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Management Strategy Evaluation (MSE) of witch flounder in Divs. 3NO to test the proposed NAFO Precautionary Approach Framework (NAFO-PAF)

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Introduction

The NAFO Commission requested that the Scientific Council (SC) carry out a undertake testing of the revised Provisional Draft Precautionary Approach Framework (PAF) testing (**NAFO, 2024c**). At an intersessional SC meeting in January 2024, approaches for generic and specific stock based testing were approved (**NAFO, 2024b**). One of the case-study stocks chosen for testing the NAFO PA framework testing is the Witch Flounder stock in NAFO divisions 3NO.

The NAFO PA working group (PAWG) was constituted in 2016 to re-evaluate and test a new PA framework. Since then, the revision of the PA has evolved over several years of work by the NAFO PAWG starting with a review of existing PAFs in Canada, ICES, and New Zealand (**NAFO, 2022a**, **2022c**, **2022b**, **2023**). The most recent provisional revised PA is defined as a 'leaf' wherein the stock could be managed based on a range of F values determined by the 'leaf' shape of the PAF (Figure 1, see NAFO (**2024c**);NAFO (**2024a**) for more details on the rationale and parameterization of the PAF 'leaf'). The stock is understood to be in the Critical Zone below B_{lim} (0.3 B_{msy}) and fishing mortality (F) is expected to be zero in this zone. In the Healthy zone, the stock biomass is above B_trigger (0.75 B_{msy}) and in this zone, F is set to F_{target} (0.85 F_{msy}); F_target is set below F_{lim} (F_{msy}) in order to ensure that the F does not exceed F_{msy} in any of the three zones. The most complex area of the implementation of the PA is the intermediate zone between B_{lim} and $B_{trigger}$, referred to as the Cautious Zone. In this zone, F at any given stock level could range between the lower and upper leaf lines (shown as the grey leaf shaped area in Figure 1. Key objectives of the PA are to have a low risk of stock biomass (B) depletion (i.e., B<B_{lim}), to rebuild B to the level associated with maximum sustainable yield (B_{msy}), to maintain stocks above B_{msy} more often than not, and to maintain average catches of approximately at MSY in the long-term (**NAFO, 2022a**, **2024a**).

Witch flounder in NAFO Divs. 3NO is currently assessed using a Bayesian Surplus production (BSP) model is understood to be in the Cautious Zone Maddock Parsons et al. (**2024**). This is a good candidate stock for testing, then, as the stock is currently in the zone where the PA 'leaf' structure will be effective. We developed an MSE for the stock using the 2022 accepted Bayesian Surplus production model (**Maddock Parsons et al., 2022**) as the operating model for the stock, as at the time of testing, this was the most recent accepted assessment for the stock. For testing the PA, the MSE applies the PA 'leaf' structure to determine the TAC advise for the stock for 25 years in the simulation. To incorporate stock specific process and observation uncertainty, the simulation is run over 350 threads. The performance of the simulation is evaluated based on performance statistics defined to test whether the PA decision rules and control points, when applied as prescribed, met the objectives of the PA framework NAFO (**2024a**).

Methods

A Management Strategy Evaluation (MSE) is a simulation process with an operating model that describes population dynamics and fisheries. The simulation process is repeated for 25 years. A BSP has been used to assess the stock since 2015 (**Morgan et al., 2015**); the model formulation was updated in 2019 (**Morgan and Koen-Alonso, 2015**) and this formulation has been used to assess the stock since then. The model fits to landings and the Canadian Spring and Fall surveys; the Canadian spring survey is split into an early (<1990) and late phase (1991-present). The model formulation follows the Schaefer surplus production form with priors on intrinsic rate of growth r, carrying capacity K. catchability parameters for the three survey series, observation error for the three surveys, and process error on the state equation. Details on data, model structure, and the specifications of the priors that inform this MSE can be found in Maddock Parsons et al. (**2022**).

Details of the MSE formulation 1. Operating model: For the Witch flounder stock, the state equation follows a Bayesian Schaefer surplus production model with process error. The original model is written in Winbugs and run from R using the package R2Winbugs. With the setting of 100000 MCMC iterations and 3 chains, the run time for each model is approximately 20 minutes. In the MSE for PA testing this stock, this assessment process needs to be repeated every year in every simulation thread adding huge computational time. The model was converted into Jags software, and run from R using package 'rjags' for easily accessing the Linux environment on the DFO HPC cluster. The Winbugs formulation included constraints on the P (B/K) variables; the variables were interval censored to remain within the range 0.001 to 5. In the jags application, this constraint was removed and we found that the model performed similarly in a comparison of estimated parameters from both the implementations.

The first year is initialized in 2021 using 350 samples from the MCMC outputs of biomass and F estimates in the terminal year of the model (i.e., the last year for which data was available in the assessment model run in 2022). Reference points for the stock, model parameters r, K, the catchability parameters, and process and observation error parameters are obtained from this model. Observed survey data are used up to the year 2021. From 2022, the simulation process generates new data. Landings information for the stock till year 2023 is used in the projection and an assumed catch of 0.505 tonnes for the year 2024 (**Maddock Parsons et al., 2024**) is used in the projections. TAC determined by the application of the PA framework is applied from year 2025 onwards.

$$P_{2021} = B_{2021}/K_{2021} \qquad (1)$$

In year 2022, the population is projected forward using the model state equation which includes a process error. Process error is sampled from the process error standard deviation estimates in the operating model σ_δ.

$$P_{t+1} = (P_t + r.P_t(1-P_t) - C_t/K)e^{\delta}, \quad \text{where } \delta_t \sim N(0,\sigma_\delta) \qquad (2)$$

F is calculated as the ratio of catch over biomass where catch is the TAC determined from the application of the PA, except in years 2022-2024 where available information on landings or projected catch is used.

$$F_t = C_t/B_t \qquad (3)$$

2. Observation model: The observation model produces data (Canadian spring and autumn survey data) for the estimation model.

