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Management Procedures for Greenland Halibut

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Summary

This document expands upon the baseline and sensitivity SCAA assessments of the Greenland halibut resource by Rademeyer and Butterworth (2017). First, projections under different levels of a constant catch are reported. These suggest that for all the cases of assessments (operating models – OMs) considered, an annual TAC of 20000t would be sustainable, but for most of these cases 30000t would not. Some variants of a simple target-based Management Procedure (MP) are applied purely as examples to illustrate the performance trade-offs and robustness considerations involved in selecting an MP.

Introduction

This document has two purposes.

1) To present constant catch projections for the assessment variants (operating models, OMs) reported in Rademeyer and Butterworth (2017).

2) To provide a few results for some example Candidate Management Procedures simply to illustrate the process and the form of outputs from which a final choice of an MP will ultimately need to be made.

Constant catch projections

Since the average catch over the last 5 years was very close to 20000t, stochastic projections have been calculated for future constant catches of 0, 10000, 20000 and 30000t (results for 40000t were not pursued as the population size dropped rapidly in those cases). The methodology used is as set out in Appendix 1.

Spawning and exploitable (taken to be ages 5-9) biomass trajectories are shown in order in Figures 1-4 for each of the four constant catch options above. These results reflect medians for 100 stochastic projections. The OMs have been renamed for reasons of space:

1a/b: baseline;
2a/b: 10+ plus group;
3a/b: M=0.12;
4a/b: 10+ and M=0.12;
5a/b: O1 survey series;
6a/b: O2 survey series;
7a/b: O3 survey series;
8a/b: h=0.5; and
9a/b: M increase;

where the a/b subscripts refer to the StartA and StartB baselines respectively.

Discussion

A few features of the projections perhaps worthy of note are the following.

- Projections are hardly sensitive to the StartA *vs* StartB baseline assessment (OM) differentiation.
- OM 8 with a low value of stock-recruitment steepness, h, shows the fastest biomass increases, but note (Rademeyer and Butterworth, 2017) that it exhibits a notably worse (penalised) log likelihood value in the model fit to the data.
- OM 9, with an increasing natural mortality M at higher ages, shows early saturation as regards biomass increase.
- The behaviour for the other OMs is fairly similar.
- These patterns are broadly preserved as the constant future catch is increased to higher levels.
- An annual catch of 20000t is sustainable for all OMs in terms of medians of projected abundance distributions.
- When that catch level is increased to 30000t however, biomasses decrease for all cases except for those with lower steepness h or M increasing with age.

Example Candidate Management Procedures

The algorithm for the example Candidate Management Procedures (CMPs) presented here is empirical. It calculates an increase or decrease of the TAC as a function of the difference between a biomass index and a target level for that index. The basis for the associated computations is set out below, with the tuning parameters for the examples reported given in Table 1.

$$TAC_{y+1} = \omega TAC_y \left(1 + \gamma_{up/down}(J_y - 1)\right) \qquad (1)$$

where
TAC_y is the TAC recommended for year y,

ω, γ_{up} and γ_{down} are tuning parameters (γ_{down} if $J_y < 1$ and γ_{up} if $J_y \geq 1$)

J_y is a measure of the immediate past level in the abundance indices that are available to use for calculations for year y; for this example three series have been used, with i = 1, 2 and 3 corresponding respectively to Canada Fall 2J3K, EU 3M 0-1400m and Canada Spring 3LNO:

$$J_y = \frac{1}{3}\sum_{i=1}^{3} \frac{J^i_{curr}}{J^i_{target}} \qquad (2)$$

with

$$J_{curr}^{i} = \frac{1}{5}\sum_{y'=y-5}^{y-1} I_{y'}^{i} \tag{3}$$

$$J_{target}^{i} = \frac{1}{5}\sum_{y'=2011}^{2015} I_{y'}^{i} \tag{4}$$

Note the assumption that when a TAC is set in year y for year y+1, indices will not at that time yet be available for the current year y.

Constraints on the maximum allowable annual change in TAC can be applied, i.e.:

if $TAC_{y+1} > TAC_y(1 + \Delta_{up})$ then $TAC_{y+1} = TAC_y(1 + \Delta_{up})$ (5)
and
if $TAC_{y+1} < TAC_y(1 - \Delta_{down})$ then $TAC_{y+1} = TAC_y(1 - \Delta_{down})$ (6)

Table 1: Tuning parameters for the example CMPs considered here.

