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NAFO Div. 3M Cod Precautionary Approach Framework (PAF) reference points proxies

by

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Abstract

In September 2024 the Commission approved the new NAFO Precautionary Approach Framework (PAF). This paper presents the results of using the different methods proposed by the PA-WG to estimate the PAF reference points proxies with the available cod Div. 3M data.

The following periods were used to estimate the mean values of the Biological Parameters and Partial Recruitment used in the equilibrium projections to estimate the reference points of the PAF: the last 3 years, 2007-2023 and the complete series (1988-2023). In the case of the cod Div. 3M, the period chosen is a key point for estimating the PAF reference points. The 2007-2023 period should give some stability to the estimated PAF reference points and better reflect the conditions that are intended to be achieved by applying the PAF.

In the case of cod Div. 3M, it is considered that the best proposed method is to estimate F_{MSY} as $F_{35\%SPR}$ using the mean values of the biological parameters of the 2007-2023 period (and F_{target} as $0.85F_{MSY}$), and B_{MSY} as the equilibrium biomass estimated with the $F_{35\%SPR}$ and the mean values of the biological parameters of the 2007-2023 period. This proposal allows us to estimate all PAF reference points with the same method (SPR) and gives us limit reference point levels similar to those used until now, that have been used to sustainably manage this stock in the last decade. Additionally, with this method it is possible to avoid the problems of poor fitting of the stock recruitment functions observed with this stock or the problems of converting total fishing mortalities to age-specific mortalities that entail the methods based in production models. Within the SPR, since it is not clear in which category classify the productivity of this stock, it is likely to be precautionary to change the current F_{MSY} proxy from $F_{30\%SPR}$ to $F_{35\%SPR}$.

Based on these results, the authors propose the following values for the PAF reference points in the case of the cod Div. 3M: $F_{lim} = F_{35\%SPR}$, $F_{target} = 0.85*F_{35\%SPR}$, $B_{MSY} = B_{MSY(Fspr35\%)}$ using the mean values of 2007-2023 as BPs and RP, $B_{trigger} = 0.75*B_{MSY}$ and $B_{lim} = 0.3*B_{MSY}$.

Introduction

In September 2024 the Commission approved the new NAFO Precautionary Approach Framework (PAF) (NAFO, 2024a) as described in the report of the NAFO Joint Commission-Scientific Council Working Group on Risk-Based Management Strategies (WG-RBMS) August 2024 meeting (NAFO 2024b).

The new PAF defines three Zones (Healthy, Cautious, and Critical) to characterize the status of the stock. These zones are defined by two biomass reference points (B_{lim} and $B_{trigger}$). Within this framework, the limit fishing mortality is defined as $F_{lim} = F_{MSY}$, and F_{target} as a fraction of F_{MSY} (Figure 1).

Reference Points could be set as a function of the type of stock being managed. As a first step in the initial implementation of the PAF the reference points in the context of Figure 1, or their best proxies, are set as follows:

Framework	**F limit (F_{lim})**	**F target (F_{target})**	**B trigger ($B_{trigger}$)**	**B limit (B_{lim})**
Reference Point	F_{MSY}	$0.85*F_{MSY}$	$0.75*B_{MSY}$	$0.3*B_{MSY}$

On the other hand, the NAFO Precautionary Approach Working Group (PA-WG) reviewed and agreed on a ranking of different methods to estimate the best proxies for the PAF reference points depending on the available data (NAFO, 2023). SC agreed in December 2024 (NAFO, 2024c) that the Designated Experts (DEs) for the stocks that are scheduled to undergo a full assessment in a given year would work towards the development of reference points that can be used in the revised PAF that year. One of the stocks that has a full assessment in June 2025 is cod Div. 3M. The last assessment of cod Div. 3M approved by the SC in 2024 was based in a Bayesian SCAA model with data from 1988 to 2023 (Garrido *et al.*, 2024). In 2014, Scientific Council decided that $F_{30\%SPR}$ (the fishing mortality which reduces Spawner Per Recruit (SPR) to 30% of its value at F = 0) is the best F_{MSY} proxy (so, F_{lim}) for cod Div. 3M (NAFO, 2014). As regards B_{lim} for this stock, during the January 2019 Scientific Council meeting it was agreed to use the 2007 SSB as B_{lim}, since this is the highest value of the three years (2005-2007) in which good recruitment lead to the stock recovery observed in the past (NAFO, 2019).

This document presents the results of using the different methods proposed by the PA-WG to estimate the PAF reference points proxies with the available cod Div. 3M data. The objective is assisting the SC in choosing the final values of the reference points to be used in the PAF in the case of cod Div. 3M.

Methods and Results

F_{MSY} defines the values of F_{lim} and F_{target} under the new PAF ($F_{lim} = F_{MSY}$ and $F_{target} = 0.85*F_{MSY}$), while B_{MSY} defines the values of the biomass PA reference points ($B_{lim} = 0.3*B_{MSY}$ and $B_{trigger} = 0.75*B_{MSY}$). PA-WG proposed different options to estimate F_{MSY} and B_{MSY} or their proxies and classified their priority as follow:

1. Direct estimate of F_{MSY} and B_{MSY} depending on the data available in each stock.

   a. from age-based analysis with well-defined stock-recruit relationship.

      Several attempts have been made to estimate F_{MSY} and B_{MSY} by fitting a stock-recruitment relationship to the data and results of the cod Div. 3M assessment. During the February 2023 PA-WG meeting, the values of $F_{MSY} = 0.075$ (F_{bar}3-5) and $B_{MSY} = 43000$ tons of Spawning Stock Biomass (SSB) were estimated using ICES eqsim tool (Simmonds *et al.*, 2019). ICES eqsim is a stochastic equilibrium R software that may be used to explore MSY reference points. To produce those values, data from the assessment conducted in 2020 were used with data from the period 1988-2019 (Gonzalez-Troncoso *et al.*, 2020). For the values of biological parameters (BPs) and selection at age (PR) in the equilibrium, the average values for the last 3 years were used.

The last attempt to estimate F_{MSY} and B_{MSY} based on stock-recruitment relationships (SRRs) was made by Gullage *et al.* (2024). Two SRRs, Beverton-Holt (BH) and Ricker models, were considered. Due to the lack of confidence in any stock-recruitment model fit, the final selection of the values of the BH and Ricker parameters relied on both model fitting and expert judgment. The SC considered BH and Ricker SRRs with a steepness of 0.7 as the best SRRs options. In this case, data from the assessment conducted in the year 2023 were used with data from the period 1988-2022 (Garrido *et al.,* 2023). For the mean values of the BPs and PR in the equilibrium, the following periods were used: the last 3 years and the complete series (1988-2022) to try to compare the stock productivities in the most recent period (last three years) and the entire assessment period (1988-2022). Subsequently, the SC suggested that MSY reference points be calculated with the mean values of the 2007-2022 for the BPs and PR as a reference for the productivity observed in the last period in which the biomass has been above B_{lim} (Varkey D. 2025, personal communication).

b. from production model with informative series of catch and indices, if age or length-based analysis is not possible.

