SCIENTIFIC COUNCIL MEETING –JUNE 2025

Outline of a Simple Approach to Develop a MSE for 3LN Redfish – Now Modified to Incorporate Density Dependent Productivity and to Fit to a Longer Time Series of Historical Data

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BUTTERWORTH, D.S., & RADEMEYER, R. A. 2025. Outline of a Simple Approach to Develop a MSE for 3LN Redfish – Now Modified to Incorporate Density Dependent Productivity and to Fit to a Longer Time Series of Historical Data**.** *NAFO Scientific Council Research Document*, SCR Doc. 25/010: 1-15.

Abstract

Earlier MSE analyses are modified to incorporate a Schaefer model for productivity and to fit that model to a longer time series of historical data. This requires some modifications to the details of the methodology, for example inclusion of additive rather than multiplicative process errors. A Base Case Operating Model is developed, together with a Baseline Candidate Management Procedure (this Procedure intends fixed fishing mortality, with some modifications at low abundance), and is based on input from a single future survey. Results are provided for a few illustrative variants of that Procedure, but further developments should first await the specification and use of surveys likely to continue into the future. Importantly, robustness tests have still to be conducted, and a prioritised set for such tests is put forward.

Background

At the short meeting of the Scientific Council held on 5 May 2025, a brief discussion took place on an earlier submission by the authors regarding the development of a simple approach for MSE for 3LN redfish (Butterworth and Rademeyer, 2025). In the light of helpful suggestions made during the course of that discussion, this document presents some relatively substantial modifications to that earlier approach, together with associated initial results.

The most important of these modifications are first to move away from an annual production which is constant in expectation to one which is parabolic in resource biomass (i.e. the Schaefer model form), and secondly to include catch and abundance index data for the full period for which these are available, rather than from 2005 onwards only.

That 5 May discussion also raised the issues of the urgency of this work, and how it compared with the possibility of using the PA approach rather than a case-specific MSE as the basis for managing the 3LN redfish resource. The following points would seem to number amongst those relevant to these issues:

- Previous approaches to developing an MSE for 3LN redfish have foundered over the difficulties of developing relatively complex Operating Models (OMs) by fitting, *inter alia*, to catch-at-length

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information. These led to estimated process errors which were deemed too large to allow for realistic projections, as needed for MSE.

- However, this should not be misinterpreted as MSE not being possible for this redfish resource. Any defensible approach to manage a resource must necessarily be capable of checking by simulation to be able to satisfactorily meet management objectives in circumstances of plausible uncertainties about resource and fishery dynamics (i.e. being checked by an MSE process). The problems referenced above related to difficulties in developing OMs adequate for this task. (It is posited here that age-aggregated population models which fit abundance index data satisfactorily, are adequate for this task.)
- Regarding the suggested alternative approach of using the revised Precautionary Approach Framework (PAF) to provide a harvest control rule (HCR), this is indeed effectively an approach based on MSE-type simulation testing to provide a generic MP. However, there are some associated concerns:
    - Although that PAF has been intensively tested, did that testing extend sufficiently to cover the likely dynamics of redfish with their occasional very strong recruitment pulses?
    - How readily might the parameter values required for that revised PAF HCR (such as an MSY level abundance) be determined for 3LN redfish?
    - A generic MP approach is necessarily inefficient, in having to cover uncertainties that may not apply in a particular case. Hence, though requiring more work, a case-specific MP tailored to the specific details that apply to the resource in question may be preferred, to allow for greater catch for the same extent of perceived risk.
- Despite the SC advising a TAC (of zero) for 2025 and 2026, the Commission at its 2024 meeting set a TAC of 6000 t for 2025 for 3LN redfish in anticipation of an MP being available as the basis to set this TAC for 2026. While the overall situation for 2026 is now somewhat unclear (given the OM difficulties reference above), the SC would seem to continue to have a responsibility to pursue the development of an MP reasonably swiftly given this previous expectation which the Commission has expressed a develop an MSE.

Approach (as now modified)

The underlying (aggregated biomass) population model assumed is now a Schaefer production model:

$$B_{y+1} = B_y + P_y - C_y + \mu_y \tag{1}$$

where:

B_y is the biomass of the resource at the start of year y,

C_y is the catch taken during year y,

$P_y = rB_y(1 - \frac{B_y}{K})$ is the productivity of the resource in year y as a function of parameters K and r, with

K the carrying capacity, and

r the intrinsic growth rate, and

μ_y is the productivity process error, taken to be distributed as $N\left(0, \left(\sigma_\mu MSY\right)^2\right)$, with the value of σ_μ an input.

Note that $MSY = \frac{rK}{4}$.

The reasons for important changes made to the earlier approach are as follows:

- Previously natural mortality was explicitly included in population model, whereas now it is included implicitly in the productivity term P_y. That earlier inclusion, when productivity was modelled as constant in expectation, was to ensure that the contribution to the biomass of a large pulse in productivity (mimicking an exceptionally large year-class) would decrease over time. However, with productivity now modelled by the Schaefer form, such a large pulse would take the biomass above K, where expected productivity becomes negative, thus resulting in the subsequent decrease in biomass to be expected, i.e. the Schaefer model implicitly incorporates this desired effect.