Calculate the indices for the surveys using the estimated catchability and observation error standard deviation estimates derived from the variance estimates from the BSP model for Witch Flounder.

$$\hat{I}_{t,s} = q_s B_t e^{\epsilon_s} \quad \text{where } \epsilon_s \sim N(0,\sigma_s) \qquad (4)$$

3. Application of the PA leaf formulation. As with the other case study on 3M cod, the PA implementation process begins in the current year 2024 wherein advice is generated for 2025. The BSP model is run within the simulation every alternate year starting 2023 to follow the assessment cycle for the stock.

i. The first step in modelling the application of PA is preparing the data for running the assessment model inside the simulation. This step includes adding the simulated indices to the available time series of indices. An year of landings is added to the time series; further an additional year of initial values (inits) are added to create the updated dataset.

ii. The Bayesian surplus production is rerun with the same controls as is run for the biannual assessment.

iii. Model the fisheries process and apply the PA by first running the assessment model with the new data. In each year of the simulation, the assessment model is rerun with the simulated data. The stock status determined from the assessment is projected forward two years. The two year projection is done to account for the time between the last year of data available in the assessment and the advice year. For example, at the 2024 assessment, data up to 2023 will be available for running the assessment and advice would be provided for 2025; so prior to applying the PA (denoted as fPA in the equation below; see NAFO (**2024a**) for the mathematical description of the function), the stock would need to be projected to 2025, the advice year. This projection uses the state equation and the TACs available for the projection years.

iv. The projected biomass in the advice year is applied to the PA 'leaf' function (fPA) to obtain the F value for the advise year and this F value from the PA is used to determine the TAC. Since advice is provided for two years at a time, TAC for the second advice year is based on F derived from application of PA on an additional projected year of biomass.

$$Fbar_{t+(2,3)} = fPA\left(B^{p}_{t+(2,3)}\right) \quad \text{where } B^{p} \quad \text{is projected biomass} \qquad (2)$$

3. Implementation model – implements TAC decisions to calculate actual annual removals. Implementation is assumed to be accurate in the base-case model version; this means that the catch taken is the same as the TAC advised.

Results

Three simulations were conducted using the lower, middle and upper leaf F relative to the estimated biomass of the stock, as defined by the leaf shape in the Cautious Zone of the provisional PA (Figure 1). Biomass for all simulations is projected to increase well into the Healthy Zone within the 25 years of the simulations, however none reach above the B_{msy} (Figure 2. It is possible, that upon extending each simulation to more years, the biomass levels might exceed B_{msy} (this remains to be tested). As expected, the projections using the lower leaf (lower F) shape performs better for biomass trends 2. In the simulations, most F values remain close to F_{target} while a few exceed F_{lim}. For this stock the F_{lim} and F_{target} are very close to each other (Figure 3). The yields reach close to MSY towards the end of the simulation (Figure 4). When the provisional PA is implemented, there is an increase in F from current levels in all the three leaf shapes (F scenarios) examined. In the short term, there is an abrupt increase in F and TAC from current levels, especially in the upper leaf (high F) shape (Figure 5).

Discussion

The witch founder stock reaches the Healthy Zone within the 25 years of simulation under all the three provisional PA leaf shapes (F scenarios) tested. An important point of observation is that except for a couple of peaks since year 2000 in the F trajectory from the 2022 assessment, the values recommended by the provisional PA in the MSE simulations are at similar or higher levels. Therefore, catch recommendations within the simulations are higher as well. The simulations predict that the stock will rebuild to the Healthy zone at F and catch levels higher than in the recent history of the stock. More detailed comparison of the recent stock trends and future simulations will help clarify if recent stock performance is similar to levels expected based on the simulation. Further, there was a decline in the stock in 2014-2016, unrelated to F levels which was dealt with in the assessment by allowing large process errors (**Maddock Parsons et al., 2022**). MSE simulations could explore the possibility of such events in the future and the robustness of the PA to adjust management accordingly.

The F_{msy} reference point from the BSP model is related to the parameter 'r' as r/2. The estimation of 'r' relies on a prior; the assessment model output shows that the central tendency of the prior and posterior are very similar. Although the priors for the model have been examined previously Morgan and Koen-Alonso (**2015**), this aspect of the model is important to be cognizant of in developing expectation of future stock performance.

Although the long-term results are similar, in the short-term, right after the implementation of the PA within the simulation, the TAC recommendations and the F and biomass trajectories are quite different between the three leaf shapes. How abrupt the changes in F and TAC are depend on the difference between the F suggested by the PA and the most recent F estimated for the stock. Similar observations about differences in trajectory of F, TAC, and biomass levels in the short-term were made in the 3M cod case-study as well.

