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Biological Reference Points for Cod Div. 3NO

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Abstract

In 2011 Fisheries Commission Working Group of Fishery Managers and Scientists on Conservation Plans and Rebuilding Strategies (WGFMS-CPRS) reviewed the cod 3NO Conservation Plan and Rebuilding Strategy (CPRS) and proposed a new one that was approved by the Fisheries Commission in 2011. The new reference points values approved for the 3NO cod CPRS were the following: B_{lim} = 60,000 t, B_{isr} = 120,000 t, F_{lim} = 0.30 and B_{msy} = 248,000 t. Concerns were raised on the high uncertainty and the lack of confidence intervals of the reference points. The WGFMS-CPRS agreed that the values of B_{isr} and B_{msy} should be further reviewed by the Scientific Council and the Fisheries Commission.

In 2012, Scientific Council noted that: *the approach used in estimation of the maximum sustainable yield (MSY) reference points may not be advisable in the case of Div. 3NO cod due to the high uncertainty in the stock-recruit relationship for this stock. Scientific Council recommends the use of proxies based on the yield per recruit (YPR) and spawner per recruit (SPR) to estimate the reference points for cod in Div. 3NO. The proxies for the limit references points estimated through YPR were very similar to the Limited reference points approved. However, the B_{msy} estimated based on the YPR was different to the B_{msy} estimated last year.* The aim of this document is to revise the values for the B_{msy} references points based on the YPR-SPR. This document presents new B_{msy} references points based on the YPR-SPR taking in account same ideas expressed during the 2012 SC meeting.

It could be proposed a value around $F_{0.1}$ (0.19) or $F_{35\%}$ (0.20) as a possible F_{target}. The reason to choose this value is that a small reduction in the YPR supposes a precautionary level of F that has a very low probability to be higher than $F_{lim} = F_{max}$ (less than 5%) and it is similar to SPR $F_{35\%}$. A good candidate for B_{target} based on the YPR estimation could be the equilibrium SSB estimated with all the recruitments produced by the SSB bigger than B_{lim}. A good B_{target} level could be the equilibrium SSB of the proposed F_{target} ($F_{0.1}$ or $F_{35\%}$) estimated with all the recruitments produced by the SSB bigger than B_{lim}. This gives a value around 180,000-185,000 tons. In the cod 3NO case, and taking a similar definition for B_{isr} as the ICES $MSYB_{trigger}$, a B_{isr} candidate could be a value around 120,000 ton if we take a very low probability (less than 5%) or 135,000 ton if we take a low probability (less 10%). These values came from biomass point which is expected with a low probability in a fully productive stock which is fished at F_{target} proposed.

Introduction

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.

The 3NO Atlantic cod (*Gadus morhua*) is managed by NAFO. The stock collapsed in the early-1990s, and was placed under moratoria on directed fishing in 1994. Spawning Stock Biomass (SSB) has been since then near its minimum levels with some increase recently (Power *et al.*, 2010). In 2007 NAFO adopted a Conservation Plan and Rebuilding Strategy for 3NO cod (CPRS) that identified a limit reference point of 60,000 t.

In 2011, NAFO Scientific Council discussed the 3NO cod reference points based on the results of the study presented by Shelton and Morgan, 2011. This study used the stock recruitment (S/R) data for 3NO cod from the most recent assessment (Power *et al.*, 2010). Six different S/R models were fit to these data. While no particular S/R approach is strongly supported by the data, the authors chose the Loess smoother fitted to log recruitment as the base for deriving reference points. The references points were estimated through simulation by running the population to equilibrium with the dynamics determined by the S/R relationship, together with weights, maturity and partial recruitment vectors. Scientific Council notes that the available data for 3NO cod do not span the entire production curve and therefore large uncertainty in the estimated reference points can be expected (NAFO SCS Doc. 11/16).

The 3NO Cod CPRS was first adopted by the Fisheries Commission in 2007 and in force since 2008 (NAFO/FC Doc. 07/24). In 2011 Fisheries Commission Working Group of Fishery Managers and Scientists on Conservation Plans and Rebuilding Strategies (WGFMS-CPRS) reviewed the 3NO cod CPRS and proposed a new one that was approved by the Fisheries Commission in 2011 (NAFO/FC Doc. 11/22). The new reference points values approved for the 3NO cod CPRS were the following: B_{lim} = 60,000 t, B_{isr} = 120,000 t, F_{lim} = 0.30 and B_{msy} = 248,000 t. Concerns were raised on the high uncertainty and the lack of confidence intervals of the reference points. The WGFMS-CPRS agreed that the values of B_{isr} and B_{msy} should be further reviewed by the Scientific Council and the Fisheries Commission.