   F_{MSY} and B_{MSY} were not estimated directly with production models because the data available and the assessment model approved by the SC is an age-structured model.

c. from production analysis of stock biomass estimates.

   F_{MSY} and B_{MSY} have been calculated through the Known-Biomass Production Models (MacCall, 2002) using the Knobi function of R with the assessment results of 2024 (Garrido *et al.,* 2024). In this case two values of these reference points have been calculated, one adjusting the total biomass and the other adjusting the SSB to a Schaefer production model. The results for F_{MSY} are: Total Biomass F_{MSY} = 0.146 and SSB F_{MSY} = 0.39. It should be noted that the Fs estimated through Knobi are not directly comparable to the Fs estimated with the models with age-structured data (F_{bar}3-5). The results for B_{MSY} are: 107110 tons (of total biomass) and 48108 tons (of SSB). Note that total Biomass/SSB ratio estimated with the 2024 approved assessment results is 0.54 so transforming the estimated value with the B_{MSY} (of total biomass) into B_{MSY} (of SSB) would result in a value of 57839 tons.

2. % Maximum Spawning Potential.

   Spawner-per-Recruit (SPR) proxies were developed to avoid recruitment overfishing by maintaining spawning potential (Gabriel *et al.*, 1989; Goodyear, 1993). A range of SPR reference points have been proposed. Based on simulations of a wide range of life histories, $F_{35\%SPR}$ is expected to maintain at least 75% of MSY in most cases (Clark, 1991). The PA-WG proposed different $\%F_{SPR}$ as proxies of F_{MSY} depending on the life history characteristics of the different species: $F_{30\%SPR}$ for stocks with relatively high productivity (e.g., high fecundity, ~10 year longevity), $F_{35\text{-}40\%SPR}$ for stocks with moderate productivity (e.g., high fecundity and/or ~20 years longevity,) and $F_{50\%SPR}$ for stocks with relatively low productivity (e.g., low fecundity and/or ~50 years longevity). In the case of cod Div. 3M, there are certain doubts about if classifying its productivity as high or medium; so, $F_{30\%SPR}$ and $F_{35\%SPR}$ have been estimated based on the F_{bar}3-5 with the data from the last assessment approved by the SC (Garrido *et al.*, 2024) using for the BPs and PR the average values of the last 3 years, the mean values of the 2007-2023 period and the complete series (1988-2023) to compare productivity in different periods.

   In cases on which a good fit of a stock-recruitment relationship cannot be found, the PA-WG recommended to estimate B_{MSY} using the Maximum Spawning Potential equilibrium method. In this method, the SPR of the $F_{30\text{-}35\%SPR}$ is estimated and multiplied by an estimated average recruitment to calculate the equilibrium SSB. In the case of cod Div. 3M, two different periods have been chosen to estimate the average recruitment: the entire period (1988-2023) and the period 2007-2023, to compare the productivity of the entire series and that of the last period where the biomass was above B_{lim}. The entire period mean recruitment has been used to estimate the equilibrium B_{MSY} when using the average of the BPs and PR of the entire series, and the 2007-2023 mean recruitment has been used to estimate the equilibrium B_{MSY} when using the average of the BPs and PR of the last three years or of the period 2007-2023.

3. Yield per Recruit (YPR) analysis.

   Yield-per-recruit (YPR) can be derived using numerical life tables (Thompson & Bell, 1934) or an analytical solution (Beverton & Holt, 1957). Although YPR reference points can be used to avoid growth overfishing (e.g., not allowing fish to achieve their optimal growth potential), they cannot be used to avoid recruitment overfishing. F_{max} is derived as the F expected to produce maximum YPR, but F_{max} is usually much greater than F_{MSY} because YPR calculations assume no stock-recruit relationship or any decrease in recruitment at high F (e.g., Horbowy & Hommik, 2022). F_{max} is also often poorly defined for fisheries that select relatively large fish. Therefore, $F_{0.1}$ (F with 10% of the initial increase in YPR from F = 0), was developed as precautionary proxy for F_{max} because it is expected to produce nearly maximum YPR at a lower F (Gulland & Boerma, 1973). Based on this, the PA-WG decided that $F_{0.1}$ is the best proxy for F_{MSY} that can be estimated with this method. $F_{0.1}$ was estimated using as BPs and PR the average values of the last 3 years, the mean values of the 2007-2023 period and the complete series (1988-2023).

   The same method used with the Maximum Spawning Potential method to estimate B_{MSY} was applied to YPR. The SPR corresponding to the values of $F_{0.1}$ were estimated and then multiplied by: 1) the average recruitment for the whole period to the SPR corresponding to the values of $F_{0.1}$ estimated with the whole period mean of the BPs and PR, and 2) the 2007-2023 mean recruitment to the SPR corresponding to the values of $F_{0.1}$ estimated with the mean of the BPs and PR of the 2007-2023 and 2021-2023 periods.

4. Historical proxies based on F and biomass levels during periods of relatively high and stable stock size or exploitation ratio (catch/survey biomass) during periods of relatively high stable stock size if information is insufficient to estimate other proxies based on the methods 1-3.

   In the cod Div. 3M case, as there are sufficient data to estimate proxies of F_{MSY} and B_{MSY} using the above mentioned methods, no proxies have been estimated applying this method.

PA-WG proposed options to estimate B_{lim} with other methods based on the stock-recruitment information. The precautionary principle is to avoid irreversible harm (UN, 1992), which is often expressed as recruitment failure in fisheries. The PA-WG recommended the point of recruitment impairment (break point of segmented regression) as a good proxy of B_{lim}, if there is contrast in stock-recruit data and a break point is clearly defined. This is not the case of the cod Div. 3M stock recruitment data.

Other proposed method for estimating B_{lim} is the lowest observed stock size that produced strong recruitment for stocks with occasional good year classes, which again is not the case with cod Div. 3M. In the past, an SSB of 20000 tons was established as cod Div. 3M B_{lim} since this is the SSB level below which only low recruitments have been observed.

The PA-WG also proposed as possible proxy of B_{lim} the $B_{recovery}$ (lowest biomass level the stock has recovered from). This is the approach of the current B_{lim} approved by the SC for the cod Div. 3M. In 2019, it was agreed to use the 2007 SSB as B_{lim}, as this is the highest value of SSB of the three years (2005-2007) in which good recruitment lead to stock recovery (NAFO, 2019). The estimated 2007 SSB value in the last approved assessment was 14625 tons.