- The productivity process error term μ_y has been made additive rather than multiplicative. This is for more straightforward interpretation, as under the previous multiplicative log-normal effect approach, the productivity would necessarily have become negative if biomass exceeded K.

This model is then fit to existing CPUE, survey abundance and annual catch data to estimate annual biomass and productivity values. The values of r and MSY are fixed externally while the initial biomass (B_{1959}) and the process error (μ_y) over 1985-2024 are estimated in the model fitting procedure. The values for r and MSY used here were based on an initial coarse fit of the model to these data. Further details of the fitting procedure are described below.

Model fitting procedure

The likelihood of the model fit is calculated assuming that the observed abundance indices (CPUE and abundance surveys) are log-normally distributed about their expected values:

$$I_y^i = \hat{I}_y^i e^{\varepsilon_y^i} \quad \text{or} \quad \varepsilon_y^i = \ell n\left(I_y^i\right) - \ell n\left(\hat{I}_y^i\right) \tag{2}$$

where:

I_y^i is the abundance index for year y and series i,

$\hat{I}_y^i = q^i \hat{B}_y$ is the corresponding model estimate,

$\hat{q}^i$ is the multiplicative bias (catchability) for abundance series i, and

ε_y^i from $N(0, (\sigma^i)^2)$.

The contribution of the CPUE/survey data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell nL = \sum_{i,y}\left[\ell n\sqrt{(\sigma^i)^2 + (\sigma_A)^2} + \left(\varepsilon_y^i\right)^2/2((\sigma^i)^2 + (\sigma_A)^2)\right] \tag{3}$$

where:

σ^i is the (minimum, when $\sigma_A = 0$) standard deviation of the residuals for the logarithms of index *i*, ,

σ_A is the square root of the additional variance for index series *i*, which is an input value, this is used as means for specifying an effective lower bound for σ^i.

σ^i is estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_y \left(\ell n(I_y^i) - \ell n(q^i \hat{B}_y)\right)^2 - (\sigma_A)^2} \tag{4}$$

where:

n_i is the number of data points for abundance index *i*.

The catchability coefficient q^i for abundance index *i* is estimated by its maximum likelihood value which is given by:

$$\ell n\hat{q}^i = \frac{1}{n_i}\sum_y\left(\ell nI_y^i - \ell n\hat{B}_y\right) \tag{5}$$

The process error on the productivity, μ_y, are estimable parameters, with their estimation being rendered possible by assuming that they follow a normal distribution, so that (in what is an *ad hoc* approach) the following term is added to $-\ell nL$ in equation (3):

$$\sum_y \left[ln(\sigma_\mu MSY) + (\mu_y)^2 / 2(\sigma_\mu MSY)^2 \right] \quad (6)$$

Since the estimation of σ_μ is confounded with that of the observation error variances for the survey series, a value for σ_μ in input with the intent of later investigation the robustness of any MP put forward to alternative values for σ_μ. For the Base Case Operating Model (OM), $\sigma_\mu = 1$ and the process error is estimated for the years 1985 to 2024.

Note:

- The process error term standard deviation is scaled by MSY to allow for a readier interpretation of its value.
- To allow μ_y to be estimable for a specific year requires at least two abundance index series to be available for that year, as otherwise the value of the process error will adjust to fit a single index for the year exactly (and naturally is inestimable if there is no index for that year). Hence these errors are estimated from 1985 only; they have to be set to zero for earlier years.
- A similar reason underlies the introduction of an additional variance parameter with a fixed input value for each series; given that the observation error variances for each series are estimated in the fitting process, that process can otherwise become unstable, according inappropriately high relative weight to a single index to fit it exactly while ignoring all the others.
- The choice of the value (1) of σ_μ was dictated by allowing this parameter to be sufficiently large to admit reasonable reflection of the main trends in the abundance indices, but no larger.

Data

The catches and survey index values given in Perreault *et al*. (2024) and the CPUE values from Rogers *et al*. (2022) are used for this analysis; they are reproduced in Tables 1 and 2 for the period starting from 1959, as is considered here.

The choice of the survey series reported in Perreault *et al*. (2024) was made as they were assumed to reflect the SC's choice of which surveys were the most reliable as representative of 3LN redfish abundance. Compared to that selection, which was as made in Butterworth and Rademeyer (2025), the CPUE series has been added here to allow estimation (especially of process error) to be extended back into the previous century.

Parameter values

For the Base Case OM:

r=0.2
MSY=25000t (K = 500 000 t)
$\sigma_\mu = 1$

The reasons for these choices are detailed above.

