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Outline of a Simple Approach to Develop a MSE for 3LN Redfish - Extended

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Abstract

An outline of a simple approach for developing a MSE for 3LN redfish is set out. This is based on a simple production model, without density dependence but incorporating annual process error, which is fit to catch and survey data from 2005 onwards. A constant fishing proportion MP provides adequate feedback control, even given the occurrence of a year with unusually strong production (mimicking a very strong year-class). Initial comments are sought before the work is extended from the current assumption of perfect knowledge of the biomass to estimating this annually given future survey information which includes observation error.

Earlier work is now extended to allow for input of a survey index of biomass incorporating observation error, and a number of robustness tests for the resultant MP are performed. It seems that sufficient work has now been completed to demonstrate that the approach suggested is viable in principle. Further comments are again sought before taking this work further; these are especially required for moving the work closer towards providing an MP that is more closely aligned with the specifics of the redfish resource concerned, such as exactly what redfish surveys can be reliably expected to take place in the future.

Background

Approaches to developing an MSE for 3LN redfish have foundered over the difficulties of developing relatively complex Operating Models (OMs) fitting, *inter alia*, to catch-at-length information. These led to estimated process errors which were deemed too large to allow for realistic projections as needed for MSE.

Absent of an MSE leading to a Management Procedure (MP), some approach remains needed to provide a basis to recommend catch limits. One suggestion has been to use the revised Precautionary Approach Framework (PAF) to produce a harvest control rule (HCR). Concerns there are, however, that though that PAF has been intensively simulation tested: i) did such testing extend sufficiently to cover the likely dynamics of redfish, and ii) how readily might the parameter values required for that revised PAF HCR (such as an MSY level abundance) be determined for 3LN redfish.

What is suggested here is a much simpler approach for a redfish MSE, working from the basis that:

- The OMs should primarily reflect recent dynamics (for the last decade or so).
- Dependence on density dependence (and hence MSY-related parameters) should desirably be avoided given that their reliable estimation is problematic.

In what follows:

- Section A duplicates what was circulated earlier.
- Section B adds further analyses which now allow for input of a survey index of biomass incorporating observation error; furthermore, a number of robustness tests for the resultant MP are performed. This work benefitted from comments received to Section A when distributed earlier, to which some responses are included below. Comments are again sought before taking this work further; these are especially required for moving the work closer towards providing an MP that is more closely aligned with the specifics of the redfish resource concerned.

SECTION A – Basic Approach with Deterministic Data Input

Approach

The underlying population model assumed is an aggregated biomass dynamics model:

$$B_{y+1} = B_y e^{-M} + P_y - C_y \qquad (1)$$

where:

B_y is the biomass at the start of year *y*,
C_y is the catch during year *y*,
P_y is the productivity of the resource in year y (a combination of somatic growth and recruitment), and
M is the annual rate of loss to natural mortality expressed in terms of mass.

This model is then fit to existing survey and annual catch data to estimate annual biomass and productivity values.

The likelihood is calculated assuming that the observed abundance index is log-normally distributed about its expected value:

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

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

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

where:

σ^i is the standard deviation of the residuals for the logarithms of index *i*, estimated in the fitting procedure by its maximum likelihood value:

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

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:

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

At the simplest level, P_y is assumed to be a constant, with a single value being estimated. At the next level, estimable process error is added:

$$P_y = P_y e^{(\mu_y - \sigma_\mu^2/2)} \qquad (6)$$

where the μ_y are estimable parameters, with their estimation being rendered possible by assuming that they follow a normal distribution, so that the following term is added to $-\ell nL$ in equation (3):

$$\sum_y (\mu_y)^2 / 2(\sigma_\mu)^2 \qquad (7)$$

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 this initial analysis of a potential MP, a simple constant fishing proportion (F) is examined. Later work will add more realism by including observation error in simulating future survey indices to be used to set catches.

Note that although the model of equation (1) is simple, is still captures the underlying dynamics and would not in principle introduce bias. Its shortcoming is that, in not modelling some of the constituent processes (and neglecting some data), the variance of some of its outputs might be larger than otherwise possible, thus necessitating a more conservative harvesting approach.

Implementation

Data
The catches and survey values given in Perreault *et al*. (2024) are used for this analysis; they are reproduced in Tables 1 and 2 for the period starting from 2005, as is considered here.

Parameter values
For this initial work, M = 0.2 .

Where considered, the process error variance in productivity P_y is set to $\sigma_\mu = 0.3$.

Future dynamics
Future annual productivity in generated from the same distribution as assumed for fitting the associated OM.

As a robustness test, to reflect the occasional very strong year-class that occurs in redfish stocks, a productivity which is 10 times the size of the estimated average annual productivity is assumed to occur in year 5 of the projections.

A single (again for initial simplicity) future survey index is suggested to be assumed to be available with a log-normal CV of 0.4.

Results

Figure 1 shows results of the model fit to the data for the $\sigma_\mu = 0$ and $\sigma_\mu = 0.3$ cases, 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:

$$\sum_i (q_i - Q)^2/\sigma_q^2 \qquad (8)$$

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

Projections

Projections into the future for a series of fixed F values are carried out for 20 years, starting in year 2024, for 500 simulations.

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

$$C_{av} = \sum_{y=2024}^{2043} C_y/20$$

$$B_{lowest} = \min(B_y) \qquad \text{over 2024 to 2043}$$

$$B_{final} = B_{2043}$$

$$AAV = \frac{1}{20}\sum_{y=2024}^{2043} \frac{(C_{y-1} - C_y)}{C_{y-1}}$$

Results for both models ($\sigma_\mu = 0$ and $\sigma_\mu = 0.3$) under the Reference Case and the robustness test are given in Table 4 for the performance statistics (medians and 90%iles in the case with ($\sigma_\mu = 0.3$) and Figures 2 and 3 for biomass and catch trajectories.

Note that absent MSY-related parameter estimates, one candidate for a LRP (Limit Reference Point) would be the estimated lowest historical biomass level from which the resource has shown the ability to increase (here the 37 000 t for the $\sigma_\mu = 0$ and 35 000 t for the $\sigma_\mu = 0.3$ scenarios in 2005 – see Table 4).