	ω	γ_{up}	γ_{down}	Δ_{up}	Δ_{down}
CMP1	1	0.05	0.05	0.15	0.15
CMP2	1	0.05	0.10	0.15	0.15
CMP3	1	0.03	0.07	0.15	0.15
CMP4	1.05	0.05	0.05	0.15	0.15

The projection procedure used for the example CMP tests is set out in Appendix 1.

Figure 5 plots projected catch and spawning and exploitable biomass for StartA baseline OM for management under CMP1. Median and 90% PI are shown as well as 10 actual trajectories ("worm plots").

Figure 6 compares medians and 90% PI for a series of catch and biomass related performance statistics for the StartA baseline OM under a 20000t constant catch and the four example CMPs to illustrate the trade-offs amongst these performance statistics across the CMPs. Note that the average annual catch variation (AAV) is not zero for the constant catch case because the constant 20000t catch starts in 2018, while the AAV is computed from 2017 (for which a TAC and catch of 14 799t is assumed).

As in Figure 6, Figure 7 compares medians and 90% PIs for a series of performance statistics, but this time across a selection of four OMs under CMP1 to provide some indication of the robustness of that CMP to alternative underlying resource dynamics. The four OMs selected for this illustration are 1a/b (the two baselines); 6a (fitted to the O2 selection of survey series); and 9a (an increase in M with age).

Discussion

It is first important to stress that the results here are **examples** shown for the purpose of providing **illustrations** of the concepts and comparisons involved in the process of developing and selecting an MP. They are **not** put forward as serious candidates for a final MP – the development and testing of such candidates will occur in the next step of the overall process.

In Figure 5 which illustrates the range of trajectories possible for catch and biomass under CMP1 for the StartA baseline OM, note that these are deterministic for the first few years. The reason is that stochasticity/uncertainty in the resource dynamics here is introduced only through recruitment uncertainty from 2011 onwards. It is important to realise that the Probability Interval (PI) envelope plots are not trajectories (nor is the median), but reflect a series of values of statistics for distributions simulated for each year. This becomes clear when considering the individual trajectories ("worm plots") shown, which each exhibit considerable variability.

Figure 6 is intended to illustrate trade-offs between performance statistics across different CMPs. While CMP1, CMP2 and CMP3 show substantial increases in biomass but only moderate increases in averages catch, CMP4 in contrast leads to much higher catches but at the expense of a decreases in biomass as well as much higher inter-annual TAC variation than the some 2% indicated for the three other CMP examples.

Figure 7 relates to robustness: given uncertainty about the true dynamics of the resource, there needs to be a check that the anticipated performance of any MP potentially selected does not vary substantially across the different OMs which reflect that uncertainty. Only four OMs have been included in Figure 7, given that it is intended to be no more than illustrative. Anticipated future performances for the two baseline OMs under CMP1 are very similar, despite their large differences in estimates of historical abundance. By comparison, for the two other OMs shown (6a for the OM fitted to the O2 selection of survey series and 9a for an increase in M with age), biomass increases are larger, but TACs are less and the inter-annual TACs appreciably less for OM 9a.

Reference

Rademeyer, RA and Butterworth, DS. 2017. Initial applications of Statistical Catch-at-Age assessment methodology to the Greenland halibut resource. NAFO document