In 2012, Scientific Council revised the maximum sustainable yield (MSY) reference points for Div. 3NO cod approved in 2011 by the Fisheries Commission based on the document presented by Gonzalez-Costas and Gonzalez-Troncoso (2012). The Scientific Council noted that: *the approach used in estimation of the maximum sustainable yield (MSY) reference points may not be advisable in the case of Div. 3NO cod due to the high uncertainty in the stock-recruit relationship for this stock. Scientific Council recommends the use of proxies based on the yield per recruit (YPR) and spawner per recruit (SPR) to estimate the reference points for cod in Div. 3NO. Using this approach Scientific Council estimated the YPR and SPR reference points with uncertainty for Div. 3NO cod. The proxies for the limit references points estimated through YPR were very similar to the* F_{msy} *estimated last year based on Loess smoother applied to log-transformed recruitment values from the VPA and the current* B_{lim}*. However, the* B_{msy} *estimated based on the YPR was different to the* B_{msy} *estimated last year. Scientific Council noted that the level of* B_{msy} *estimated from YPR-SPR depends on assumptions about the level of recruitment. Scientific Council concluded that more research about the possibility of changes in productivity is needed to better estimate this reference point* (NAFO SCS Doc. 12/19*).*

The aim of this document is to revise the values for the B_{msy} references points based on the YPR-SPR analysis made by Gonzalez-Costas and Gonzalez-Troncoso in 2012. This document presents new B_{msy} references points based on the YPR-SPR taking in account same ideas expressed during the 2012 SC meeting.

Data

The data used in this document are exactly the same used by González-Costas and González-Troncoso in 2012 (NAFO SCR Doc. 12-020). A summary of these data is the following:

The biological data and the results of the last approved NAFO assessment for 3NO cod (Power *et al.*, 2010) for the 1959-2009 period.

The Partial Recruitment (PR) was calculated for each year as the F at age divided by the maximum F at age of each year. The mean PR by age for the period 1959-2009 was calculated; these means were referenced to mean PR ages 4 to 6.

Partial recruitment, stock weight, catch weights and maturity vectors used in the YPR analysis were calculated as long-term average (1959-2009). The reasons to choose the long term average is to capture the variability observed in

the inputs to estimate the candidate for a long term reference points more than the usual three years average used in the medium term projections.

Figure 1 presents the SSB and F assessment results and the Biological References Points (BRPs) approved in 2011 by the NAFO Fisheries Commission.

Yield per Recruit (YPR) and Spawning per Recruit (SPR) reference points

In the present analysis, the YPR reference points (F_{max} and $F_{0.1}$) were estimated as well as the Spawning per Recruit (SPR) reference points for $F_{30\%}$, $F_{35\%}$ and $F_{40\%}$ of the SSB unfished level. For these reference points, biological uncertainty was incorporated in growth, maturation and in the fishery through variability in the partial recruitment. To incorporate the uncertainty, a bootstrap with 1000 iterations was carried out over the years to the whole period (1959-2009). Maturity, partial recruitment, stock and catch weights were bootstrapped together from the selected year range. The main reason to perform the bootstrap over the years was that more of the variability of weights, maturity and partial recruitment should be related with the particular environmental conditions of each year. With this bootstrap data, a new mean was calculated for weights, maturity ogive and partial recruitment and YPR and SPR analyses were carried out with these new means.

Table 1 and Figure 2 presents the values for the different fishing mortality YPR and SPR reference points estimated without uncertainty and the median, the 90^{th} and 80^{th} percentile values of the Bootstrap distribution. In all F references points the deterministic values are quite close to the median of the bootstrap distribution. F_{max} values are the highest of the F BPRs estimated and $F_{0.1}$ and $F_{35\%}$ have very similar levels.

Figure 3 shows the YPR and SPR median curves for different F values. It also showed the F_{max}, $F_{0.1}$, $F_{30\%}$, $F_{35\%}$ and $F_{40\%}$ median values. It can be observed that the YPR curve presents a maximum quite well defined and that the SPR reference points estimated are around the $F_{0.1}$ value.