The last B_{lim} proxy proposed by PA-WG is a $\%B_0$, based on life history characteristics of the stock: $10\%B_0$ for moderately productive stocks and $25\%B_0$ for less productive stocks. The cod Div. 3M can be classified as moderately productive stock. The same method used with the Maximum Spawning Potential method to estimate B_{MSY} was applied to $\%B_0$. The SPR corresponding to the value of F = 0 with different means of BPs and PR were estimated and multiplied by the average recruitment for the whole or the 2007-2023 periods depending on the case as the B_{MSY} were estimated in equilibrium with the SPR and YPR methods.

Figure 2 presents the values of BPs and PR for the periods of the last three years, 2007-2023, and the entire period (1988-2023). The estimated BPs means of the whole and the 2007-2023 periods are quite similar and slightly different from the last three years ones. The PR varies greatly depending on the period chosen for averaging.

Figure 3 shows the stock/recruitment plot with the results of the 2024 assessment as well as the average recruitment for the entire period (1988-2023) and for the period 2007-2023, which is the last period with biomass above B_{lim}. These are the recruitment levels chosen to estimate B_{MSY} proxies using the SPR, YPR and B_0 methods. Note that the average for the entire period includes 10 years in which biomass was well below B_{lim}.

Table 1 and Figure 4 shows the values of the fishing mortality reference points estimated by the different methods recommended by the PA-WG and the different periods chosen to calculate the average values of the BPs and PR. The F_{MSY} values estimated with the Knobi R function are much higher than the rest. They are not comparable with the values estimated with the age-structured methods since the F_{MSY} values obtained refer to overall fishing mortality while the age-structured ones are referenced to the F_{bar} for ages 3 to 5. In the case of the eqsim, the F_{MSY} was only estimated using the average of the biological parameters from the last three years and with data up to 2019, so it is not totally comparable with the rest of the values.

The estimated fishing mortality reference points depend on the period chosen to calculate the values of the BPs and PR and on the method used. The values estimated by the different methods increase as the period chosen to calculate the BPs and PR increases. The $F_{lim} = F_{MSY}$ estimated with age-structured data and assuming stock-recruitment relationships (BH and Ricker) are quite similar to each other and similar to the $F_{0.1}$ value for the same period and different from the proxies estimated by SPR which give higher values for the possible proxies of F_{MSY}. It should be noted that one of the most important limitations in the usage of the stock recruitment methods is the lack of a good fit of the stock-recruitment relationships, which is the case of cod Div. 3M. Therefore, the results of these methods are uncertain in this case.

Table 2 and Figure 5 shows the values of the B_{MSY} or its proxy estimated by the different methods recommended by the PA-WG. As in the case of the fishing mortality reference points, the values of the estimated biomass reference points depend on the period chosen to calculate the values of the BPs and on the method used. In this case, the B_{MSY} values estimated by the Beverton-Hold and Ricker methods are similar to each other using the average BPs for the entire series and for 2007-2023 period and similar to the proxies estimated with $F_{0.1}$, and are higher than those estimated with the SPR methods.

Discussion

The period that should be chosen in the case of cod Div. 3M to estimate the values of the biological parameters and the selectivity at age to be used in the equilibrium is a key point to estimate the reference points of the PAF. The last three years may be a very short period and not very convenient to maintain some stability in the estimates of these values, since in this stock these biological parameters can vary widely as was observed in the past. On the other hand, the use of the full period to estimate these values, which includes 10 years with biomass levels well below B_{lim} and the fishery closed, may not reflect in this case the conditions that are intended to be obtained by applying the PAF, keeping the fishery open and the biomass at levels around B_{MSY}. So, for this stock, it is considered that the period 2007-2023, with biomass above B_{lim} and the fishery open since 2010, is the most appropriate period to estimate the average of biological parameters and age-specific selectivity. Moreover, the estimated means for BPs with the whole period and the period 2007-2023 are very similar and what is really different between these periods are the averages of the PR. Note that in the 2007-2023 period the mean PR is mainly the mean of the directed cod fishery while the whole period mean is a mixture of the target fishery and by-catch. The 2007-2023 period should give some stability to the estimated PAF reference points and better reflect the conditions that are intended to be achieved by applying the PAF, maintaining biomass above $B_{trigger}$ and the fishery open.

Regarding the different methods, in this case it is considered that the best method for estimating F_{MSY} are via SPR and YPR, in order to avoid the problems of poor fitting of the stock recruitment relationships and the problems of converting total fishing mortalities to age-specific mortalities when using methods based in production models. SC selected $F_{30\%SPR}$ as the best F_{MSY} proxy for this stock (NAFO, 2014). Normally, cod as a species is classified as medium productivity but it is also true that the age-specific composition of cod Div. 3M is more similar to that of a high productivity species. Initial studies indicate that values of $F_{30\%SPR}$ to $F_{40\%SPR}$ could be used as proxies for F_{MSY} (Goodyear, 1993; Mace and Sissenwine, 1993). Further studies by Clark (1991, 1993) concluded that $F_{35\%SPR}$ and higher percentage were robust proxies for F_{MSY}, considering uncertainty in stock-recruitment functions and or recruitment variability. Mace and Sissenwine (1993) found that the Atlantic

cod has the smallest mean replacement %SPR of 90 stocks analyzed, 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 case of cod Div. 3M, 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) and proposed by González-Costas and González-Troncoso (2014). Since it is not clear in which category (medium or high) classify the productivity of this stock, it is likely to be precautionary to change the current F_{MSY} proxy from $F_{30\%SPR}$ to $F_{35\%SPR}$. Also, $F_{35\%SPR}$ is closer to the $F_{0.1}$ value although it is higher.

Estimates of B_{MSY} with methods based on the age-structured models and stock-recruitment relationships (BH and Ricker) and $F_{0.1}$ with the mean of the biological parameters of the 2007-2023 period give levels quite similar among them, around 65000-70000, with B_{lim} values around 20000 tons. The B_{MSY} proxies estimated with the SPR methods (35%) with the average values of the biological parameters from 2007-2023 are 52413 tons for B_{MSY} and 15724 for B_{lim}, very similar to the current B_{lim} ($SSB_{2007} = B_{recovery} = 14625$) with which the fishery has been managed in recent years. This B_{lim} value is also similar to the $10\%B_0$ which is a possible B_{lim} proxy recommended by the PA-WG. These levels seem more adequate than those estimated by Beverton-Hold and Ricker based on the recruitment/biomass plot, as above 60000 tons only medium/low recruitments have been observed, while above 50000 tons medium/high recruitments have been observed (Figure 6).