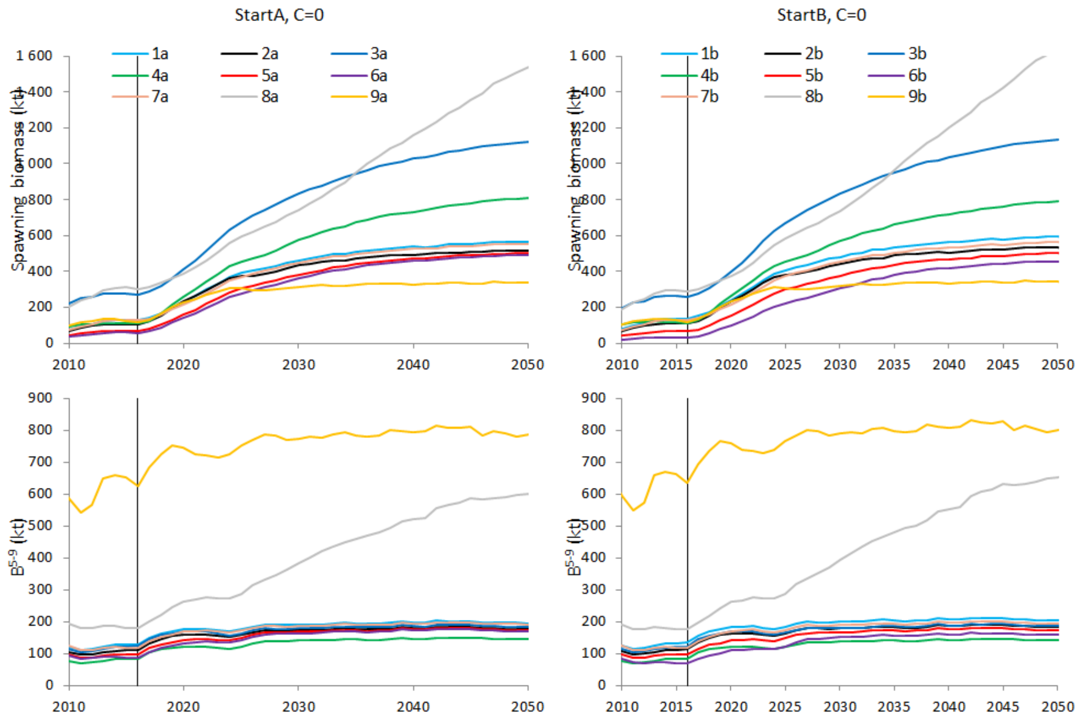

Fig. 1. Catch=0, constant catch projections for all OMs (medians).

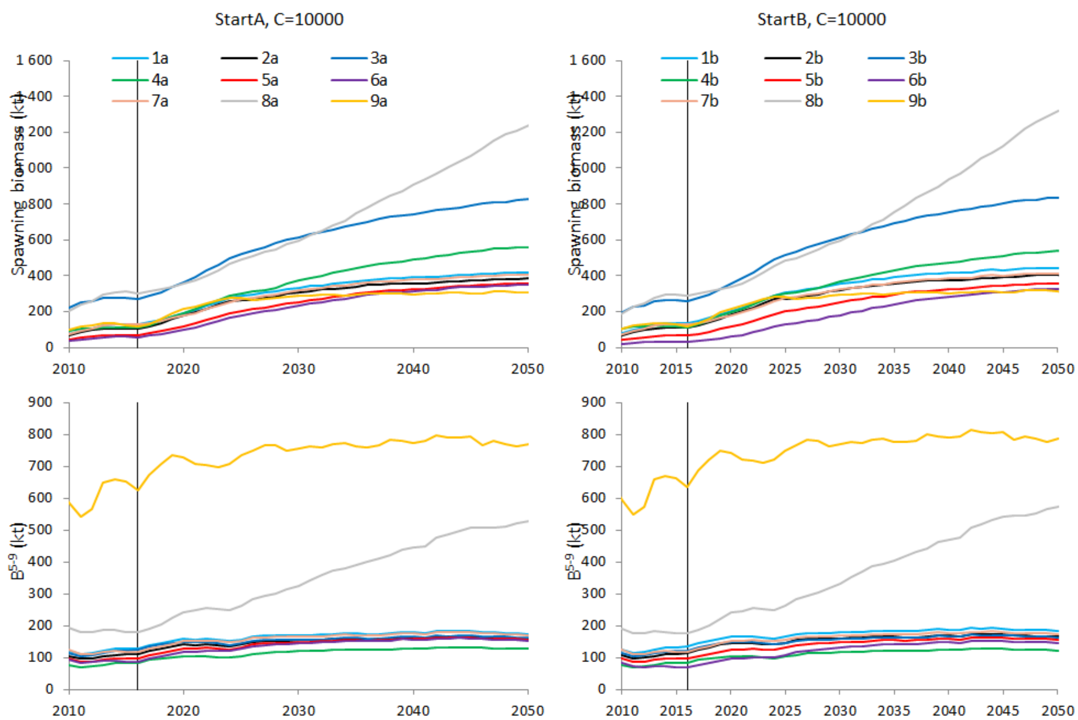

Fig. 2. Catch=10000t, constant catch projections for all OMs (medians).

Note:
1a/b: baseline; 2a/b: 10+ plus group; 3a/b: M=0.12;
4a/b: 10+ and M=0.12; 5a/b: O1 survey series; 6a/b: O2 survey series;
7a/b: O3 survey series; 8a/b: h=0.5; and 9a/b: M increase.
where the a/b subscripts refer to the StartA and StartB baselines respectively.