Suggestions for leaf shape: Based on the observations on TAC variability, we suggest that the PA leaf shape should be informed by the current position of the stock on the PA map in order to reduce the abrupt changes to advice upon implementation of PA. For the witch flounder stock, if the leaf is set to pass through the current stock position, then the 'leaf' shape would be close to linear 6. Further exploration of this idea suggests that if the current position of the stock lies near the midpoint of the cautious zone (both for biomass and F - see orange dots in figure 7), then the shape could be close to a linear shape; stocks in the lower right triangle of cautious zone could adopt the lower leaf, and stocks in the top left triangle could adopt the upper leaf shape (see orange dots in figure 7).

Acknowledgements

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References

Maddock Parsons, D., Rideout, R., and Rogers, B. (2022). An assessment of the witch flounder resource in NAFO divisions 3NO. *NAFO SCR Doc*, *22/014*.

Maddock Parsons, D., Skanes, K., and Rideout, R. (2024). An assessment of the witch flounder resource in NAFO divisions 3NO. *NAFO SCR Doc*, *24/018*.

Morgan, J., Hvingel, C., and Koen-Alonso, M. (2015). Surplus production models in a Bayesian framework applied to witch flounder in NAFO Div. 3NO. *NAFO SCR Doc*, *15/37*.

Morgan, J., and Koen-Alonso, M. (2015). Exploration of priors used in surplus production model in a Bayesian framework applied to witch flounder in NAFO Div. 3NO. *NAFO SCR Doc*, *19/29*.

NAFO. (2022a). Achieving NAFO convention objectives with a precautionary approach framework precautionary approach working group (PA-WG) october 2021. *NAFO SCS Doc*, *22/02*. **https://www.nafo.int/Portals/0/PDFs/sc/2022/scs22-02.pdf**

NAFO. (2022b). Report of the NAFO precautionary approach working group (PA-WG) december 2022. *NAFO SCS Doc*, *22/26*. **https://www.nafo.int/Portals/0/PDFs/sc/2022/scs22-26.pdf**

NAFO. (2022c). Report of the NAFO precautionary approach working group (PA-WG) may 2022. *NAFO SCS Doc*, *22/15*. **https://www.nafo.int/Portals/0/PDFs/sc/2022/scs22-15.pdf**

NAFO. (2023). Report of the NAFO precautionary approach working group (PA-WG) february 2023. *NAFO SCS Doc*, *23/07*. **https://www.nafo.int/Portals/0/PDFs/sc/2023/scs23-07.pdf**

NAFO. (2024a). Report of the NAFO precautionary approach working group (PA-WG) april 2024. *NAFO SCS Doc*, *24/05*. **https://www.nafo.int/Portals/0/PDFs/sc/2024/scs24-05.pdf**

NAFO. (2024b). Scientific council intersessional meeting. *NAFO SCS Doc*, *24/02*. **https://www.nafo.int/Portals/0/PDFs/sc/2024/scs24-02.pdf**

NAFO. (2024c). The Commission's Request for Scientific Advice on Management in 2025 and Beyond of Certain Stocks in Subareas 2, 3 and 4 and Other Matters. *NAFO SCS Doc*, *24/01*. **https://www.nafo.int/Portals/0/PDFs/sc/2024/scs24-01.pdf**

Figures

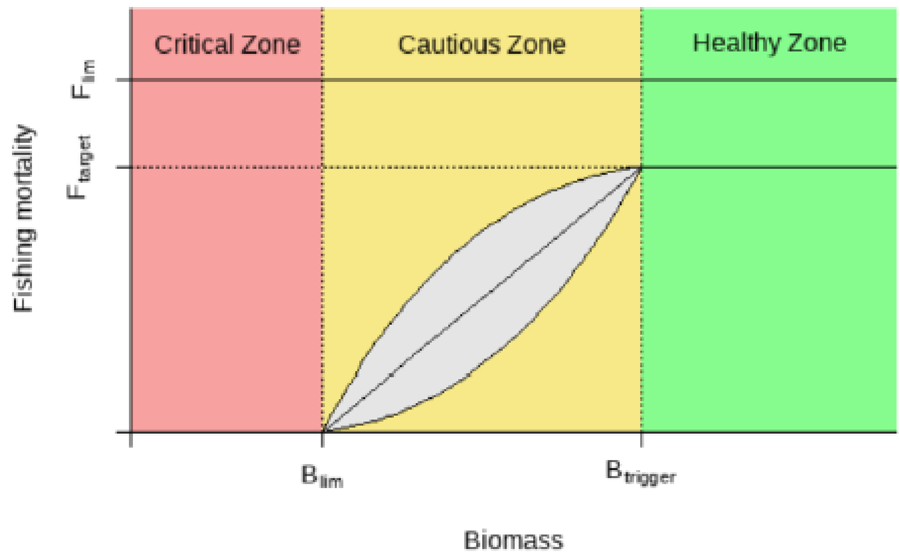

Figure 1. The NAFO Precautionary Approach Leaf shape. In the healthy zone, F is set to Ftarget which is a level below Flim. In the cautious zone, the F is determined based on the grey shaded leaf area.

