SECTION I
(pages 1 to 60)

Report of the FC Working Group on Greenland Halibut Management Strategy Evaluation (WGMSE)
16-17 September 2010
Halifax, Nova Scotia, Canada

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(FC Doc. 10/30)

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1. Opening

The Co-Chair (Sylvie Lapointe, Canada) opened the meeting at 1000 hrs on Thursday, 16 September 2010 at the World Trade and Convention Centre and welcomed the participants to Halifax (Annex 1). She recapped the discussions and accomplishments by the working group at the two previous meetings. She reminded the participants as per the terms of reference of this group, an outstanding deliverable remained -- the formulation of recommendations and options concerning Management Strategy Evaluation (MSE)-approach in the determination of Total Allowable Catch (TAC) for Greenland halibut.

2. Appointment of Rapporteur

Ricardo Federizon (NAFO Secretariat) was appointed Rapporteur.

3. Adoption of Agenda

The provisional agenda as previously circulated was adopted (Annex 2).

4. Presentation of Consultants' Reports on SCAA and XSA

Peter Shelton (Canada) presented the results of the MSE from Extended Survival Analysis (XSA)-conditioned operating models (FCWGMSE WP 10/16 Draft 2); and Douglas Butterworth (EU) presented the results of the MSE from Statistical Catch-at-age (SCAA)-conditioned operating models (FCWGMSE WP 10/13-15). The Consultants' Reports are compiled in Annex 3.

The MSE were run on the operating models agreed upon at the May 2010 Meeting. A suite of Management Strategies (MS) were developed on the combinations of alternative choices on three factors: the λ values in the Harvest Control Rule (HCR), the starting TAC control parameter values, and constraints on the extent of TAC variation from one year to the next – the latter two elements being explored for the first time during this meeting. A smaller set of MS were selected for further consideration based on their performance relative to the established Performance Targets (See FC Doc. 10/5).

5. New Management Strategies Specifications for Evaluation

Discussions on the Management Strategies Specifications centered on:

- Comparability of the results between XSA- and SCAA-conditioned operating models in the MSE runs, and
- Starting TAC input, constraint levels, and λ values in the Harvest Control Rule.

A number of MS were considered by the Working Group and after considerable discussion no consensus could be reached as to what single MS could be recommended to the Fisheries Commission. Subsequently, two options were identified for consideration by the Fisheries Commission.

The initial input parameters in the HCR vary between the two MS: 16 000 and 17 500 t as starting TAC; 1.25 and 2.00 as λ values when slope is negative; and ± 10% and ± 5% constraint levels. A λ value of 1.00 applies to both MS when the slope is positive.

6. Recommendations to be forwarded to the Fisheries Commission

In the formulation of recommendations/management strategy specifications for the Fisheries Commission, the Working Group discussed how the MSE approach complements the current Greenland Halibut Rebuilding Plan and "exceptional circumstances" under which management strategy output for a TAC should be over-ridden.

While no consensus could be reached on a single MS, participants broadly endorsed the MSE approach and agreed to put forth a recommendation to the Fisheries Commission which included two management strategies for consideration. The recommendation also included guidance on and follow-up related to implementation.

As such, it was agreed that the following recommendations be forwarded to the Fisheries Commission on behalf of the Working Group:

Recognizing that Contracting Parties agreed in 2003 to implement a fifteen-year rebuilding programme for the Greenland halibut stock in Subarea 2 + Divisions 3KLMNO,

Acknowledging the continued uncertainty of the 2009 assessment for the Greenland halibut stock in Subarea 2 + Divisions 3KLMNO,

Desirous to move forward with a risk management approach for this stock,

Desirous to achieve the objectives of the rebuilding programme,

Recalling that at the 2009 annual meeting of NAFO, the Fisheries Commission established a Working Group to develop a Management Strategy Evaluation (MSE) framework to help inform management of Greenland halibut in Subarea 2 + Divisions 3KLMNO (FC Doc 09/18)**,**

Consistent with its terms of reference, the Working Group considered alternative management strategies with their harvest control rules, selected appropriate performance indicators, defined acceptable levels of risk, and projected/evaluated outputs of the risk management framework utilizing a range of assessment models,

Noting that the Fisheries Commission will consider the report from this Working Group including any recommendations contained therein as the basis for a risk management based decision on the TAC level for 2011 and beyond,

The following recommendations will be forwarded to the Fisheries Commission.

