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Precautionary Approach Review progress: Different advices produced under the alternative PA frameworks for example stocks (3M cod and 3LNO yellowtail flounder)

by
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Abstract

Alternative PA frameworks were applied to two NAFO example stocks (cod Div. 3M and yellowtail flounder Divs. 3LNO) using information available from their most recent assessments. Catch advice under each alternative was compared to the recent advice.

In the case of cod Div. 3M the qualitative advice based on measuring risk over a two-year period and the Harvest Control Rule (HCR) gives catch levels quite similar to the catch level of the original advice. On the other hand, qualitative advice based on measuring risk over a one-year period gives lower catch levels than the original advice.

In the case of the yellowtail flounder Div. 3LNO, the alternative advice depends largely on how F_{target} is estimated in the alternative frameworks. In the case of estimating it based on the distribution of F_{lim}, the estimated value of F_{target} is quite close to F_{lim} and gives a higher catch harvest than the original, while if F_{lim} is defined as 75% of F_{msy} the alternative catch advice is lower than the original since this corresponded to a level of 85% of F_{msy}.

Introduction

One of the conclusions of the NAFO Joint Commission and Scientific Council Precautionary Approach Framework (PAF) Workshop held in August 2022 was that participants highlighted the need for additional information that could help inform the development of a proposal to revise the NAFO Precautionary Approach Framework (NAFO, 2022a). At the subsequent NAFO Joint Commission-Scientific Council Working Group on Risk Based Management Strategies (RBMS) meeting (NAFO, 2022b), it was agreed that one way to present this additional information could be as follows:

- Develop a small set of revised PA Frameworks based on the conclusions of the workshop,
- apply in an illustrative way the revised PA Framework to selected NAFO stocks,

- select the revised PA Frameworks and/or the key features within those frameworks that will need to be consider for the development of simulation testing.

Subsequently, the NAFO Precautionary Approach Working Group (PA-WG) agreed to develop three alternative frameworks based on the conclusions of the NAFO Joint Commission and Scientific Council Precautionary Approach Framework Workshop and apply these three frameworks to a selection of NAFO stocks to produce the alternative advice to be presented at the July 2023 RBMS meeting (NAFO, 2022c).

The conclusions of the PAF Revision workshop support the basic ideas of the current NAFO PAF (NAFO, 2004a), in particular the definition of the boundary reference points (B_{lim} and F_{lim}) as well as the pre-agreed management actions that are conditional on stock status and fishing status. The workshop also discussed possible revisions, clarifications and additions to the current Framework such as: The establishment of a F_{target} as well as the possible implementation of an intermediate biomass reference point or multiple biomass reference points that are between B_{lim} and B_{msy}. Based on these conclusions the NAFO Scientific Council (SC) decided to develop the following three alternatives:

> Option 1: With an intermediate biomass reference point (B_{buffer}) defined in order to avoid approaching B_{lim}.
>
> Option 2: With an intermediate biomass reference point ($B_{trigger}$) defined based on not moving away from the target biomass.
>
> Option 3: With two intermediate reference points: with a B_{buffer} with a low probability that the biomass will be less than B_{lim} and with a $B_{trigger}$ similar to option 2.

Three example NAFO stocks were chosen to represent a range of stock assessment information for applying the PA Framework: cod in Div. 3M, redfish in Div. 3M and yellowtail flounder in Divs. 3LNO.

At the February 2023 PA-WG meeting (NAFO, 2023), the structure and table of management actions of the three alternative frameworks were presented (Annex 1). It was also decided the ranking of the possible proxies of the different reference points ordered by their level of preference. The possible reference points values to be used in the frameworks of the stocks chosen as examples to produce the alternative advice were also discussed and approved for cod Div. 3M and yellowtail flounder Divs. 3LNO. No agreement was reached on the reference points that should be used in the alternative frameworks for the redfish Div. 3M. More work would be done to see a possible reference points proposal to use in the alternative frameworks for this stock. In this meeting it was also agreed that the alternative advises would be made with the last approved assessment of each one of the chosen stocks.

In this document, the different advices produced under the agreed alternative frameworks are presented for cod Div. 3M and yellowtail flounder Divs. 3LNO.

Material and Methods

Cod in Div. 3M. This stock is currently assessed using a Statistical Catch at Age model (SCAA). B_{lim} = $B_{recovery}$ = SSB_{2007} and F_{lim}=$F_{30\%SPR}$ have been adopted by SC as reference points for this stock (NAFO, 2019). The last SC approved full assessment was in 2022 (González-Troncoso *et al.*, 2022). In the February 2023 meeting of the PA-WG (NAFO, 2023) it was agreed that for this stock, reference points shown in the alternative frameworks will be the following:

- $B_{lim} = B_{recovery} = SSB_{2007}$
- $F_{lim} = F_{30\%SPR}$
- $B_{trigger} = 0.8*B_{msy}$

- F_{target} = both $F_{40\%SPR}$ and based on the risk (40th percentile of the F_{lim} distribution) to be above F_{msy} are presented;
- B_{buffer} for alternative framework Option 1 = B_{bisr} = 2*B_{lim}
- B_{buffer} for alternative framework Option 3: two values will be shown, the average of $B_{trigger}$ and B_{lim} as well as the risk (90th percentile of the B_{lim} distribution) of being below B_{lim}.

Yellowtail flounder Divs. 3LNO. This stock is currently assessed using a Schaefer surplus production model in a Bayesian framework. The last SC approved full assessment was in 2021 (Maddock Parsons *et al*, 2021). Aging data is not available for the stock. Table 1 shows the parameter estimates from the last accepted assessment of yellowtail flounder in Divs. 3LNO. Reference points agreed by SC for this stock are given as relative to B_{msy} and F_{msy}; B_{lim} is 30% B_{msy} and F_{lim} is F_{msy} (NAFO, 2004b). No other reference points have been determined to date. In the February 2023 meeting of the PA-WG (NAFO, 2023) it was agreed that for this stock, reference points shown in the alternative frameworks will be the following:

- B_{lim} = 30% B_{msy}
- F_{lim} = F_{msy}
- $B_{trigger}$ = 0.8* B_{msy}
- F_{target} = both 75% F_{msy} and risk (40%) to be above F_{msy} (=0.95)
- B_{buffer} for alternative framework Option 1 = B_{bisr} = 2*B_{lim}
- B_{buffer} for alternative framework Option 3: two values will be shown, the average of $B_{trigger}$ and B_{lim} as well as the risk (10%) of being below B_{lim} (=0.39)

The advice produced under the alternative frameworks is provided using qualitative management actions and HCRs. Under the qualitative management actions in the Danger Zone of the Options 1 and 2, advice is based on the F that is expected to allow SSB not to decrease (neutral risk), and alternatively the F that is expected to allow SSB to increase with 60% in the Recovery Zone Option 3 or 90% probability in the Danger Zone Option 3 (Annex 1). Annex 2 shows the method that has been used to estimate these F and the risk that the biomass in the projected years are less than those of 2022 for the cod Div. 3M case.

Results

Cod in Div. 3M

The values of the different proxies of the agreed reference points based on the results of the last SC approved assessment are presented in Table 2 and Figure 1. The estimated F target value based on the risk (40%) to be above F_{msy} ($F_{targ\_Risk>Flim}$) is very close to F_{lim} because the risk tolerance (40%) is relatively high and the SPR reference point does not include all sources of uncertainty in assumed parameters (e.g., M, weight at age). The estimated B_{buffer} value based on the risk (10%) of being below B_{lim} ($B_{buf\_Risk<Blim}$) is very close to B_{lim}, because the 2007 SSB appears to be well estimated, but also does not include uncertainty in some of the assumed parameters.