Discussion

Figure 3b for constant F projections for the model with process error ($\sigma_\mu = 0.3$), given its greater biomass variability, probably provides the best immediate basis on which to judge the potential for taking this analysis further to a full MSE. Even for the robustness test with the very strong year class after 5 years, constant F control would seem to provide adequate feedback control for F values up to at least 3, combining both reasonable catches and reasonably low resource risk.

Of course, the results thus far benefit from the unrealistic advantage of knowing the biomass B exactly. The next step is to add a future annual estimation component, where surveys generated with realistic error are added for the years projected. These then are input to a model estimating a biomass time series, which in turn provides the recent B value to use multiply by a selected value for F to provide a TAC each year. The extra uncertainty associated with this process will lead to poorer performance than indicated in Table 4, and hence to lower values of F for acceptable performance than that Table might suggest.

We consider that this approach is worth progressing further towards such greater realism, but first feedback comments would be appreciated, for example regarding the penalty function approach used to decrease estimates of survey catchability q leading towards what would seem to us to be more realistic resource biomass values.

SECTION B – Extension towards Greater Realism with a Survey Biomass with Error for Input

Candidate Management Procedure (CMP)

A simple CMP is implemented to compute TACs in the future based 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:

$$TAC_y = TAC_{y-1}\left[1 - \alpha(\frac{J_{y-2}}{J_{targ}} - 1)\right] \qquad (9)$$

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 and J_{targ} the CMP's tuning parameters.

Furthermore, TACs are subject to a maximum inter-annual decrease or increase of 20%.

Results under the Reference Case OM and the robustness test with a spike in productivity in 2028 are given in Table 5 for the performance statistics (medians and 90%iles) for the case with ($\sigma_\mu = 0.3$), and Figure 4 provides biomass and catch trajectories for three values of the J_{targ} parameter. The tuning parameter a is kept at 1 (at this stage).

Robustness tests

Performance statistics for the robustness tests described below are compared to those of the Reference Case OM ($\sigma_\mu = 0.3$) in Table 6. For all these tests, future TACs are computed using the CMP with $J_{targ} = 1.2$.

Density dependent productivity

In the Reference Case the expected productivity is taken to be independent of biomass, so that reducing the stock to a very low level involves no danger of following diminished recruitment. That is an extreme case. To address this, for this robustness test the (expected) productivity is taken to be constant only above a biomass level B_{hinge}, and decreases linearly below this level to zero at zero biomass. Plots of productivity vs biomass are shown in Figure 5 for the Reference Case (no density dependence) and two robustness tests with density dependent productivity: B_{hinge} = 100 kt and B_{hinge} = 130 kt.

Time trajectories of biomass, catch and productivity are plotted in Figure 6 for the RC and these two robustness tests.

Different level of process error variance for productivity

The Reference Case assumes $\sigma_\mu = 0.3$, both in the past and in the projections. Sensitivity to this assumption is tested with $\sigma_\mu = 0.1$ and $\sigma_\mu = 0.5$, first for the projections only (i.e. keeping $\sigma_\mu = 0.3$ in the past) (Figure 7a) and then both in the past and in the projections (Figure 7b).

Penalty on catchability

The RC includes a penalty factor in the log likelihood to reduce the q estimates towards more realistic values – see equation 8 above. Two robustness tests have been run with $\sigma_q^2 = 0.6$ and $\sigma_q^2 = 1.0$ to decrease the effect of this penalty. The results are plotted in Figure 8.

Upper cap on future TACs

In the robustness with a spike in productivity in 2028, the resulting increase in TACs leads in some instances to a later resource crash, as TACs which increase substantially in response to the spike do not decrease sufficiently rapidly thereafter. Results for a CMP with a 15 kt cap on the TAC to attempt to avoid this are plotted in Figure 9.

Discussion

Some observations from the new results are as follows:

- Implementing the CMP with survey observation error raises B_{lowest} and secures a better AAV, but C_{av} is lower (Table 5, Figure 4)
- There is no effect on performance of having a B_{hinge} value at 100kt, because any future biomass pretty much stays above this level in all the simulations (Figure 6).
- There is also little effect with B_{hinge} at 130 kt. This reduces productivity and catches are reduced accordingly (Figure 6), but in any case this value seems unrealistically high given past values for resource productivity (Figure 5)
- There is little effect for different values of different σ_μ, in the future only, but somewhat more when σ_μ is changed in the past as well as the future. The worst B_{lowest} occurs for the higher σ_μ (σ_μ=0.5) (Figure 7)
- Reducing the penalty on the survey catchability (i.e. increasing σ_q) decreases the scale of the total biomass and productivity, and results in slightly higher future caches (Figure 8)
- With a 15 kt cap on TACs, the resource does not crash following a spike in productivity (Figure 9). Note that this is a very simple modification to obtain satisfactory performance in this instance; more complex approaches would be considered for a practical CMP.

Further work

Discussion is needed on issues which will arise when further extending the present work into a form at might provide an MP candidate for 3LN redfish. Such issues include:

1) The value for σ_q – which gives the most realistic estimate of biomass in absolute terms?

2) What surveys can be safely assumed to continue reliably into the future?

3) Further robustness tests, including especially more complex forms of spikes in recruitment, need to be considered.

Reference

Andrea Perreault, Laura Wheeland, Paul Regular, Mariano Koen-Alonso and Rick Rideout. 2024. An Assessment of the Status of Redfish in NAFO Divisions 3LN. NAFO SCR Doc. 24/048, 20 pp

Table 1. Total landings (in t) of redfish in Divs. 3LN for 2005 to 2023 (from Perreault *et al.*, 2024).

Year	Landings ('000t)
2005	0.656
2006	0.496
2007	1.664
2008	0.597
2009	1.051
2010	4.12
2011	3.672
2012	4.316
2013	6.232
2014	5.695
2015	9.94
2016	8.457
2017	11.815
2018	11.279
2019	13.05
2020	11.091
2021	10.172
2022	8.961
2023	8.224

Table 2. Survey biomass ('000 t) from bottom trawl surveys in Divs. 3LN considered in the assessment (from Perreault *et al.*, 2024).

	Spring Campelen	Autumn Campelen	EU Spain 3N	EU Spain 3L	Spring Teleost
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

Table 3. -ln*L*, estimated survey *s* and *q*'s for the models with $\sigma_{\mu} = 0$ (constant productivity) and $\sigma_{\mu} = 0.3$ (variable productivity).