1. Management Strategy Evaluation (MSE)

The Fisheries Commission shall implement an MSE approach for Greenland halibut stock in Subarea 2 + Divisions 3KLMNO.

2. Management Strategy (Harvest Control Rule)

A simple model-free management strategy shall be adopted consistent with NAFO SCR 09/37. The harvest control rule (HCR) will adjust the total allowable catch (TAC) from year (y) to year (y+1), according to:

$TAC_{y+1} = TAC_{y} \ (1 + \lambda \times slope)$

where :

slope = measure of the recent trend in survey biomass. The TAC is subject to constraints on a percentage change from one year to the next.

Two management strategies were put forward for consideration by Fisheries Commission based on the HCR identified above:

	Management Strategy 1	Management Strategy 2
Starting TAC Control Parameter	16, 000 t	17, 500 t
λ if slope is negative	1.25	2.00
λ if slope is positive	1.00	1.00
Constraint on the rule-generated TAC change	± 10%	± 5%

Full details of the application of the management strategies are provided in Annex 4. Results of these applications are provided in Annex 5.

3. Implementation

The management strategy shall be implemented initially for 4 years. It shall be annually monitored by the Scientific Council to ensure that the data being input into the management strategy is consistent with the MSE process. If exceptional circumstances arise, this shall provide a scientific justification for over-riding the TAC provided by the HCR

Guidelines on how to address exceptional circumstances for adoption by Fisheries Commission in 2011 shall be developed intersessionally by WGMSE with the advice of the Scientific Council.

The Fisheries Commission shall review the progress of this management strategy in four (4) years with advice from Scientific Council.

[The FC shall consider undertaking a revision of the Greenland halibut rebuilding programme to reflect the implementation of the Management Strategy.]

The WGMSE will remain in place at least until 2011 to allow for further refinement of the MSE following initial implementation.

7. Other Matters

The Co-Chair Antonio Vazquez (European Union) would communicate with the Scientific Council and keep it informed concerning the results of this meeting.

8. Adoption of Report

This report was adopted through correspondence after the meeting.

9. Adjournment

The meeting was adjourned at 18hrs on Friday, 17 September 2010.

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Annex 2. Agenda

1. Opening
2. Appointment of Rapporteur
3. Adoption of the Agenda
4. Presentation of Consultants' Reports on SCAA and XSA
5. New Management Strategies Specifications for Evaluation
6. Recommendations to be forwarded to the Fisheries Commission
7. Other Matters
8. Adoption of Report
9. Adjournment

Annex 3. Compilation of Consultants' Reports

(FCWGMSE WP 10/16 Draft 2)

Performance Statistics for NAFO Greenland halibut management strategy evaluation from XSA-conditioned operating models

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Background

A study funded by the Canadian International Governance Programme commenced work in 2007 on developing a management strategy evaluation (MSE) for NAFO 2+3KLMNO Greenland halibut. A Study Group on Rebuilding Strategies for Greenland halibut was struck by NAFO SC in 2007 based on promising preliminary results (NAFO SCR Doc. 07/58). The SG met in Vigo in February 2008 to make further progress (NAFO SCS Doc, 08/13). Research documents providing the results of analyses were tabled at the June SC meetings in both 2008 and 2009 (NAFO SCR Docs. 08/25 and 09/037) and advice was provided by NAFO SC to NAFO FC in both years regarding the desirability of adopting a prescribed management strategy (MS) based on a feedback harvest control rule.

