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Northwest Atlantic Fisheries Organization

Serial No. N6313 **NAFO SCR Doc. 14/19**

SCIENTIFIC COUNCIL MEETING – JUNE 2014

Biological Reference Points of 3M cod

by

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Abstract

The aim of this document is to propose the values for F_{msy} proxies references points based on the YPR-SPR analysis taking in account the possibility of changes in productivity and the level of recruitment. It was analyzed the YPR and SPR inputs (mean weights, partial recruitment and maturity ogive) to study the possibility of changes in productivity in the past and its impact in the reference points estimated values. Based on the results we proposed estimate the Fmsy proxies with the long period (1972-2012) data to avoid the clear inputs (weights, maturity, partial recruitment) trends in the most recent period. We also propose to chose F30% SPR as the Fmsy best proxy in the 3M Cod case to avoid the risk of recruitment overfishing.

Introduction

The assessment of the NAFO 3M cod stock has been performed every year since 2008 using the Bayesian model (Fernández *et al.*, 2008). A B_{lim} of 14 000 tons was proposed by the NAFO Scientific Council in 2000. The appropriateness of this value given the results from the new method used to assess the stock was examined in 2008, concluding that it is still an appropriate reference.

The NAFO Fisheries Commission formally adopted a Precautionary Approach (PA) framework in 2004 (NAFO/FC Doc. 04/17) as proposed by NAFO Scientific Council (NAFO SCS Doc. 03/23). The SC framework provides a structure that included limits, buffers, targets and management strategies that would adjust fishing mortality to keep stocks in the Safe Zone. In 2012, Fisheries Commission requested to Scientific Council: *to provide B_{msy} and F_{msy} for cod in Div. 3M.*

In 2013, NAFO Scientific Council discussed the 3M cod reference points based on the results of the study presented by Gonzalez-Troncoso et al, 2013. This study used the stock recruitment (S/R) data for 3M cod 2013 assessment (Gonzalez-Troncoso et al., 2013). Three different S/R models were fit to these data. Results show that no stock recruitment relationship fits appropriately the 3M cod data and the Scientific Council (NAFO, 2013) noted that the level of B_{msy} estimated from Yield per Recruit (YPR) and Spawning Per Recruit (SPR) depends on assumptions about the level of recruitment. So, more research about the possibility of changes in productivity and the level of recruitment that should be used to estimate the MSY is needed.

A major management objective in fisheries is to keep stocks at levels capable of producing maximum sustainable yields (MSYs). Management objectives based on MSY or related reference points (e.g. fishing mortality that produces MSY (F_{msy}); spawner-per-recruit proxies) are in use for many species and stocks worldwide. The various reference points require different amounts and types of information, ranging from biological information (e.g. natural mortality, growth, and stock-recruitment relationship) and fisheries characteristics (e.g. age-specific selectivity), to absolute estimates of biomass and exploitation rates.

The Fisheries Commission and Scientific Council Joint Working Group on Risk-Based Management Strategies (FC SC RBMS) proposed for 3M cod two HCRs to be tested under the MSE approach (NAFO, 2014). The first one is based on fishing mortality assessment model results (model based HCR) and the second one is based on survey indices (model free HCR). Four different levels of F will be considered as Ftarget, corresponding to probabilities of 20%, 30%, 40% and 50% of exceeding F_{msy}. If F_{msy} is not available, an appropriate proxy (e.g. F_{max}, current proxy) should be used.

The aim of this document is to propose the values for F_{msy} proxies references points based on the YPR-SPR analysis taking in account the possibility of changes in productivity and the level of recruitment.

Material and Methods

The 3M cod assessment performed since its reopening fishery in 2010 uses a Bayesian XSA model. In 2014 this assessment was approved during the Scientific Council meeting of June using commercial data from 1972 to 2013 and the Canadian survey (1978-1985) and the EU survey (1988-2013) as tuning series. Ages used were 1-8+. The number of iterations made for the Bayesian assessment was 5000, so we have 5000 iterations of all the parameters of the assessment. To see the details about this assessment, see González-Troncoso (2014).