Constant productivity (σ_{μ}=0)					
Total: -*lnL*	-3.12				
P penalty	0.00				
q^i penalty	0.05				
	Spr Camp	Aut Camp	EU Sp 3N	EU Sp 3L	Spr Tel
-*lnL*	-1.74	-6.37	2.52	1.62	0.79
σ^i	0.52	0.40	0.70	0.68	0.74
q^i	1.44	2.05	1.62	0.87	1.27
Variable productivity (σ_{μ}=0.3)					
Total: -*lnL*	-8.96				
P penalty	5.35				
q^i penalty	0.07				
	Spr Camp	Aut Camp	EU Sp 3N	EU Sp 3L	Spr Tel
-*lnL*	-2.57	-11.46	0.29	-1.06	0.41
σ^i	0.48	0.28	0.62	0.57	0.67
q^i	1.42	2.05	1.66	0.86	1.48

Table 4a. Performance statistics for a series of *F* values for the model with constant productivity, for the Reference Case (constant P) OM and for the robustness test with a peak in productivity (10*P) in 2028. Note that historically the lowest B value is 37 000t in 2005. Values for Cav, Blowest and Bfinal are in '000t.

F	Cav	Blowest	Bfinal	AAV
Reference Case				
0	0	133	185	-
0.1	12	120	120	0.09
0.2	19	88	88	0.18
0.3	23	65	70	0.28
0.4	26	42	58	0.39
Robustness test (P*10 in 2028)				
0	0	133	200	-
0.1	18	121	121	0.27
0.2	27	88	88	0.41
0.3	33	49	70	0.61
0.4	27	0	0	1.53

Table 4b. Performance statistics (median and 90%iles) for a series of *F* values for the model with $\sigma_\mu = 0.3$., for the Reference Case OM and for the robustness test with a peak in productivity (10*P) in 2028. Note that historically the lowest B value is 34 000t in 2005. Values for Cav, Blowest and Bfinal are in '000t.

F	Cav	Blowest	Bfinal	AAV
Reference Case				
0	0 (0; 0)	110 (110; 110)	179 (156; 214)	-
0.1	12 (10; 13)	96 (83; 108)	116 (96; 150)	0.13 (0.11; 0.16)
0.2	18 (16; 20)	67 (55; 78)	85 (67; 115)	0.22 (0.20; 0.26)
0.3	22 (20; 24)	48 (39; 58)	67 (51; 95)	0.33 (0.29; 0.37)
0.4	25 (22; 27)	35 (24; 44)	56 (38; 84)	0.44 (0.39; 0.51)
Robustness test (P*10 in 2028)				
0	0 (0; 0)	110 (110; 110)	195 (169; 232)	-
0.1	17 (14; 21)	101 (88; 110)	117 (97; 150)	0.28 (0.21; 0.39)
0.2	26 (22; 32)	69 (57; 81)	85 (67; 115)	0.42 (0.33; 0.57)
0.3	31 (27; 38)	41 (22; 55)	67 (51; 95)	0.61 (0.46; 0.86)
0.4	31 (24; 37)	0 (0; 31)	0 (0; 76)	1.36 (0.67; 1.90)

Table 5 (Section B). Performance statistics (median and 90%iles) for a series of **CMPs** (so that there is observation error in the survey biomass index values input) for the model with $\sigma_\mu = 0.3$, for the Reference Case OM and for the robustness test with a peak in productivity (10*P) in 2028. Note that historically the lowest B value is 34 000t in 2005. Values for Cav, Blowest and Bfinal are in '000t.

CMP	Cav	Blowest	Bfinal	AAV
Reference Case				
C=0	0 (0; 0)	110 (110; 110)	179 (156; 214)	-
J_{targ}=1.1	7 (3; 15)	105 (55; 110)	133 (61; 180)	0.14 (0.11; 0.17)
J_{targ}=1.2	4 (2; 10)	110 (89; 110)	152 (96; 190)	0.15 (0.12; 0.18)
J_{targ}=1.3	3 (2; 8)	110 (101; 110)	161 (121; 197)	0.15 (0.12; 0.18)
Robustness test (P*10 in 2028)				
C=0	0 (0; 0)	110 (110; 110)	195 (169; 232)	-
J_{targ}=1.1	14 (8; 27)	61 (0; 110)	64 (0; 131)	0.17 (0.15; 0.19)
J_{targ}=1.2	10 (6; 20)	101 (6; 110)	105 (7; 156)	0.18 (0.15; 0.20)
J_{targ}=1.3	7 (5; 16)	108 (44; 110)	125 (44; 167)	0.18 (0.15; 0.20)

Table 6 (Section B). Performance statistics (median and 90%iles) for a series of robustness tests under the CMP with Jtarg=1.2. Note that historically the lowest B value is 34 000t in 2005. Values for Cav, Blowest and Bfinal are in '000t.

Sensitivity	Cav			Blowest			Bfinal			AAV		
Density dependent productivity												
no dependency RC)	4	(2;	10)	110	(89;	110)	152	(96;	190)	0.15	(0.12;	0.18)
with dependency (B_{hinge}=100)	4	(2;	10)	110	(88;	110)	152	(91;	190)	0.15	(0.12;	0.18)
with dependency (B_{hinge}=130)	3	(2;	9)	105	(78;	110)	157	(90;	193)	0.15	(0.12;	0.18)
Productivity process error (past and future)												
σ_μ=0.1	5	(2;	9)	110	(104;	110)	152	(106;	174)	0.15	(0.12;	0.18)
σ_μ=0.3 (RC)	4	(2;	10)	110	(89;	110)	152	(96;	190)	0.15	(0.12;	0.18)
σ_μ=0.5	4	(2;	11)	101	(65;	110)	149	(80;	216)	0.16	(0.12;	0.19)
Productivity process error (future - past σ_μ=0.3)												
σ_μ=0.1	3	(2;	7)	131	(128;	131)	170	(141;	184)	0.14	(0.11;	0.17)
σ_μ=0.3 (RC)	4	(2;	10)	110	(89;	110)	152	(96;	190)	0.15	(0.12;	0.18)
σ_μ=0.5	6	(3;	16)	85	(28;	92)	125	(31;	198)	0.16	(0.13;	0.19)
Penalty on survey catchability												
σ_q=0.2 (RC)	4	(2;	10)	110	(89;	110)	152	(96;	190)	0.15	(0.12;	0.18)
σ_q=0.6	5	(2;	11)	88	(60;	88)	121	(65;	158)	0.15	(0.12;	0.18)
σ_q=1.0	6	(3;	12)	74	(39;	74)	101	(45;	139)	0.16	(0.12;	0.18)
Cap on future TACs (robustness test with productivity spike)												
no cap (RC)	10	(6;	20)	101	(6;	110)	105	(7;	156)	0.18	(0.15;	0.20)
C<15 kt	8	(6;	11)	110	(99;	110)	131	(104;	167)	0.14	(0.10;	0.19)