Based on progress, NAFO FC struck the Working Group on Greenland Halibut Management Strategy Evaluation (WGMSE) in 2009. WGMSE met in Brussels in January 2010 (NAFO/FC Doc. 10/2) and in Halifax in May 2010 (NAFO/FC Doc. 10/5). The decision was taken to review two sets of results for management strategy evaluation at a further meeting in September 2010 just prior to the Annual NAFO meeting – results from analyses conditioned on the NAFO SC June 2010 XSA assessment of the stock and results from an alternative Statistical Catch at Age Approach (SCAA) applied to the same input data.

Update on assessment and status from the June 1010 NAFO SC meeting

Estimates of exploitable biomass from the June 2010 assessment are higher than previously reported estimates over 2004-2008 (Fig. 1). This difference primarily arises as a result of the addition of the deep-water information from the EU survey to the analysis as well as a reduction in the amount of F-shrinkage applied. (see Healey et *al*. (2010) NAFO SCR 10/40 for technical detail and rationale for these changes.)

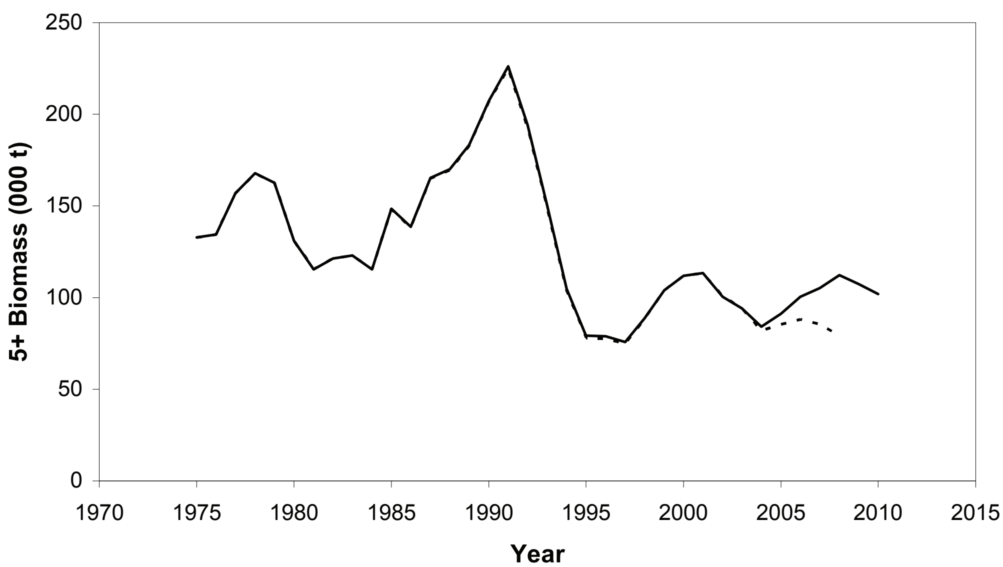


Fig. 1. Estimated ages 5+ biomass (000 t) from the 2008 SC assessment (dashed line) and from the 2010 SC assessment.

Brief review of MS, OMs and HCRs

More details can be found in the above cited NAFO documents available online. Management Strategy Evaluation (MSE) involves evaluating candidate Management Strategies (MSs) against alternative hypotheses regarding how the real world behaves, captured in a set of simulations called Operating Models (OMs). Depending on the management objectives, a set of Performance Statistics (PSs) can be developed to compare alternative MSs. The PSs comprise explicit quantifications of the management objectives and typically incorporate risk tolerances that are desired to be met with regard to not achieving specific objectives. PSs were suggested in Brussels and refined in Halifax (see NAFO/FC Doc. 10/5, especially Annex 3).

The core of an MS is typically a feedback Harvest Control Rule (HCR). It was agreed by the WGMSE that the model-free (survey-based) HCR described in NAFO SCR Doc. 09/037 would be applied. Assuming the first year is 2010 and the TAC is known to be 16kt, this HCR adjusts TACs in 2011 and onwards based on the trend in the survey indices. The rule as described in NAFO/FC Doc. 10/5 has a parameter λ that adjusts the change in TAC based on the estimated average survey slope. It was decided to have the option of setting different values for λ depending on whether the average survey slope is negative or positive, termed λ-down and λ-up. Tuning the HCR involves finding the set of λ parameters that best meet the management objectives for the fishery as quantified through the PSs.