Future dynamics

Future annual productivity process error takes autocorrelation into account (as the model fits suggest that this is not insubstantial):

$$\mu_y = \rho\mu_{y-1} + \sqrt{1-\rho^2}\varphi_y \quad (7)$$

φ_y from $N(0, \sigma_\mu^{out} MSY)$
$\sigma_\mu^{out} = 0.8$ is the approximate standard deviation of the 1985-2024 estimated μ_y values
ρ is the serial correlation coefficient, which is input ($\rho = 0.3$ is the estimated value).

A single (for initial simplicity) future survey index I_y is assumed to be available with a log-normal CV of 0.4. This will later be replaced by a number of the existing survey indices considered likely to continue to be available in the future.

Candidate Management Procedure (CMP)

A simple CMP is implemented to compute TACs in the future which is based on J_y, a three-year average of the survey index I_y; note that the assumption is made that the survey value would be available only up to two years before the year for which the TAC would be being recommended:

$$TAC_y = TAC_{y-1}\left[1-\alpha(\frac{J_{y-2}}{J_{targ}}-1)\right] \quad (8)$$

Furthermore, if J_{y-2} relative to J_{2023} falls below a fixed specified threshold ($J_{threshold}$), the resulting TAC is decreased further:

$$TAC_y \rightarrow TAC_y \frac{J_{y-2}}{J_{2023}} \quad (9)$$

with

$J_y = \sum_{y-2}^{y} I_y \Big/ 3$

$I_y = qB_y e^{\varepsilon_y - \sigma^2/2}$ the survey index in year y

$\varepsilon_y \sim N(0,\sigma^2)$ with $\sigma = 0.4$ and,

α, J_{targ} and $J_{threshold}$ the CMP's tuning parameters.

Note that for $\alpha = 1$, this corresponds to an intended constant fishing mortality strategy, except that if abundance falls below $J_{threshold}$ that mortality is reduced linearly to zero as abundance falls to zero.

Furthermore, TACs are subject to a maximum inter-annual decrease or increase of 20%, except if J_{y-2} relative to J_{2023} falls below $J_{threshold}$, in which case the maximum decrease increases to $(100-\frac{80}{Jthresh}\frac{J_{y-2}}{J_{2023}})\%$

For the Baseline CMP, $\alpha = 1, J_{targ} = 1.2$ and $J_{threshold}$=0.8.

Results and Discussion

Base Case Operating Model

Figure 1 shows results of the model fit to the data, giving the historical catch, the annual productivity, the biomass trajectory and the fits to each survey series, while Table 3 provides the associated estimates of parameter values.

Note that in initial implementation, the survey catchability parameters q were estimated to be fairly high, implying a large amount of herding by the survey nets and a consequently low biomass. The results shown here include a penalty factor in the negative log likelihood to reduce these q estimates towards arguably more realistic values:

$$\sum_i (q_i - Q)^2 / \sigma_q^2 \qquad (2)$$

where Q =2 and $\sigma_q = 0.2$.

The fits to the abundance index data in Figure 1 are reasonable for the most part. The one clear exception is that for the Spring Campelen series, for which the data are well below the model fit for the 1980s, but well above the fit for 2012 to 2015. This early part of that survey series is clearly in conflict with the high CPUE at that time, and also seems implausible given the high landings then; this suggests that this survey series is not that reliable as an index of abundance, so that this poor fit is not of particular concern. There is some indication of model over-parametrization in the fit to the Autumn Campelen series in the 1990s (the model fit following data variations too closely), but the overall biomass pattern over time nevertheless does not seem unrealistic.

Projections

For illustrative purposes, projections into the future for a few initial CMPs have been carried out for 20 years, starting in year 2025, for 500 simulations. The 2025 catch is set at 6000t TAC for this year.

Results are summarised using the fairly standard MSE performance statistics for catch, resource risk and catch variability:

$$C_{av} = \sum_{y=2025}^{2044} C_y / 20$$

$$B_{lowest} = \min\,(B_y) \qquad \text{over 2025 to 2044}$$

$$B_{final} = B_{2044}$$

$$AAV = \frac{1}{20} \sum_{y=2025}^{2044} \frac{|C_{y-1} - C_y|}{C_{y-1}}$$

Results for a Baseline CMP for a 20-year projection period are shown in Figure 2 and in Table 4 under the Base Case OM. To assist interpretation from a "bounding" perspective, they are shown together with those for two constant catch scenarios: no future catches, and the annual TACs maintained at the 2025 level of 6000t.

The baseline CMP sees TACs in median terms decrease immediately, returning to their current level only ten years hence, and thereafter increasing further. The median biomass continues to increase, but at the lower 10%ile remains broadly steady at the current abundance. For maintaining the current TAC of 6000 t however, there are problems, with the biomass at the lower 10%-ile dropping to zero in a little more than a decade's time.

CMP variants

Results for a few variants only of the Baseline CMP are reported here, as these really first require specification of what surveys will be available in the future upon which to base a TAC formula in the MSE, so as to provide reliable results. Hence these variants are restricted to the baseline tuning choice and "complexities" introduced to the initial aim of the simple form of a constant intended fishing mortality formulation of the Baseline CMP to obtain satisfactory resource conservation performance (i.e. avoiding the lower tail of the future biomass distribution dropping very low).