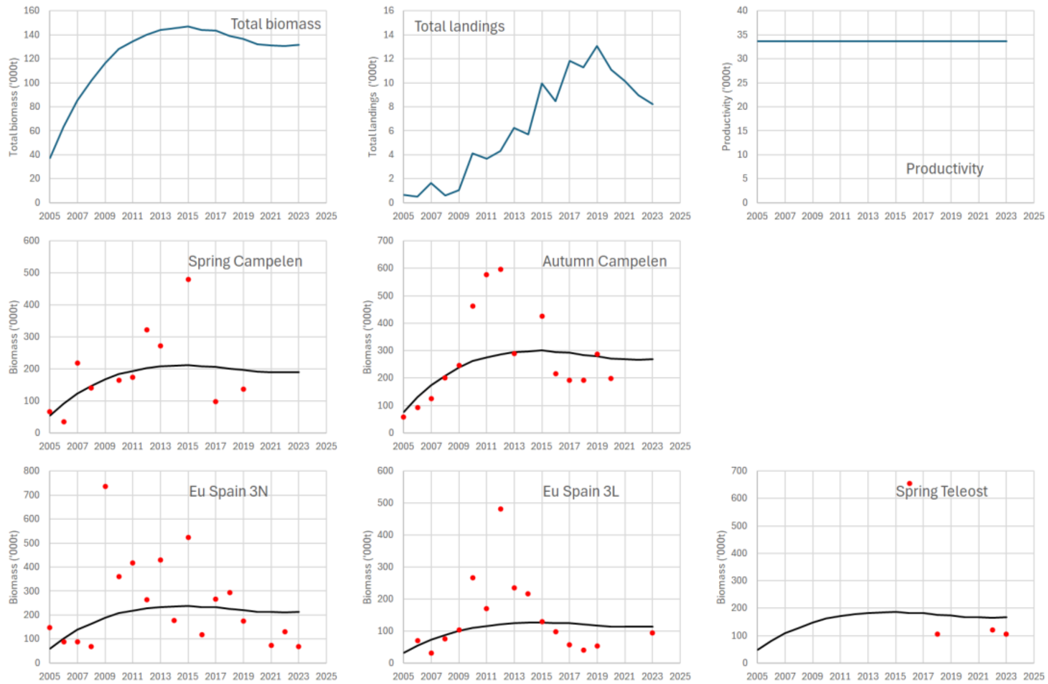

Figure 1a. Estimated total biomass, productivity (in '000t) and total landings (in '000t) for the model with constant productivity P. The fits of the model to the survey data series are also shown.

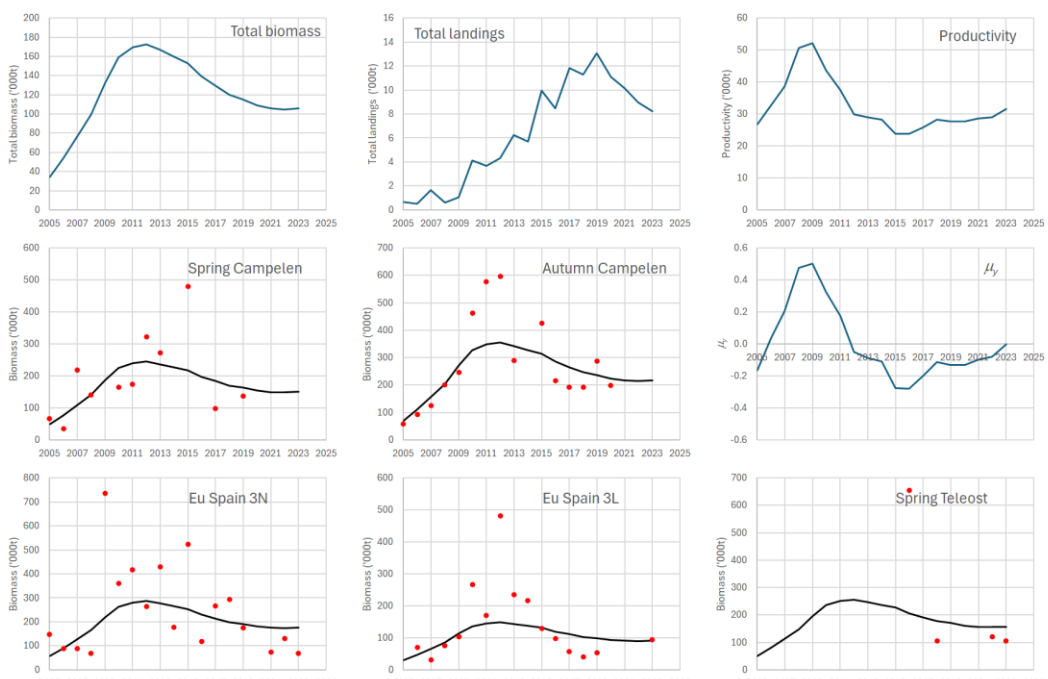

Figure 1b. Estimated total biomass, productivity (in '000t) (and process error associated with it) and total landings (in '000t) for the model with $\sigma_\mu = 0.3$. The fits of the model to the survey data series are also shown.