Graphical illustration of the relationship between change in TAC and λ

In the application of the survey-based HCR, next year's total allowable catch (TAC) in the simulations is computed from trends in the survey data. Specifically, the TAC in year (y+1) is defined by:

$$TAC_{y+1} = TAC_y \left(1 + \lambda \cdot slope\right)$$

where:

slope=the average of the slopes of regression models fit to the log values of each of the survey data series over the past 5 years – considered to be indicative of the change in the size of the stock.

λ is a scaling parameter which can be altered to "tune" the rule to optimize its performance with respect to the PSs and the associated risk of not meeting the risk tolerances defined for each PS (except the magnitude of catch PSs). In several instances, a pair of λ values are applied in a single MSE, by setting:

$$\lambda = \begin{cases} \lambda_u & \text{if} \quad slope > 0 \\ \lambda_d & \quad\quad otherwise \end{cases}$$

Independent choices of λ in the case of a perceived increase (*slope*>0) or decrease in the stock permits a different "rate of reaction" in the TAC depending on the trajectory of the stock.

Parameterizing the HCR

The initial TAC generated by the HCR within the MSE is for the fishery in 2011. It is computed from the 2010 TAC (16kt), the trend in the survey data over the period 2005-2009 (via *slope*) and the scaling parameter λ.

Of interest in 2011 and subsequent years is not just the magnitude of the TAC, but the one-year relative change in the TAC:

$$\Delta TAC = \frac{TAC_{y+1} - TAC_y}{TAC_y} = \lambda \cdot slope$$

Thus the change in TAC is fully determined by the product of the slope and the scaling parameter.

Note that:

- TAC is unchanged in a year (i.e. relative change=0) if *slope*=0. Also true if $\lambda = 0$, but this case is unhelpful as annual TAC would remain at TAC_{2010} over all years.

- The TAC change is constant provided product $\lambda \cdot slope$ is constant. For example the TAC would increase by 25% if either λ=1 and slope=1.25 or λ=1.25 and slope=1.

Fig. 2a illustrates the one-year percent change in TAC over a range of slope and λ values. It is meant as a guide towards informative choices for λ (or alternatively, λ_d and λ_u). This is the only parameter selection for the WG to make as the value of slope is computed directly from the survey data within the MSE simulation (unless alternative starting TAC levels for 2010 are considered).

