.25), being quite similar in the other periods (0.18 for the first period and 0.21 for the last period). Note that for the last time period all the age classes have a posterior median higher than the prior median, with a mean value of 0.23.

For Assess 2 the mean of M is 0.19; for Assess 3, 0.19; and for Assess 4, 0.21. So, it seems that the more priors that we consider, the higher is the posterior median of M and more similar to the median of the prior. Figure 2 presents the priors and posterior distribution of M in each scenario; we can see that in some of the cases the update of the prior distribution is important.

It is curious that in Assess 3 we find two of the main updated values of the series, but one is lower than the prior median (first period, 0.13) and the other is higher (third period, 0.24).

In table 3 the values of the Deviance Information Criterion (DIC) for all the scenarios are shown. It is difficult to say what would constitute an important difference in DIC. Very roughly, differences of more than 10 might definitely rule out the model with the higher DIC, differences between 5 and 10 are substantial, but if the difference in DIC is, say, less than 5, and the models make very different inferences, then it could be misleading just to report the model with the lowest DIC (The Bugs Project, http://www2.mrc-bsu.cam.ac.uk/bugs/winbugs/dicpage.shtml#q3). In our case, based on the DIC values, the best scenario seems to be Assess 4, with M variable by age and time, with a DIC value of 757.6, and the worst Assess 1, with a DIC of 772.6. But the differences are not so evident and the way the DIC works is unclear, so more technical investigation about the method to choose between models is needed.

Discussion

The M value estimated in Assess 1 (M constant for ages and time) is the second lowest of the all scenarios (0.15) and is very low compared with the M value assumed in other cod stocks of the NAFO area. The other scenarios present similar means M values, around 0.2. This value is more similar to the M value assumed in other cod stocks of the NAFO area.

When we just make variable the age (Assess 2), the highest update in the prior distribution is on ages 3-5, and when we only vary the time period (Assess 3), it is in years 1972-1995. When both, age and time, are variable (Assess 4), the highest variation is at ages 3-5 and years 1972-1995, too. So, it seems to be a consistence in those values. On the other hand, the highest value of M, that is reached in Assess 4 to ages 6-8+ and years 1996-2008, has no a correspondence in Assess 2 (by ages) and in Assess 3 (by years). The second highest, reached in ages 3-5 for years 2009-2012, agrees with Assess 3 but no with Assess 2.

The scenarios with time variable (Assess 3 and Assess 4) have some inconsistent results; in the first period (1972-1995), Assess 3 estimates a M value very low (0.13) compared with the mean value estimated for this period in Assess 4 (0.17). The second and last periods have quite consistent results in both scenarios, with a lower M value in the second period (1996-2008) compared with the last period (2009-2012).

The scenarios with age variation in M (Assess 2 and Assess 4) also present inconsistencies in their results. The M estimates for ages 3-5 and 6-8+ in the scenario 2 are quite lower than those in the scenario 4 for these age ranges. The low value of M (0.15) estimated in scenario 2 for ages 3-5 is striking compared with the mean value estimated for these ages in the scenario 4 for all the periods. In this scenario it is difficult to explain the high value estimated in the last period for the range age 3-5 (0.25).

Shelton *et al.* (2006) found that M for cod stocks had increased significantly between mid-nineties and mid last decade and that this was one of the reasons why cod stocks did not recover despite being in fishing moratorium. The results of our analysis are somewhat contradictory to those found by Shelton *et al.* (2006) and show regular values of M in more or less the same period and higher values in the most recent period when the biomass and abundance have increased considerably.

The high values found in the scenario 4 for ages 6-8+ could be related with some migration tax. De Cardenas *et al.* (1992) found that when cod reaches maturity, a migration from Flemish Cap to Grand Banks would take place, its intensity varying from year to year. For these ages the highest estimated M (0.25) was in the period 1996-2008. This high M value could be the cause of the lack of recovery of the 3M cod in this period as described by Swain (2010) for the cod stock in the Southern Gulf of St. Lawrence (SGSL). This stock, as the 3M cod stock, collapsed in the early 1990s and has shown no recovery since then, due mainly to high natural mortality of adult cod.