The mean weights (both in catch and in stock), maturity ogive and partial recruitment at age inputs used in this study to estimate the YPR and SPR Reference Points (RP) were the same of the 3M Cod 2014 approved assessment. This was a stochastic assessment having 5000 iterations. Mean-weight-at-age in the catch and mean-weight-at-age in the stock are assumed with no uncertainty, so the value of these parameters for the 5000 iterations is the same. The natural mortality M was assumed constant for all years and ages and was estimated for each of the iterations. The median M value estimated in the last assessment was 0.156.

Data Time Series trends

YPR can be used to explore the expected yield under equilibrium conditions, of growth, maturity and natural mortality, for a given or assumed fishery pattern, across a range of exploitation levels. Weights at age and maturities change with time and are affected by density dependence. The selection pattern used should reflect the contemporary situation to take in account of contemporary trends.

It was analyzed the YPR and SPR inputs (mean weights, partial recruitment and maturity ogive) to study the possibility of changes in productivity in the past and its impact in the reference points estimated values.

Mean Weights at Age and Abundance: It was chose the mean weight for ages 3 to 5 to observe the stock mean weight at age trends. Figure 1 present the stock mean weights at age (3-5) and the abundance for ages 3 to 5. It can be observed different trends: 1972-1985 the mean weights were variable; 1985-1995 the mean weights were more or less stables, 1996-2007 a clear increase trend in the mean weights and 2008-2013 a clear decrease trend in the mean weight. Since the middle of the eighties these mean weights trends seems to be negative correlated with the abundance, low abundance have a high mean weights and when the abundance increase the mean weight decrease.

Recruits per Spawner: Figure 2 presents the recruits per spawner for the median SSB and recruitment. Trend in the 1972-1991 was very variable with high and low levels. The 1992-2003 presents a constant very low level. Since 2003 till 2006 the recruits per spawner increased and since then till 2013 decrease to mean levels. It should be noted that the 2013 point is poorer estimated due to uncertainty in recruitment.

Maturity at Age: Figure 3 shows the median and the 95% confidence interval of the age of 50% maturity. The period 1972-1992 present a quite constant age of 50% maturity around 5 years old. From 1993 till 2002 this age decreased till 3 years old. Since then increase till 2011 where the age of 50% maturity was around 4 years old. In the last two years the 50% maturity age has decrease until 3.4.

Maturity and mean weights at age seem to be correlated with the abundance, high abundances present low mean weights and older age of 50% of maturity while low abundances present the opposite. Based on these parameters trends and in the different biomass levels it was decided to divide the time series in three different periods depending on if the SSB was below or above the Blim (14.000 t) (Figure 4):

1972-1995: Mean weights at age and recruits per spawner were variable and maturity at age was high and constant till 1990 where start to decline. SSB was variable but normally higher than Blim . The fishery was open.

1996-2008: SSB and abundance were very low, mean weights present and 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 Blim. The fishery was closed from 1999 to 2009.

2009-2013: Mean weights at age and recruits per spawner decrease. The age of 50% maturity decrease to levels around 3.5 years old. The SSB was during all period above Blim and the fishery was open in 2010.

Partial Recruitment: The median partial recruitment by age was estimated for each year as the median F at age divided by the Fbar (3-5). A partial mean recruitment at age was estimated for the different periods. The exploitation patters of these different periods and for the whole series (1972-2013) are show in Figure 5. It can be seen that the1972-1995, 2009-2013 and the 1972-2013 partial recruitments are similar between then and different to the period 1996-2008 where the stock started to decline and SSB was below Blim. Despite SSB being below Blim the fishery was open until 1998. Fishery was closed in 1999 until 2009.

YPR and SPR Results

YPR reference points F_{max} and $F_{0.1}$ and the SPR reference points $F_{20\%}$, $F_{30\%}$ and $F_{40\%}$ were estimated in the periods above described and for the whole series 1972-2013. The reasons to choose these SPR levels were that values in the range $F_{20\%}$-$F_{30\%}$ have frequently been used to characterize recruitment overfishing thresholds (Rosenberg *et al.*, 1994), while values in the range $F_{30\%}$ to $F_{40\%}$ have been proposed as F_{msy} proxies (Gabriel and Mace, 1999). The percentage SPR level to use as F_{msy} proxy depends on the resilience to fishing of the species.