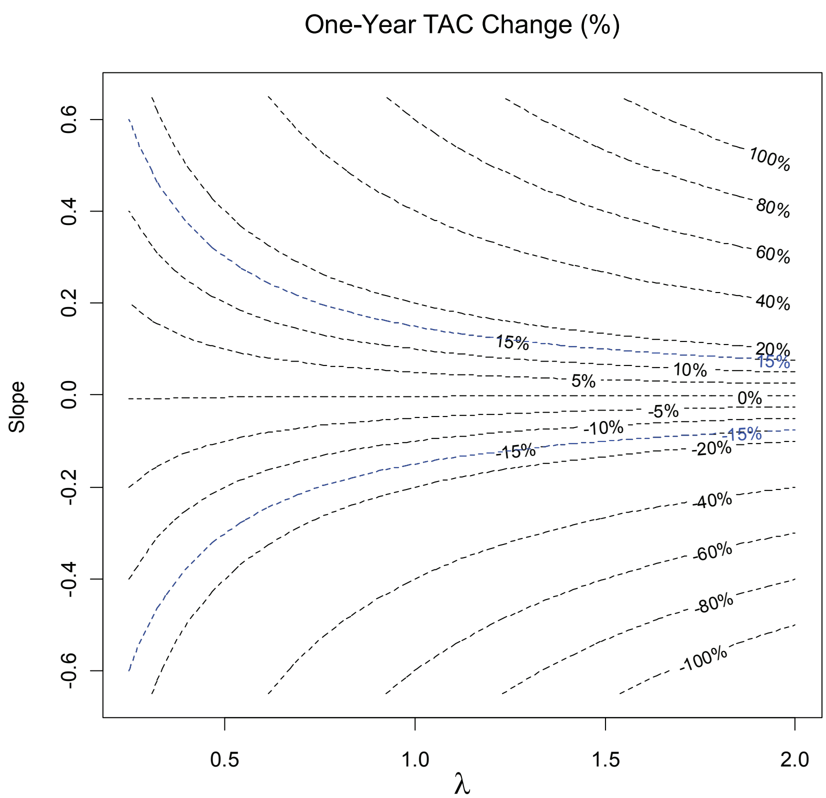


Fig. 2a. Contour plot of One-Year change in TAC (%). The +/-15% contours are highlighted, as they relate to the maximum average annual variation in TAC agreed to by the WG at its May meeting.

Note that the range of TAC change is decreasing as λ decreases. By way of example, slope values in the range of (-0.2, 0.2) will lead to TAC changes of +/- 40% if $\lambda = 2$. However, if $\lambda = 0.5$ the TAC change for the same ranges of slope will be only 10%. An illustration of the one year TAC change if λ_d =1.5 and λ_u =1.0 is provided in Fig. 2b.

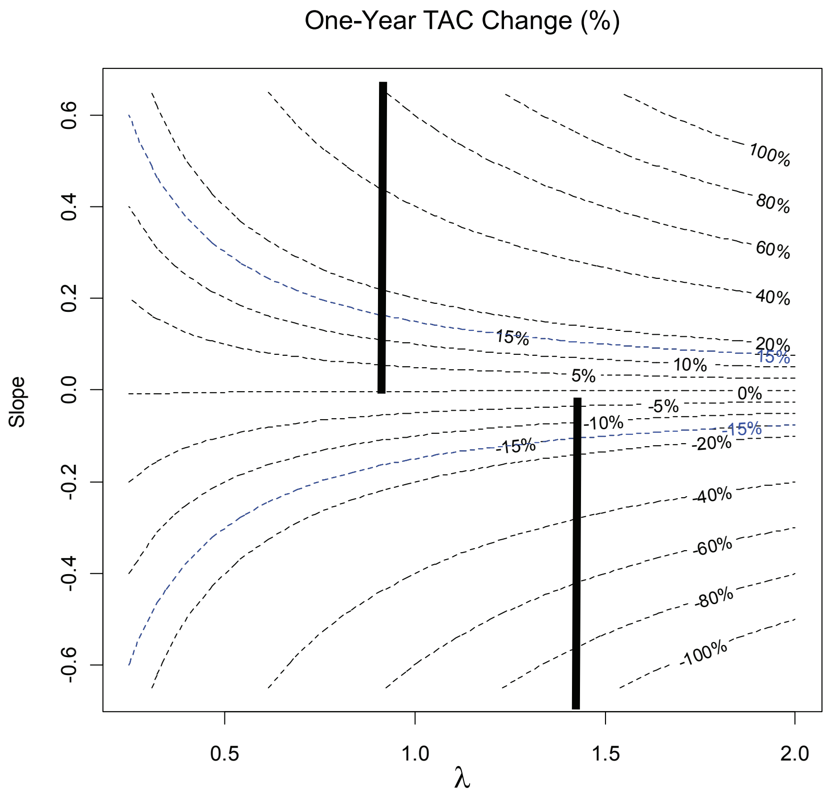


Fig. 2b. Contour plot of One-Year change in TAC (%). Vertical lines indicate what the TAC change would be across slope values of -0.7 to 0.7, assuming λ_d =1.5 and λ_u =1.0.

Further information that is useful in making decisions on λ is available from the survey data over 1996 – 2009. Over this time period, we can compute the *slope* parameter as specified in the HCR (red horizontal lines) and overlay this on the profile of the TAC change (Fig. 3). From this plot it can be seen that for λ >1.5 a number of the historic slopes values would have lead to TAC changes >15%.