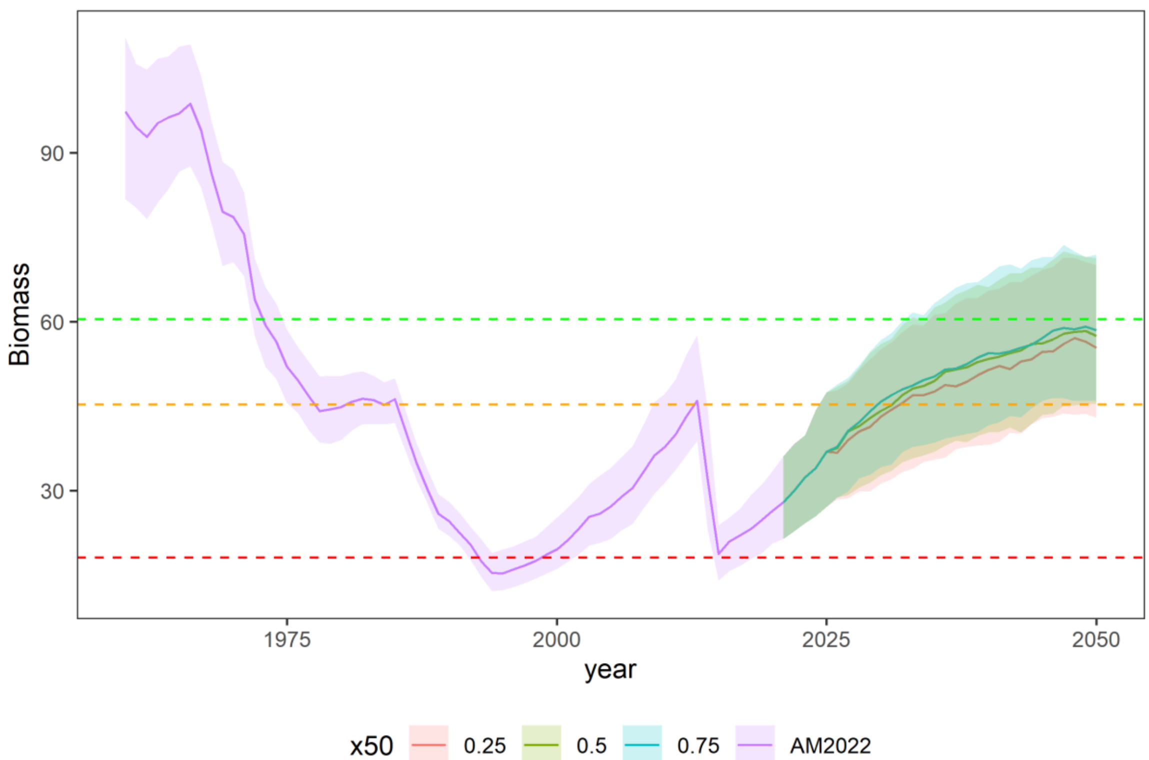

Figure 2. Median and 75% CIs for stock biomass under the three PA leaf trends.

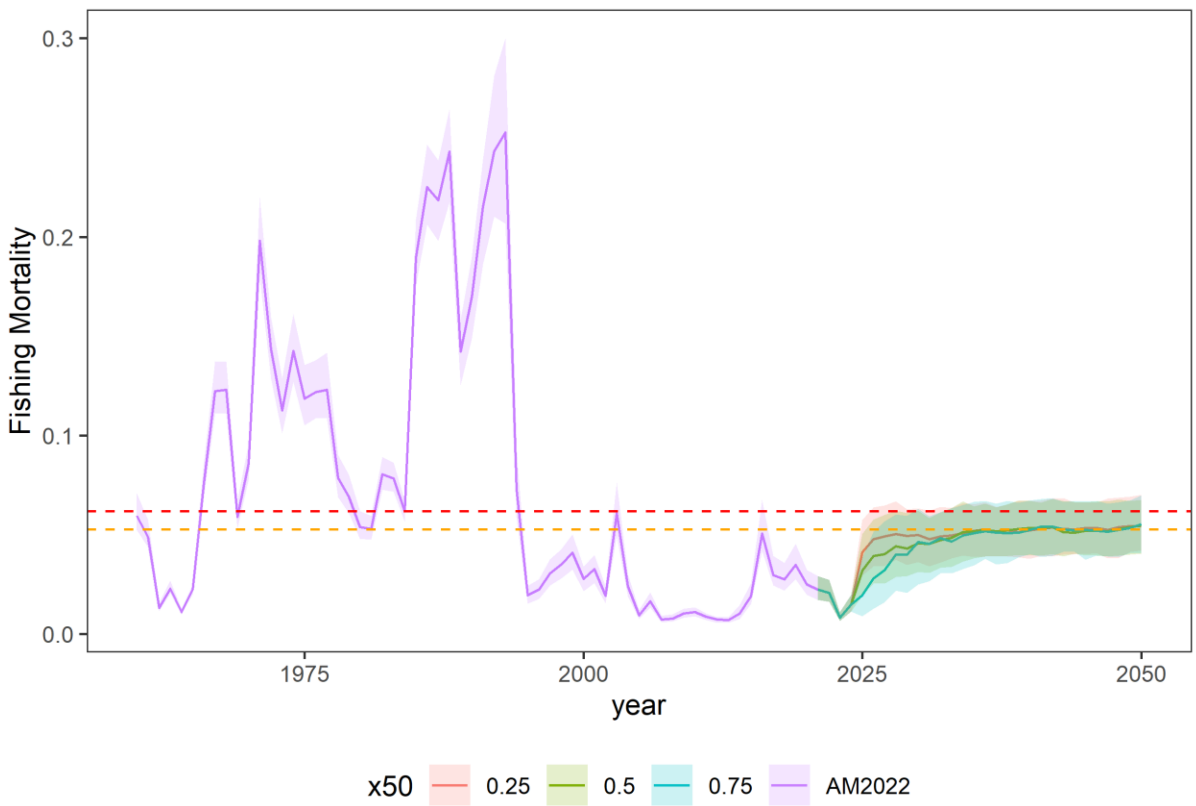

Figure 3. Median and 75% CIs for stock F levels under the three PA leaf trends.