To estimate the B_{msy} and B_{isr} levels based on the YPR and SPR reference points it was decided to carry out a bootstrap only with the recruitment produced by level of biomass more than the B_{lim} approved (60,000 t). Table 2 presents the SSB and the recruits produced by this SSB of the last approved assessment. The deterministic equilibrium yield and SSB for all F reference points were calculated with the mean recruitment produced by level of biomass more than the B_{lim} applied to the deterministic YPR and SPR estimated for the different F reference points. With uncertainty, for each iteration was calculated a mean bootstrap recruitment produced by the SSB bigger than B_{lim} (60.000 t) and applied to the YPR and SPR. Table 3 presents the deterministic, median, 80^{th} and the 90^{th} percentiles of the Bootstrap distribution for these values. In the case of the equilibrium SSB and yield, the median of both values are very close to the deterministic values in all scenarios.

Discussion

NAFO Fisheries Commission (NAFO/FC Doc. 11/22) adopted in 2011 the Interim 3NO cod CPRS. This document established the following cod 3NO reference points (Figure 1): Blim = 60,000 t, Bisr = 120,000 t, Bmsy = 248,000 t and Flim=Fmsy = 0.30. The base for some of these values was the SCR 11/39 by Shelton and Morgan.

Shelton and Morgan chose the Loess logs fit between the Ricker, Beverton-Holt, Segmented Regression, Loess, Loess logs and GAM to estimate the Biological References points. The lack of fit of the S/R relationships is one of the mayor problems in 3NO cod as showed in González-Costas and González-Troncoso (2012). In 3NO cod, there are not strong justifications to choose one among the several analyzed stock-recruit relationships as noted the Scientific Council (2012): *the approach based on the stock-recruit relationship for the estimation of the maximum sustainable yield (MSY) reference points may not be advisable in the case of Div. 3NO cod due to the high uncertainty in the stock-recruit relationship for this stock and recommended the use of proxies based on the yield per recruit (YPR) and spawner per recruit (SPR) to estimate the B_{msy} reference points for cod in Div. 3NO*.

The proxies for the limit references points (F_{lim} and B_{lim}) estimated through YPR by González-Costas and González-Troncoso (2012) were very similar to the estimated in 2011 based on Loess smoother applied to log-transformed

recruitment values from the VPA by Shelton and Morgan. The mayor different were in the B_{msy} values estimated by the two methods. The basic idea used in this document to estimate the B_{msy} reference points through the YPR is to use only the recruitments produced by the SSBs that are greater than B_{lim} to estimate the equilibrium biomass and yield corresponding to the different values of the YPR and SPR F references points (F_{max}, $F_{0.1}$, $F_{30\%}$, $F_{35\%}$ and $F_{40\%}$) to choose the best candidate as B_{msy} proxy in the cod 3NO case. We assume that the mean recruitments produced by the SSB bigger than B_{lim} should give in the equilibrium a proxy of B_{msy}.

One of the problems assuming this level of recruitment could be the possibility of changes in productivity as pointed out the Scientific Council (2012). In the 3NO cod case, all the recruitments produced by the SSBs greater than B_{lim} have occurred before 1988 and since then the SSB never reach the B_{lim} values (Table 2). If this was due to changes in productivity and now the productivity regime is different than the observed before 1988, the values estimated in this document probably are not the good ones in this new productivity scenario. There is very little information available about the productivity regime in the cod 3NO case. We have the example of the 3M cod, which after a long series of years of very low recruitment and SSB, these were recovered in recent years to levels even higher than those observed before the 90´s. Probably, as more data become available, it will be easier to understand the productivity regime of this stock and calculate a more appropriate PA references points.