Figure 6 shows the results for the fishing mortality YPR (F_{max} and $F_{0.1}$) and SPR ($F_{20\%}$, $F_{30\%}$ and $F_{40\%}$) reference points with uncertainty for the different periods and Table 1 presents the median values estimated. The results shows that all reference points values estimated in the last period (2009-2013) and in the whole period (1972-2013) are very similar and slightly higher than those of the 1972-1995 period while the values for the period 1996-2008 are very different and much higher than the previous ones.

Sensitive Analyses

Natural mortality (M) is one of the most influential quantities in fisheries stock assessment and the calculation of management advice. M relates directly to the productivity of the stock, the yields that can be sustained, and 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 the stock assessment.

In the 2013 cod 3M assessment approved, the natural mortality M was assumed constant for all years and ages and was estimated for each of the iterations. The median M value estimated was 0.156. 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 assessment. We analyzed the sensitive of the RP to different values of M. The median for the whole period data for mean weights, partial recruitment, maturity ogive and M at age were used to test the sensibility in deterministic way. Figure 7 shows the equilibrium SSB results for different M values for F_{max}, $F_{0.1}$ and $F_{20\%}$. Results show a high sensitivity to the M value.

Gonzalez-Troncoso and Gonzalez-Costas (2014) analyzed different M assumptions and their impact in the 3M cod 2013 assessment. The assumptions analyzed were M variable in time and age and the SC concluded that it is better to maintain the actual structure of the assessment model about M (M constant for all ages and period) because it is very difficult to the model estimate so much parameters when we assumed M variable. The median M value constant for all ages (1-8+) and period (1972-2013) estimated in the 2014 assessment was 0.156.

Discussion

If a time series of YPR inputs are available, the objective to choose the inputs in the short term projections should be sufficient year range to smooth out short term noise or measurement error but short enough to take account of contemporary trends. But to establish limited reference points with uncertainty we understand that it will better take as long as possible the data to include all the past variation in the estimation provided that this long term values are not very different of the contemporary situation.

In the 3M cod case we propose take the long period (1972-2013) data to estimate the F_{msy} proxy because the long term period have a quite similar results in all proxies to the actual period (2009-2013) although the long term has incorporated the variability observed in all the inputs time series and the most actual period have a very big trend in all inputs (weights, maturity, partial recruitment) and we do not know how these trends will evolutionary in the future. Based on these reasons we discuss only the results of the long term (1972-2012) YPR and SPR F references points presented in the Figure 6.

The NAFO PA Framework (NAFO, 2003) defined F_{lim} as a fishing mortality rate that should only have a low probability of being exceeded. F_{lim} cannot be greater than F_{msy}. If F_{msy} cannot be estimated, then an appropriate surrogate may be used instead.

The lack of fit of the S/R relationships is one of the major problems in 3M cod to estimate F_{msy} (Gonzalez-Troncoso *et al*., 2013). F_{max} was one of the earliest measures used as a proxy for F_{msy}. However, it was often believed to be an overestimate of F_{msy}, because it does not account for the fact that recruitment must decline at low spawning stock sizes. Computer models have also demonstrated that F_{max} invariably overestimates F_{msy} if a Beverton-Holt stock-recruitment relationship applies, although F_{msy} can sometimes exceed F_{max} with a Ricker curve. The ICES Workshop on Implementing the ICES FMSY framework (ICES, 2010) recommended that if there is clear peak at low F in the YPR analysis, and there is no evidence of recruitment dependence on SSB, then a check should be made that the equilibrium SSB implied by this target F is within the observed range of SSB, under this condition F_{max} may be appropriate proxy of F_{msy}.

In the 3M cod there are clear evidences of recruitment dependence on SSB at low SSB levels, low recruitment have been observed at SSB less than 14.000 tons. The recruitment dependence on biomass is less clear at medium and high SSB levels although a certain decrease of the recruitment at high SSB levels can be observed in the R/SSB plot (Gonzalez-Troncoso *et al.*, 2013). Figure 8 shows the YPR and SPR curves for the long term period (1972-2013) periods and it can be observed the curves present a clear maximum peak (F_{max}). It is not clear for us if the F_{max} in the 3M cod case is the best F_{msy} proxy due to the recruitment decline at low spawning stock sizes and probably F_{max} overestimate F_{msy}.