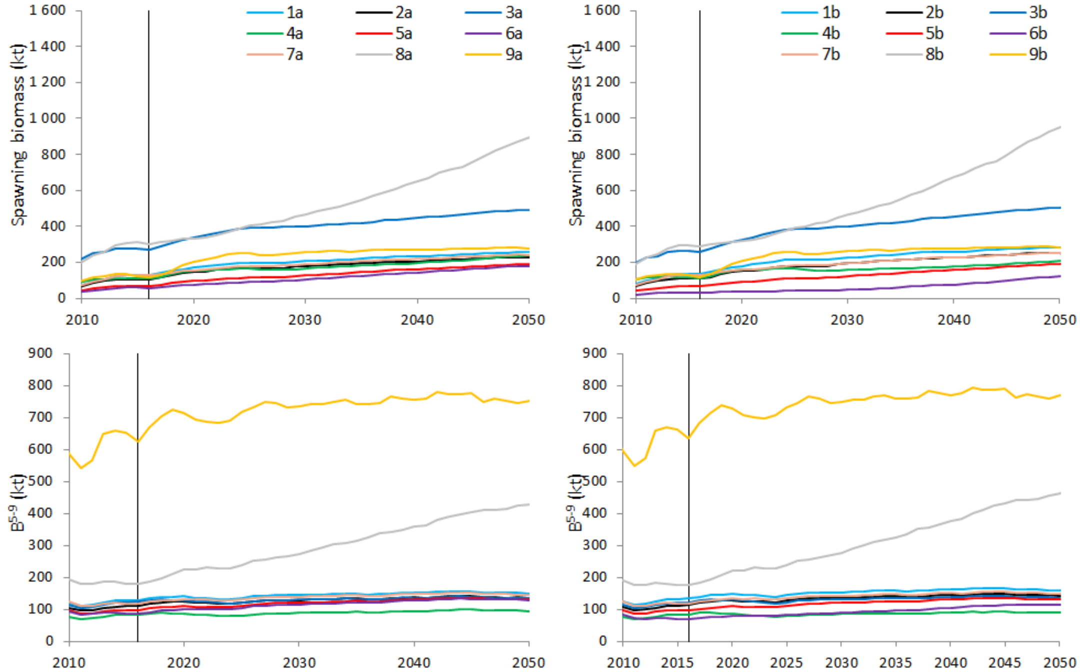

Fig. 3. Catch=20000t, constant catch projections for all OMs (medians).

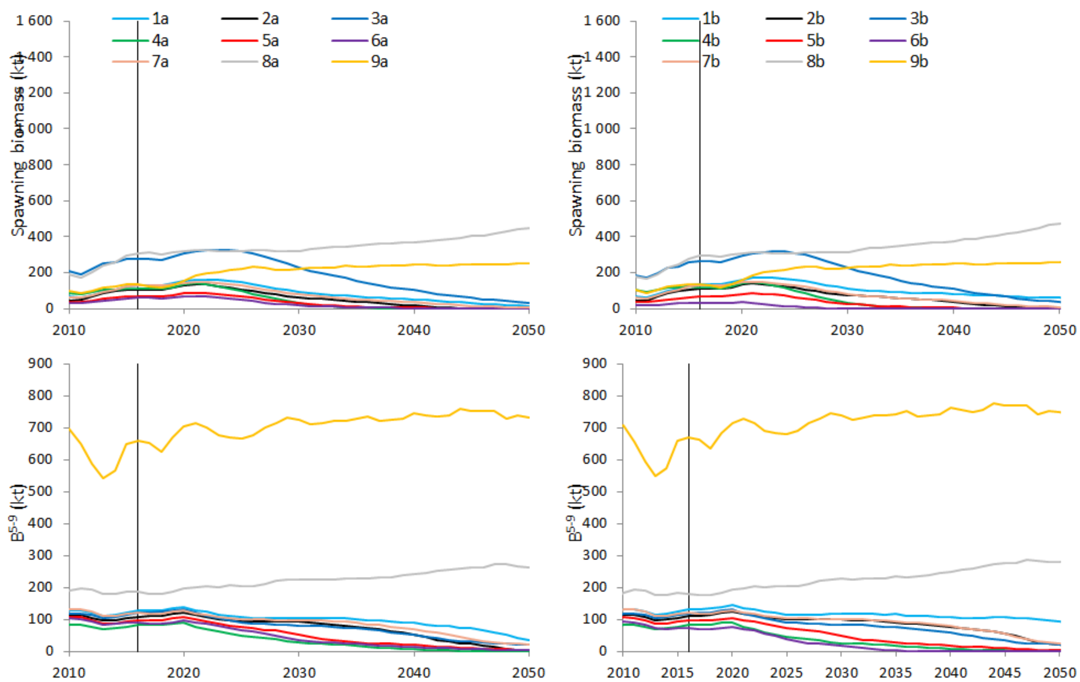

Fig. 4. Catch=30000t, constant catch projections for all OMs (medians).