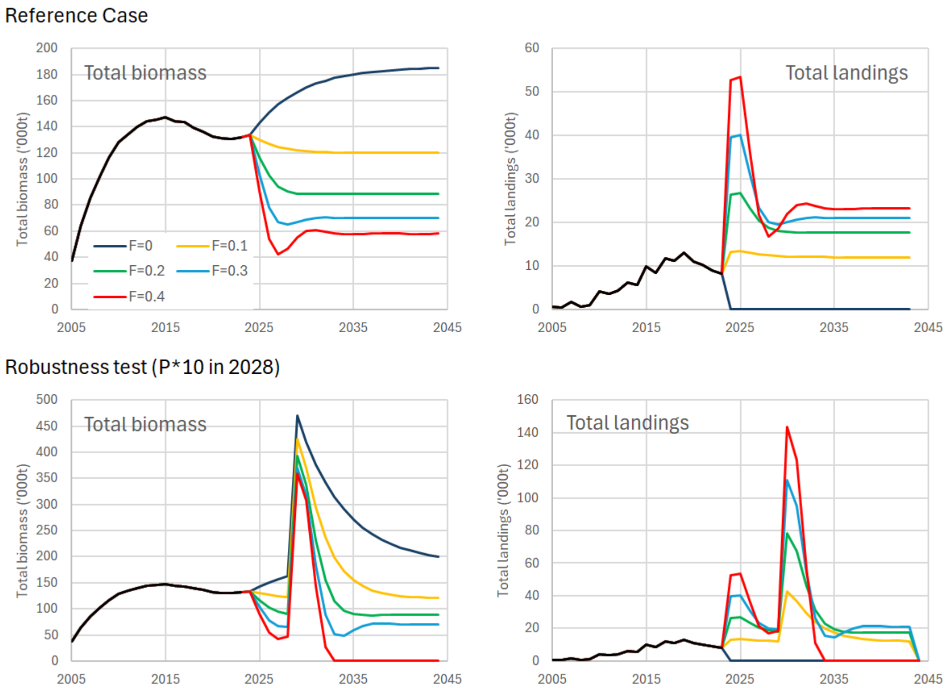

Figure 2. Projected total biomass and landings for the model with constant productivity P for the Reference Case (constant P) and the robustness test with a peak in productivity in 2028. Results are shown for five different values of the fishing proportion *F*. Note that the vertical scales differ for the two cases.

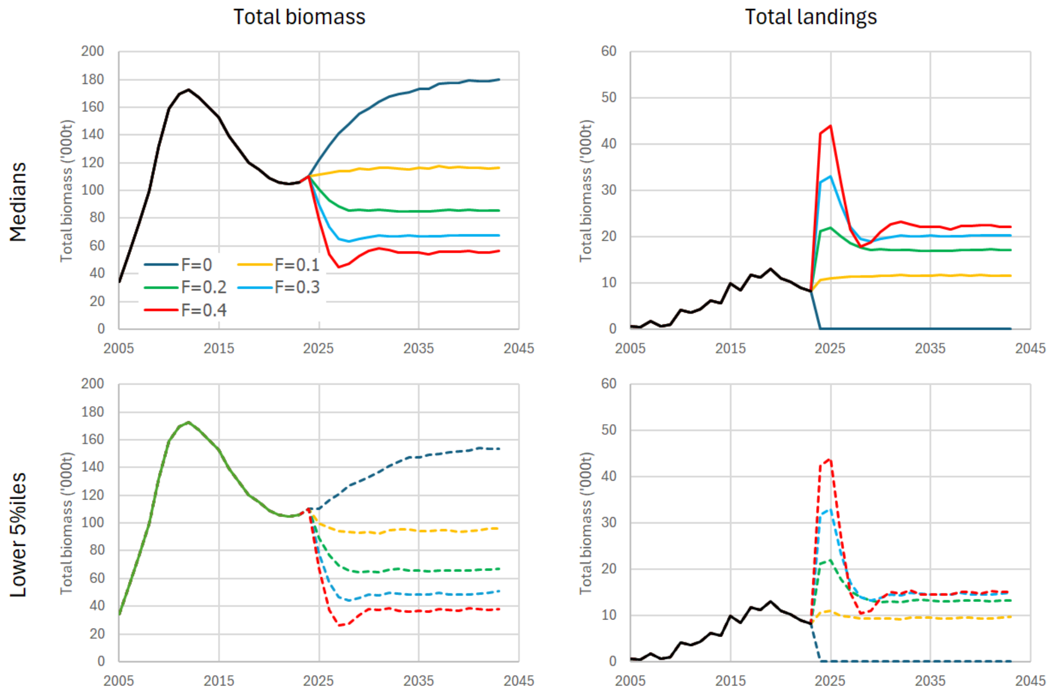

Figure 3a. Projected total biomass and landings (medians top row and lower 5%iles bottom row) for the model with $\sigma_\mu = 0.3$. Results are shown for five different values of the fishing proportion F.

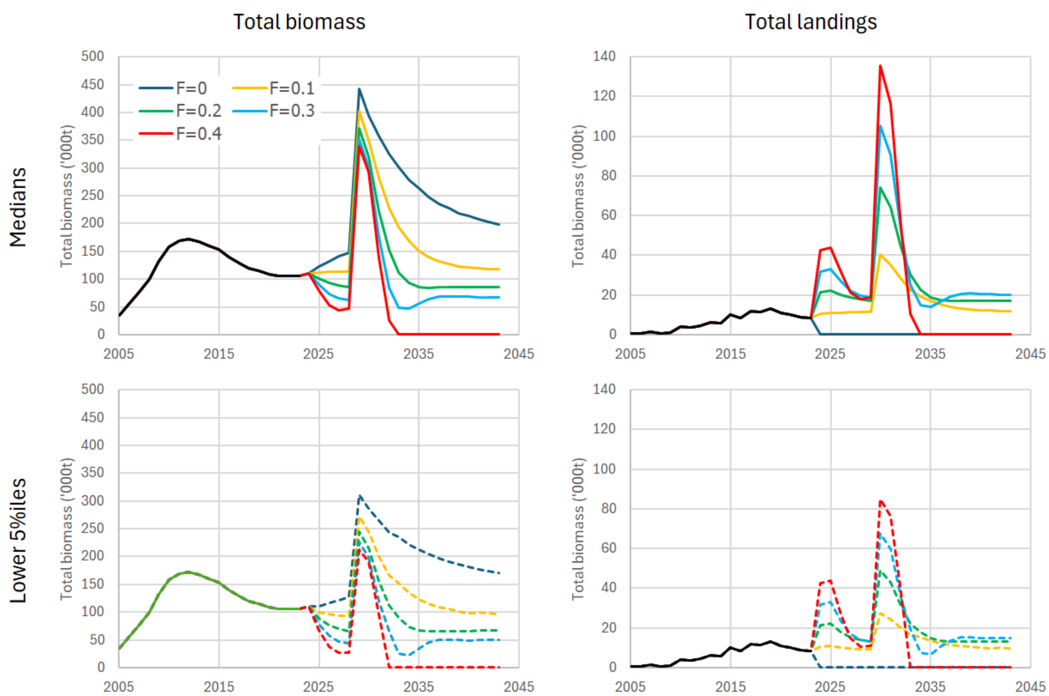

Figure 3b. Projected total biomass and landings (medians top row and lower 5%iles bottom row) for the model with $\sigma_\mu = 0.3$ in the case of a robustness test with a peak in productivity in 2028. Results are shown for five different values of the fishing proportion F.