Spawner biomass per recruit analysis should be routinely evaluated in addition to YPR; an advantage of SPR based proxies is that they take into account directly the reproductive capacity of the stocks. Several studies have provided range values for guidelines on percentage for spawner per recruit ratios (in reference to unexploited stocks) expected for different life history types of exploited stocks. There is not a single level of % SPR that is optimal for all stocks and the proposal for F_{msy} should include some consideration of life history. Values in the range of $F_{20\%}$ to $F_{30\%}$ (% SPR relative to SPR at F=0) have been characteristic of recruitment overfishing (Rosenberg et al. 1994). Initial studies show that values of $F_{30\%}$ to $F_{40\%}$ could be used as proxies for F_{msy} (Goodyear 1993, Mace and Sissenwine 1993). These studies suggested $F_{20\%}$ as a minimum threshold for avoiding recruitment overfishing for stock with average resilience (Mace and Sissenwine 1993). Further studies by Clark (1991, 1993) concluded that $F_{35\%}$ and higher were robust proxies for F_{msy}, considering uncertainty in stock-recruitment functions and or recruitment variability.

The NAFO Study Group on Limit Reference (NAFO, 2004) considered that when a SR relationship or a production relationship cannot be determined from the available data, consideration should be given to SPR analysis as a means of determining F_{lim}. The determination of the appropriate %SPR for use as F_{lim} depends on the biology of the population. For some stocks 35%SPR may be too low and values of 40% or 50% may be more appropriate. Although this approach provides a useful way to scale the F to the biology of the species, it is not easy to link it to sustainable F levels equivalent to F_{msy}. It was noted that %SPR would be very sensitive to changes in stock productivity such as an increase in M. Despite these shortcomings, %SPR provides an approach that can be applied to stocks when other analyses are not possible. %SPR of 35% should be used as a default F_{lim} for such stocks in the absence of meta analysis considerations or other considerations to suggest it should be higher or lower.

Mace and Sissenwine (1993) found that the Atlantic cod has the smallest mean replacement %SPR of the 90 stocks analyzed by them, suggesting that it has relatively high resilience to fishing with the degree of resilience being inversely related to the magnitude of the replacement %SPR. In the 3M cod case this high resilience to fishing could be confirmed by the rapid stock recovery in the last few years. This low replacement % SPR could suggest a low F%SPR as F_{msy} proxy as was suggested by Mace and Sissenwine (1993). We propose a $F_{30\%}$ (% SPR relative to SPR at F=0) as a candidate to F_{msy} proxy in the case of the 3M cod.

Table 2 present the 10, 20, 30, 40, 50, 60, 70, 80 and 90 percentiles of the distribution of F_{max} and $F_{30\%}$ SPR estimated with the 1972-2013 data.

The Fisheries Commission and Scientific Council Joint Working Group on Risk-Based Management Strategies (FC SC RBMS) proposed for 3M Cod two HCRs to be tested under the MSE approach (NAFO, 2014). The first one is based on fishing mortality assessment model results (model based HCR) and the second one is based on survey indices (model free HCR). Four different levels of F will be considered as Ftarget, corresponding to probabilities of 20%, 30%, 40% and 50% of exceeding Fmsy. If Fmsy is not available, an appropriate proxy (e.g. F_{max}, current proxy) should be used. Table 3 presents the Yield Per Recruit, Spawning Per Recruit, the equilibrium yield and SSB for these probabilities of the F_{max} and F30% SPR distribution calculated with the 1972-2013 data. To estimate the equilibrium situation by iteration we have used the mean of the recruitment of the 1972-2013 periods of each iteration. We decided to use all the recruitment series because we are looking for a limited reference points more than a target. Results show that even the F values for F_{max} and F30% SPR are different the yield are quite similar for both cases while the SSB show a slight different being higher in the F30% SPR case.

Conclusions

Based on the results we proposed estimate the Fmsy proxies with the long period (1972-2013) data to avoid the clear inputs (weights, maturity, partial recruitment) trends in the most recent period.

We also propose to chose F30% SPR as the Fmsy best proxy in the 3M Cod case to avoid the risk of recruitment overfishing.

Acknowledgements

This research was funded by the European Union founds under the Framework Contract MARE/2012/21 - "Scientific advice for Fisheries beyond EU Waters" - Specific Contract No 2 (SI2.681887) “Provision of advice on the development of a multiannual management plan and the evaluation of a management strategy for cod in NAFO Division 3M (SAFEwaters-2)”.