Based on the above, it seems that one way to move forward with this stock is to estimate F_{MSY} as $F_{35\%SPR}$ using the mean values of the biological parameters of the 2007-2023 period (and F_{target} as $0.85F_{MSY}$), and B_{MSY} as the equilibrium biomass estimated with the $F_{35\%SPR}$ and the mean values of the biological parameters of the 2007-2023 period. This proposal (Table 3) allows us to estimate all PAF reference points with the same method (SPR) and gives us limit reference point levels similar to those used until now, that have been used to sustainably manage this stock in the last decade. Figure 7 presents the PAF figure with the proposed reference point values and the results of the last cod assessment approved by the SC in June 2024. With the estimated 2023 biomass level and applying the old PAF, an advice was given by the SC for 2025 at a level of F = 0.086, quite close to the mid value of the leaf of the proposed PAF for this stock (F = 0.076). Finally, the Commission approved a TAC based on F = 0.102, which is very close to the upper level of the leaf (F = 0.109). This proposed PAF option would not imply major changes in the advice when implementing the new PAF.

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References

Beverton, R.J.H., and Holt, S.H. 1957. On the dynamics of exploited fish populations. Fish. Invest. Ser. II. Mar. Fish. G.B. Minist. Agric. Fish. Food No. 19

Clark, W.G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci. 48:734-750

Clark W.G. 1993 The effect of recruitment variability on the choice of target level of spawinig stock biomass per recruit. In Proceedings of the International Symposium on management strategies for exploited fish populations Alaska Sea Grant College Programme AK-SG-93- 02 1993. Pp 233-246.

Gabriel, W.L., Sissenwine, M.P., and Overholtz, W.J. 1989. Analysis of spawning stock biomass per recruit and example for Georges Bank haddock. N. Am. J. Fish. Manag. 9: 383–391.

González-Costas, F. and Diana González–Troncoso. 2014. Biological Reference Points of 3M cod. Serial No. N6313 NAFO SCR Doc. 14/19.

González-Troncoso, D., Carmen Fernández and Fernando González-Costas. 2020. Assessment of the Cod Stock in NAFO Division 3M. Serial No. N7079 NAFO SCR Doc. 20/031REV.

Goodyear, C.P. 1993. Spawning stock biomass per recruit in fisheries management: foundation and current use. In Risk evaluation and biological reference points for fisheries management. Edited by S.J. Smith, J.J. Hunt, and D. Rivard. Can. Spec. Publ. Fish. Aquat. Sci. No. 120. pp. 67–81.

Garrido Irene, Diana González-Troncoso and Fernando González-Costas. 2023. Assessment of the Cod Stock in NAFO Division 3M. Serial No. N7396 NAFO SCR Doc. 23/009

Garrido Irene, Diana González-Troncoso and Fernando González-Costas. 2024. Assessment of the Cod Stock in NAFO Division 3M. Serial No. N7521 NAFO SCR Doc. 24/016.

Gullage Nick, Rajeev Kumar and Divya Varkey. 2024. Re-estimation of equilibrium reference points for NAFO Division 3M Cod for application in MSE simulations. . Serial No. N7561 NAFO SCR Doc. 24/051.

Gulland, J.A., and L.K. Boerma. 1973. Scientific advice on catch levels. Fishery Bulletin 71: 325-335.

Horbowy J, and K Hommik. 2022. Analysis of F_{msy} in light of life-history traits – Effects on its proxies and length-based indicators. Fish and Fisheries 23: 663-679

Mace, P.M. and M.P. Sissenwine. 1993. How much spawning per recruit is enough? In S.J. Smith, J.J. Hunt and D. Rivard [eds.] Risk evaluation and biological reference points for fisheries management. Canadian Special Publications in Fisheries and Aquatic Sciences 120:101-118.

MacCall, A. (2002). Use of Known-Biomass Production Models to Determine Productivity of West Coast Groundfish Stocks. North American Journal of Fisheries Management, 22:272-279.

NAFO 2024a. Report of the NAFO Commission and its Subsidiary Bodies (STACTIC and STACFAD) 46th Annual Meeting of NAFO, 23-27 September 2024. Serial No. N7600 NAFO/COM Doc. 24-25.

NAFO 2024b. Report of the NAFO Joint Commission-Scientific Council Working Group on Risk-Based Management Strategies (WG-RBMS) Meeting. 08–10 August 2024 Bergen, Norway. Serial No. N7571 NAFO/COM-SC Doc. 24-03.

NAFO. 2024c. Report of the Scientific Council Intersessional and Precautionary Approach Working Group Meeting, 5 December 2024, via Webex. NAFO SCS Doc. 24/21.

NAFO. 2024d. Report of the Scientific Council Meeting 31 May - 13 June 2024 Halifax, Nova Scotia. Serial No. N7556 NAFO SCS Doc. 24/16.

NAFO. 2023. Report of the NAFO Precautionary Approach Working Group Meeting (PA-WG), 28 February 2023, via Webex. NAFO SCS Doc. 23/07.

NAFO, 2019. Report of the NAFO Scientific Council Flemish Cap (NAFO Div. 3M) Cod Stock Management Strategy Evaluation (MSE). North East Atlantic Fisheries Commission (NEAFC) headquarters London, UK, 28-31 January 2019. Serial No. N6911 NAFO SCS Doc. 19/04.

NAFO. 2014. Report of the Scientific Council June meeting – 2014. Serial No. N6343 NAFO SCS Doc. 14/17.

Simmonds J., Hjorleifsson E., Millar C. 2019. MSY: estimation of equilibrium reference points for fisheries. R package version 0.1.19. http://github.com/ices-tools-prod/msy.

Thompson WF, and FH Bell. 1934. Effect of changes in intensity upon total yield and yield per unit of gear. Rep. Int. Fish. Comm. 8: 7–49.

UN (United Nations). 1992. Report of the United Nations Conference on Environment and Development (Rio de Janeiro, 3-14 June 1992). https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pd

Table 1. PAF fishing mortality reference points or their proxies estimated by the different methods recommended by the PA-WG and with the mean values of the BPs and PR used in the equilibrium. In red the current F_{lim} approved by the SC.

3 Years Mean PR and BPs			2007-2023 series Mean PR and BPs			Whole series Mean PR and BPs		
F_{MSY} Proxy	**F_{lim}**	**F_{target}**	**F_{MSY} Proxy**	**F_{lim}**	**F_{target}**	**F_{MSY} Proxy**	**F_{lim}**	**F_{target}**
F_{MSY}_eqsim	0.075	0.064	F_{MSY}_eqsim			F_{MSY}_eqsim		
F_{MSY}_knobi_Total	0.146	0.124	F_{MSY}_knobi_Total	0.146	0.124	F_{MSY}_knobi_Total	0.146	0.124
F_{MSY}_knobi_SSB	0.387	0.329	F_{MSY}_knobi_SSB	0.387	0.329	F_{MSY}_knobi_SSB	0.387	0.329
F_{MSY}_BH_0.7	0.112	0.095	F_{MSY}_BH_0.7	0.143	0.122	F_{MSY}_BH_0.7	0.179	0.152
F_{MSY}_RK_0.7	0.100	0.085	F_{MSY}_RK_0.7	0.136	0.115	F_{MSY}_RK_0.7	0.168	0.143
$F_{30\%SPR}$	0.152	0.129	$F_{30\%SPR}$	0.210	0.179	$F_{30\%SPR}$	0.249	0.212
$F_{35\%SPR}$	0.124	0.105	$F_{35\%SPR}$	0.171	0.145	$F_{35\%SPR}$	0.206	0.175
$F_{0.1}$	0.108	0.092	$F_{0.1}$	0.128	0.109	$F_{0.1}$	0.171	0.145

Table 2. B_{MSY} and PAF biomass reference points or their proxies estimated by the different methods recommended by the PA-WG and with the mean values of the BPs and PR used in the projections. In red the current B_{lim} approved by the SC.