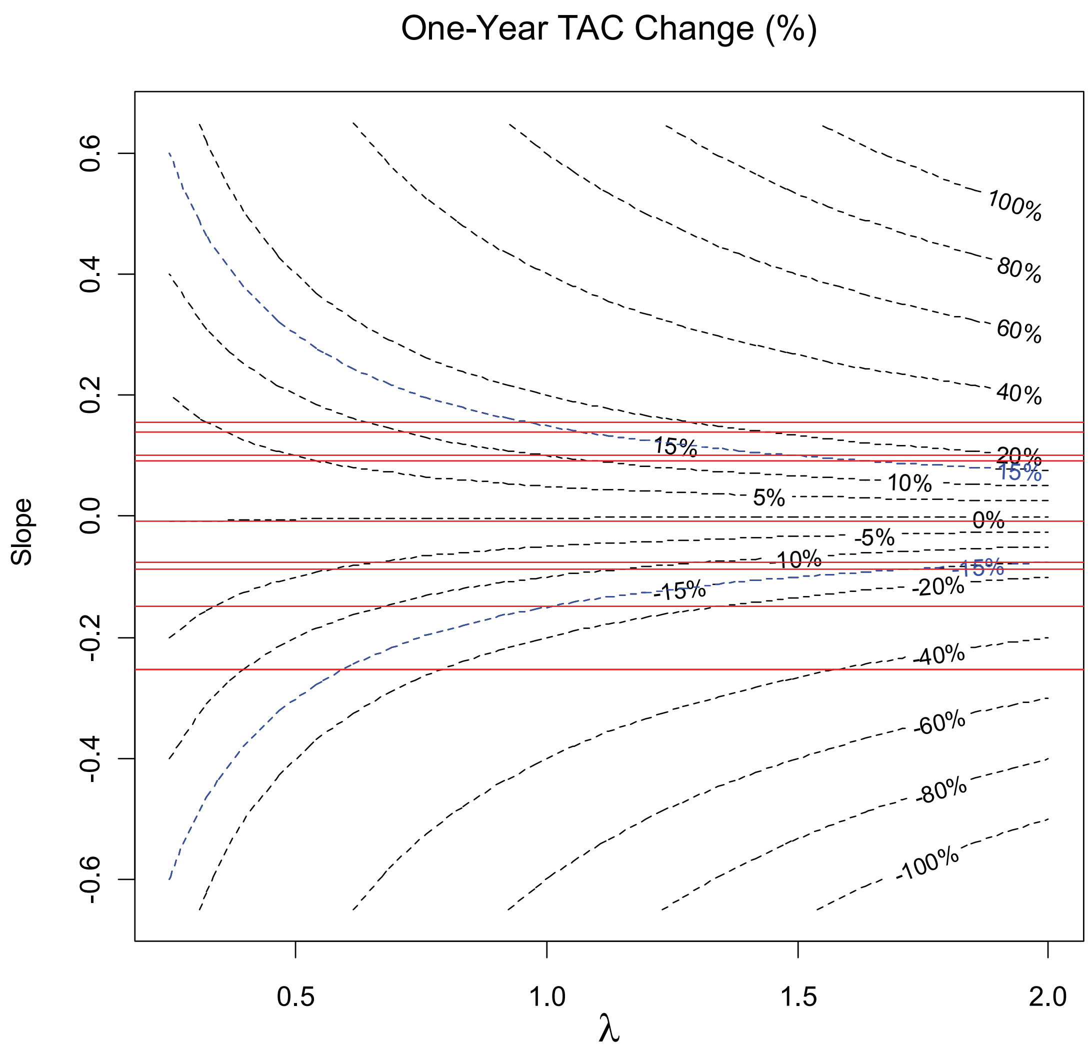


Fig. 3. Contour plot of One-Year change in TAC (%), with 'survey slope' from each five-year window in 1996-2009 overlaid (red lines). Slope is computed as per the HCR specifications.