The NAFO PA Framework specifies that F_{target} should be chosen to ensure that there is a low probability (<20%) that F exceeds F_{lim}, and a very low probability (<5-10%) that biomass will decline below B_{lim} within the foreseeable future (5-10 years). Table 1 shows the different values estimated for the YPR F reference points (F_{max} and $F_{0.1}$) as well as the Spawning per Recruit (SPR) F reference points for $F_{30\%}$, $F_{35\%}$ and $F_{40\%.}$ It can be observed that all the F YPR and SPR reference points ($F_{0.1,}$ $F_{30\%}$, $F_{35\%}$ and $F_{40\%}$) have a very low probability to exceed the F_{lim} approved (F_{lim}=0.30), similar to the value estimated for F_{max}. It could be proposed a value around $F_{0.1}$ (0.19) or $F_{35\%}$ (0.20) as a possible F_{target}. The reason to choose this value is that a small reduction in the YPR supposes a precautionary level of F that has a very low probability to be higher than F_{lim} = F_{max} (less than 5%) and it is similar to SPR $F_{35\%.}$ This value (35% maximum SPR) what suggested by Clark (1991) as a management target that should be capable of achieving high yields for a wide range of plausible spawning-recruitment relationships. The replacement biological reference points can be used as a basis for recruitment overfishing definitions because they do not take account of compensation (Mace and Sissenwine, 1993). They found that Cod have a relative low value of replacement %SPR (7%SPR) suggesting relatively high resilience to fishing. This %SPR value of replacement is very low compare with the suggested target of the 35%SPR.

A good candidate for B_{target} based on the YPR estimation could be the equilibrium SSB estimated with all the recruitments produced by the SSB bigger than B_{lim}. The reason to choose only these recruitments is because to estimate the target levels should be taking in account only the recruitments produced by a fully productive stock, in this case SSB bigger than B_{lim}. Figure 3 shows fishing mortality YPR (F_{max} and $F_{0.1}$), SPR ($F_{30\%}$, $F_{35\%}$ and $F_{40\%}$) as well as their correspondent SSB (Figure 4) and Yield (Figure 5) assuming mean recruitment produced by the SSB bigger than B_{lim} (Table 3). Based on these reasons a good B_{target} level could be the equilibrium SSB of the proposed F_{target} ($F_{0.1}$ or $F_{35\%}$) estimated with all the recruitments produced by the SSB bigger than B_{lim}. This gives a value around 180,000-185,000 tons. There is a very low probability, less than 5%, in long term fishing with the proposed target mortalities the biomass was less than the B_{lim} value.

The adopted Interim 3NO Cod Conservation Plan and Rebuilding Strategy established an intermediate stock reference point (B_{isr}) with the intention of delimiting the zone between B_{lim} and B_{msy}. The value approved for B_{isr} in 3NO cod was the double of B_{lim} (120,000 t). There was not biological reason to choose this value. The Scientific Council (2012) noted that: *Providing advice on a new intermediate reference point and selecting an appropriate level depends on the purpose and on the properties that such a reference point would have. The purpose of the proposed B_{isr} is not clear to Scientific Council. If the purpose is to serve as a 'milestone' for the Fisheries Commission to track rebuilding, then the reference point can have any value that the Fisheries Commission wishes. If the purpose of the B_{isr} is to mark the beginning of the safe zone, or to mark an SSB above which h there is a high probability of being above B_{lim}, or if the purpose is to mark any zone for which there would be some change in an HCR, then analyses as to the appropriate level would need to be conducted. Scientific Council can not advise on particular levels until it is clear as to the purpose of B_{isr}.*

Waiting for the Fisheries Commission purpose and definition of the B_{isr}, and if the purpose of this new reference point is similar to the ICES concept of a trigger point $MSYB_{trigger}$, which simply triggers action of reducing the

exploitation from F_{msy} or F_{target} under the condition where the biomass moves out of the expected range. $MSYB_{trigger}$ is a biomass point which is expected with a low probability in a fully productive stock which is fished at F_{msy} or F_{target}. $B_{trigger}$ should be selected as a biomass that is encountered with low probability if F_{msy} is implemented. In the 3NO case, and taking a similar definition for B_{isr} as the ICES $MSYB_{trigger}$, a B_{isr} candidate could be a value around 120,000 ton if we take a very low probability (less than 5%) or 135,000 ton if we take a low probability (less 10%). These values came from biomass point which is expected with a low probability in a fully productive stock which is fished at F_{msy} or F_{target} proposed (Table 3).

Figure 6 shows 2010 fishing mortality and SSB assessment results with the new proposed biomass and fishing mortality Reference points.

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Table 1.- YPR reference points (F_{max} and $F_{0.1}$) and SPR reference points ($F_{30\%}$, $F_{35\%}$ and $F_{40\%}$) estimated without uncertainty and the median, the 90th and 80th percentile values of the Bootstrap distribution.