In the scenario 4 for ages 1-2, the different levels found for the different periods could be explained by the abundance in these periods. The cannibalism in cod is described by different authors. This cannibalism is related with the abundance of adult cod. In our results, the highest M found for these ages was in the 2009-2012 period, when the abundance of 3M cod was quite high, especially for the adult cod.

Based on these results, the inconsistencies in the results make very difficult to choose one of the scenarios based on the information available. We think that it would be better to explore more deeply how the Bayesian approach works in terms of updating the prior over M before changing the current assessment model. However, we think that it would be advisable that this uncertainty on M will be tested in the MSE process. Scenario 4 could be a good Operating Model to analyse the uncertainty on M in the 3M cod MSE since this is the scenario that collects more variability over M.

Acknowledgements

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Table 1.- Medians of SSB, R and F for the four scenarios.

	SSB				R				F			
Year	Assess 1	Assess 2	Assess 3	Assess 4	Assess 1	Assess 2	Assess 3	Assess 4	Assess 1	Assess 2	Assess 3	Assess 4
1972	36391	37486	36003	37024	15740	17815	14820	17650	0.714	0.700	0.724	0.707
1973	20050	20552	19830	20335	54135	61205	50305	60755	0.606	0.592	0.613	0.598
1974	14862	15555	14686	15245	107400	121500	100000	120600	1.411	1.373	1.435	1.393
1975	7613	8007	7502	7792	19850	22585	18290	22350	0.710	0.675	0.727	0.692
1976	8451	9103	8231	8793	8820	9956	8202	9902	0.357	0.347	0.366	0.352
1977	20662	21532	20399	21114	2592	3004	2373	2938	0.480	0.466	0.488	0.473
1978	28139	29064	27754	28639	17680	19910	16465	19820	0.488	0.474	0.496	0.481
1979	23838	25235	23560	24472	11810	13575	10960	13360	0.743	0.722	0.756	0.733
1980	11425	12042	11268	11729	6535	7550	5976	7454	0.582	0.561	0.593	0.571
1981	13055	13669	12774	13292	18210	20670	16880	20480	0.524	0.513	0.535	0.519
1982	13004	13420	12776	13190	17975	20370	16620	20180	0.630	0.606	0.642	0.617
1983	11895	12552	11653	12232	11320	12840	10510	12740	0.295	0.280	0.304	0.287
1984	19076	20112	18618	19564	12785	14630	11850	14440	0.247	0.238	0.251	0.242
1985	20521	21218	20265	20890	51070	57555	47520	57150	0.600	0.582	0.610	0.591
1986	15301	15903	15065	15603	105700	118700	99265	118100	0.779	0.755	0.794	0.767
1987	12374	12967	12156	12701	66980	74980	63020	74640	0.458	0.440	0.469	0.450
1988	18924	19499	18528	19160	13800	15510	12870	15430	0.520	0.507	0.532	0.514
1989	33285	33987	32589	33594	18600	20840	17510	20730	0.877	0.859	0.892	0.868
1990	25188	25856	24714	25479	23560	26330	22330	26200	0.915	0.890	0.931	0.902
1991	17541	18277	17152	17932	59850	66210	57150	66070	0.504	0.494	0.513	0.499
1992	20769	21466	20516	21142	54180	60350	51725	60395	1.563	1.539	1.581	1.551
1993	10410	10698	10239	10536	2924	3258	2893	3321	1.044	1.020	1.061	1.030
1994	21322	21773	21014	21576	3996	4680	4355	5132	0.963	0.954	0.970	0.953
1995	19144	19449	19049	19442	2109	2438	2366	2648	1.417	1.384	1.390	1.353
1996	3461	3588	3645	3762	126	151	161	171	0.669	0.640	0.631	0.611
1997	3259	3461	3482	3655	121	146	158	167	0.749	0.701	0.690	0.656
1998	3318	3582	3573	3816	187	220	233	243	0.307	0.278	0.276	0.256
1999	2375	2660	2593	2829	32	37	39	41	0.290	0.260	0.261	0.240
2000	2170	2391	2331	2517	305	361	390	418	0.195	0.182	0.174	0.167
2001	1776	1959	1858	2050	541	651	693	731	0.035	0.033	0.032	0.031
2002	2015	2101	2040	2151	65	78	82	86	0.014	0.014	0.014	0.014
2003	2325	2317	2296	2327	1160	1377	1472	1535	0.011	0.011	0.011	0.011
2004	3464	3364	3359	3327	76	90	96	97	0.003	0.003	0.003	0.003
2005	3786	3708	3709	3684	3464	4169	4782	4874	0.006	0.006	0.006	0.006
2006	4089	4256	4185	4314	7094	8498	10060	10410	0.217	0.204	0.197	0.196
2007	5787	6000	6039	6144	9299	10870	12990	13790	0.029	0.028	0.028	0.027
2008	10059	10711	11399	11588	7517	8666	10350	10810	0.075	0.069	0.067	0.067
2009	19205	20310	21848	22306	12300	14340	16975	17455	0.043	0.040	0.038	0.038
2010	32152	34028	34736	35360	19385	21990	25315	26070	0.283	0.270	0.256	0.251
2011	33436	35175	33867	34537	48170	55070	59885	62520	0.302	0.287	0.280	0.274
2012	29060	30646	28604	29408	28025	30620	32395	33445	0.363	0.343	0.361	0.346