Figure 2, 3 and 4 shows the graph of the PA framework Option 1, 2 and 3 respectively with the results of the last assessment approved by the SC for Div. 3M cod in 2022. The Harvest Control Rules (HCRs) agreed have also been included in these figures. The mathematical formulation of the agreed HCRs is a function of the most recent stock estimate (B):

HCR "Danger" zone Option 1

$$F_{HCR} = -\frac{F_{target} * B_{lim}}{B_{buf} - B_{lim}} + \frac{F_{target}}{B_{buf} - B_{lim}} * B$$

HCR "Danger" zone Option 2

$$F_{HCR} = -\frac{F_{target} * B_{lim}}{B_{trig} - B_{lim}} + \frac{F_{target}}{B_{trig} - B_{lim}} * B$$

HCR Option 3

- "Recovery" zone

$$F_{HCR} = F_{target} - \frac{(2/3 - 1) * F_{target} * B_{trig}}{B_{buf} - B_{trig}} + \frac{(2/3 - 1) * F_{target}}{B_{buf} - B_{trig}} * B$$

- "Danger" zone

$$F_{HCR} = -\frac{(2/3) * F_{target} * B_{lim}}{B_{buf} - B_{lim}} + \frac{(2/3) * F_{target}}{B_{buf} - B_{lim}} * B$$

The last advice approved by SC for the cod Div. 3M in 2022 (NAFO, 2022 d), was as follow: "*Yield corresponding to F less than or equal to 3/4 F_{lim} in 2023 results in a very low probability (≤10%) of SSB being below B_{lim} in 2024 and a very low probability (≤10%) of exceeding F_{lim}.*

However, given the present level of the SSB and projected decline of total biomass under any fishing scenario, in order to promote growth in SSB with more than 60% probability, Scientific Council advises scenarios with F no more than $F_{statusquo}$.". This advise was based on the results of the PA risks table of the projections presented in Table 3.

Table 4 presents the PA risk table of the qualitative management actions to be taken in the Danger and Recovery zones of the alternative frameworks. This table presents the yields for two years of projections (2023 and 2024) and the approved TAC for 2022. It also shows the probabilities that F > F_{lim}, SSB < B_{lim} for the projected years and SSB_{2024} or SSB_{2025}>SSB_{2022}, since the last advice approved by the SC is based on the SSB increase at the end of two years of projections (2025>2022).

Alternative framework Option 1: In Figure 2 it can be seen that the 50th percentile of the estimated 2022 SSB of cod Div. 3M is in the Danger zone (SSB_{lim}<SSB_{2022}<SSB_{buffer}); in particular, P(SSB_{2022}<SSB_{buffer})=0.66 and so, according to the table Management Strategies and Courses of Action of the Option 1, the management measures to take should be the following:

Management Strategies and Courses of Action Option 1		
PA Zone	**Qualitative management actions**	**harvest control rule (HCR)**
Danger Zone (SSB_{lim}<B<SSB_{buffer})	consider F expected to promote rebuilding	HCR F=f(biomass); straight line with a maximum value F= F_{target} in SSB_{buffer} and a minimum value F=0 in B_{lim}

In Table 4 we can observe that the levels of F that allow the biomass to increase in 2024 or 2025 in 50% of the cases with respect to 2022 are 0.049 and 0.098 respectively, corresponding to yields in 2023 of 3 314 tons and 6 319 tons. Applying the agreed HCR based on the observed SSB level in 2022, we would have to recommend a catch level of 7 666 tons which correlates to a level of F = 0.104. Table 5 shows the advices in F levels and catches for 2023 under the current PA framework and the alternative Option 1.

Alternative framework Option 2: In Figure 3, it can be seen that the 50th percentile of the estimated 2022 SSB of cod Div. 3M is in the Danger zone ($SSB_{lim}<SSB_{2022}<SSB_{trigger}$); in particular, $P(SSB_{2022}<SSB_{trigger})=0.98$, and the management measures to take according to the table Management Strategies and Courses of Action of the Option 2 are the following:

Management Strategies and Courses of Action Option 2		
PA Zone	**Qualitative management actions**	**harvest control rule (HCR)**
Danger Zone ($SSB_{lim}<SSB<SSB_{trigger}$)	consider F expected to promote rebuilding	HCR F=f(biomass); straight line with a maximum value F= F_{target} in $SSB_{trigger}$ and a minimum value F=0 in B_{lim}

The qualitative management actions are the same as in Option 1, so the results and the qualitative advice are equal as in Option 1, explained above. Applying the agreed HCR for the Option 2 based on the observed SSB level in 2022, we would have to recommend a catch level of 5 668 tons which correspond to a level of F = 0.074. Table 6 shows the advices in F levels and catches for 2023 under the current PA framework and the alternative Option 2.

Alternative framework Option 3: In Figure 4, it can be observed that the 50th percentile of the estimated 2022 SSB of cod Div. 3M is in the Recovery zone ($SSB_{buffer}<SSB_{2022}<SSB_{trigger}$); in particular, $P(SSB_{buffer}<SSB_{2022}<SSB_{trigger})=0.85$, and the management measures to take according to the table Management Strategies and Courses of Action of the Option 3 should be the following:

Management Strategies and Courses of Action Option 3		
PA Zone	**Qualitative management actions**	**harvest control rule (HCR)**
Recovery Zone ($SSB_{buffer}<SSB<SSB_{trigger}$)	F that allows a low risk (40%) of stock decline in the projections period.	HCR F=f(biomass); straight line with a maximum value F= F_{target} in $SSB_{trigger}$ and a minimum value $F=2/3*F_{target}$ in SSB_{buffer}

In Table 4 we can observe that the levels of F that allow the SSB to increase in 2024 or 2025 in 60% of the cases with respect to 2022 are 0.041 and 0.089 respectively, corresponding to yields in 2023 of 2 808 tons and 5 764 tons. Applying the agreed HCR based on the observed SSB level in 2022, we would have to recommend a catch level of 7 666 tons, which correlates to a level of F = 0.104. Table 7 shows the advices in F levels and catches for 2023 under the current PA framework and the alternative Option 3. Note that the original advice is given considering the 1000 iterations and the TAC is calculated as the median of 1000 values, while in the HCR option is estimated using the median SSB and the TAC is a unique value. As a result, a slightly lower level of F results in a slightly higher level of yield.

Yellowtail flounder Divs. 3LNO

The values of the different proxies of the agreed reference points based on the results of the last SC approved assessment for the yellowtail flounder Divs. 3LNO are presented in Table 8. The B_{buffer} and F_{target} estimates based on B_{lim} or F_{lim} risk are very close to the B_{lim} and F_{target} estimates as was the case for cod Div. 3M.

In 2021, SC advised "*that fishing mortality up to 85% Fmsy, corresponding to catches of 22 100 t, 20 800 t, and 19 900 t in 2022 to 2024 respectively, have risk of no more than 30% of exceeding Flim, and are projected to maintain the stock above Bmsy*".

Alternative framework Option 1, 2 and 3:

Figure 5, 6 and 7 show the graphs of the PA framework option 1, 2 and 3 respectively with the results of the last assessment approved by the SC of yellowtail flounder Divs. 3LNO in 2021. The stock trajectory for yellowtail flounder as estimated using the Bayesian surplus production model in the last SC approved assessment placed the 2020 estimate of relative F and relative Biomass in the Safe Zone of all the three PA alternative frameworks. In this Zone, the qualitative management action and HCR management action is the same for the three alternatives frameworks and indicate that advice should be framed to maintain F equal or below F_{target}.

Management Strategies and Courses of Action Option 1, 2 and 3		
PA Zone	**Qualitative management actions**	**harvest control rule (HCR)**
Safe Zone ($B>B_{buffer}$ and $F<F_{target}$)	F equal or below F_{target}.	F equal or below F_{target}.

In Table 9 we can observe the original F advice ($85\%F_{msy}$) approved by the SC and their corresponding catches for the period 2022-2024 as well as the alternative catch advice for the same period of the alternatives frameworks options 1, 2 and 3 based on the agreed F_{target} of 75% of F_{msy} and F_{target} 95% of F_{msy} estimated based on the risk of be above F_{msy} (40 percentile of normal distribution around F_{msy}). Table 10 shows the PA risk table for the different F scenarios. If F_{target} is 95% F_{msy} (40 percentile of normal distribution around F_{msy} =0.197), then advice from the last assessment would have been conservative and the alternative advice in this scenario would be as follows "SC advises that fishing mortality should be equal or below 95% F_{msy} and should not exceed 24 760, 22 790 and 21 500 t in 2022 to 2024 respectively.". If F_{target} is 75% F_{msy}, however, advice should be framed to maintain F equal or below 75% F_{msy}. For the last assessment, then, the advice might have been "SC advises that fishing mortality should be below 75% F_{msy} and should not exceed 19 500 t, 18 800 t and 18 300 t in 2022 to 2024 respectively."