The historic percentage change in TAC that would have occurred based on observed survey slopes is illustrated in Fig. 4 for three sets of λ values. This historic trajectory over time is purely illustrative in nature as the catches which impacted stock dynamics were very different from the TACs that would have been generated by historic application of the HCR. Note that the average of the log survey slopes for the most recent 5 year interval (2005-2009) gives a small percentage decrease in TAC in 2011 for a range of λ's , the first year for which the harvest control rule will generated by the HCR, if adopted.

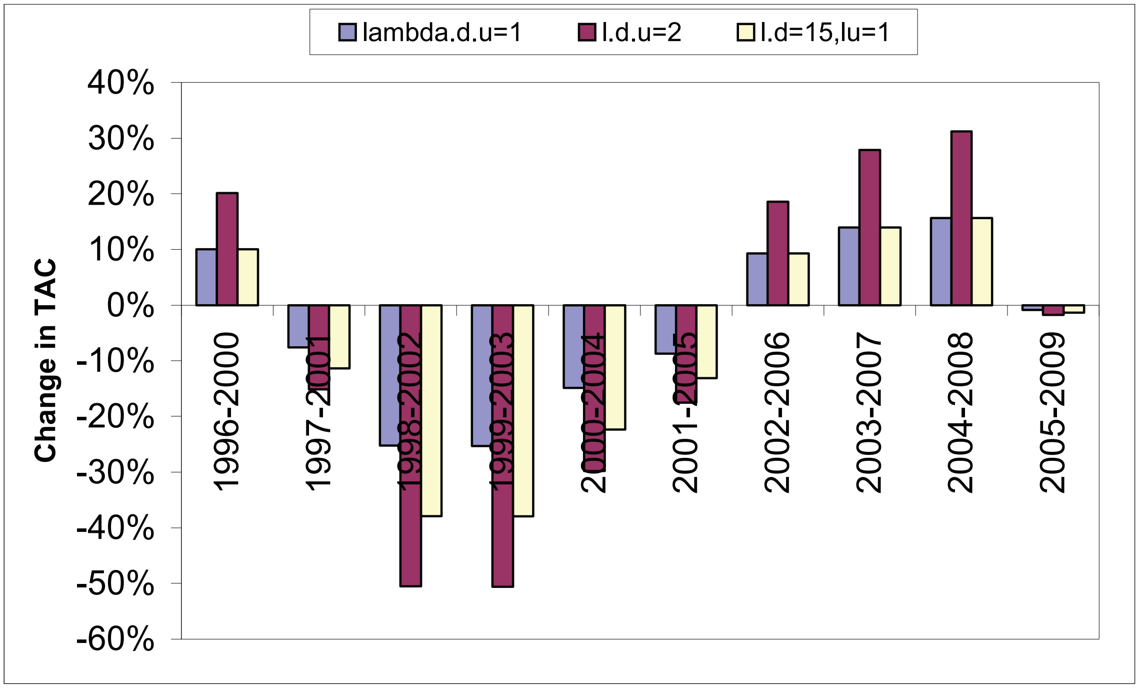


Fig. 4. Historic percentage change in TAC that would have occurred based on survey slopes given λ values (both up and down) of 1, 2 or down 1.5 and up 1.

Performance statistics

The PSs for 14 pairs of λ values are provided in Appendix Table 1. The first column gives the λ values applied. (The nomenclature "ld" refers to lambda down, the value of lambda if slope <0. Similarly, "lu" refers to lambda up.) The next column lists the PSs as described in NAFO/FC Doc. 10/5. An additional statistic is computed, PS4_alt, representing the original NAFO rebuilding target which was to rebuild the 5+ biomass to 140kt by 2019, which corresponds to the 1975-1999 mean value by 2019. The next column gives a brief description of what is measured by the PS (see NAFO/FC Doc. 10/5 Annex 3 for details). The next column indicates what aspect of the performance statistic is given under each OM. For PS1 and PS4 this indicates that "All" the data are used to compute the straight probability from the 100 replicates under each OM. For PS2 it is the median "50%" of the distribution of probabilities from the 100 replicates under each OM and for PS3 it is the median catch. The following 6 columns to the right provide the probabilities or catch values under each OM. The second last column from the right gives the risk tolerance as specified by managers and industry at the May 2010 Halifax WGMSE meeting. The probabilities need to be compared against these risk tolerances to determine whether or not the specific tuning of the harvest control rule being evaluated has performed satisfactorily or not. The last column on the right gives the outcome in terms of Pass or Fail for PS1, 2, 4 and in terms of mean of the medians of the catch for PS3.