	F_{max}	$F_{0.1}$	$F_{30\%}$	$F_{35\%}$	$F_{40\%}$
Deterministics	0.296	0.193	0.232	0.200	0.173
5%	0.275	0.180	0.221	0.190	0.164
10%	0.280	0.183	0.224	0.193	0.166
50%	0.296	0.193	0.231	0.199	0.172
90%	0.314	0.204	0.239	0.206	0.178
95%	0.319	0.207	0.242	0.208	0.180

Table 2.- SSB and the recruits produced by this SSB of the last approved assessment. In bold and shaded the years were the SSB was more than B_{lim}.

Year	SSB (tons)	Recruits (age2)	Year	SSB (tons)	Recruits (age2)
1959	72220	130098	**1985**	81743	15495
1960	65509	94606	**1986**	79667	15391
1961	73881	135041	**1987**	78905	6149
1962	72532	195488	1988	58126	6811
1963	74393	252970	1989	48380	24281
1964	81886	221171	1990	39188	7694
1965	125043	121541	1991	29456	779
1966	107524	154111	1992	13493	483
1967	67006	96818	1993	6488	920
1968	58904	101648	1994	4150	1281
1969	73065	74517	1995	5306	453
1970	69149	42188	1996	7247	2733
1971	66962	44123	1997	7658	5798
1972	63752	27761	1998	7782	5409
1973	58130	32961	1999	7799	2130
1974	59946	54555	2000	6896	974
1975	31040	50004	2001	7206	944
1976	9138	20887	2002	7262	1950
1977	12062	23691	2003	9133	5037
1978	15311	33041	2004	6867	4447
1979	23488	26242	2005	7439	11698
1980	38313	42436	2006	6940	22362
1981	71097	49761	2007	6354	7656
1982	88262	39415	2008	8083	12605
1983	87632	10598	2009	9559	
1984	87826	7770			

Table 3.- Equilibrium SSB and yield in tons for the YPR reference points (F_{max} and $F_{0.1}$) and SPR reference points ($F_{30\%}$, $F_{35\%}$ and $F_{40\%}$) estimated without uncertainty and the median, the 90th and 80th percentile values of the Bootstrap distribution. The equilibrium SSB and Yield were calculated with the recruitments produced by the SSB more than B_{lim} (60,000 tons).

	B_{max}	$B_{0.1}$	$B_{30\%}$	$B_{35\%}$	$B_{40\%}$
Deterministics	114315	185521	155159	181038	206841
5%	76030	123242	102632	119531	136440
10%	85165	138885	117393	136864	156635
50%	113883	185545	154978	180677	206512
90%	141811	229758	190928	223084	254911
95%	147985	241071	199719	233808	266944

	Y_{max}	$Y_{0.1}$	$Y_{30\%}$	$Y_{35\%}$	$Y_{40\%}$
Deterministics	54173	51527	53246	51829	49885
5%	36080	34307	35416	34470	33145
10%	40816	38826	39971	38939	37420
50%	54295	51653	53442	51935	49944
90%	66443	63180	65379	63707	61316
95%	70384	66818	69142	67243	64668