Specifically then, there is first the tuning parameter *Jtarg*. Figure 3a and Table 5 provide results for alternatives to the baseline value choice of *Jtarg*=1.2. The Figure shows that a lower choice of *Jtarg* results in resource biomass dropping to zero at the lower 10%-ile, whereas a higher choice leads to a large drop in TAC in the short term. The value of 1.2 chosen seems a reasonable compromise.

Figure 3b and Table 5 show results for different choices for the value of *Jthreshold*. the parameter that determines the survey value below which the intended fishing mortality starts dropping linearly towards zero. The sensitivity of results here is not as great as for *Jtarg* above; the baseline choice of 0.8 again involves a trade-off with a higher value giving better biomasses but somewhat reduced catches.

Finally Figure 3c and Table 5 show the effect of imposing restrictions on TACs in the initial period, as might be sought for better initial industrial stability: specifically, the Baseline CMP TAC fixed at 5000 t for the first three years, or at 5000 t permanently. This last option is inadequate (as was the fixed 6000 t option) from a resource conservation standpoint, with biomass dropping to zero at the lower 10%-ile.

Further work

The first requirement is specification of what surveys can be safely assumed to continue reliably into the future. The CMP work conducted above needs to be repeated, and then taken further, based on those specified surveys and their observation errors as indicated by the fit of the model.

Then of particular importance are robustness tests, to check whether the baseline CMP proposed here, or some variant thereof, shows adequately robust performance to model uncertainty. These tests should include the following (in rough order of priority). Note that it will not necessarily prove straightforward to condition these tests on the data. The underlying population model is "parameter heavy", given all its many estimable process error parameters, so that convergence of any fit can take time to achieve.

- Variations of the Schaefer model *r* and *MSY* parameters, while still maintaining and adequate fit to the abundance data.
- Alternative choices for the survey catchability weighting parameter Q.
- A strong positive pulse in productivity early in the projection period, to mimic the effect of a very strong year-class.
- Exploration of whether the high pre-1990 catches can be better explained by a few very strong positive positive productivities (strong year classes). This would be in place of the current model which interprets these as the relatively steady output from a Schaefer form, followed by resource reduction as a result of the high and unsustainable catches of the late 1980s. The near absence of survey series during this earlier period precludes the model used here from estimating productivity variations of this nature. Note that qualitative examination of catch-at-length data, or of assessments of other redfish stocks, may provide further insight on this.
- Alternative choices for the process error variance-related parameter σ_μ.
- Omission of the Spring Campelen survey from the model fitting, given that it seems to conflict with other data.

Once that work has been completed and a defensible CMP developed, that will need to be discussed with stakeholders (e.g. in an RBMS meeting) for advice on desired tradeoffs, so that the CMP can be adjusted further to achieve those trade-offs without sacrificing adequately robust performance.

References

Butterworth DS and Rademeyer RA. 2025. Outline of a simple approach to develop a MSE for 3LN redfish-extended. NAFO SCR Doc. 25/005, 20pp.

Perreault A., Wheeland L., Regular P., Koen-Alonso M. and Rideout R. 2024. An Assessment of the Status of Redfish in NAFO Divisions 3LN. NAFO SCR Doc. 24/048, 20pp.

Rogers B., Perreault A., Simpson M., Varkey D. 2022. Assessment of 3LN redfish using the ASPIC model in 2022 (*Sebastes mentella* and *S. fasciatus*). NAFO SCR Doc. 22/013. 31pp.

Table 1. Total landings (in t) of redfish in Divs. 3LN for 2005 to 2023 (from Perreault *et al.*, 2024). The value for 2024 is as kindly advised by Bell MacCallum (*pers. commn*).

Year	Landings ('000t)	Year	Landings ('000t)	Year	Landings ('000t)
1959	44.585	1981	24.28	2003	1.334
1960	26.562	1982	21.547	2004	0.637
1961	23.175	1983	19.747	2005	0.659
1962	21.439	1984	14.761	2006	0.496
1963	27.362	1985	20.557	2007	1.664
1964	10.261	1986	42.805	2008	0.597
1965	23.466	1987	79.031	2009	1.051
1966	16.974	1988	53.266	2010	4.12
1967	27.188	1989	33.649	2011	3.672
1968	17.66	1990	29.105	2012	4.316
1969	24.75	1991	25.815	2013	6.232
1970	14.419	1992	27.283	2014	5.695
1971	34.37	1993	21.308	2015	9.94
1972	28.933	1994	5.741	2016	8.457
1973	33.297	1995	1.989	2017	11.815
1974	22.286	1996	0.451	2018	11.279
1975	17.871	1997	0.63	2019	13.05
1976	20.513	1998	0.899	2020	11.091
1977	16.516	1999	2.318	2021	10.172
1978	12.043	2000	3.141	2022	8.961
1979	14.067	2001	1.442	2023	8.231
1980	16.03	2002	1.216	2024	9.403

Table 2. Survey biomass estimates ('000 t) from bottom trawl surveys in Divs 3LN considered in the assessment (from Perreault *et al.*, 2024) and standardized CPUE for Div. 3LN, 1959-1994 (from Rogers *et al*., 2022).