Discussion

In the case of cod and yellowtail flounder, the B_{buffer} and F_{target} estimates based on percentiles of the B_{lim} and F_{lim} distributions give values very close to B_{lim} and F_{lim}, so the area between the limit reference points and the B_{buffer} and F_{target} is very narrow and does not make much operational sense. Therefore, it has been decided in the case of cod to use only F_{target} as $F_{40\%SPR}$ and B_{buffer} in Option 3 as the average of $B_{trigger}$ and B_{lim} in the different alternative frameworks to produce the different advices.

In the case of cod Div. 3M, the alternative qualitative advice depends on the period used to see the risk that the biomass does not decrease. If a period similar to that used in the original advice (two years) is used, the advisable catch levels are quite similar in all three options to the original advice. Whereas if the

period is only one year, the alternative harvest advice is much lower than the original advice. In the cases of the alternative advice based on the HCR, Option 1 gives an alternative advice of catches much higher than the original advice, while Option 2 gives a value very close to the original and Option 3 a little higher than the original. In general, the qualitative advice based on measuring risk over a two-year period and in HCR gives catch levels quite similar to the catch level of the original advice. On the other hand, qualitative advice based on measuring risk over a one-year period gives much lower catch levels than the original advice. In this case, one of the advantages of alternative frameworks is that the production of advice is much better defined in the Danger and Recovery Zones than in the current framework, which avoids discussions in the SC to produce the advice and making more or less arbitrary decisions.

In the case of the yellowtail flounder Divs. 3LNO, we have seen that in alternative frameworks the stock is in the Safe Zone and that the original advice was based on the fact that at the end of the projection period the risk of F being greater than F_{lim} is equal to or less than 30 % and that the risk that the biomass being less than B_{lim} is equal to or less than 10%. Alternative frameworks' management measures are based on F levels equal to or less than F_{target}, so the alternative capture advice depends largely on how F_{target} is estimated in the alternative frameworks. In the case of estimating it based on the distribution of F_{lim}, the estimated value of F_{target} is quite close to F_{lim} and gives a higher catch harvest than the original, while if F_{lim} is defined as 75% of F_{msy} the alternative catch advice is lower than the original since this corresponded to a level of 85% of F_{msy}. In the Safe Zone of alternative frameworks, the production of advice is structured in a similar way than in the current framework.

References

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Table 1. Parameter estimates from the last accepted assessment of Yellowtail flounder Divs. 3LNO (Bayesian surplus production model; SCR 21-018).

Run Prior on r (mean, sd) Prior on K (mean,sd)	2021 Assessment uniform 0.01-2 Normal (150,1500)
B_{msy}	89 790 t
MSY	18 700 t
F_{msy}	0.2085
K	180 000 t
r	0.42

Table 2. Reference points proxies values for the alternative PA frameworks options estimated for the cod Div. 3M.

	Option 1	Option 2	Option 3
$F_{lim}=F_{30\%SPR}$	0.166	0.166	0.166
$F_{targ\_Risk>Flim}$	0.162	0.162	0.162
$F_{target}=F_{40\%SPR}$	0.113	0.113	0.113
$B_{lim}=SSB_{2007}$	15 028	15 028	15 028
$B_{buffer}=2*B_{lim}$	30 056		
$B_{trigger}=0.8*B_{msy}$		36 241	36 241
$B_{buf}=(B_{lim}+B_{trig})/2$			25 634
$B_{buf\_Risk<Blim}$			17 427

Table 3. PA Risk Table used by the SC to produce the advice for 2023.

	Yield			P(SSB < Blim)				P(Fbar > Flim)			
	2022	2023	2024	2022	2023	2024	2025	2022	2023	2024	P(SSB25 >SSB22)
Fsq = 0.089	4000	5791	6987	<1%	<1%	<1%	<1%	<1%	<1%	<1%	60%
F=0	4000	0	0	<1%	<1%	<1%	<1%	<1%	<1%	<1%	100%
F2021 = 0.022	4000	3425	4429	<1%	<1%	<1%	<1%	<1%	<1%	<1%	95%
1/2Flim = 0.083	4000	5446	6610	<1%	<1%	<1%	<1%	<1%	<1%	<1%	67%
2/3Flim = 0.111	4000	7032	8128	<1%	<1%	1%	1%	<1%	<1%	<1%	39%
3/4Flim = 0.125	4000	7787	8790	<1%	<1%	1%	1%	<1%	<1%	3%	27%
Flim = 0.166	4000	9915	10431	<1%	<1%	3%	6%	<1%	50%	50%	9%
C = 4000t	4000	4000	4000	<1%	<1%	<1%	<1%	<1%	<1%	<1%	94%
C = 5000t	4000	5000	5000	<1%	<1%	<1%	<1%	<1%	<1%	<1%	86%

Table 4. PA Risk Table used to produce the alternative advices for 2023 under the different alternative PA frameworks.

	Yield			P(SSB<Blim)				P(Fbar>Flim				
	2022	2023	2024	2022	2023	2024	2025	2022	2023	2024	P(SSB24>SSB22)	P(SSB25>SSB22)
F_Option_1_2_Danger_24 = 0.049	4000	3314	4325	0%	0%	0%	0%	0%	0%	0%	50%	95%
F_Option_3_Recov_24 = 0.041	4000	2807	3721	0%	0%	0%	0%	0%	0%	0%	60%	98%
F_Option_3_Danger_24 = 0.017	4000	1203	1670	0%	0%	0%	0%	0%	0%	0%	90%	100%
F_Option_1_2_Danger_25 = 0.098	4000	6319	7511	0%	0%	0%	0%	0%	0%	0%	6%	50%
F_Option_3_Recov_25 = 0.089	4000	5764	6979	0%	0%	0%	0%	0%	0%	0%	10%	60%
F_Option_3_Danger_25 = 0.060	4000	4047	5170	0%	0%	0%	0%	0%	0%	0%	36%	90%

Table 5. Fishing mortality and catch advice for 2023 approved by the SC in 2022 (2022 adv), and qualitative advice of Option 1 looking at risk in 2024 (Qualitative_2024) or 2025 (Qualitative_2025) and applying the HCR.

Option 1	2022_adv	Qualitative_2024	Qualitative_2025	HCR
F_adv	0.089	0.049	0.098	0.104
TAC_adv	5 791	3 314	6 319	7 666

Table 6. Fishing mortality and catch advice for 2023 approved by the SC in 2022 (2022 adv), and qualitative advice of Option 2 looking at risk in 2024 (Qualitative_2024) or 2025 (Qualitative_2025) and applying the HCR.

Option 2	2022_adv	Qualitative_2024	Qualitative_2025	HCR
F_adv	0.089	0.049	0.098	0.074
TAC_adv	5 791	3 314	6 319	5 668

Table 7. Fishing mortality and catch advice for 2023 approved by the SC in 2022 (2022 adv), and qualitative advice of Option 3 looking at risk in 2024 (Qualitative_2024) or 2025 (Qualitative_2025) and applying the HCR.

Option 3	2022_adv	Qualitative_2024	Qualitative_2025	HCR
F_adv	0.089	0.041	0.089	0.087
TAC_adv	5 791	2 807	5 764	6 540

Table 8. Reference points proxies values for the alternative PA frameworks options estimated for yellowtail flounder Divs. 3LNO.

Reference Point	Option 1	Option 2	Option 3	Source/notes
$\mathbf{F_{lim}}=F_{msy}$	0.2085	0.2085	0.2085	STACFIS 2004
$\mathbf{B_{lim}}=30\%B_{msy}$	26.94 kt	26.94 kt	26.94 kt	STACFIS 2004
$\mathbf{F_{target}}=75\%\ F_{msy}$	0.156	0.156	0.156	
$\mathbf{F_{target}}=$ risk $F>F_{lim}$ (upper 40 percentile)	0.198	0.198	0.198	95% F_{msy}
$\mathbf{B_{buffer}}=2*B_{lim}$	53.87 kt			
$\mathbf{B_{buffer}}=$ Risk (10%) of being below B_{lim}			35 kt	0.39 B_{msy}
$\mathbf{B_{buffer}}=(B_{lim}+B_{trigger})/2$			49.39 kt	0.55 B_{msy}
$\mathbf{B_{trigger}}=0.8*B_{msy}$		71.83 kt	71.83 kt	

Table 9. Fishing mortality and catch advice in tons for 2022-2024 period approved by the SC in 2022 (Original Adv), and the F and catch advice in tons for the same period under the alternative frameworks.