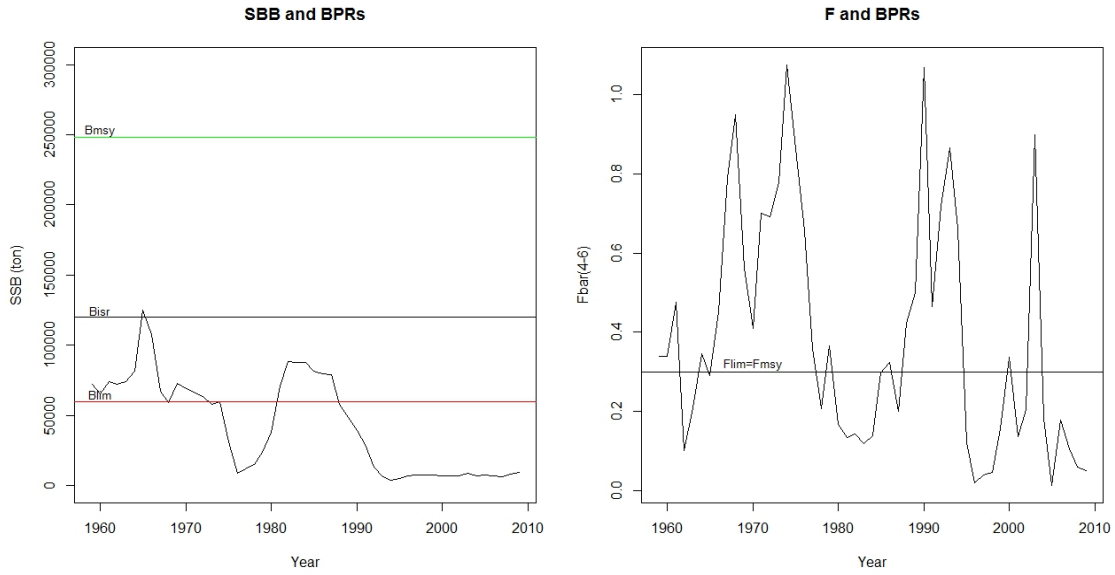

Figure 1.- NAFO 3NO Cod SSB and F from the 2010 assessment results and Biological References Points (BRPs) approved in 2011 by the Fisheries Commission.

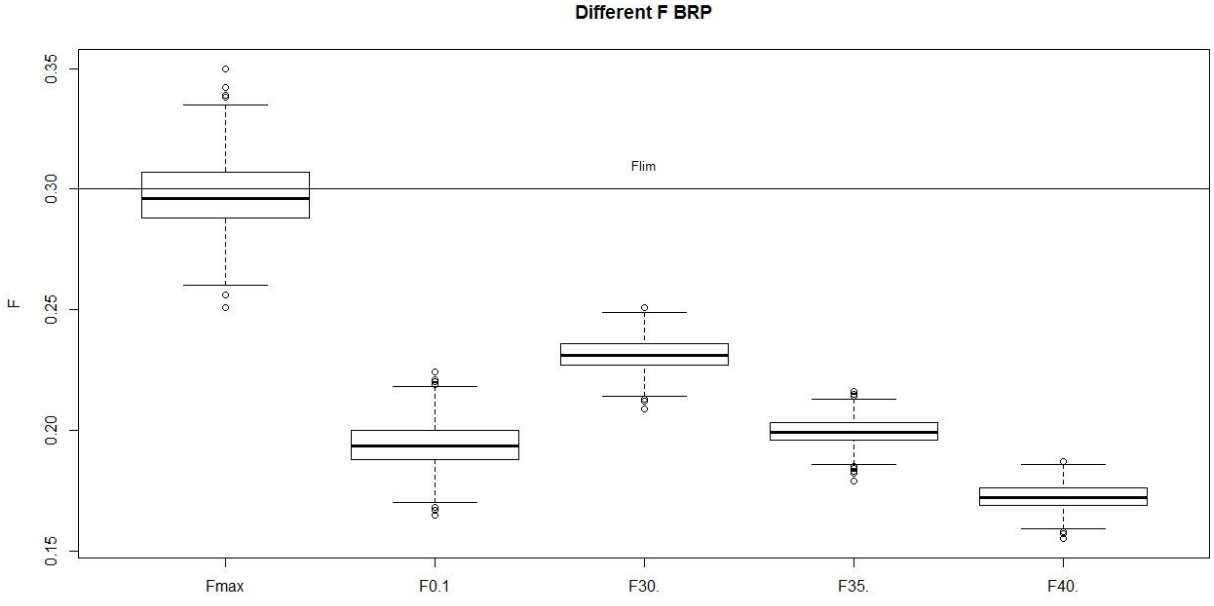

Figure 2.- Fishing mortality YPR (F_{max} and $F_{0.1}$) and SPR ($F_{30\%}$, $F_{35\%}$ and $F_{40\%}$) reference points.