	Spring Campelen	Autumn Campelen	EU Spain 3N	EU Spain 3L	Spring Teleost
1985	140	-	-	-	-
1986	11.4	-	-	-	-
1987	24	-	-	-	-
1988	16.5	-	-	-	-
1989	8.4	-	-	-	-
1990	6.8	22.6	-	-	-
1991	10.7	37.9	-	-	-
1992	10.1	136.4	-	-	-
1993	22.7	19.2	-	-	-
1994	4.1	31.8	-	-	-
1995	5.9	90.4	46.1	-	-
1996	22.8	8.8	6.6	-	-
1997	15	57.8	4.8	-	-
1998	59.4	110.6	22.5	-	-
1999	61.5	71.9	46.5	-	-
2000	87.9	75.6	68.9	-	-
2001	41.6	130.3	53.9	-	-
2002	31.4	50.1	7.6	-	-
2003	27.7	70.9	11	81.8	-
2004	79.7	50.1	27	30.8	-
2005	66.5	58.6	146.9	-	-
2006	35.3	91.9	87.8	70.1	-
2007	218.9	124.8	87.6	31.4	-
2008	140.0	201.0	68.1	75.6	-
2009	-	246.8	735.7	103.7	-
2010	165.4	461.5	359.5	266.8	-
2011	173.7	576.2	418.3	170.6	-
2012	322.0	596.7	265.2	481.5	-
2013	271.6	289.0	429.5	235.2	-
2014	-	-	178.1	216.4	-
2015	480.6	425.1	523.5	130.4	-
2016	-	215.3	117.3	98.8	654.3
2017	98.8	192.2	265.9	56.6	-
2018	-	191.4	292.8	40.3	106.0
2019	136.5	286.5	174.6	54.0	-
2020	-	199.3	-	-	-
2021	-	-	73.2	-	-
2022	-	-	131.1	-	121.8
2023	-	-	68.1	94.2	106.7

	Standardized CPUE
1959	1.426
1960	1.602
1961	1.697
1962	1.631
1963	1.632
1964	1.812
1965	2.185
1966	1.781
1967	1.893
1968	0.922
1969	1.338
1970	1.367
1971	1.346
1972	1.387
1973	1.643
1974	1.290
1975	1.669
1976	1.292
1977	1.251
1978	1.106
1979	1.451
1980	1.761
1981	1.594
1982	1.661
1983	1.556
1984	1.049
1985	1.084
1986	1.413
1987	1.374
1988	1.029
1989	1.251

Table 3. -ln*L*, estimated survey *s* and *q*'s for the Base Cas OM.

Base Case						
Total: -*lnL*	-21.23					
Process error:	likelihood	σ^{μ} - in	σ^{μ} - out	lag-1 autocorr.		
σ^{m} (in, out, lag1 autocorr)	13.92	**1.0**	0.8	0.3		
survey *q* penalty	0.24					
	Spr Camp	Aut Camp	EU Sp 3N	EU Sp 3L	Spr Tel	CPUE
-*lnL*	15.23	-18.55	5.02	-2.16	-0.10	-34.83
σ^{i}	0.98	0.24	0.71	0.50	0.54	0.20
σ^{i}_{add}	**0.40**	**0.40**	**0.40**	**0.40**	**0.40**	**0.00**
q^{i}	0.83	2.10	1.26	0.92	1.77	1.1×10^{-5}
K	**500000**					
MSY	**25000**					
r	**0.20**					
	Absolute	Rel. to *K*				
B_{1959}	179503	0.36				
B_{2023}	85891	0.17				

Note: The σ_A values were set sufficiently high (but no higher) to prevent exact fitting of a single series. Introduction of this addition was unnecessary for the CPUE series as that extends back in time to before the year for which process error is first introduced.

Table 4. Performance statistics (median and 80%iles) for the Baseline CMP and for zero and 6000t constant catch management approaches, for Base Case OM. Values for Cav, Blowest and Bfinal are in '000 tons. The management period considered is 2025 to 2044.

CMP	Cav	Blowest	Bfinal	AAV
Baseline MP	9.2 (1.7; 20.2)	90.7 (10.5; 90.7)	310.3 (50.2; 424.6)	0.20 (0.17; 0.25)
C=0	0.3 (0.3; 0.3)	90.7 (59.6; 90.7)	442.3 (297.0; 519.8)	0.07 (0.07; 0.07)
C=6000t	6.0 (3.6; 6.0)	90.7 (0.0; 90.7)	372.8 (0.0; 474.5)	0.02 (0.02; 0.02)

Note: Cav is not zero for the zero constant catch approach because of the 6000t TAC already agreed for 2025.

Table 5. Performance statistics (median and 80%iles) for a series of CMP variants for the Base Case OM. Values for Cav, Blowest and Bfinal are in '000 tons.