Note:

1a/b: baseline;	2a/b: 10+ plus group;	3a/b: *M*=0.12;
4a/b: 10+ and *M*=0.12;	5a/b: O1 survey series;	6a/b: O2 survey series;
7a/b: O3 survey series;	8a/b: *h*=0.5; and	9a/b: *M* increase.

where the a/b subscripts refer to the StartA and StartB baselines respectively.

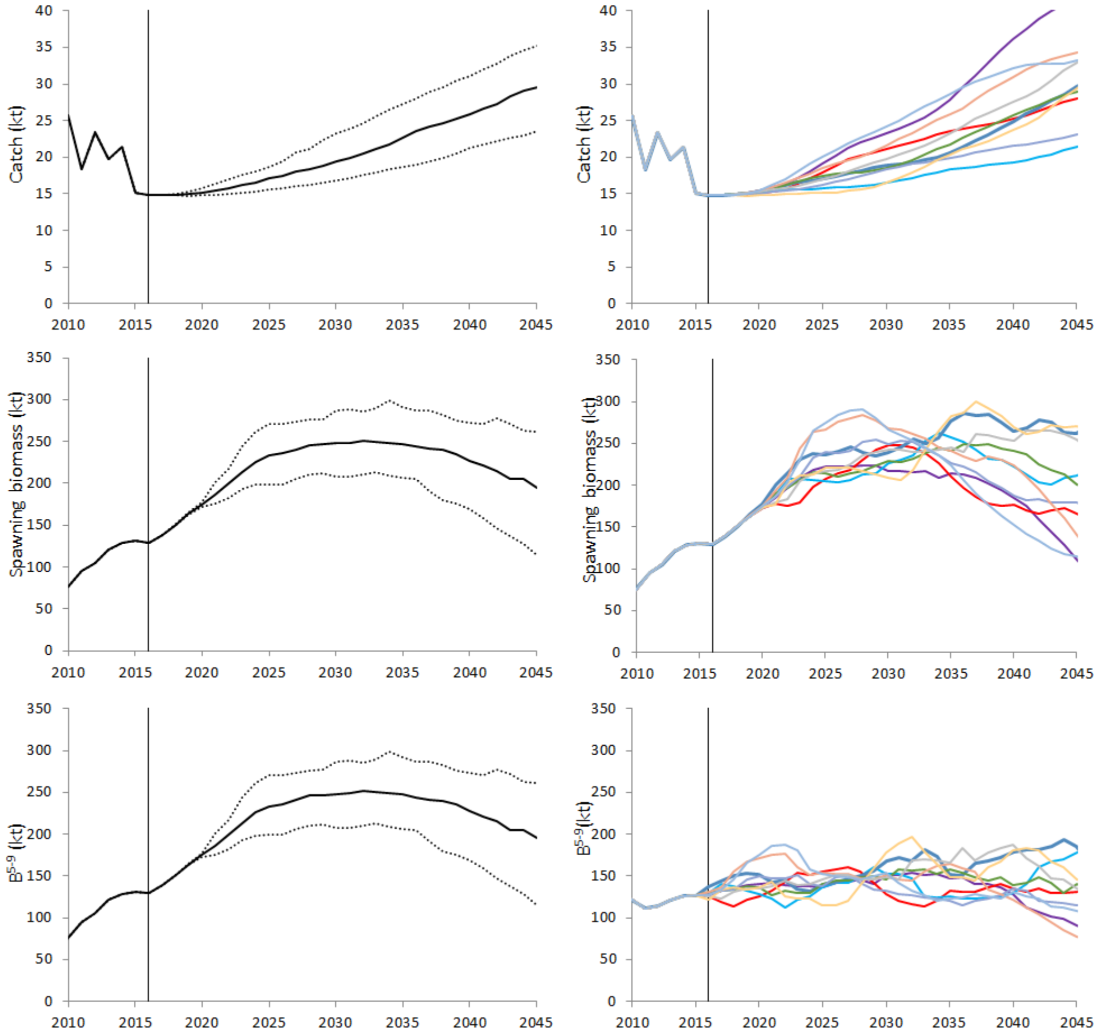

Fig. 5. Median and 90% PI envelopes (left side) and worm plots (right side) for projected catch, spawning biomass and exploitable biomass under **CMP1** for the **StartA** baseline OM.