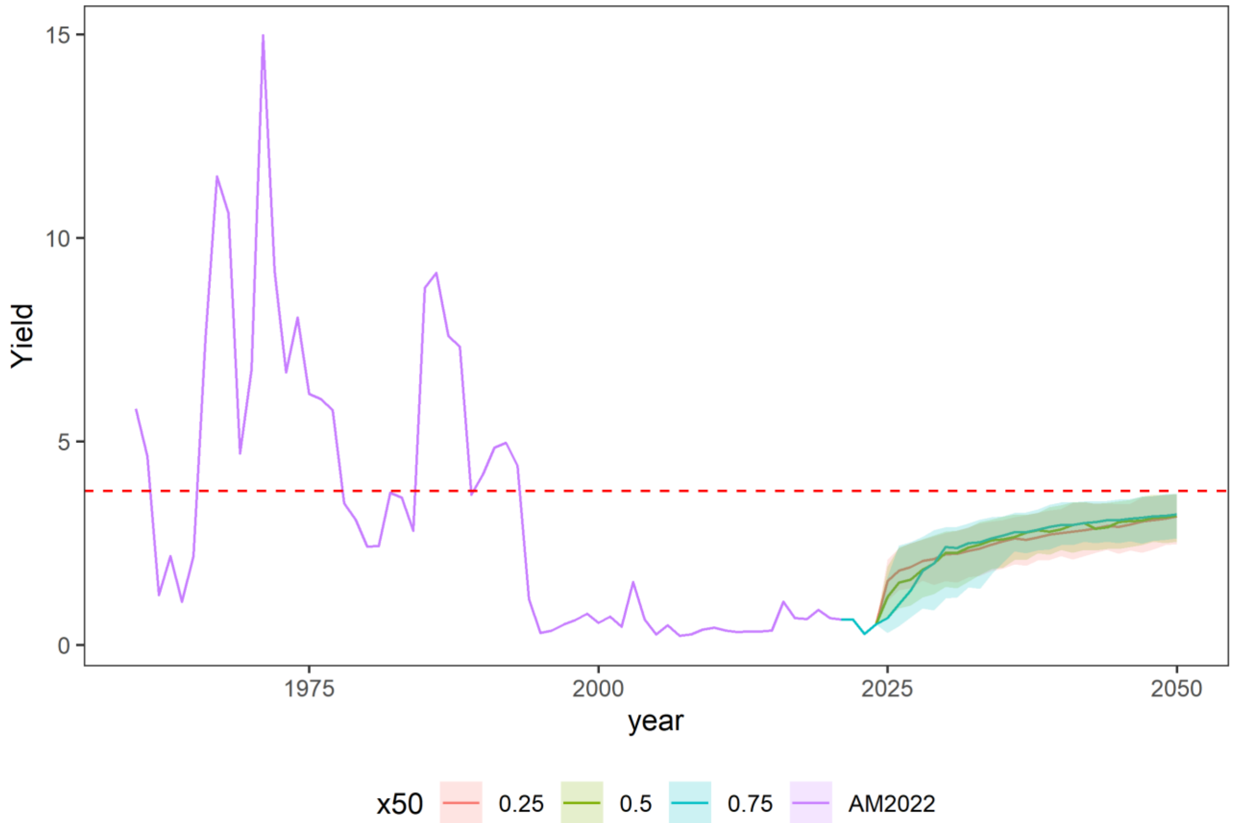

Figure 4. Median and 75% CIs for yield levels under the three PA leaf trends.