Table 2.- Median of M for the four different scenarios.

Assess 1	1-8+		
1972-2012	0.15		

Assess 2	1-2	3-5	6-8+
1972-2012	0.20	0.15	0.21

Assess 3	1-8+		
1972-1995	0.13		
1996-2008	0.20		
2009-2012	0.24		

Assess 4	1-2	3-5	6-8+
1972-1995	0.20	0.14	0.18
1996-2008	0.21	0.18	0.25
2009-2012	0.23	0.25	0.21

Table 3.- DIC value for the different scenarios

	DIC
Assess 1	772.6
Assess 2	767.4
Assess 3	762.9
Assess 4	757.6

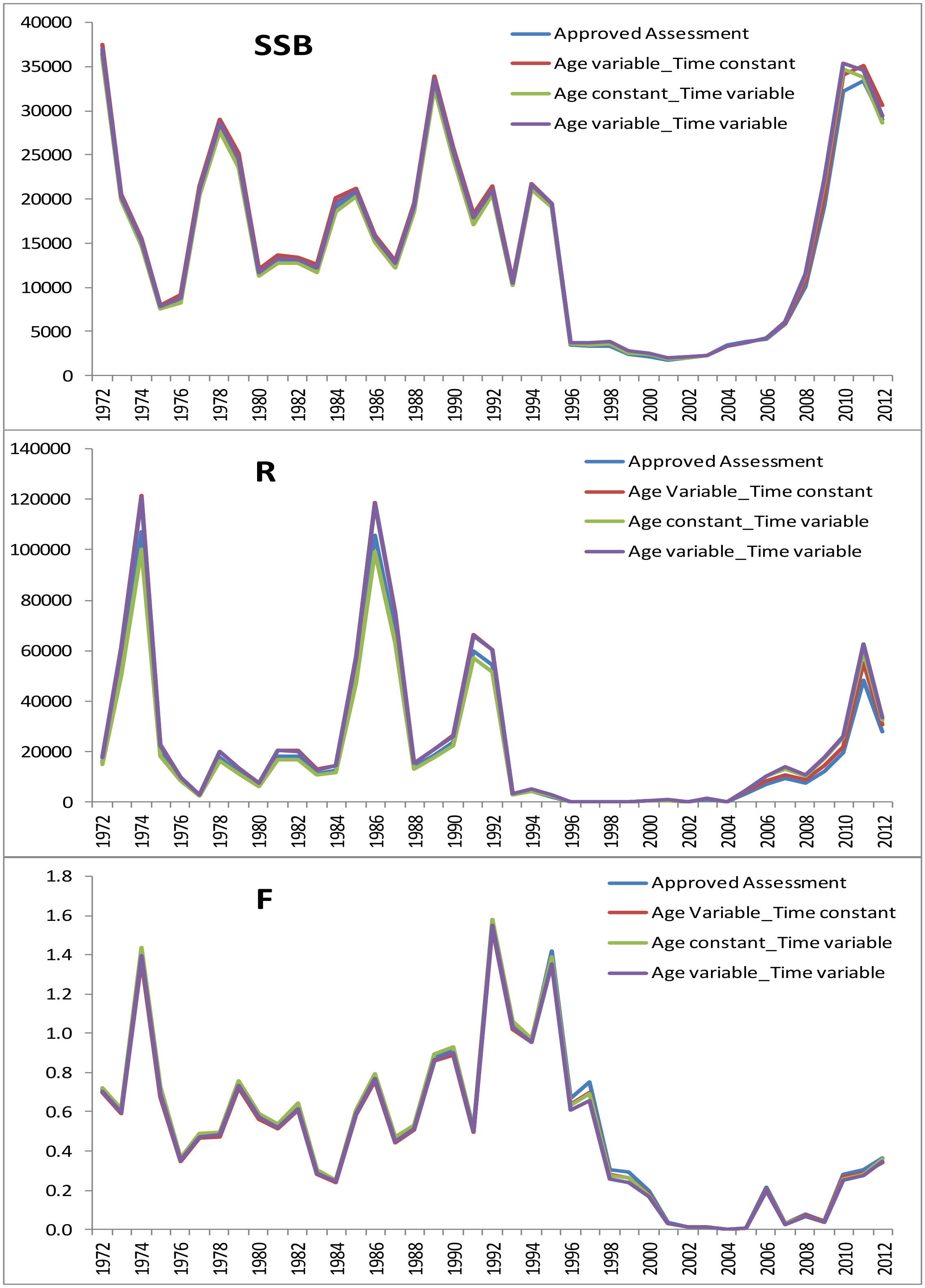
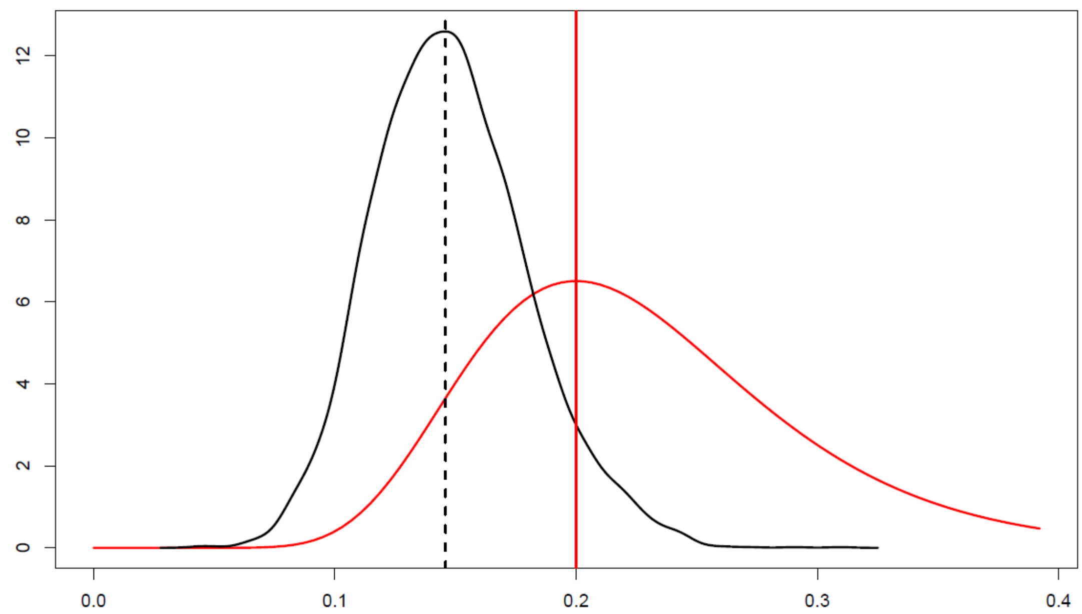