CMP	Cav			Blowest			Bfinal			AAV		
Varying Jtarg												
Jtarg=1.2 (Baseline MP)	9.2	(1.7;	20.2)	90.7	(10.5;	90.7)	310.3	(50.2;	424.6)	0.20	(0.17;	0.25)
Jtarg=1.0	16.9	(2.4;	32.4)	73.0	(0.0;	90.7)	176.0	(0.0;	369.6)	0.19	(0.17;	0.26)
Jtarg=1.4	5.8	(1.5;	14.5)	90.7	(35.3;	90.7)	356.7	(116.4;	453.1)	0.20	(0.17;	0.24)
Varying Jthreshold												
Jthreshold=0.8 (Baseline MP)	9.2	(1.7;	20.2)	90.7	(10.5;	90.7)	310.3	(50.2;	424.6)	0.20	(0.17;	0.25)
Jthreshold=0.6	9.3	(1.8;	20.2)	90.7	(10.5;	90.7)	310.3	(50.2;	425.2)	0.20	(0.17;	0.25)
Jthreshold=1.0	8.2	(1.4;	19.7)	90.7	(18.0;	90.7)	320.0	(71.1;	436.6)	0.20	(0.18;	0.27)
Min TAC												
no min TAC (Baseline MP)	9.2	(1.7;	20.2)	90.7	(10.5;	90.7)	310.3	(50.2;	424.6)	0.20	(0.17;	0.25)
5000t min TAC till 2028	12.4	(1.9;	26.7)	87.3	(0.0;	90.7)	248.7	(0.0;	397.4)	0.18	(0.16;	0.26)
5000t min TAC	15.4	(4.1;	25.9)	86.2	(0.0;	90.7)	211.2	(0.0;	341.6)	0.16	(0.08;	0.19)