3 Years PR and BPs mean

Proxy	B_{MSY}	$B_{trigger}$	B_{lim}
B_{MSY}_eqsim	43000	32250	12900
B_{MSY}_knobi_Total	107110	80333	32133
B_{MSY}_knobi_SSB	48108	36081	14433
B_{MSY}_BH_0.7	37627	28220	11288
B_{MSY}_RK_0.7	40955	30716	12287
$B_{30\%SPR}$_R(2007-2023)	30169	22627	9051
$B_{35\%SPR}$_R(2007-2023)	35213	26410	10564
$B_{recovery} = SSB_{2007}$			14625
B_0_R(2007-2023)	50150	37613	10030
$F_{0.1}$	40134	30101	12040

2007-2023 series PR and BPs mean

Proxy	B_{MSY}	$B_{trigger}$	B_{lim}
B_{MSY}_eqsim			
B_{MSY}_knobi_Total	107110	80333	32133
B_{MSY}_knobi_SSB	48108	36081	14433
B_{MSY}_BH_0.7	70220	52665	21066
B_{MSY}_RK_0.7	64803	48602	19441
$B_{30\%SPR}$_R(2007-2023)	44921	33691	13476
$B_{35\%SPR}$_R(2007-2023)	52413	39310	15724
$B_{recovery} = SSB_{2007}$			14625
B_0_R(2007-2023)			14947
$F_{0.1}$	64125	48094	19238

Whole series PR and BPs mean

Proxy	B_{MSY}	$B_{trigger}$	B_{lim}
B_{MSY}_eqsim			
B_{MSY}_knobi_Total	107110	80333	32133
B_{MSY}_knobi_SSB	48108	36081	14433
B_{MSY}_BH_0.7	70287	52715	21086
B_{MSY}_RK_0.7	65469	49102	19641
$B_{30\%SPR}$_R(1988-2023)	34376	25782	10313
$B_{35\%SPR}$_R(1988-2023)	40121	30091	12036
$B_{recovery} = SSB_{2007}$			14625
B_0_R(1988-2023)			11440
$F_{0.1}$	46747	35060	14024

Table 3. PAF reference points proxies estimated with the BPs and PR of the period 2007-2023 proposed for the case of the cod Div. 3M.

PAF	F limit (F_{lim})	F target (F_{target})	B trigger ($B_{trigger}$)	B limit (B_{lim})
Reference Point	$F_{MSY} = F_{35\%SPR}$	$0.85*F_{MSY}$	$0.75*B_{MSY\ (Fspr35\%)}$	$0.30*B_{MSY}$ (Fspr35%)
Estimated Value (2007-2023)	0.171	0.145	39310 tons SSB	15724 tons SSB

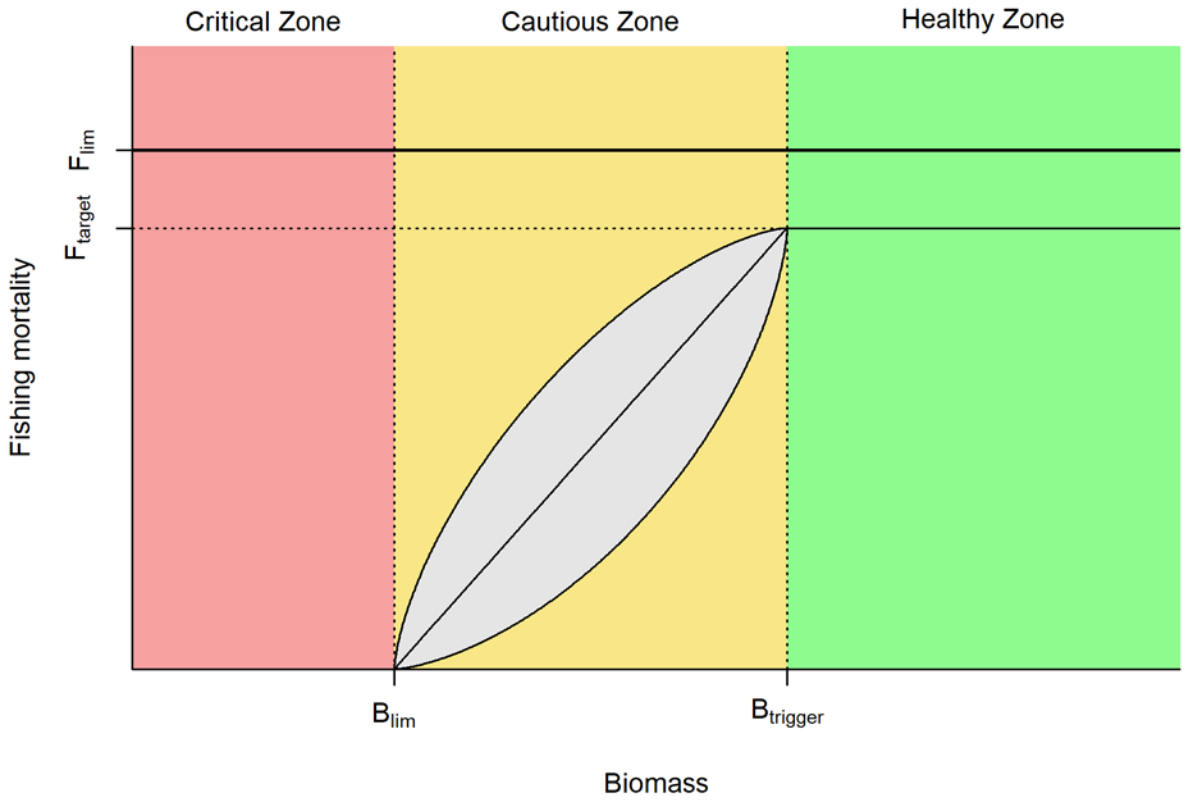

Figure 1. Schematic representation of the NAFO Precautionary Approach, including the leaf space to define fishing levels within the Cautious Zone.