Figure 1.- Medians of SSB, R and F for the four scenarios

Assess 1



Assess 2

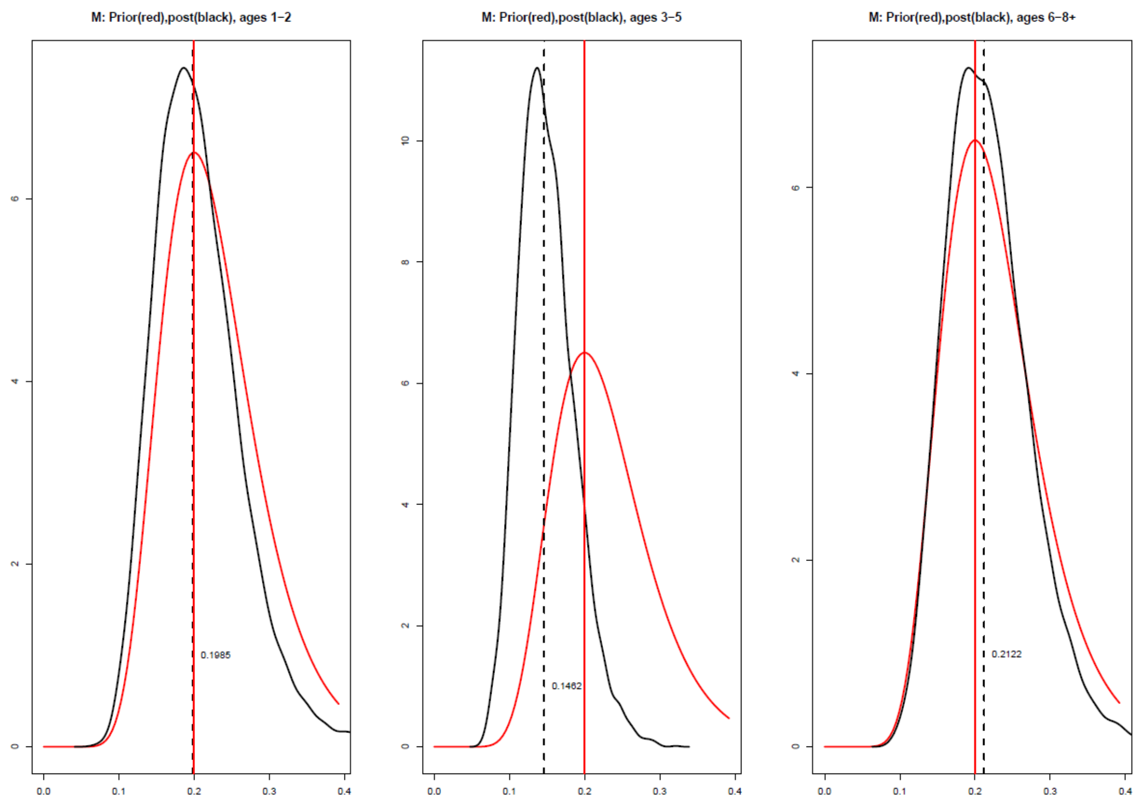
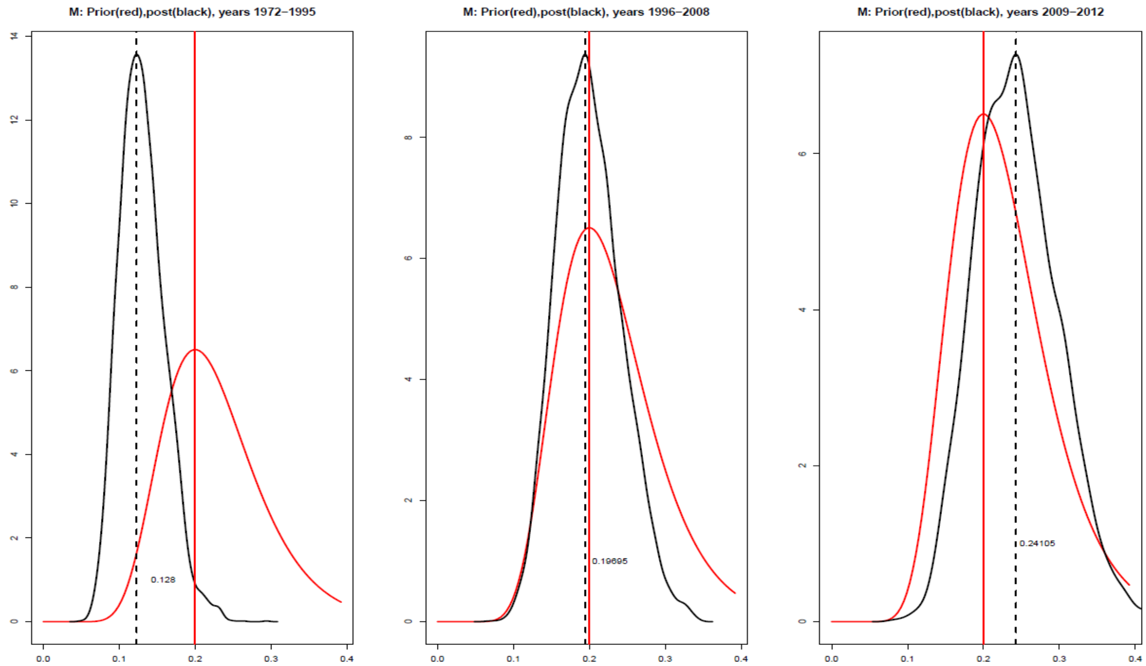