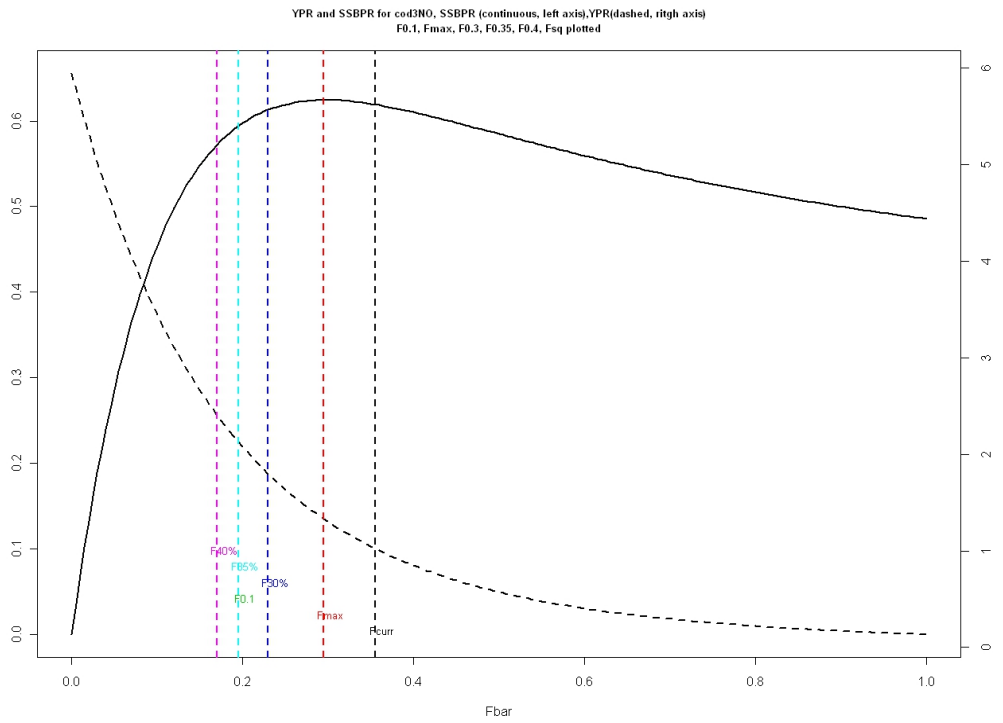

Figure 3.- Median Yield per Recruit (YPR) and SSB per Recruit (SPR) curve. The dash lines represent the median values of the Bootstrap distribution for the Biological References Points (F_{max}, $F_{0.1}$, $F_{30\%}$, $F_{35\%}$ and $F_{40\%}$).

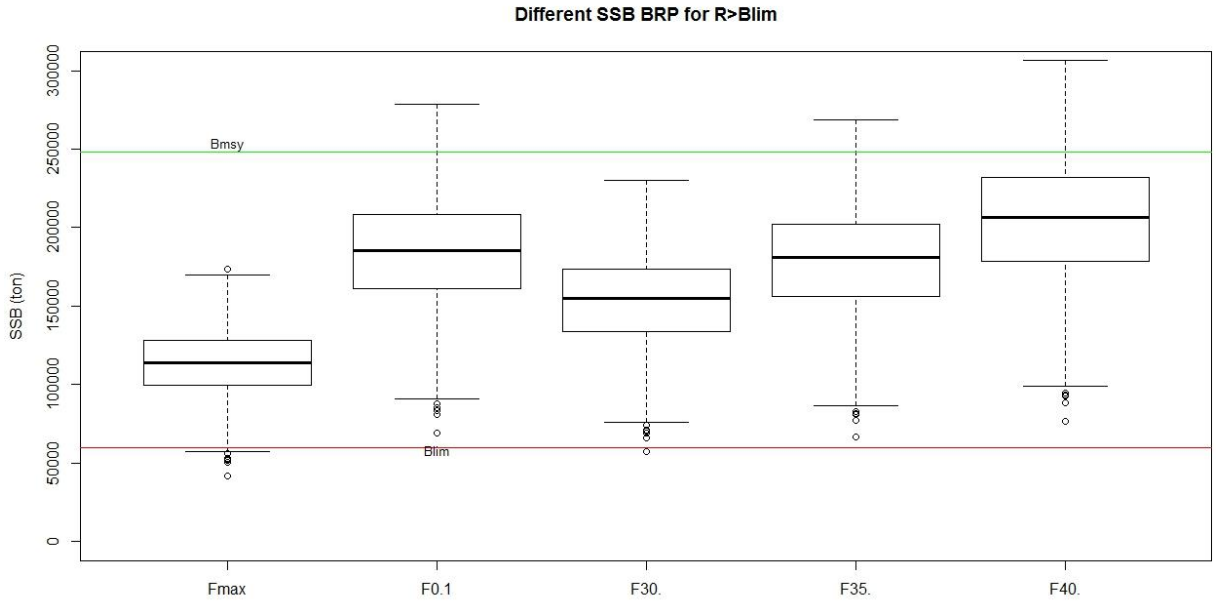

Figure 4.- Equilibrium SSB, assuming mean recruitment produced by the SSB more than B_{lim}, corresponding to Fishing mortality YPR (F_{max} and $F_{0.1}$) and SPR ($F_{30\%}$, $F_{35\%}$ and $F_{40\%}$) reference points. The lines represent the Biological References Points (BRPs) approved in 2011 by the Fisheries Commission.