	F(22-24)	TAC 2022	TAC 2023	TAC 2024
Original Adv.	85%Fmsy	22 100	20 800	19 900
Options 1,2 and 3	Ftarget_75%Fmsy	19 500	18 800	18 300
Options 1,2 and 3	Ftarget_95%Fmsy	24 760	22 790	21 500

Table 10. Risk Table used of the original advice for the yellowtail flounder based on 85% F_{msy} and the alternative advices based on the 75% and 95% F_{msy} for 2022-2024 period under the different alternative PA frameworks.

	$P(F>F_{lim})$				$P(B<B_{lim})$				$P(B<B_{msy})$				
Catch2021=17000 ton	2022	2023	2024	2025	2022	2023	2024	2025	2022	2023	2024	2025	$P(B_{2025}>B_{2021})$
Original 85%Fmsy=0.177	27%	28%	29%	30%	<1%	<1%	<1%	<1%	9%	14%	20%	24%	32%
Ftarget_75%Fmsy=0.157	15%	16%	17%	19%	<1%	<1%	<1%	<1%	9%	13%	16%	19%	37%
Ftarget_95%Fmsy=0.199	42%	43%	43%	44%	<1%	<1%	<1%	<1%	9%	17%	24%	30%	28%

Figures

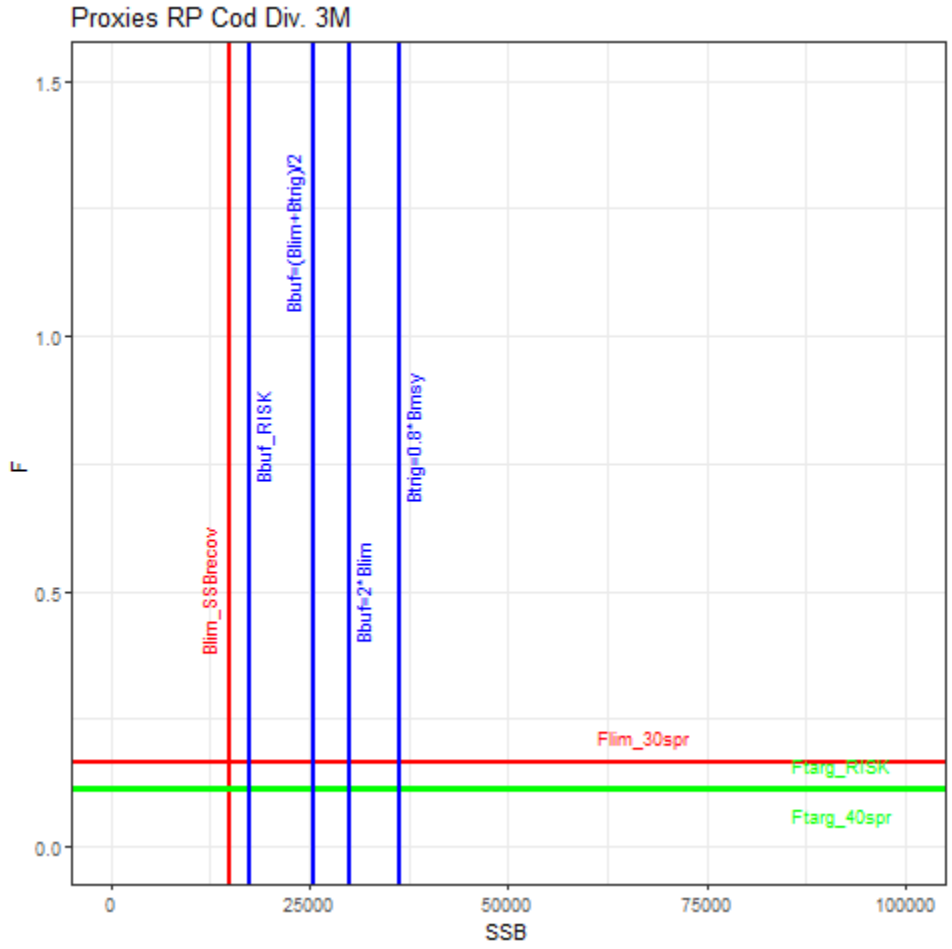


Figure 1. PA proxies reference points values for cod Div. 3M. $B_{lim\_SSBrecov}$ red vertical line is the B_{lim}, B_{buf_RISK} blue vertical is the B_{buffer} estimated as the percentile 90 of the B_{lim} distribution, $B_{buf}=(B_{lim}+B_{trig})/2$ blue vertical line is the B_{buffer} estimated as a mid-point between B_{lim} and $B_{buf}=2*B_{lim}$ blue vertical line is the B_{buffer} estimated as two times B_{lim}. $B_{trigger}=0.8*B_{msy}$ blue vertical line is the $B_{trigger}$. F_{lim_30spr} red horizontal line is the F_{lim}, F_{targ_RISK} green horizontal line is the F_{target} estimated as the percentile 40 of the F_{lim} distribution and F_{targ_40spr} green horizontal line is the F_{target} estimated based on the $F_{40\%spr}$.

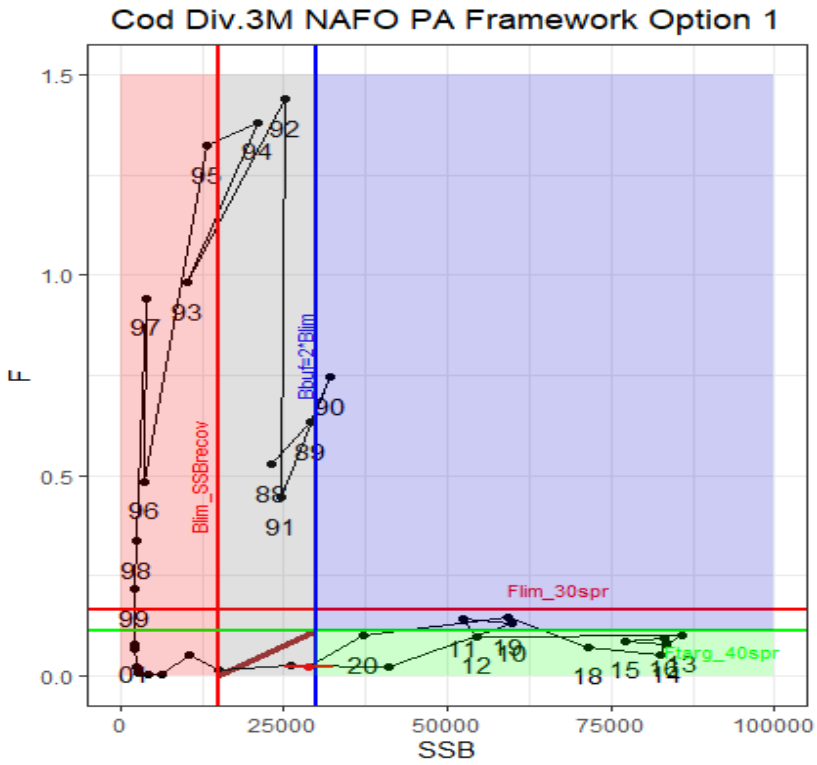


Figure 2. PA Framework Option 1 with the Div. 3M cod F and SSB 2022 assessment results. B_{lim}=15 028 tons (red vertical line), B_{buf}=2*B_{lim}= 30 056 tons (blue vertical line), F_{lim}=F_{msy}=$F_{30\%SPR}$= 0.166 (red horizontal line), F_{target}=$F_{40\%SPR}$=0.113 (green horizontal lime). Black dots are the results of the Div. 3M cod SSB and F and the red one is the 2022 value with the 10/90 percentiles. Garnet line is the HCR. Safe Zone (green) = SSB>B_{buf} and F<F_{target}; Danger Zone (grey) = B_{lim}<SSB<B_{buf}; Collapse Zone (red) = SSB<B_{lim}.