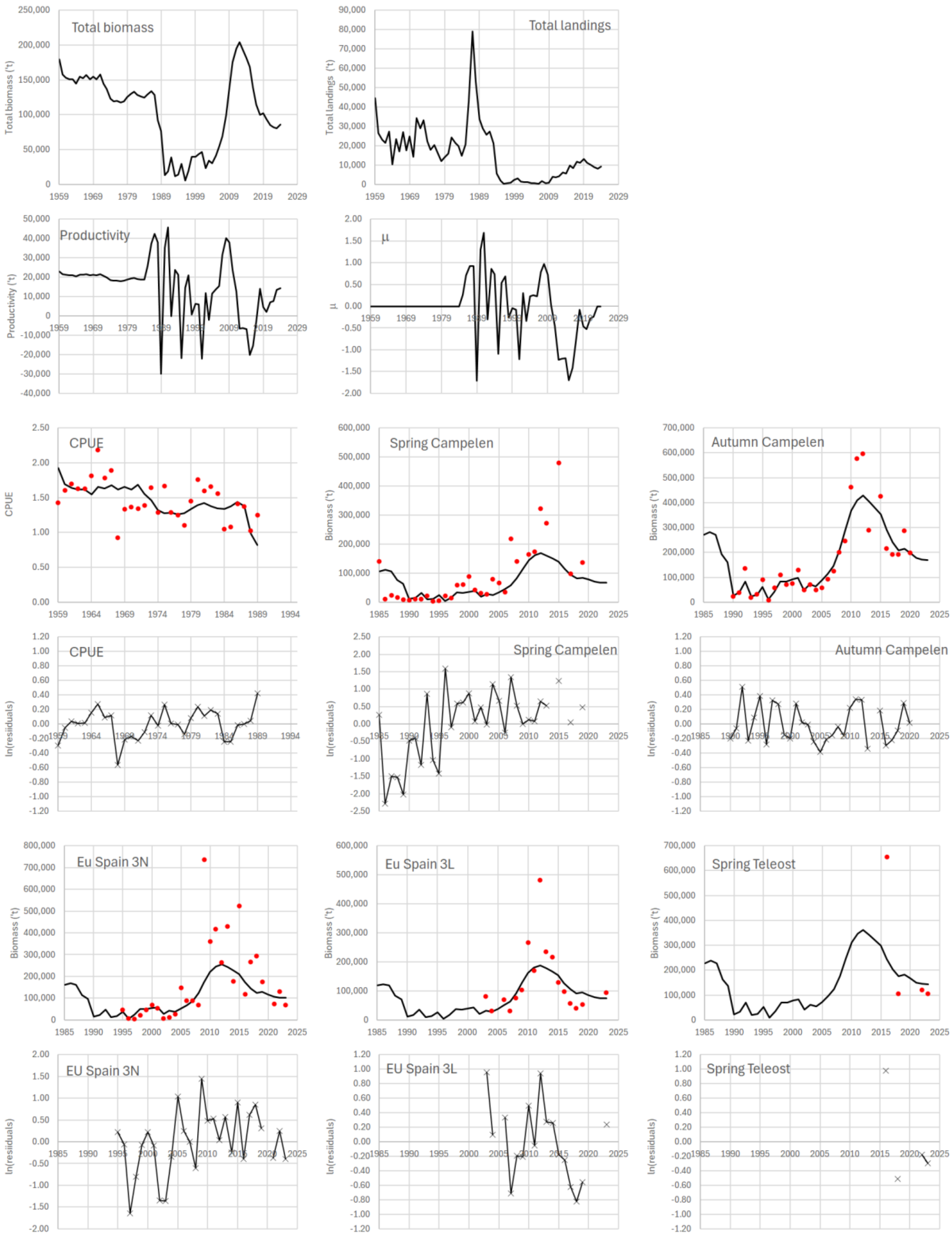

Figure 1. Historical total annual landings together with estimated annual total biomass, total and productivity (including process error) (in t) for the model for which expected productivity is taken to have a Schaefer form. The fits of the model to the CPUE and survey data series are also shown.

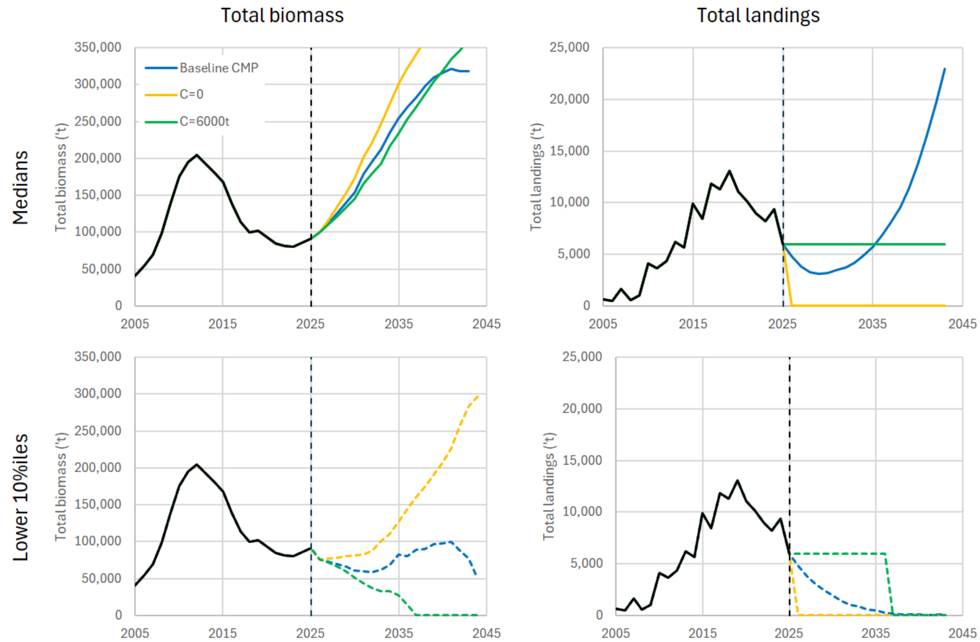

Figure 2. Projected total biomass and landings (medians top row and lower 10%iles bottom row) for the Base Case OM under the Baseline CMP, and future zero and 6000t constant catches.

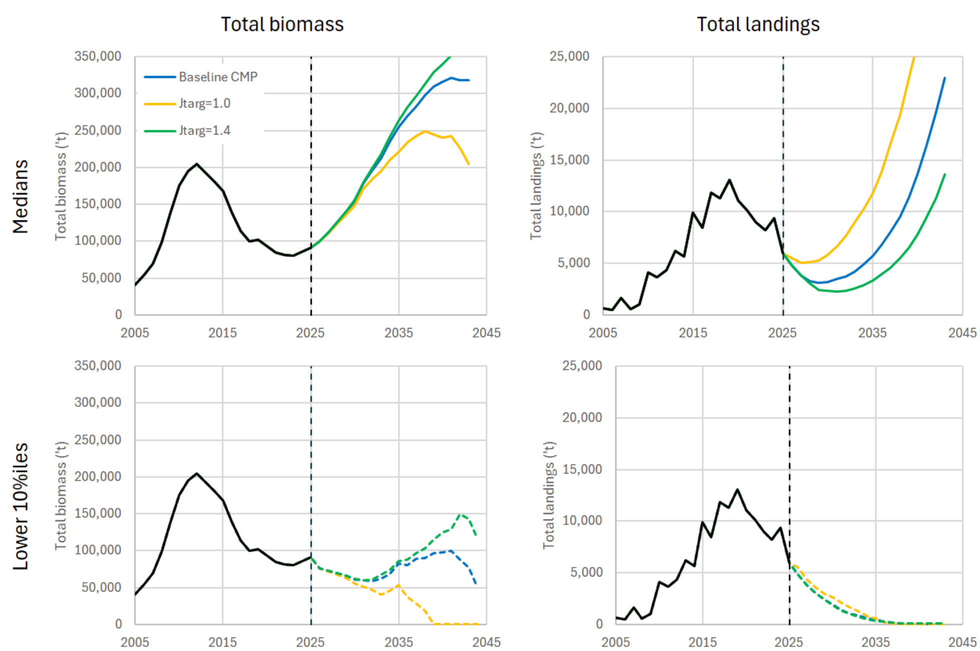

Figure 3a. Projected total biomass and landings (medians top row and lower 10%iles bottom row) for the Base Case OM under a series of CMPs (**varying** $\boldsymbol{J_{targ}}$). Jtarg=1.4 (green curve) covers the Baseline CMP (blue curve) in the total landings lower 10%iles (bottom-right).