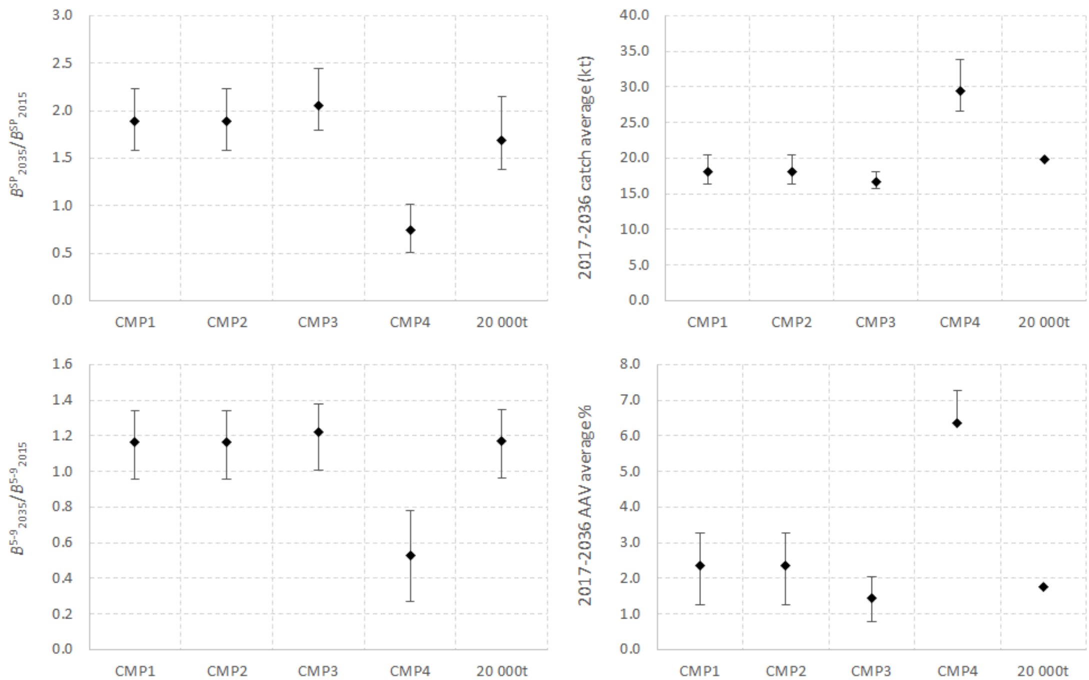

Fig. 6. Medians and 90% PIs for a series of performance statistics for StartA baseline OM managed under a 20000t constant catch scenario, and CMP1 to CMP4.