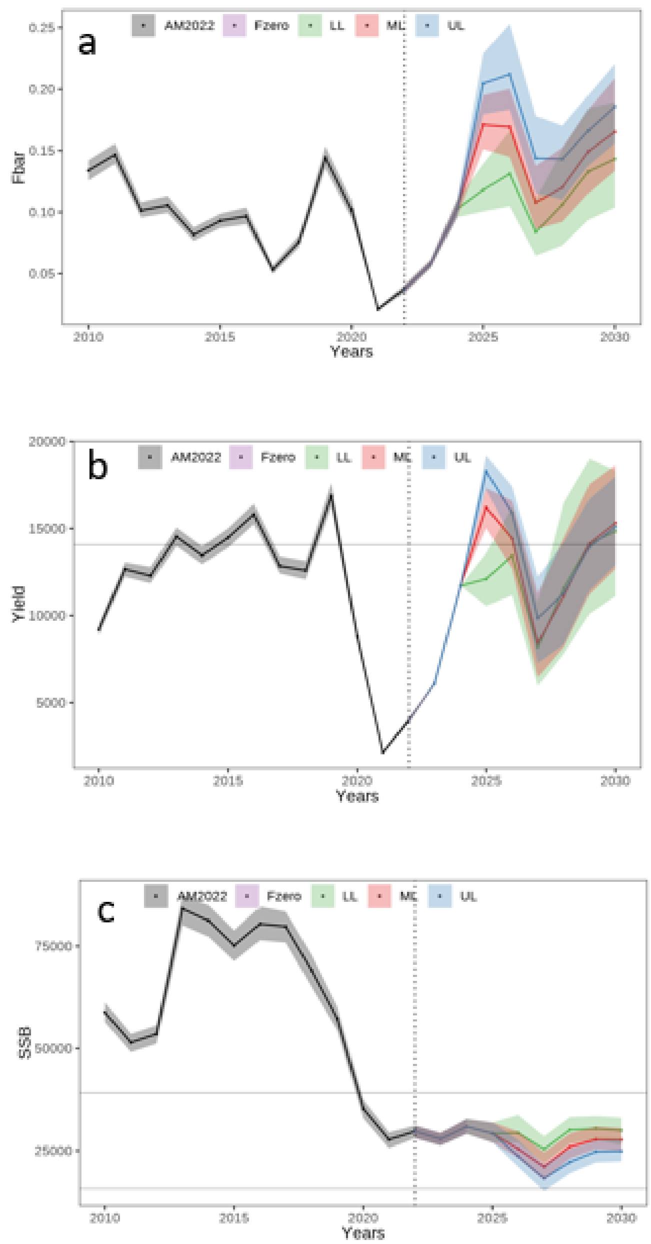

Figure 5. Short-term trends in F, Yield and Biomass under the three PA leaf options.

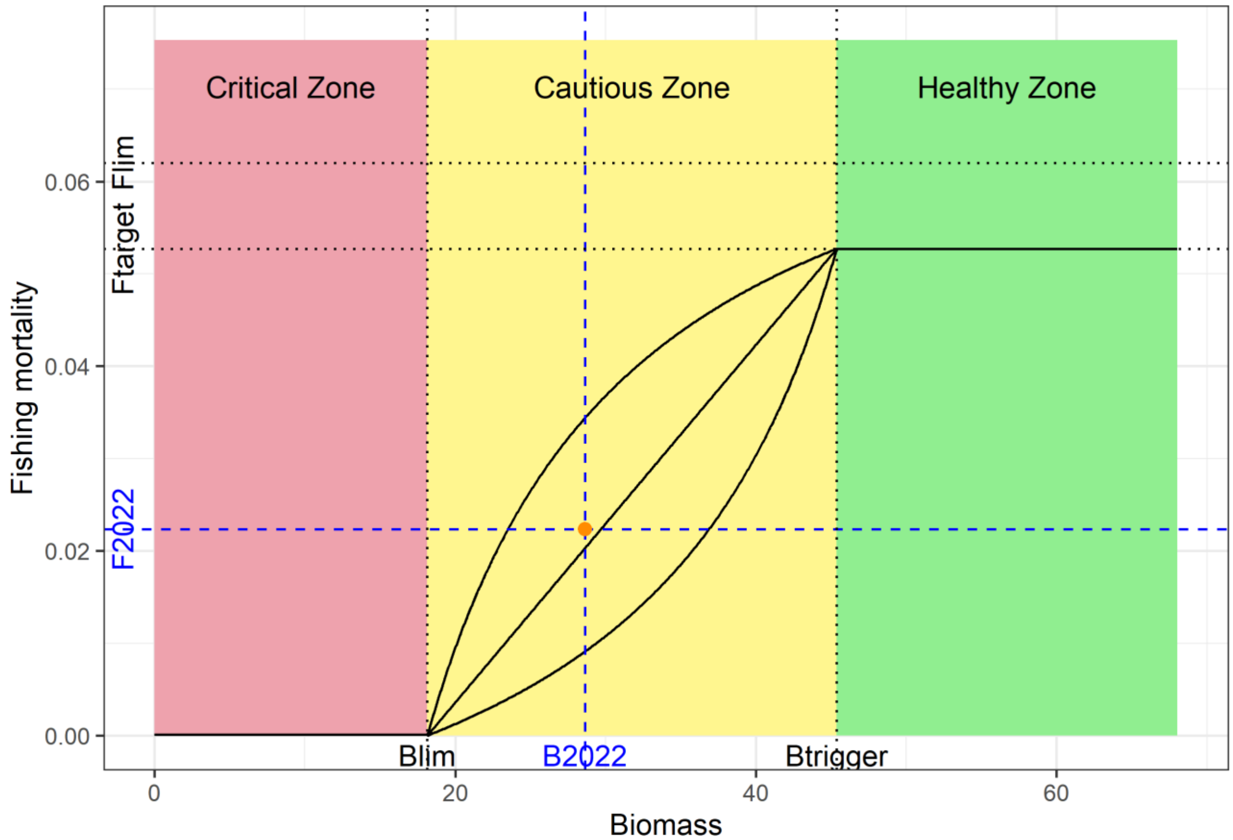

Figure 6. Current position on the PA map of the Witch Flounder stock. Current position is based on the biomass and F levels determined in the 2022 assessment; Reference points: Blim=18.15, Btrigger=45.37, Bmsy=60.49, Fmsy=0.062, Ftarget=0.0527.