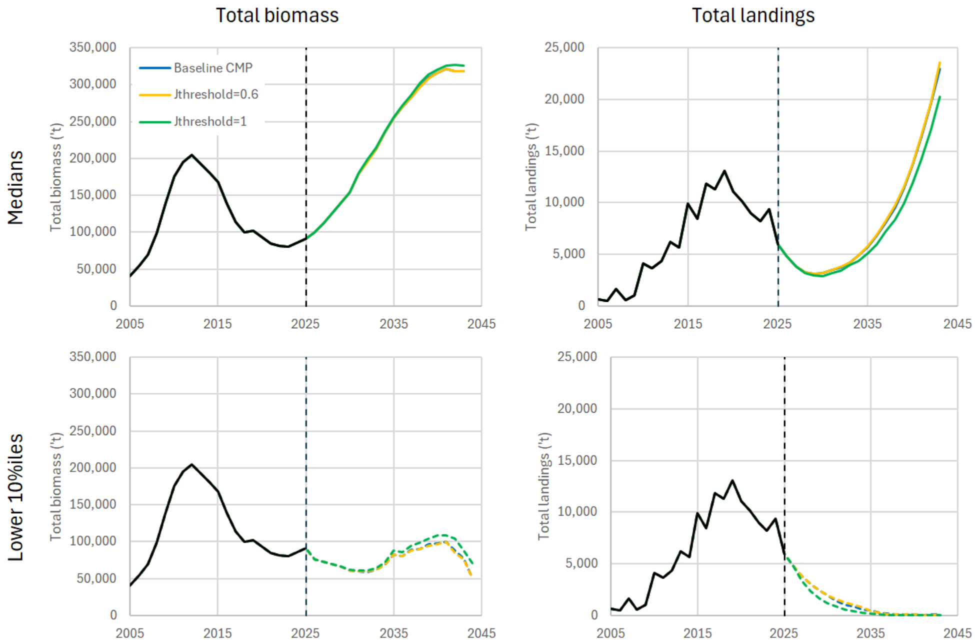

Figure 3b. Projected total biomass and landings (medians top row and lower 10%iles bottom row) for the Base Case OM under a series of CMPs (**varying** $\boldsymbol{J_{threshold}}$).

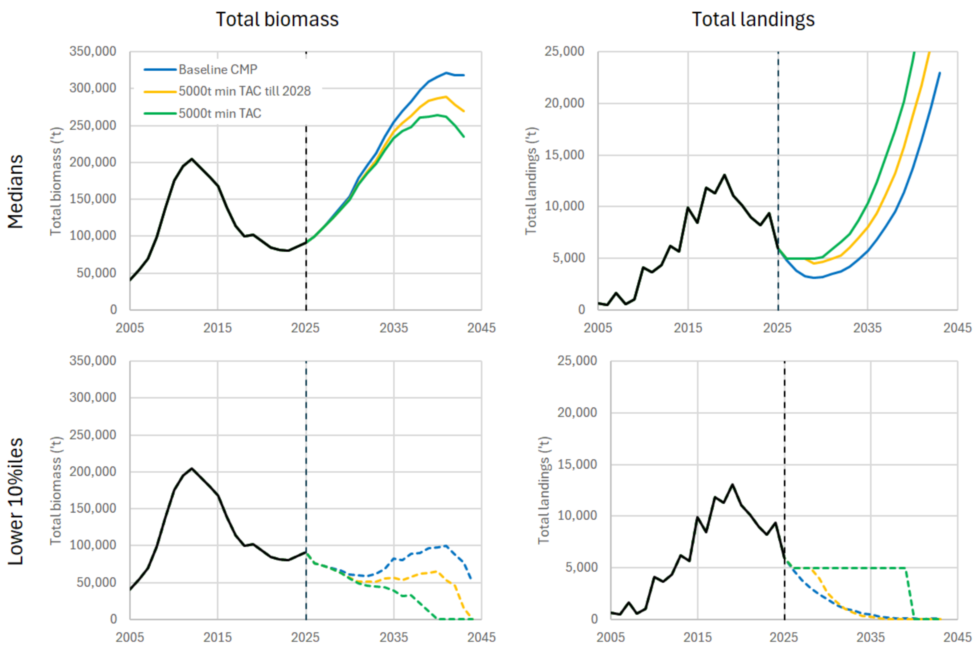

Figure 3c. Projected total biomass and landings (medians top row and lower 10%iles bottom row) for the Base Case OM under a series of CMPs (**lower limit on future TACs**).