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Table 1.- Median values estimated for Fishing mortality YPR (F_{max} and $F_{0.1}$) and SPR ($F_{20\%}$, $F_{30\%}$ and $F_{40\%}$) reference points for the different periods and total time series inputs.

	Fmax	F0.1	F20%	F30%	F40%
1972-1995	0.128	0.074	0.164	0.106	0.074
1996-2008	0.315	0.193	0.300	0.210	0.151
2009-2013	0.139	0.081	0.209	0.134	0.091
1972-2013	0.163	0.094	0.201	0.133	0.091

Table 2.- Percentiles (10, 20, 30, 40, 50, 60, 70, 80 and 90) of the distribution of F_{max} and $F_{30\%}$ SPR estimated with the 1972-2013 data.

	Fmax	F30%
10%	0.138	0.109
20%	0.145	0.116
30%	0.151	0.121
40%	0.156	0.128
50%	0.163	0.133
60%	0.168	0.137
70%	0.174	0.143
80%	0.181	0.149
90%	0.194	0.159

Table 3.- Yield Per Recruit, Spawning Per Recruit, the equilibrium yield and SSB for the 10, 20, 30, 40, 50, 60, 70, 80 and 90 percent probabilities of exceeding F_{max} and F30% SPR.

	Fmax	YPR	SSBPR	Yield (t)	SSB (t)
10%	0.138	0.818	3.091	20174	141818
20%	0.145	0.911	3.674	21000	128020
30%	0.151	0.980	4.158	21687	118414
40%	0.156	1.041	4.588	22255	110930
50%	0.163	1.102	5.046	22812	104503
60%	0.168	1.164	5.517	23423	98330
70%	0.174	1.233	6.078	24101	92225
80%	0.181	1.317	6.784	24916	84764
90%	0.194	1.438	7.832	26084	76585

	F30% SPR	YPR	SSBPR	Yield (t)	SSB (t)
10%	0.109	0.810	3.711	19995	176509
20%	0.116	0.902	4.421	20810	157646
30%	0.121	0.971	5.014	21478	144446
40%	0.128	1.031	5.539	22033	134758
50%	0.133	1.090	6.105	22570	126545
60%	0.137	1.152	6.704	23167	118453
70%	0.143	1.220	7.427	23832	110942
80%	0.149	1.301	8.350	24610	101929
90%	0.159	1.419	9.761	25726	91931

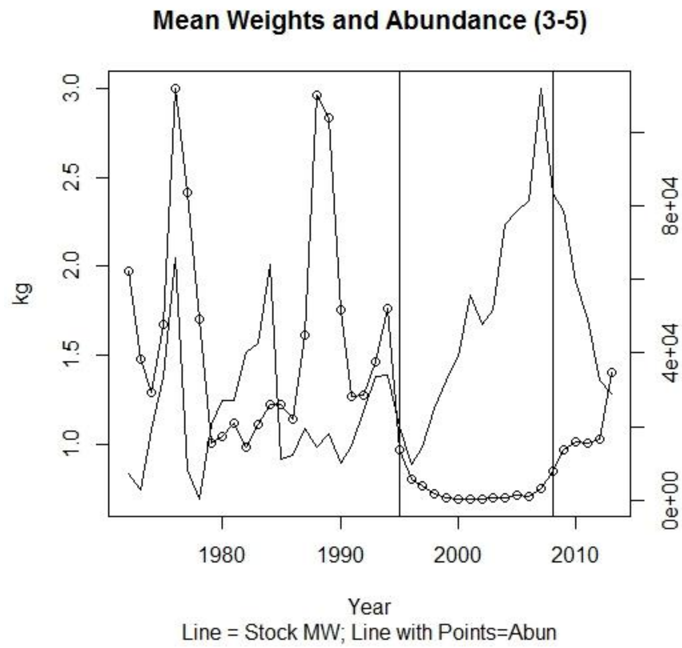

Figure 1.- Cod 3M; stock mean weights at age (3-5) and the abundance for ages 3 to 5 series 1972-2013 from the 2014 assessment. Vertical lines are the time periods suggested in this document to analyze the YPR and SPR RP.