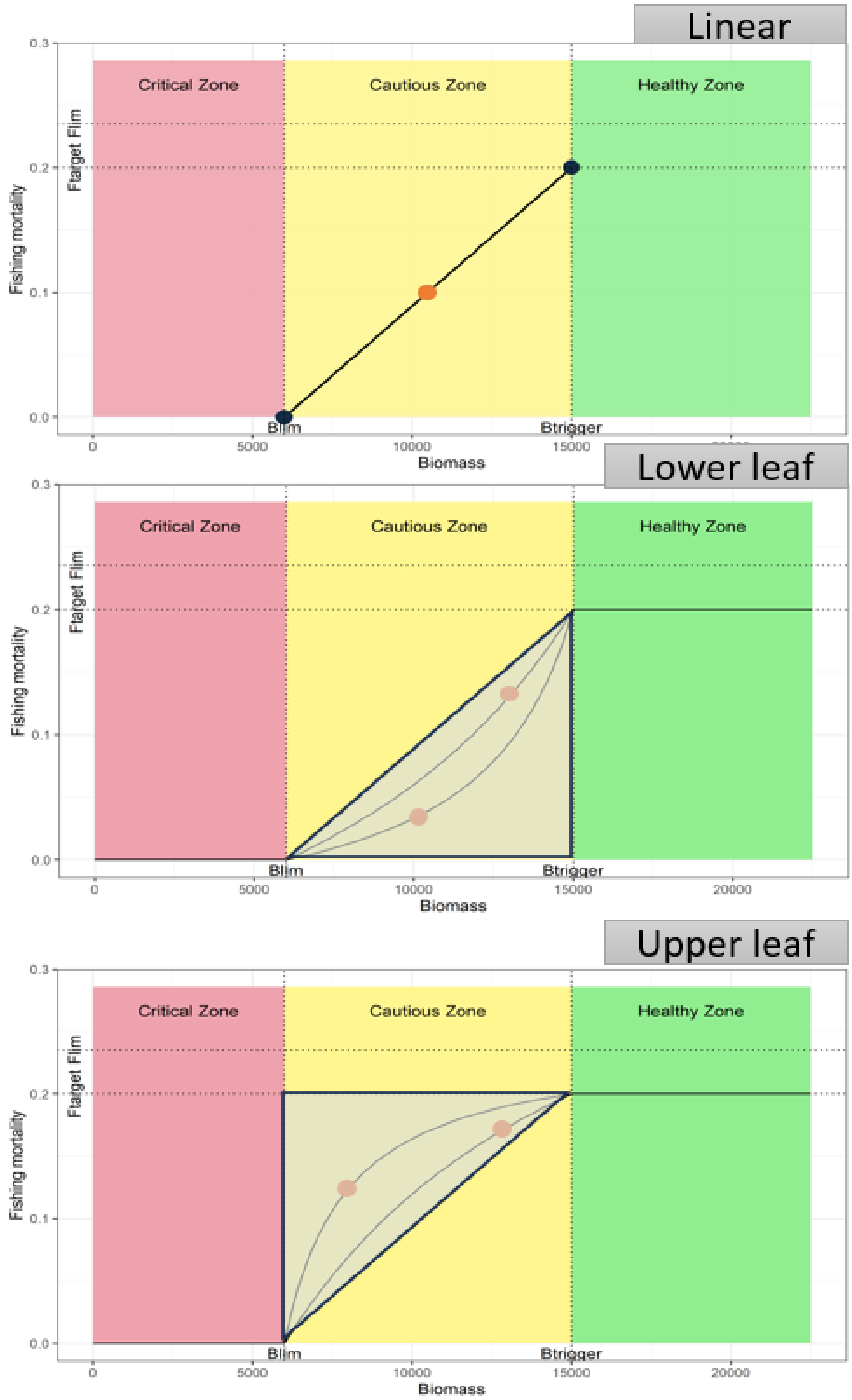

Figure 7. Example of leaf shape that could be adopted depending on current position of the stock on the PA map. In the figures, the orange dots indicate a few possible positions any given stock could be on; the shaded triangles indicate the overlap with the upper or lower leaf shapes.

Appendix Performance metrics

Fourteen Performance Metrics (PMs) were tested for the 3NO witch flounder MSE, each with their own criterion to determine objective success or failure. Each PM was derived for all HCRs, including the $F = 0$ run, to determine how each HCR performed. Below is a brief list of the PMs:

(1) Very low risk of stock depletion

$$Prop(B < B_{lim}) \leq 0.10$$

(2) Risk of stock falling below $B_{trigger}$

$$Prop\left(B < B_{trigger}\right) \leq 0.30$$

(3) Maintain stocks above B_{MSY}

$$Prop(B > B_{MSY}) \geq 0.75$$

(4) Low risk of overfishing

$$Prop(F < F_{MSY}) \geq 0.70$$

(5) Rebuild stocks to the vicinity of B_{MSY}

$$Prop\left(\bar{\mu}\left(B_{(T-10):T}\right) > B_{trigger}\right) \geq 0.80$$

(6) Monitor short term growth

$$Prop(B_{t=5} > B_{t=1}) \geq 0.75$$

(7) Monitor medium term growth

$$Prop(B_{t=15} > B_{t=1}) \geq 0.75$$

(8) Monitor medium term growth

$$Prop(B_{t=25} > B_{t=1}) \geq 0.75$$

(9) Absolute time to recovery

$$Count_t\left(B \rightarrow B_{trigger}\right)$$

(10) Relative time to recovery

$$\frac{Count_t^{F=HCR}\left(B \rightarrow B_{trigger}\right)}{Count_t^{F=0}\left(B \rightarrow B_{trigger}\right)} \leq 1.2$$