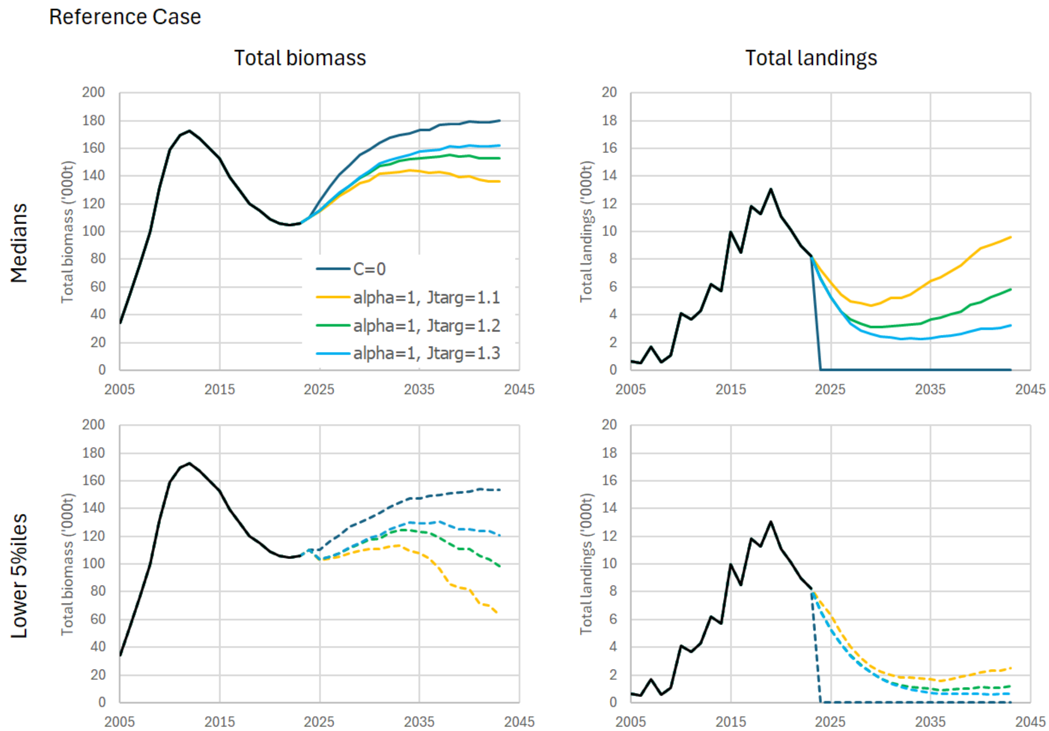

Figure 4a (Section B). Projected total biomass and landings (medians top row and lower 5%iles bottom row) for the model with $\sigma_{\mu} = 0.3$. Results are shown for a series for CMPs.

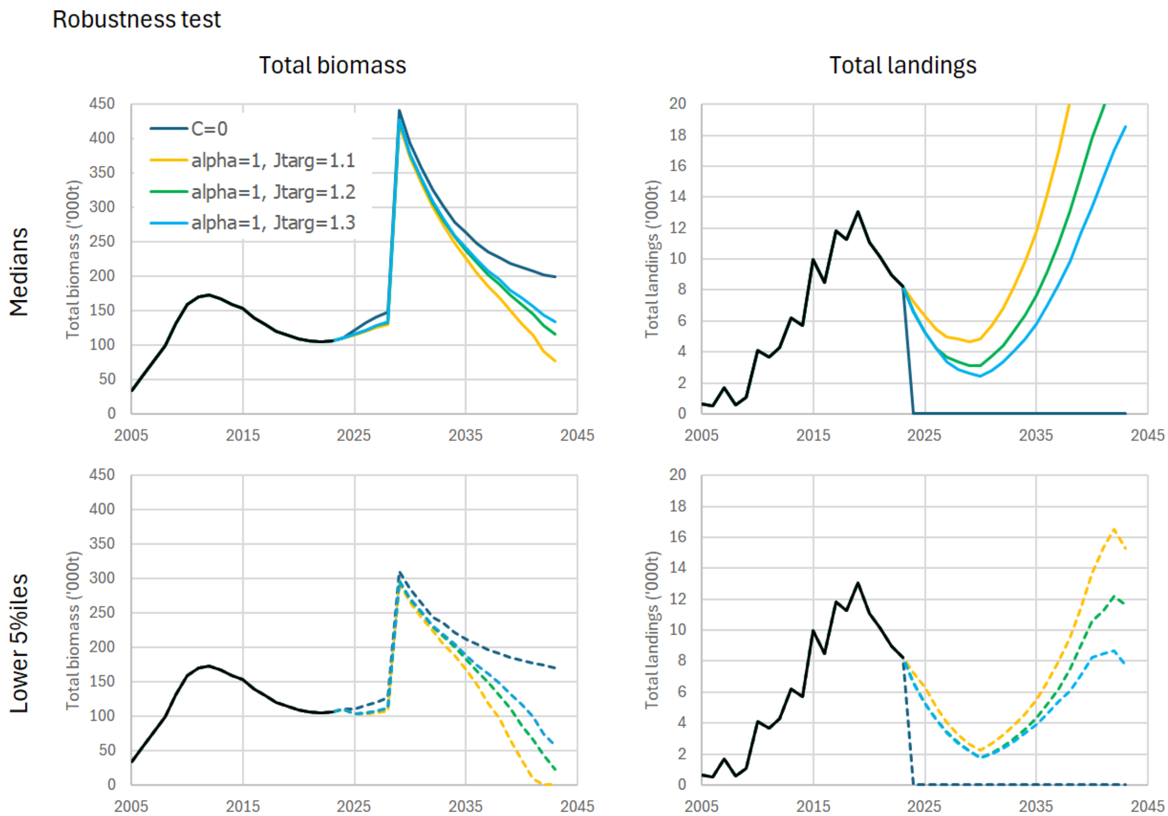

Figure 4b (Section B). Projected total biomass and landings (medians top row and lower 5%iles bottom row) for the model with $\sigma_{\mu} = 0.3$ for the case of a robustness test with a peak in productivity in 2028. Results are shown for a series for CMPs.