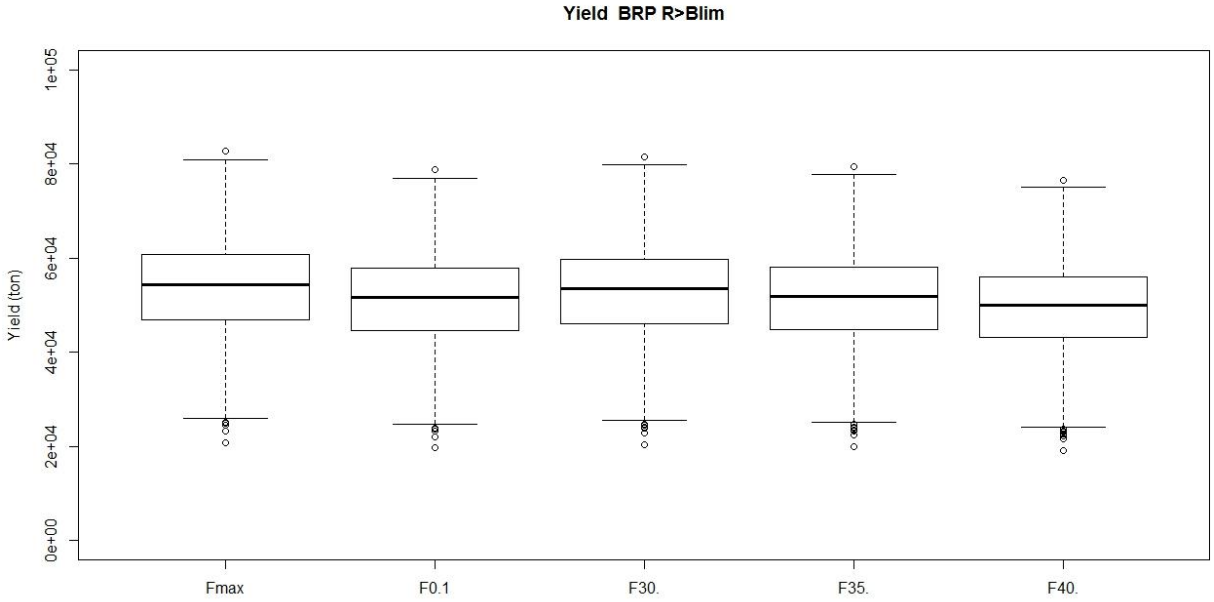

Figure 5.- Equilibrium yield, assuming mean recruitment produced by the SSB more than B_{lim}, corresponding to Fishing mortality YPR (F_{max} and $F_{0.1}$) and SPR ($F_{30\%}$, $F_{35\%}$ and $F_{40\%}$) reference points.

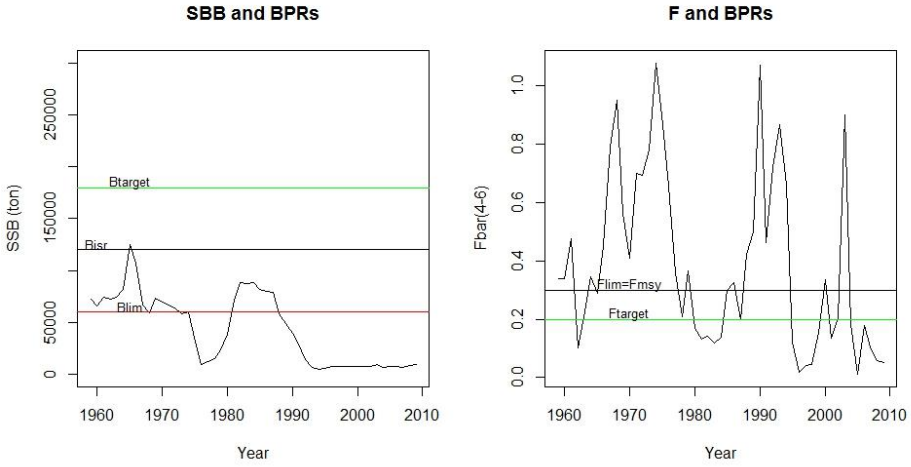

Figure 6.- NAFO 3NO cod SSB and Fishing mortality 2010 assessment results and the new propose values for the Biological References Points (BRPs).