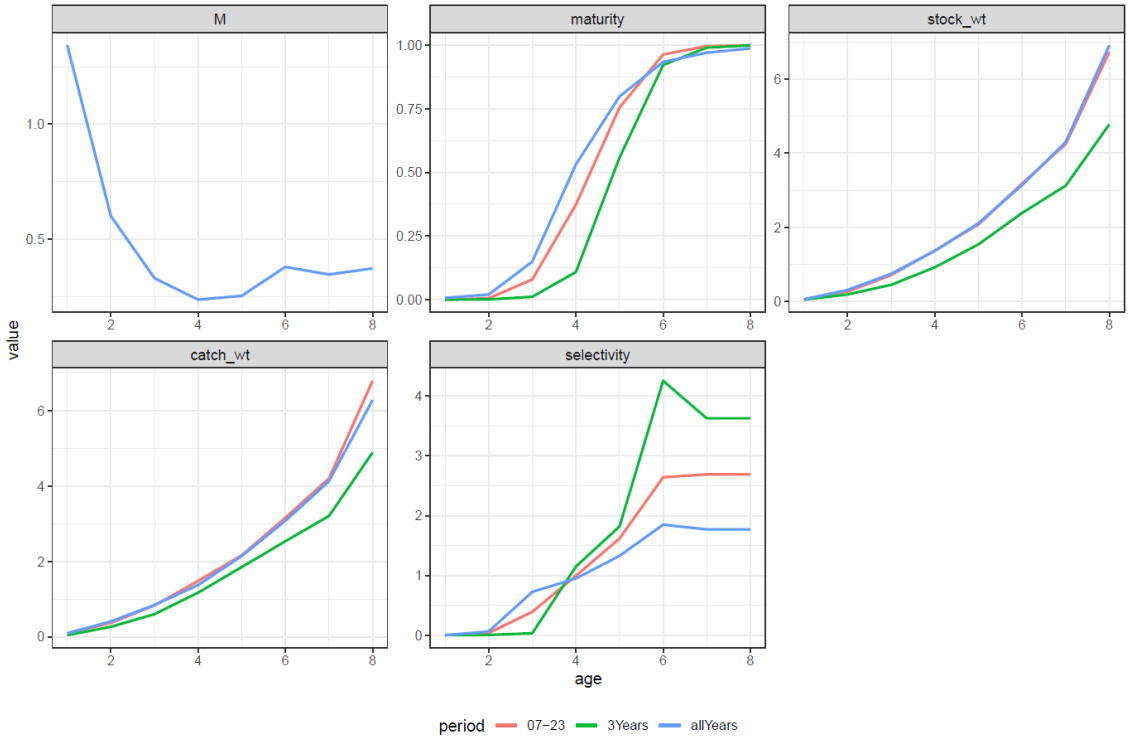

Figure 2. Cod Div. 3M biological parameters at age (natural mortality (M), maturity, stock weights and catch weights) and selectivity estimated with the annual mean values of the 1988-2023 (blue line), 2007-2023 (red line) and 2021-2023 (green line) periods.

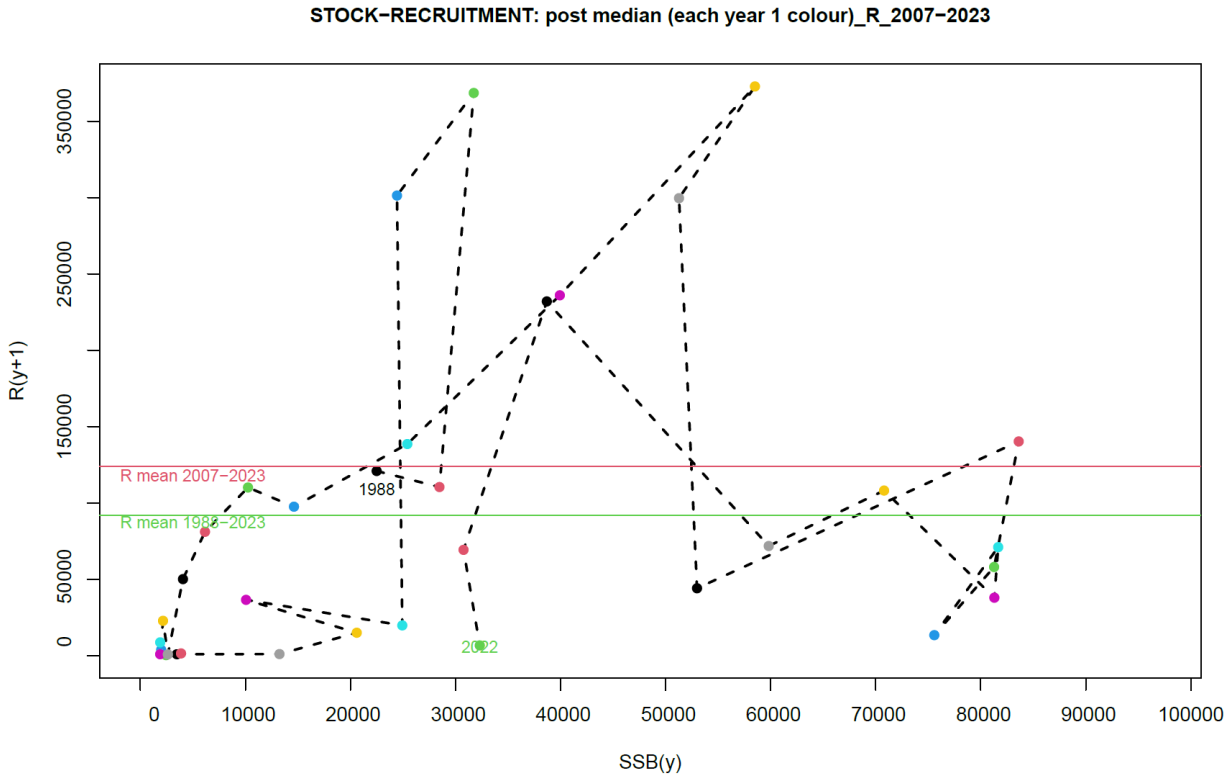

Figure 3. Cod Div. 3M recruitment/SSB scatter plot. Horizontal lines show the mean of the recruitment (median) for the periods 1988-2023 and 2007-2023.