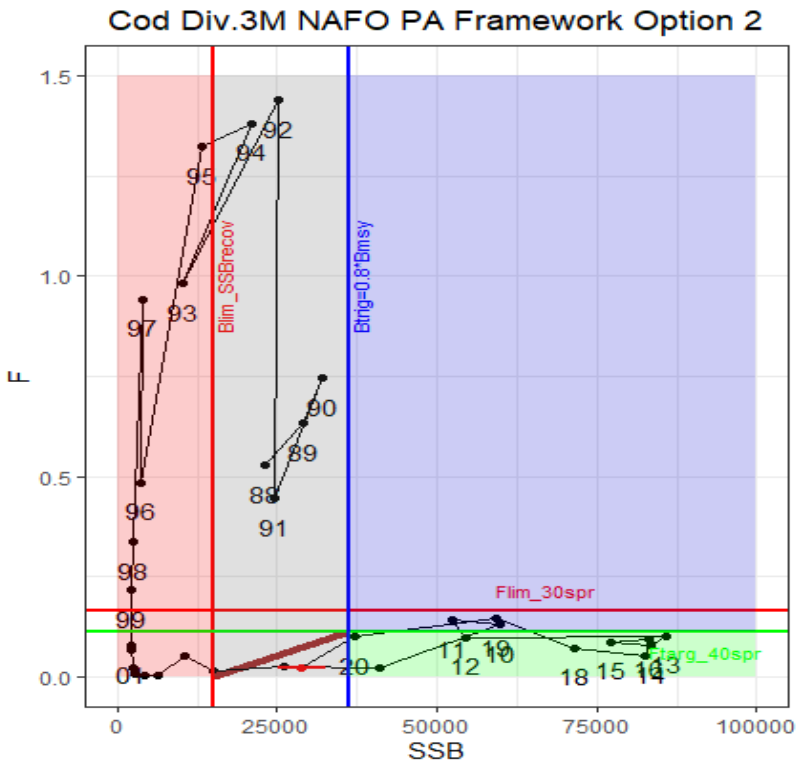


Figure 3. PA Framework Option 2 with the Div. 3M cod F and SSB 2022 assessment results. B_{lim}=15 028 tons (red vertical line), $B_{trigger}$=0.8*B_{msy}= 36 241 tons (blue vertical line), F_{lim}=F_{msy}=$F_{30\%SPR}$= 0.166 (red horizontal line), F_{target}=$F_{40\%SPR}$= 0.113 (green horizontal lime). Black dots are the results of the Div. 3M cod SSB and F and the red one is the 2022 value with the 10/90 percentiles. Garnet line is the HCR. Safe Zone (green) = SSB>B_{buf} and F<F_{target}; Danger Zone (grey) = B_{lim}<SSB<$B_{trigger}$; Collapse Zone (red) = SSB<B_{lim}.

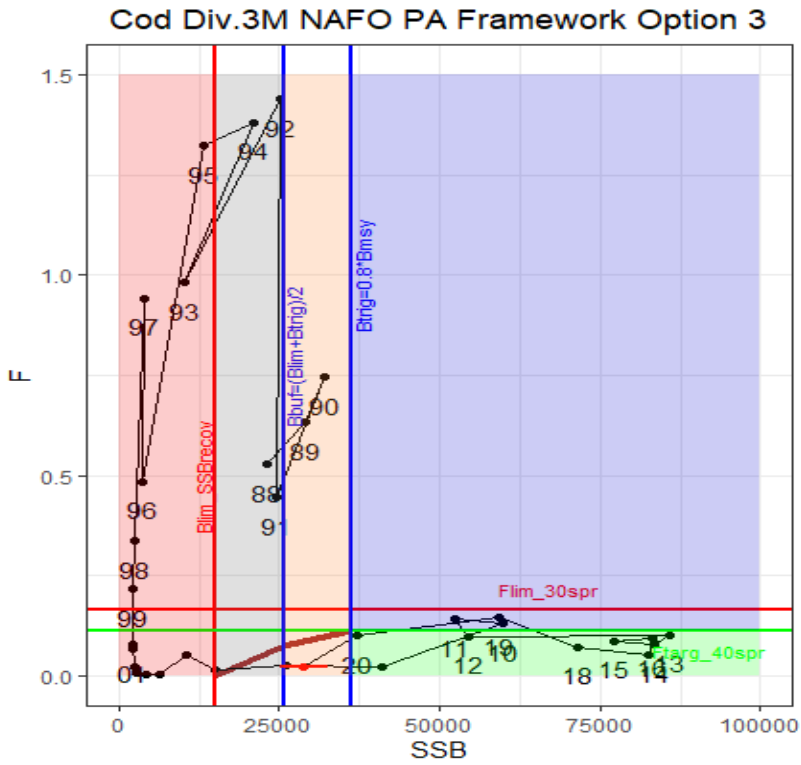


Figure 4. PA Framework Option 3 with the Div. 3M cod F and SSB 2022 assessment results. B_{lim}=15 028 tons (red vertical line), $B_{buf}=(B_{lim}+B_{trig})/2$= 25 634 tons (blue vertical line), $B_{trigger}=0.8*B_{msy}$= 36241tons (blue vertical line), $F_{lim}=F_{msy}=F_{30\%SPR}$= 0.166 (red horizontal line), $F_{target}=F_{40\%SPR}$= 0.113 (green horizontal lime). Black dots are the results of the Div. 3M cod SSB and F and the red one is the 2022 value with the 10/90 percentiles. Garnet line is the HCR. Safe Zone (green) = $SSB>B_{buf}$ and $F<F_{target}$; Danger Zone (grey) = $B_{lim}<SSB<B_{buffer}$; Recovery Zone (cream) =$B_{buffer}<B<B_{trigger}$ and Collapse Zone (red) = $SSB<B_{lim}$.

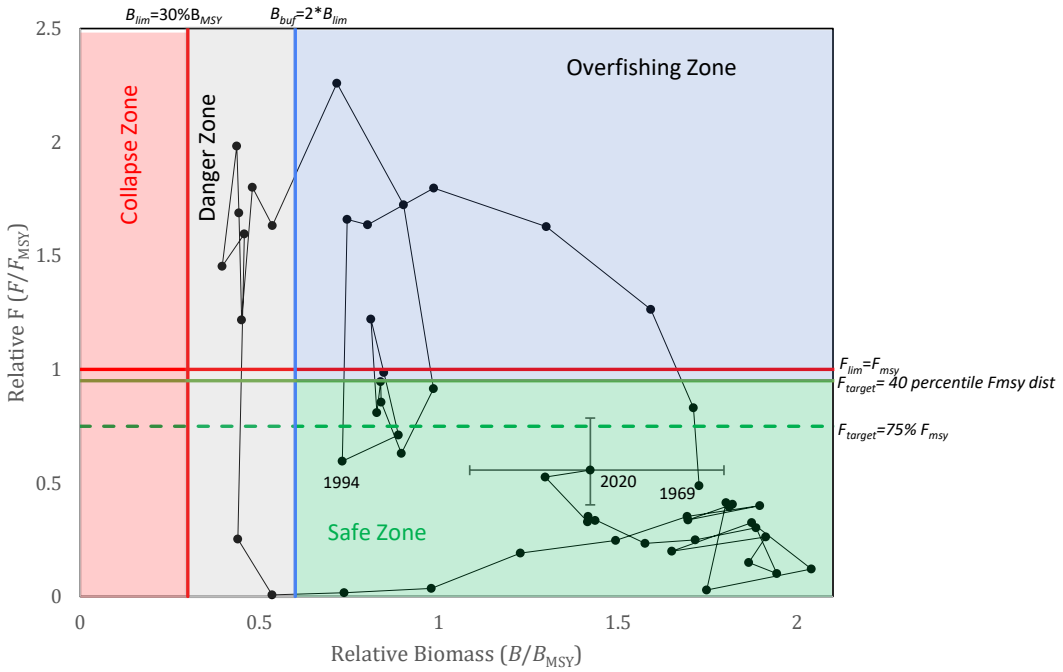


Figure 5. PA Framework Option 1 with the Yellowtail flounder Divs. 3LNO assessment results (relative F and Biomass estimates from a Bayesian surplus production model). B_{lim} =30% B_{msy} (red vertical line), B_{buffer} =2* B_{lim} (blue vertical line), F_{lim}=F_{msy} (red horizontal line), F_{target}= 75% F_{msy} (hatched green horizontal line) and risk (40%) to be above F_{msy} (=0.95; horizontal green line).