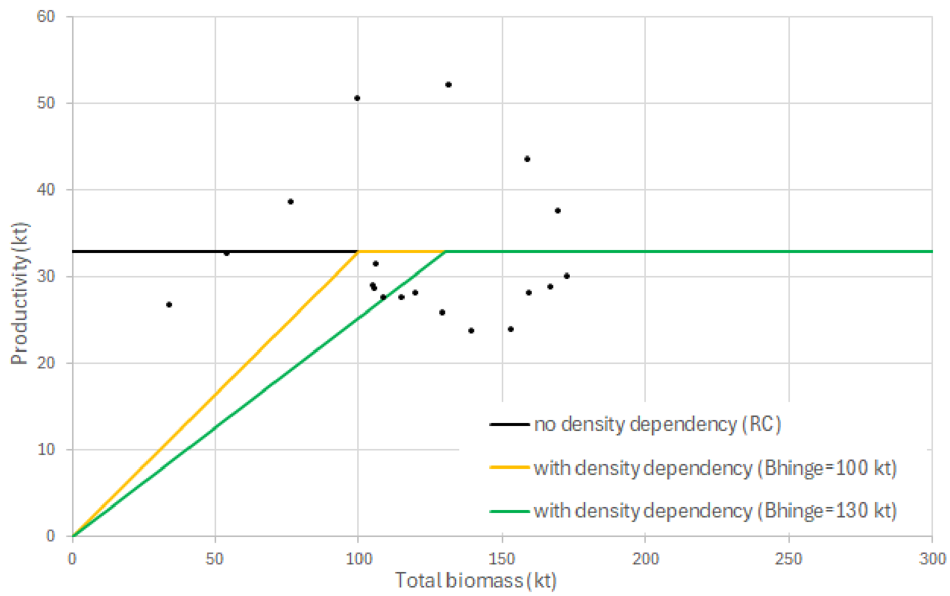

Figure 5 (Section B). Productivity vs total biomass for the Reference Case (productivity independent of biomass level) and two sensitivities where productivity decreases linearly below Bhinge. Black dots show the estimated biomass vs productivity over the 2005-2023 period.

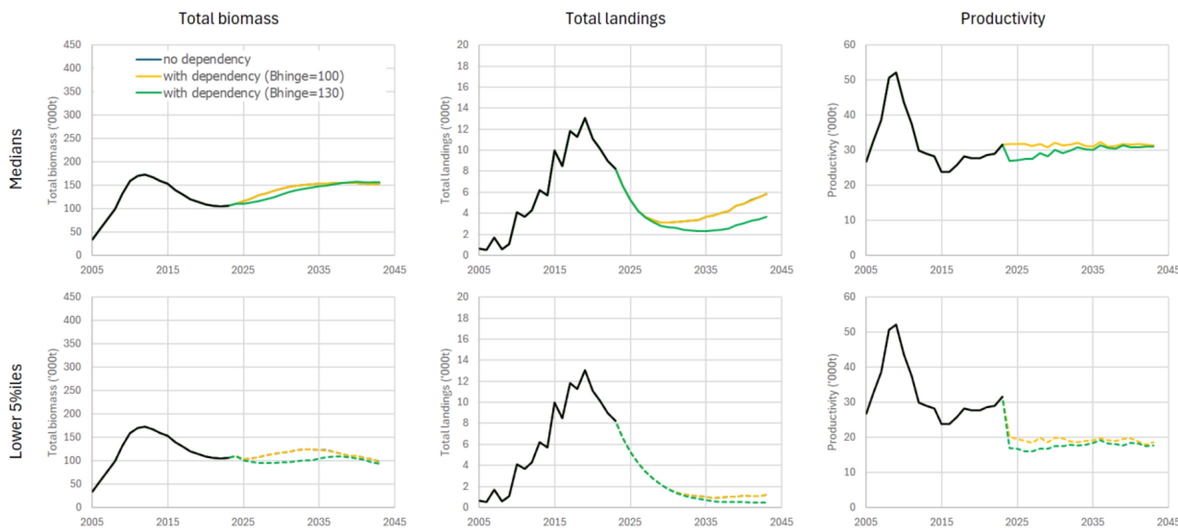

Figure 6 (Section B). Projected total biomass, landings and productivity (medians top row and lower 5%iles bottom row) for the Reference Case OM and two robustness tests with density dependent productivity. Future TACs are computed with the CMP with J_{targ}=1.2. Note: the robustness test plots for Bhinge=100 sit on top of those for the Reference Case OM ("no dependency").