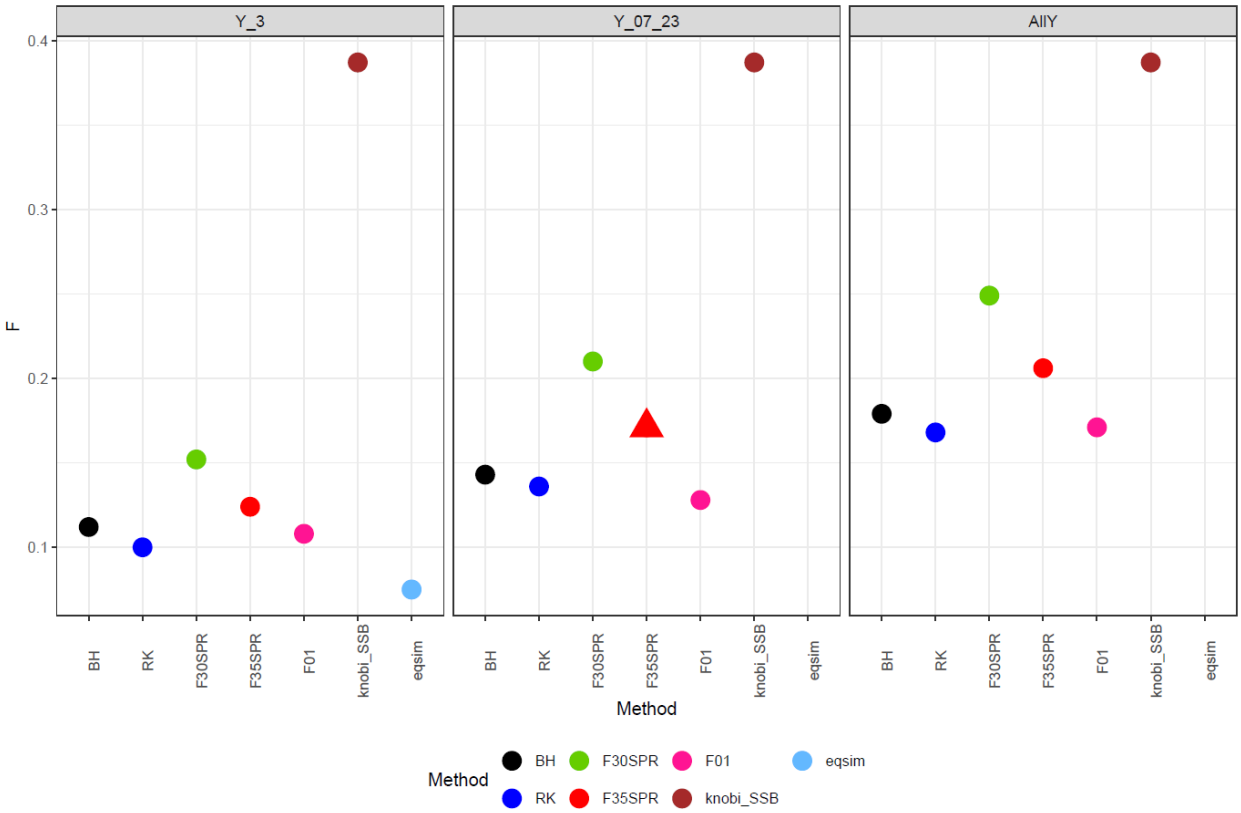

Figure 4. Values of F_{lim} depending on the period used for the BPs and the R and the method use. The triangle indicates the proposed F_{lim} for the cod Div. 3M.

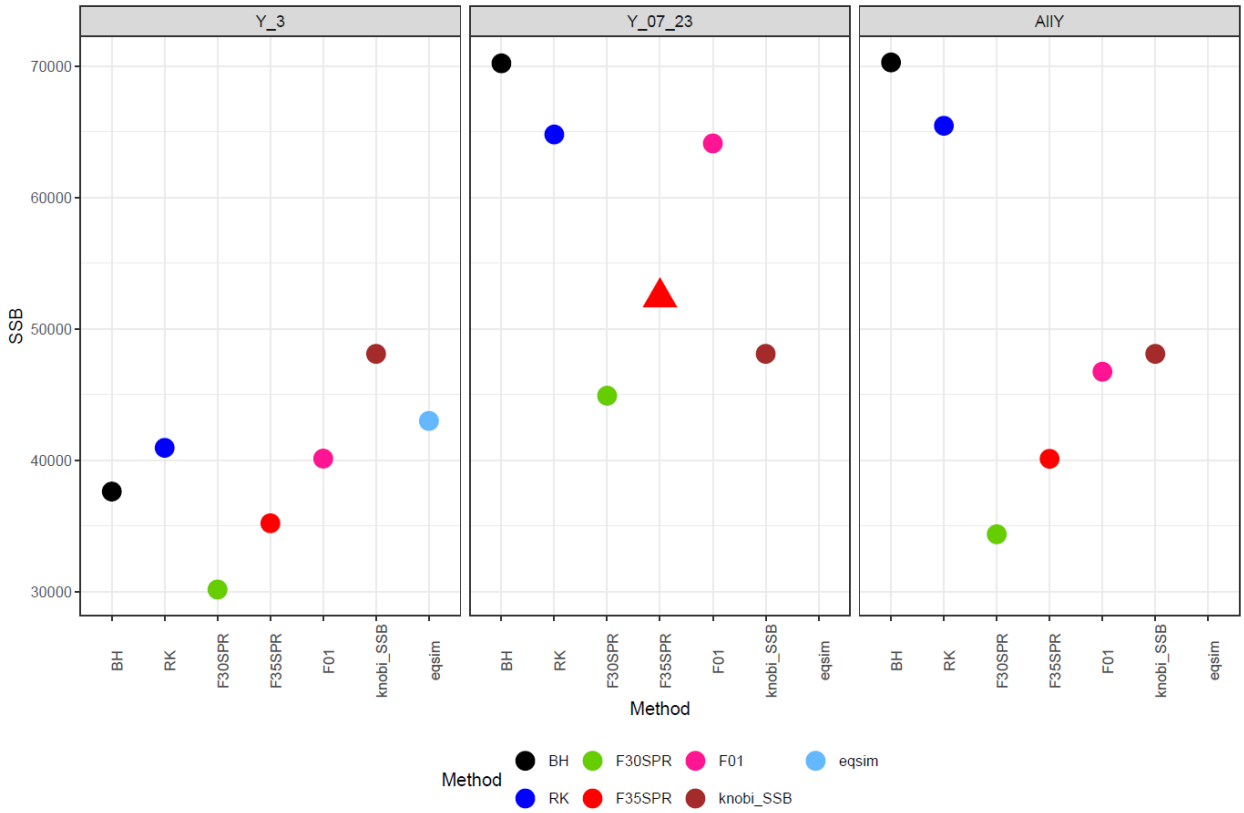

Figure 5. Values of B_{MSY} depending on the period used for the BPs and the R and the method use. The triangle indicates the proposed B_{MSY} for the cod Div. 3M.