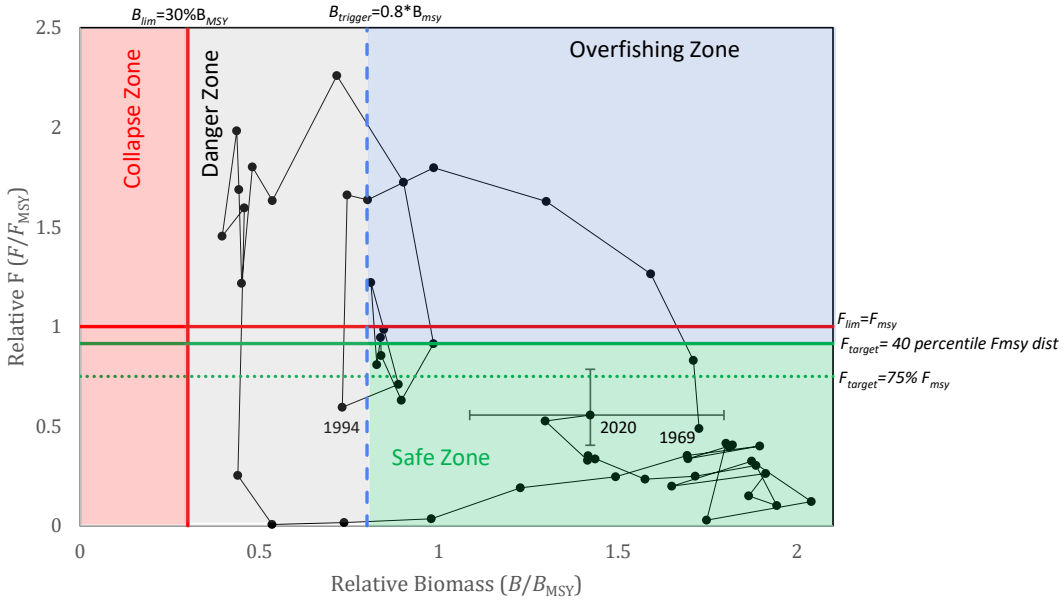


Figure 6. PA Framework Option 2 with the Yellowtail flounder Divs. 3LNO assessment results (relative F and Biomass estimates from a Bayesian surplus production model). B_{lim} =30% B_{msy} (red vertical line), $B_{trigger}$ =0.8* B_{msy} (blue hatched vertical line), F_{lim}=F_{msy} (red horizontal line), F_{target}= 75% F_{msy} (hatched green horizontal line) and risk (40%) to be above F_{msy} (=0.95; horizontal green line).

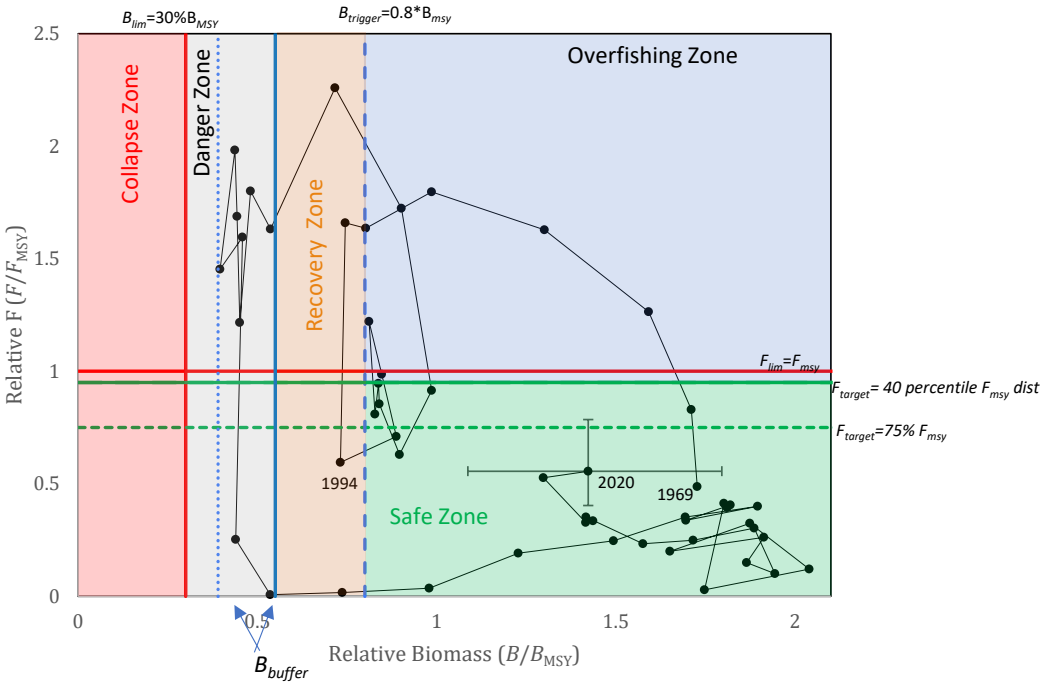
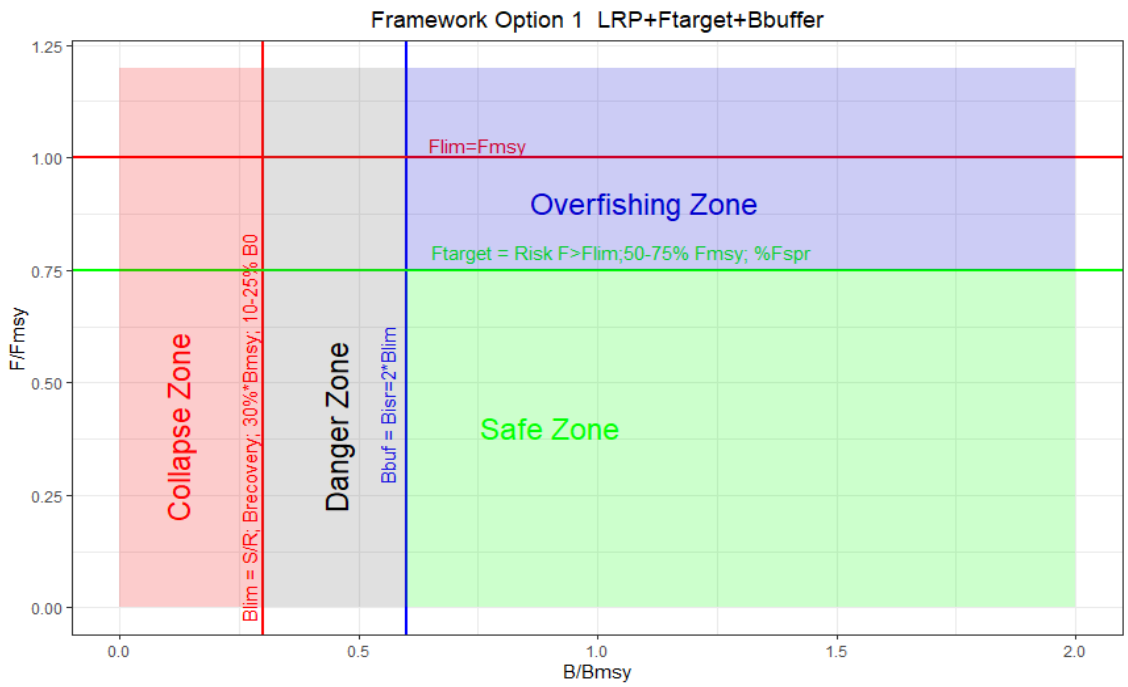


Figure 7. PA Framework Option 3 with the Yellowtail flounder Divs. 3LNO assessment results (relative F and Biomass estimates from a Bayesian surplus production model). B_{lim} =30% B_{msy} (red vertical line), $B_{trigger}$ =0.8* B_{msy} (blue hatched vertical line), B_{buffer}= (B_{lim}+ $B_{trigger}$)/2 or B_{buffer}= risk (<10%) of being below B_{lim} (blue vertical dotted line), F_{lim}=F_{msy} (red horizontal line), F_{target}= 75% F_{msy} (hatched green horizontal line) and risk (40%) to be above F_{msy} (=0.95; horizontal green line).