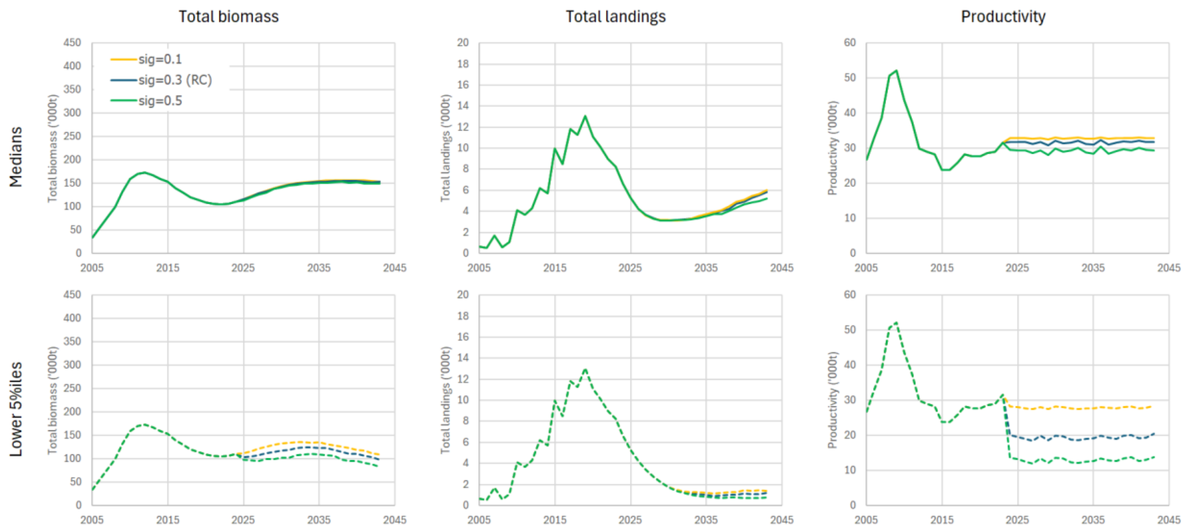

Figure 7a (Section B). Projected total biomass, landings and productivity (medians top row and lower 5%iles bottom row) for the Reference Case OM (s_m=0.3) and two robustness tests with different levels of process error variance for productivity sig (s_m=0.1 and s_m=0.5) in the projections only (i.e. (s_m=0.3 remains for the 2005-2023 period). Future TACs are computed using the CMP with J_{targ}=1.2.

Figure 7b (Section B). Projected total biomass, landings and productivity (medians top row and lower 5%iles bottom row) for the OM (s_m=0.3) with a spike in productivity in 2028 and two robustness tests with different levels of process error variance for productivity sig (s_m=0.1 and s_m=0.5) in the past and for the projections. Future TACs are computed using the CMP with J_{targ}=1.2.

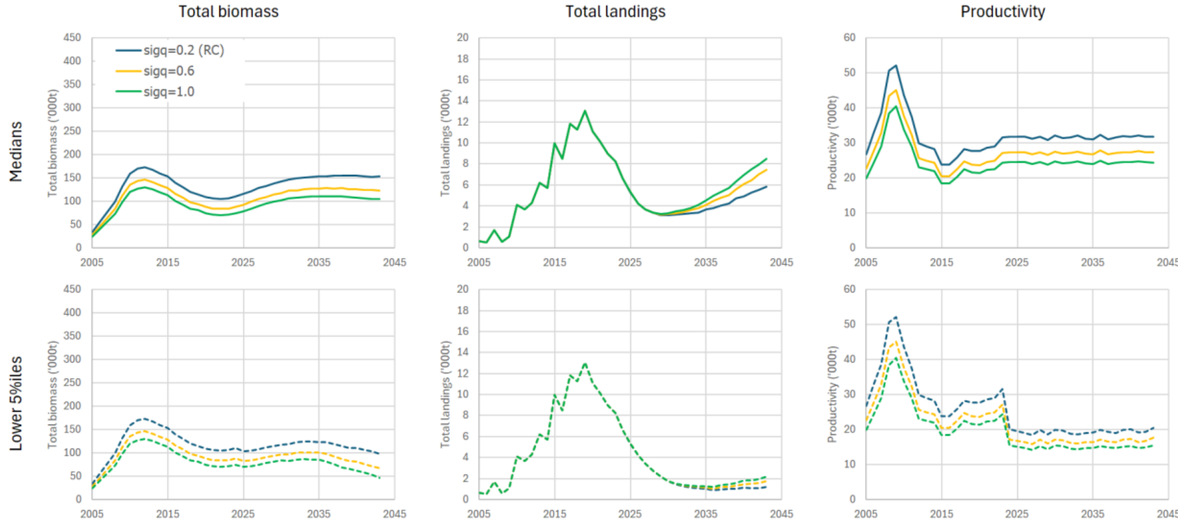

Figure 8 (Section B). Projected total biomass, landings and productivity (medians top row and lower 5%iles bottom row) for the Reference Case OM (s_q=0.2) and two robustness tests reducing the penalty on the survey catchability (s_q=0.6 and s_q =1.0) in the past and for the projections. Future TACs are computed using the CMP with J_{targ}=1.2.

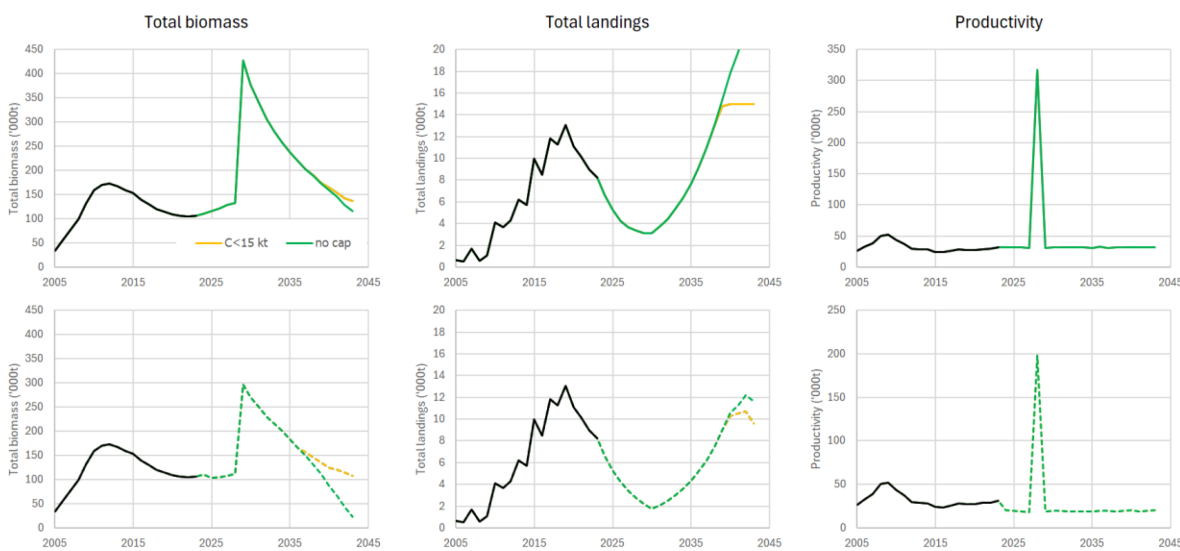

Figure 9 (Section B). Projected total biomass, landings and productivity (medians top row and lower 5%iles bottom row) for the robustness test with a spike in productivity in 2028 with and without a cap of 15 kt on future TACs