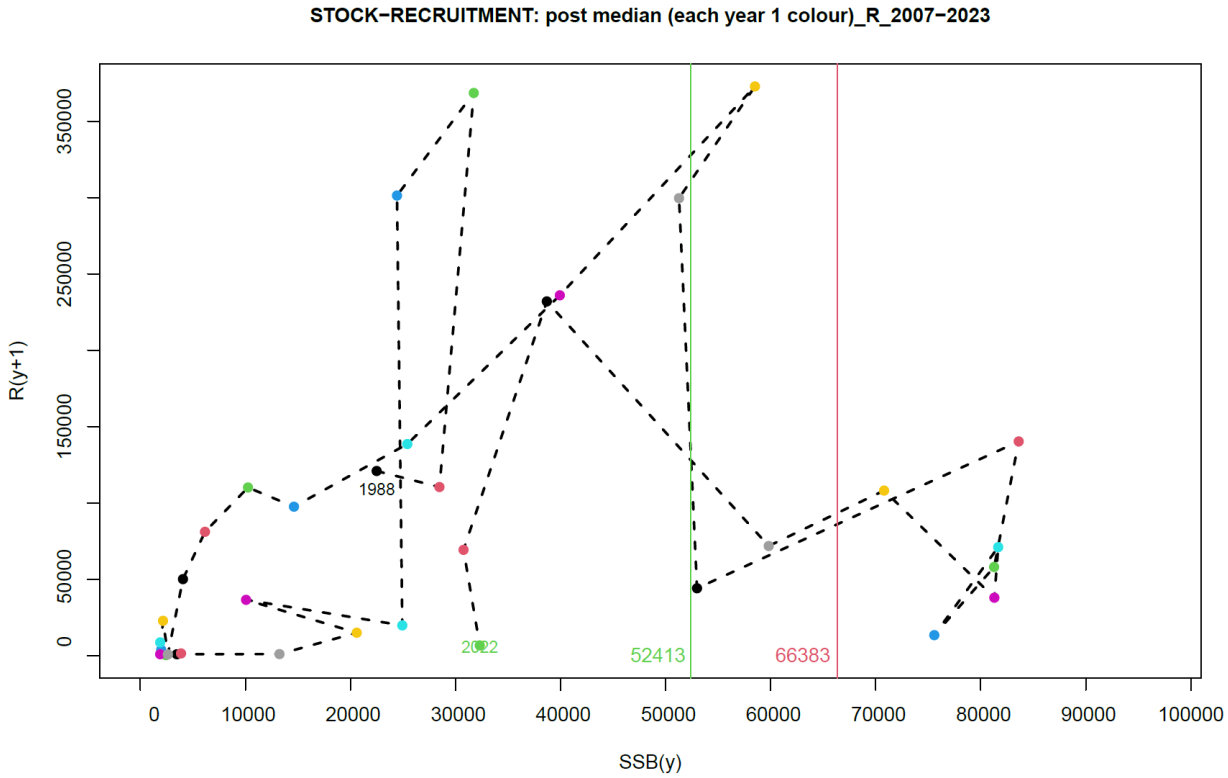

Figure 6. Cod Div. 3M recruitment/SSB scatter plot. Vertical lines show a value of SSB as the mean of the B_{MSY} of Ricker, Beverton and Holt and $F_{0.1}$ (red) and the B_{MSY} from $F_{35\%SPR}$ (green).

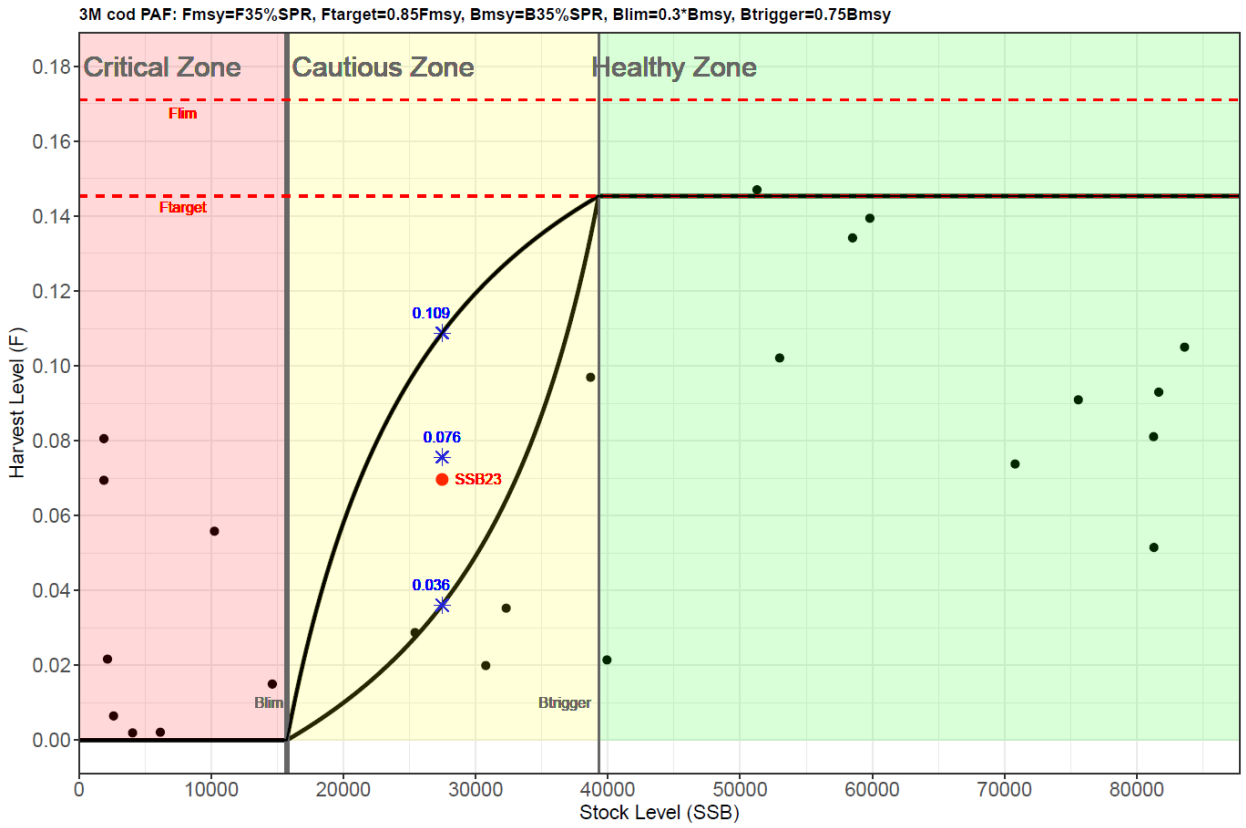

Figure 7. Cod Div. 3M PAF plot with fishing mortality (F) reference points (F_{lim}, F_{target}) and SSB reference points ($B_{trigger}$ = 0.75*B_{MSY} and B_{lim} = 0.3*B_{MSY}) estimated based on 35%SPR. The figure also includes the value of the F/SSB 2023 (red point) estimated in the last assessment approved by the SC and the estimated Fs of the lower, mid and upper leaf corresponding to the SSB 2023. The black dots correspond to the estimated values of F/SSB in the period 2000-2023 in the last assessment.