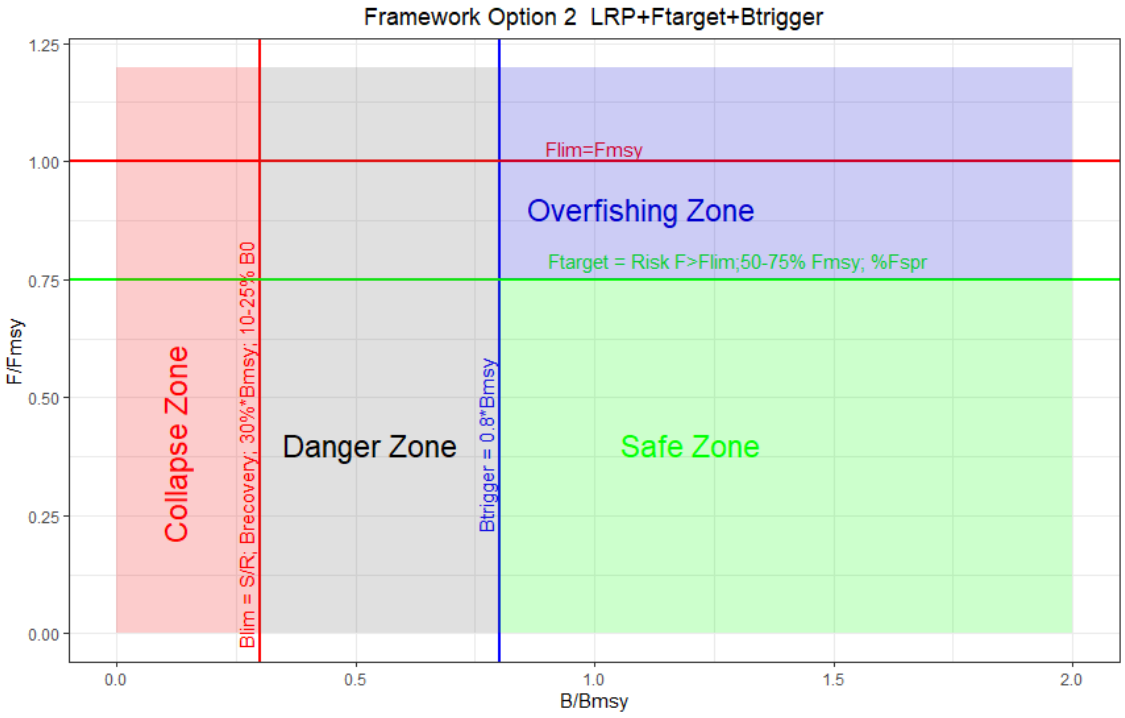
ANNEX 1

Option 1: With one intermediate biomass reference point: B_{buffer}.



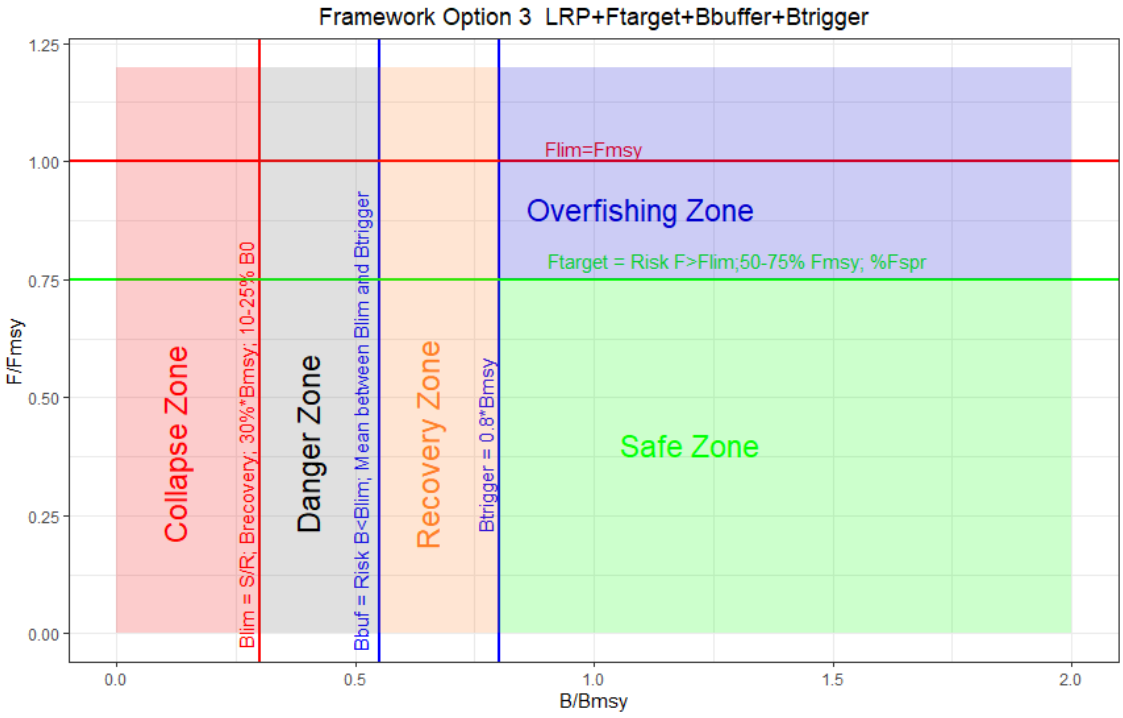
Management Strategies and Courses of Action Option 1		
PA Zone	Qualitative management actions	harvest control rule (HCR)
Safe ($B>B_{buffer}$ and $F<F_{target}$)	F equal or below F_{target}.	F equal or below F_{target}.
Overfishing ($B>B_{buffer}$ and $F>F_{target}$)	Reduce F to equal/below F_{target}.	Reduce F to equal/below F_{target}.
Danger Zone ($B_{lim}<B<B_{buffer}$)	consider F expected to promote rebuilding	HCR F=f(biomass); straight line with a maximum value F= F_{target} in B_{buffer} and a minimum value F=0 in B_{lim}
Collapse Zone ($B<B_{lim}$)	F should be set as close to zero as possible.	F should be set as close to zero as possible.

Option 2: With one intermediate biomass reference point: $B_{trigger}$.



Management Strategies and Courses of Action Option 2		
PA Zone	**Qualitative management actions**	**harvest control rule (HCR)**
Safe ($B>B_{trigger}$ and $F<F_{target}$)	**F equal or below F_{target}.**	**F equal or below F_{target}.**
Overfishing ($B>B_{trigger}$ and $F>F_{target}$)	**Reduce F to equal/below F_{target}.**	**Reduce F to equal/below F_{target}.**
Danger Zone ($B_{lim}<B<B_{trigger}$)	**consider F expected to promote rebuilding**	**HCR F=f(biomass); straight line with a maximum value F= F_{target} in Btrigger and a minimum value F=0 in B_{lim}**
Collapse Zone ($B<B_{lim}$)	**F should be set as close to zero as possible.**	**F should be set as close to zero as possible.**

Option 3: With two intermediate biomass reference points: B_{buffer} and $B_{trigger}$.