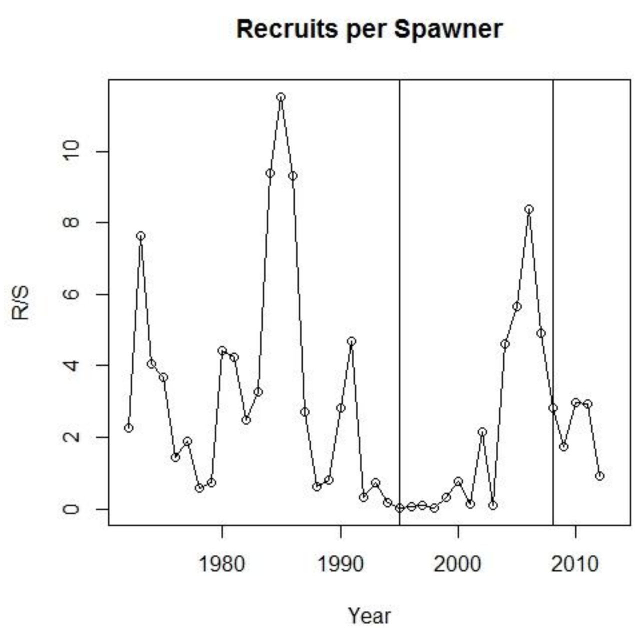

Figure 2.- Recruits per spawner for the median SSB and recruitment estimated in the 2014 3M cod assessment. Vertical lines are the time periods suggested in this document to analyze the YPR and SPR RP.

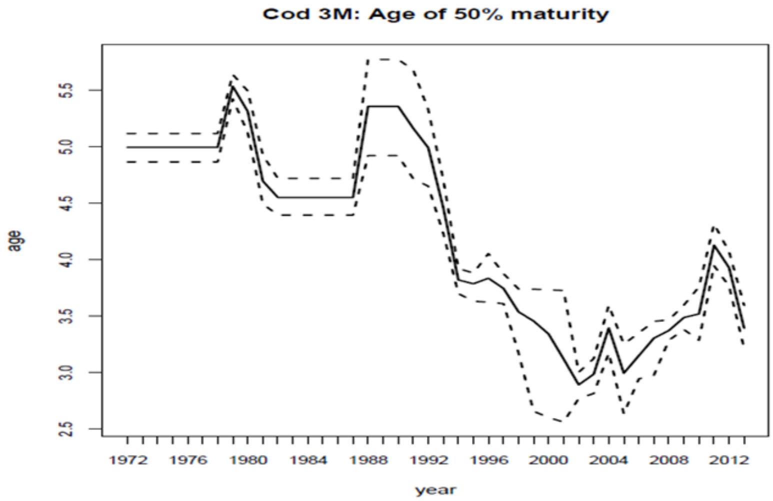

Figure 3.- Median and the 95% confidence interval of the age of 50% maturity. Vertical lines are the time periods suggested in this document to analyze the YPR and SPR RP.

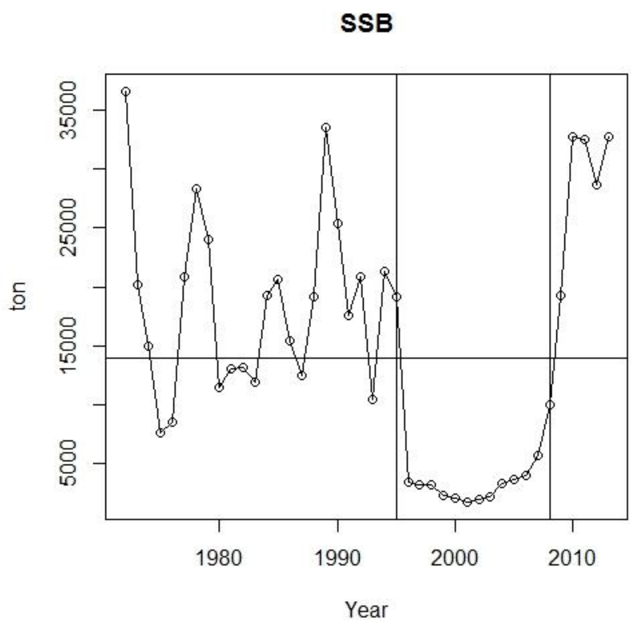

Figure 4.-SSB results for the 3M cod 2014 assessment. The horizontal line is the Blim value (14.000 ton) and the vertical lines are the period suggested in this document to analyze the YPR and SPR RP.