(11) Extra time to recovery

$$Count_t^{F=HCR}\left(B \rightarrow B_{trigger}\right) - Count_t^{F=0}\left(B \rightarrow B_{trigger}\right)$$

(12) Maintain approximately MSY catches in the long-term

$$Prop\left(0.8 \geq \frac{Meidan\left(C_{(T-10):T}\right)}{MSY} < 1.2\right) \geq 0.80$$

(13) Measure the inter-annual TAC variation

$$Median\left(\frac{|C_{t+1} - C_t|}{C_t}\right) \leq 0.20$$

(14) Catch during the maximum recovery window

$$\frac{\sum_{1:t_{max}} C_t}{t_{max}}$$

Many PMs passed their respective criterion for success regardless of which HCR was used, and most others others failed regardless of HCR choice, with some exceptions. The zero catch (i.e. F = 0) HCR passed all SSB-based PM objectives and failed all catch-based PM objectives. All HCRs (i.e., F_{upper}, F_{linear}, and F_{lower}) had a very low risk of stock depletion *(1)*. The F_{lower} HCR achieved a low risk of being below $B_{trigger}$ *(2)*, but the F_{upper} and F_{linear} HCRs just failed to pass same objective for being below $B_{trigger}$, and no HCRs maintained B_{MSY} *(3)* or rebuilt to B_{MSY} *(5)*. All HCRs had a low risk of overfishing *(4)*, but no HCRs maintained a long-term catch close to MSY *(12)*. All HCRs achieved growth in the short- *(6)*, medium- *(7)*, or long-term *(8)*, although some only just passed this objective (e.g., short-term growth for the F_{upper} HCR). The absolute *(9)* and extra *(11)* times to recovery objectives do not have criteria for success, but values are very similar across all HCRs, where the absolute (and therefore extra) recovery time are equal for the F_{upper}, F_{lower}, and $F = 0$ and 1 additional year for the F_{linear} HCR. A similar trend to absolute recovery time occurs for the relative time to recovery *(10)*, for which all HCRs passed the objective. The median inter-annual variability in TAC *(13)* passed the objective for all HCRs. Catch of maximum recovery *(14)* does not have an assigned success criterion, but all HCRs have the same levels of average catches (excluding $F = 0$, which only has catches in 2024).

Description	Performance Metric	OM	F_{linear}	F_{upper}	F_{lower}	F = 0
Very low risk of stock depletion	$Prop(B < B_{lim}) \leq 0.10$	3NO Witch Flounder	0.000	0.000	0.000	0.000
Risk of stock falling below $B_{trigger}$	$Prop\left(B < B_{trigger}\right) \leq 0.30$	3NO Witch Flounder	0.308	0.308	0.269	0.115
Maintain stocks above B_{MSY} more often than not	$Prop(B > B_{MSY}) \geq 0.75$	3NO Witch Flounder	0.192	0.154	0.192	0.731
Low risk of overfishing	$Prop(F < F_{MSY}) \geq 0.70$	3NO Witch Flounder	0.788	0.769	0.769	1.000

Description	Performance Metric	OM	F_{linear}	F_{upper}	F_{lower}	F = 0
Rebuild stocks to the vicinity of B_{MSY}	$Prop(\bar{\mu}(B_{(T-10):T}) > B_{trigger}) \geq 0.80$	3NO Witch Flounder	0.726	0.689	0.757	0.986
Monitor short term growth	$Prop(B_{t=5} > B_{t=1}) \geq 0.75$	3NO Witch Flounder	0.797	0.766	0.823	0.949
Monitor medium term growth	$Prop(B_{t=15} > B_{t=1}) \geq 0.75$	3NO Witch Flounder	0.860	0.851	0.886	0.971
Monitor long term growth	$Prop(B_{t=25} > B_{t=1}) \geq 0.75$	3NO Witch Flounder	0.903	0.891	0.903	0.983
Time to recovery (absolute)	$Count_t(B \rightarrow B_{trigger})$	3NO Witch Flounder	5	4	4	4
Time to recovery (relative)	$\frac{Count_t^{F=HCR}(B \rightarrow B_{trigger})}{Count_t^{F=0}(B \rightarrow B_{trigger})} \leq 1.2$	3NO Witch Flounder	1.167	1.200	1.111	-
Time to recovery (additional years)	$Count_t^{F=HCR}(B \rightarrow B_{trigger}) - Count_t^{F=0}(B \rightarrow B_{trigger})$	3NO Witch Flounder	1	1	1	-
Maintain approximately MSY catches in the long-term	$Prop\left(0.8 \geq \frac{Median(C_{(T-10):T})}{MSY} < 1.2\right) \geq 0.80$	3NO Witch Flounder	0.446	0.397	0.469	0.000
Measure the inter-annual TAC variation	$Median\left(\frac{\lvert C_{t+1} - C_t \rvert}{C_t}\right) \leq 0.20$	3NO Witch Flounder	0.069	0.064	0.077	-
Catch during the maximum recovery window	$\frac{\sum_{1:t_{max}} C_t}{t_{max}}$	3NO Witch Flounder	2.49	2.50	2.48	0.00