Figure 2.- Prior and posterior of M over all the scenarios

Assess 3



Assess 4

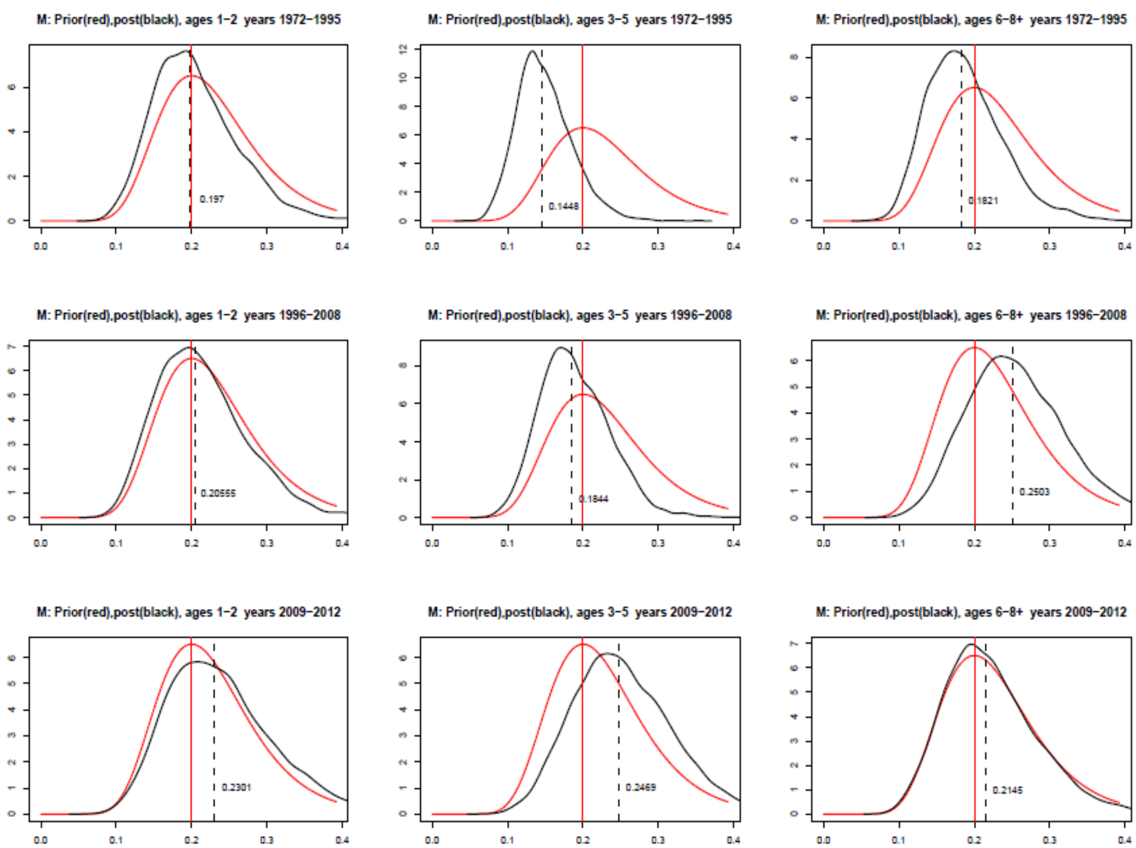


Figure 2 (cont.).- Prior and posterior of M over all the scenarios