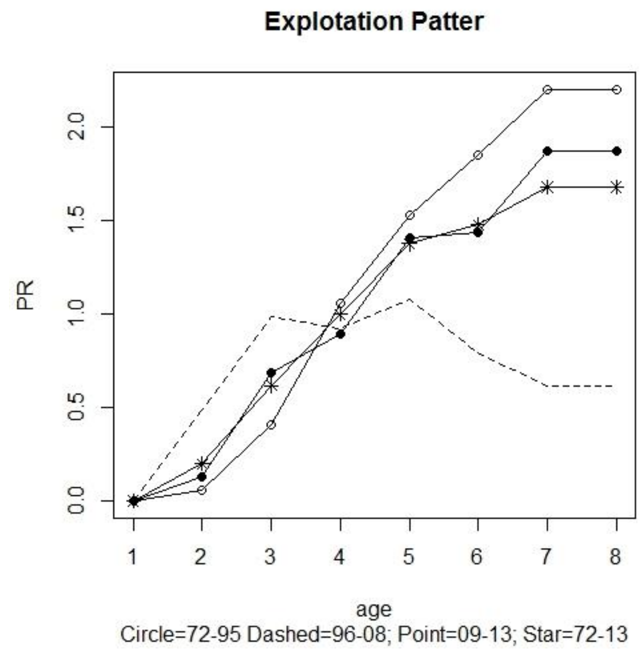

Figure 5.- Median partial recruitment by age for the different time periods.

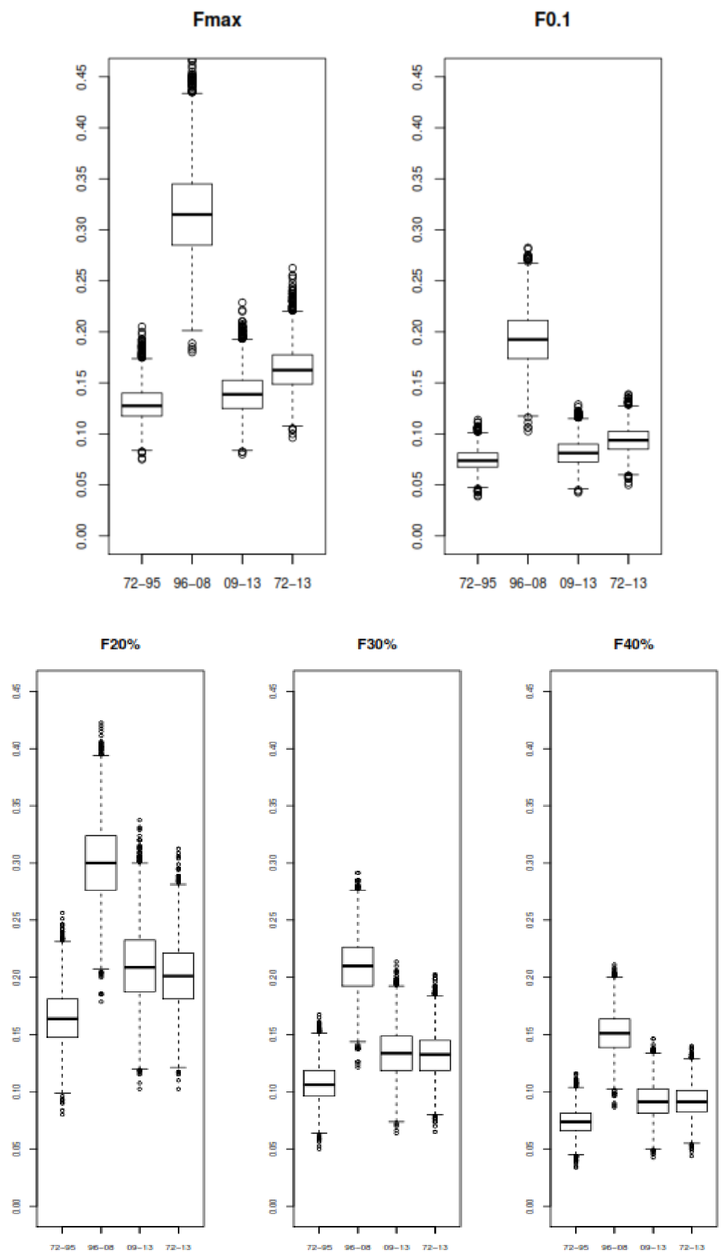

Figure 6.- Fishing mortality YPR (F_{max} and $F_{0.1}$) and SPR ($F_{20\%}$, $F_{30\%}$ and $F_{40\%}$) reference points with uncertainty for the different periods and total time series inputs.