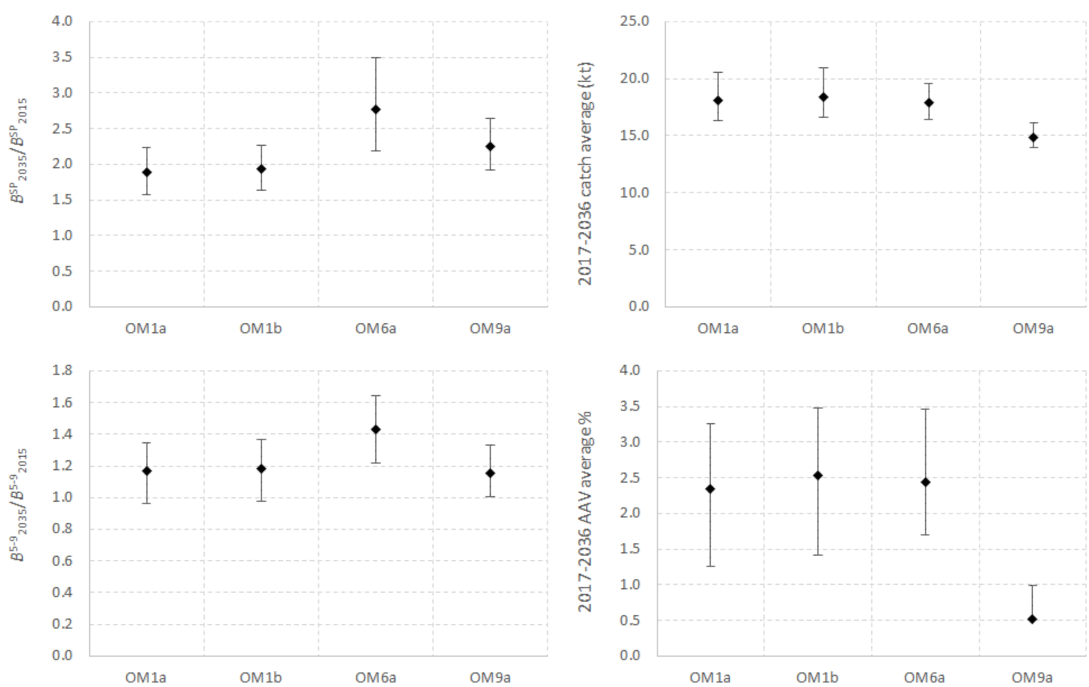

Fig. 7. Medians and 90% PIs for a series of performance statistics for four OMs with management under CMP1. The four OMs are 1a/b (the two baselines); 6a (fitted to the O2 selection of survey series); and 9a (an increase in *M* with age).

Appendix 1: Candidate Management Procedures Testing Methodology

Projection methodology

Projections into the future under a specific Candidate Management Procedure (CMP) are to be evaluated using the following steps.

Step 1: Begin-year numbers at age

The components of the numbers-at-age vector at the start of 2016 ($N_{2016,a}$: a = 0,…, m) are obtained from the MLEs for an assessment of the resource. Error is included for ages 0 to 5 to allow for estimation imprecision in the assessment, i.e.:

$$N_{2016,a} \rightarrow N_{2016,a} e^{\varepsilon_a} \qquad \varepsilon_a \; from \; N(0, (\sigma_R)^2) \tag{1}$$

where σ_R is the standard deviation of the stock-recruitment residuals (input here as $\sigma_R = 0.2$). Equation 1 is approximate in that it omits to adjust for past catches from the year-class concerned, but these are so small that the differential effect is negligible.

Step 2: Catch

These numbers-at-age are projected one year forward at a time given a catch for the year concerned.

For 2016 and 2017 the 2016 TAC is assumed:

$$C_y = 14799 \text{ t} \tag{2}$$

From 2018 onwards:

C_y is as specified by the CMP.

This requires specification of how the catch is disaggregated by age to obtain $C_{y,a}$, and how future recruitments are specified.

Step 3: Catch-at-age (by number)

The $C_{y,a}$ values are obtained under the assumption that the commercial selectivity function estimated for the last period (2000 to 2015) continues in the future. F_y is solved iteratively to achieve that the annual catch by mass:

$$C_y = \sum_{a=0}^{m} w_{y,a}^{mid} N_{y,a} S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a} \tag{3}$$

where $w_{y,a}^{mid}$ is taken as the average of the last 10 years (2006-2015) weight-at-age vectors, and hence that:

$$C_{y,a} = N_{y,a} S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a} \tag{4}$$

The numbers-at-age can then be computed for the beginning of the following year (y+1):

$$N_{y+1,0} = R_{y+1} \tag{5}$$

$$N_{y+1,a+1} = N_{y,a} e^{-Z_{y,a}} \quad \text{for } 0 \le a \le m-2 \tag{6}$$

$$N_{y+1,m} = N_{y,m-1} e^{-Z_{y,m-1}} + N_{y,m} e^{-Z_{y,m}} \tag{7}$$

The plus-group m is 10 or 14 depending on the OM.

Step 4: Recruitment

Future recruitments for the baseline and sensitivity SCAA operating models are provided by a Beverton-Holt stock-recruitment relationship:

$$R_y = \frac{4hR_0B_y^{sp}}{b_0(1-h)+(5h-1)B_y^{sp}}e^{(\varphi_y-(\sigma_R)^2/2)} \quad (8)$$

Log-normal fluctuations are introduced by generating φ_y factors from $N(0,(\sigma_R)^2)$ where σ_R is input (0.2). b_0 is as estimated for that Operating Model. For the baseline SCAA, h is fixed (0.9).

$$B_y^{sp} = \sum_{a=1}^{m} f_a\, w_{y,a}^{strt} N_{y,a} \quad (9)$$

where $w_{y,a}^{strt}$ is taken to be the average of the last 10 years (2006-2015) weight-at-age vectors.

Step5:

The information obtained in Step 1 is used to generate values of the abundance indices I_{2016}^i (in terms of biomass or of numbers), and similarly for following years. The EU survey is assumed to continue sampling the 0-1400m depth zone. Indices of abundance in future years will not be exactly proportional to true abundance, as they are subject to observation error. Log-normal observation error is therefore added to the expected value of the abundance index evaluated, i.e.:

$$I_y^i = q^i B_y^i e^{\varepsilon_y^i} \quad (10)$$

with

ε_y^i from $N(0,(\sigma^i)^2)$

where

B_y^i is the biomass available to the survey:

$$B_y^i = \sum_{a=0}^{m} w_{y,a}^i S_a^i N_{y,a} e^{-Z_{y,a}T^i/12} \quad (11)$$

The survey selectivities are assumed to remain unchanged.