Management Strategies and Courses of Action Option 3		
PA Zone	Qualitative management actions	harvest control rule (HCR)
Safe ($B>B_{trigger}$ and $F<F_{target}$)	F equal or below F_{target}.	F equal or below F_{target}.
Overfishing ($B>B_{trigger}$ and $F>F_{target}$)	Reduce F to equal/below F_{target}.	Reduce F to equal/below F_{target}.
Recovery Zone ($B_{buffer}<B<B_{trigger}$)	F that allows a low risk (40%) of stock decline in the projections period.*	HCR F=f(biomass); straight line with a maximum value F= F_{target} in $B_{trigger}$ and a minimum value F=2/3*F_{target} in B_{buffer}
Danger Zone ($B_{lim}<B<B_{buffer}$)	F that allows a very low risk (10%) of stock decline in the projections period.*	HCR F=f(biomass); straight line with a maximum value F= F2/3*F_{target} in B_{buffer} and a minimum value F=0 in B_{lim}
Collapse Zone ($B<B_{lim}$)	F should be set as close to zero as possible.	F should be set as close to zero as possible.

ANNEX 2

How the F that gives $P(SSB_{2025}>SSB_{2022})=0.5$ is calculated.

From the last approved assessment, we have 1000 values of N_{2022}, SSB_{2022} (iterations), and with the TAC_{2022} (an only value for all iterations) we can get 1000 values of N_{2023} and SSB_{2023}.

To project from 1 January 2023 to the future, we use a grid of F (in our case, we use a grid from 0 to 0.2 with a step of 0.0002, so we have 1001 values of F).

Now, for each F value of the grid, we project from N_{2023} the N_{2024}. So, we have an array with 1000x1001 values of N_{2024} (iterations x number of F grid steps). From N_{2023} and the F values of each step of the grid, we can get $Yield_{2023}$ (1000 x 1001), and for each of the steps of the grid we take the median of yield of 2023 ($medianYield_{2023}$). So, $medianYield_{2023}$ has 1001 values, one for each value of the grid of the F. From the N_{2023} (1000 x 1001) and $medianYield_{2023}$ (1001), we can get the $F_{bar\_real\_2023}$ (1000*1001), that is the value of F that gives us in all the 1000 iterations of N_{2023} the value of median $Yield_{2023}$ for each value of the F grid. This allows us to estimate the N_{2024} values and measure the $P(F_{real}>F_{lim})$. Then, we calculate the F that allows that $P(SSB_{2024}>SSB_{2022})=0.5$. For teach step of the grid, first we calculate $dif_{24}=SSB_{2022}-SSB_{2024}$, for each iteration. Then, we sort the values of dif_{24} and get the highest iteration in which $dif_{24}<0$ (so, $SSB_{2022}<SSB_{2024}$) for each step of the grid. For that step of the grid, the percentile in which $P(SSB_{2024}>SSB_{2022})=0.5$ is that iteration/1000 (number of iterations).

And in the following year of projections and to measure the $P(SSB_{2025}>SSB_{2022})$ we make the same steps as in 2023.

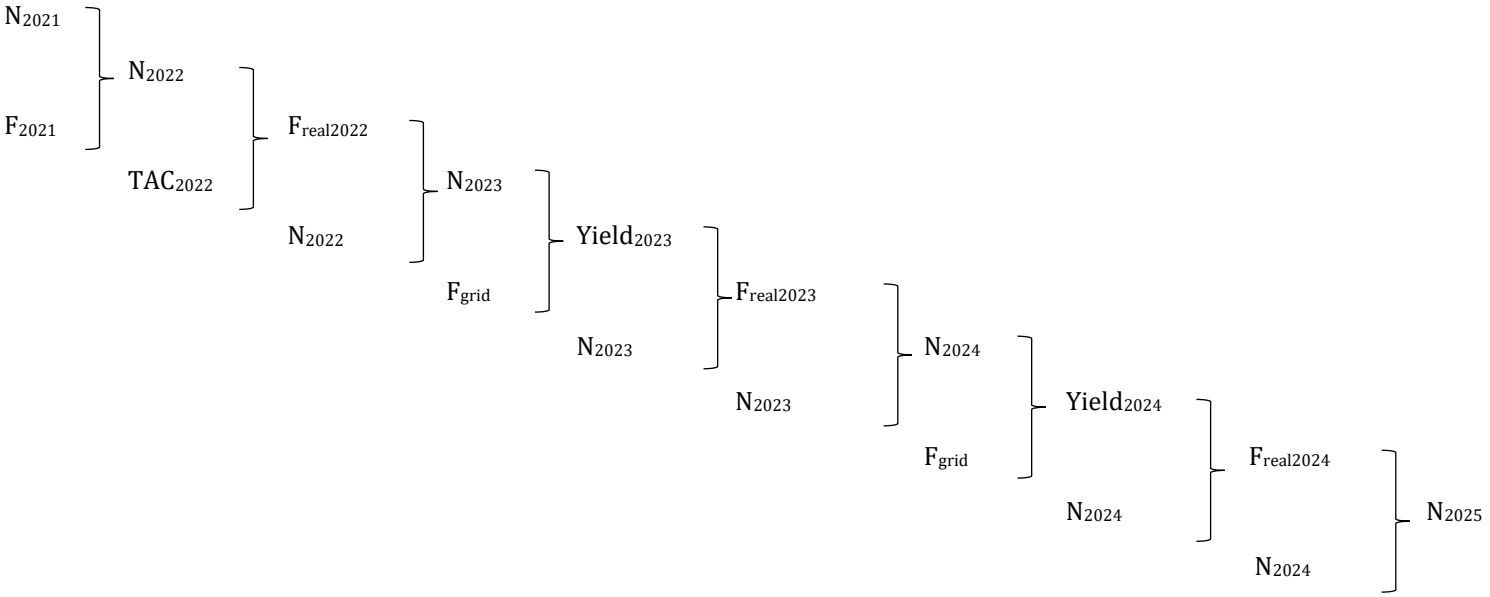
For knowing which F corresponds to $P(SSB_{2024}>SSB_{2022})=0.5$, we look in the last row of the table below the closest value above 0.5, and that´s the corresponding F. In the second step, we calculate the F that allows that $P(SSB_{2025}>SSB_{2022})=0.5$.

With a probability of 0.5, the Qualitative management actions for the Danger Zone "consider F expected to promote rebuilding" of Framework Option 1 and 2 could be applied.

With the probability 0.4, the Qualitative management actions for the Recovery Zone of framework Option 3 could be applied "F that allows a low risk (40%) of stock decline in the projections period". And with the probability 0.1, the Qualitative management actions for the Danger Zone of framework Option 3 could be applied "F that allows a very low risk (10%) of stock decline in the projections period"

Iteration	**F=0**	**F= 0.0002**	**...**	**F=0.1048**	**..**	**F=0.1998**	**F=0.2**
1	$dif_{24\_1\_F=0}$	$dif_{24\_1\_F=0.0002}$		$dif_{24\_1\_F=0.1048}$		$dif_{24\_1\_F=0.1998}$	$dif_{24\_1\_F=0.2}$
2	$dif_{24\_2\_F=0}$	$dif24\_2\_F=_{0.0002}$		$dif_{24\_2\_F=0.1048}$		$dif_{24\_2\_F=0.1998}$	$dif_{24\_2\_F=0.2}$
...							
500	$dif_{24\_500\_F=0}$	$dif_{24\_500\_F=0.0002}$		$dif_{24\_500\_F=0.1048}$		$dif_{24\_500\_F=0.1998}$	$dif_{24\_500\_F=0.2}$
...							
999	$dif_{24\_999\_F=0}$	$dif_{24\_999\_F=0.0002}$		$dif_{24\_999\_F=0.1048}$		$dif_{24\_999\_F=0.1998}$	$dif_{24\_999\_F=0.2}$
1000	$dif_{24\_1000\_F=0}$	$dif_{24\_1000\_F=0.0002}$		$dif_{24\_1000\_F=0.1048}$		$dif_{24\_1000\_F=0.1998}$	$dif_{24\_1000\_F=0.2}$
Percentile $dif_{24}<0$	0.974	0.973		0.028		0.000	0.000

Scheme



$F_{real2023}$ = > $P(F_{2023}>F_{lim})$

N_{2024} => SSB_{2024} => $P(SSB_{2024}<B_{lim})$; $P(SSB_{2024}>SSB_{2022})$

$F_{real2024}$ = > $P(F_{2024}>F_{lim})$

N_{2025} => SSB_{2025} => $P(SSB_{2025}<B_{lim})$; $P(SSB_{2025}>SSB_{2022})$