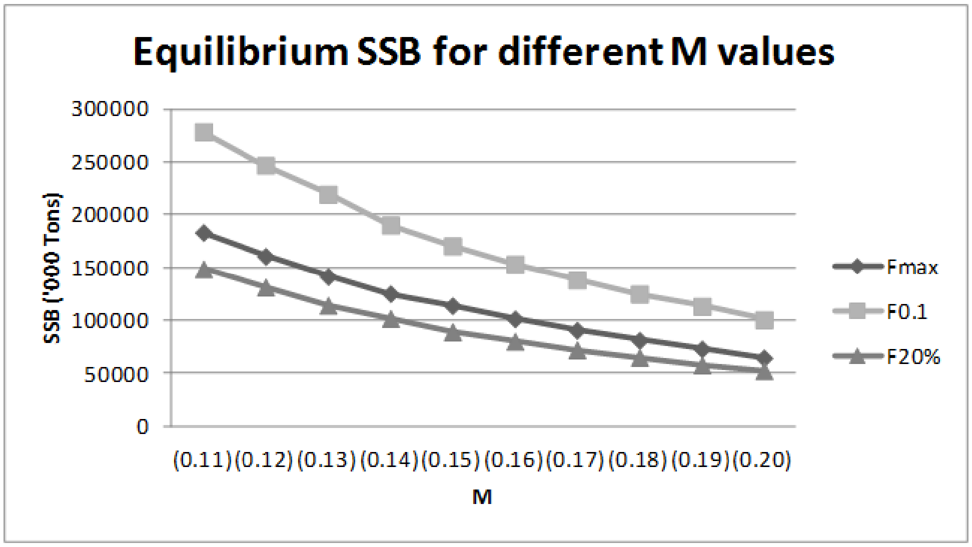

Figure 7.- Equilibrium SSB results for different M values for F_{max}, $F_{0.1}$ and $F_{20\%}$..These values are deterministic and were estimated with the median inputs for the weights, maturity at age and partial recruitment of the whole series.

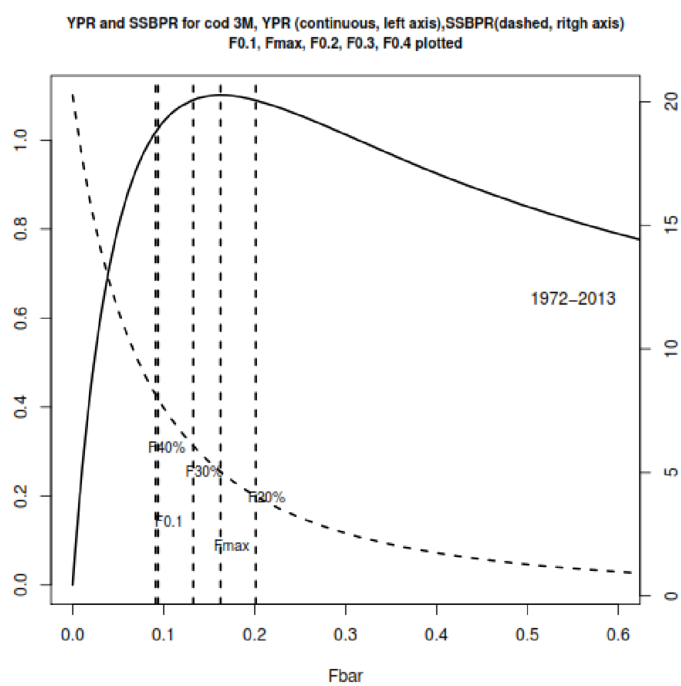

Figure 8.- YPR and SPR curves for the long term period (1972-2013) period. Vertical lines are the YPR (F_{max} and $F_{0.1}$ means) and SPR ($F_{30\%}$, $F_{35\%}$ and $F_{40\%}$ means) references points levels.