The constant of proportionality q^i and residual standard deviation σ^i are as were estimated directly in the associated assessment.

Step 6:

Given the new survey indices I_y^i compute TAC_{y+1} using the CMP (aside from the fixed values assumed for 2016 and 2017).

Step 7:

Steps 1-6 are repeated for each future year in turn for as long a period as desired, and at the end of that period the performance of the candidate MP under review is assessed by considering statistics such as the average catch taken over the period and the final spawning biomass of the resource.

Performance Targets and Statistics

NAFO/FC-SC Doc. 17-xx lists the following general management objectives:

1. Restore to within a *prescribed period of time* or maintain at B_{msy}
2. The risk of failure to meet the B_{msy} target and interim biomass targets within a *prescribed period of time* should be kept moderately low
3. Low risk of exceeding F_{msy}
4. Very Low risk of going below an established threshold (e.g. B_{lim}* or B_{lim} proxy)
5. Maximize yield in the short, medium and long term
6. The risk of steep decline of stock biomass should be kept moderately low
7. Keep inter annual TAC variation below established thresholds

A number of mathematical expressions (Performance Statistics) are proposed here to capture these objectives:

(a) P_{2025}/P_{2015}, P_{2035}/P_{2015} and P_{2045}/P_{2015}, where P_y is the population size in year *y*;

(b) P_{lowest}/P_{2015}, where P_{lowest} is the lowest population size during evaluation period (2016-2046);

(c) P_{lowest}/P_{min}, where P_{min} is the lowest population size during the assessment period (1975-2015);

(d) P_{2035}/P_{target}, where P_{target} is pre-defined recovery target population size, for which the average value over the period 1975 to 1999 for the assessment/operating model concerned will be used for the moment pending further discussions;

(e) P_{2035}/P_{MSY} and P_{2045}/P_{MSY} where P_{MSY} is the population level when maximum sustainable yield is achieved;

(f) F_{2035}/F_{MSY} and F_{2045}/F_{MSY} where F_{MSY} is the fishing mortality rate needed to achieve maximum sustainable yield.

In each of them, population can be measured as total numbers (N_y^{tot}), total biomass (B_y^{tot}), exploitable numbers (ages 5 – 9) (N_y^{5-9}), exploitable biomass (B_y^{5-9}), survey index (B_y^i) or spawning biomass (B_y^{sp}), (though with primary focus on exploitable biomass for P_{target}) where:

$$N_y^{tot} = \sum_{a=0}^{m} N_{y,a} \qquad (12)$$

$$B_y^{tot} = \sum_{a=0}^{m} w_{y,a}^{st} N_{y,a} \qquad (13)$$

$$N_y^{5-9} = \sum_{a=5}^{9} N_{y,a} \qquad (14)$$

$$B_y^{5-9} = \sum_{a=5}^{9} w_{y,a}^{mid} N_{y,a} \qquad (15)$$

B_y^i: equation 11

B_y^{sp}: equation 9

The fishing mortality rate refers to the apical fishing mortality rate (age at which selectivity is 1 – age 8 for the baseline OMs).

The catch-related objectives can be captured by:

(g) (Average) annual catch over short, medium and long terms:

$$C_{2017}, C_{2018}, C_{2019}, \sum_{y=2017}^{2021} C_y/5, \sum_{y=2017}^{2026} C_y/10, \sum_{y=2017}^{2036} C_y/20$$

(h) Average annual variation in catch over short and long terms:

$AAV_{2017-2021} = \frac{1}{5}\sum_{y=2017}^{2021} \left|C_y - C_{y-1}\right|/C_{y-1}$ and

$AAV_{2017-2036} = \frac{1}{20}\sum_{y=2017}^{2036} \left|C_y - C_{y-1}\right|/C_{y-1}$

$P > 15\%$ being the proportion of years during the projection period where $\frac{|C_y - C_{y-1}|}{C_{y-1}} > 0.15$

A total of 100 forward projections will be run for each trial, with results presented as the 5^{th}, average of 50^{th} and 51^{st} and 96^{th} in an ordered set (i.e. median with 90% probability intervals).

Plots of annual catch and $B^{5\text{-}9}$ may be produced for each trial, the first showing the median and 90% probability envelopes, and the second showing the first 5 realisations ("worm plots").