Guidance to decision-makers in selecting an appropriate tuning of the HCR

A two step approach is recommended in dealing with the results from the MSE (see NAFO SCR Doc. 09/037). In the first step each MS (in this case alternative tunings of the HCR) must "satisfice" the risk tolerances specified by the decision-makers. In the second step, MSs that pass the first step are subject to trade-off analysis as quantified by the performance statistics.

All HCR tunings meet the specified risk tolerances for the "conservation" PS1. All HCR tunings also meet the risk tolerance for PS4 with the exception of λ-down=2 λ-up=2 which fails for the CAV_domed OM (Annex Table 1, Fig. 5). All tunings meet a <25% risk tolerance for PS4_alt across all OMs except for MP16 and barely in the case of CAV_domed for λ-down=2 λ-up=2 (Fig. 6). PS4_alt corresponds to the FC target of rebuilding the exploitable biomass to 140kt by 2019, but is not an agreed PS from the May WGMSE meeting in Halifax because it was thought to be difficult to achieve under the then more pessimistic XSA-based analyses.

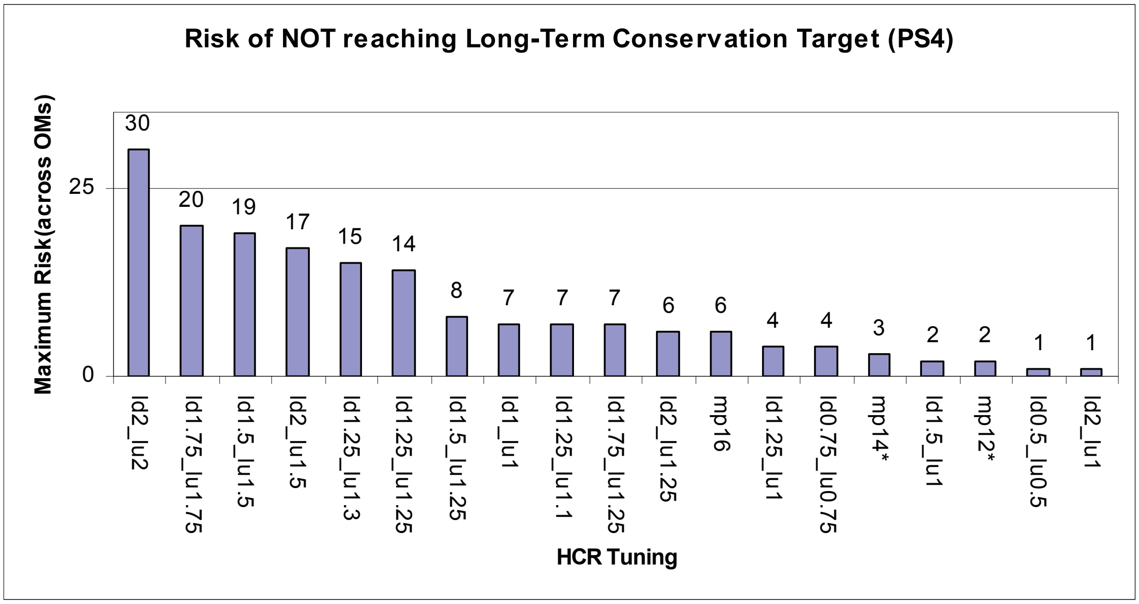


Fig. 5. Risk of not reaching the long-term interim conservation target or milestone by 2031 (PS4). The maximum risk across OMs is plotted for each HCR tuning. The horizontal line indicates the risk tolerance specified by decision-makers.

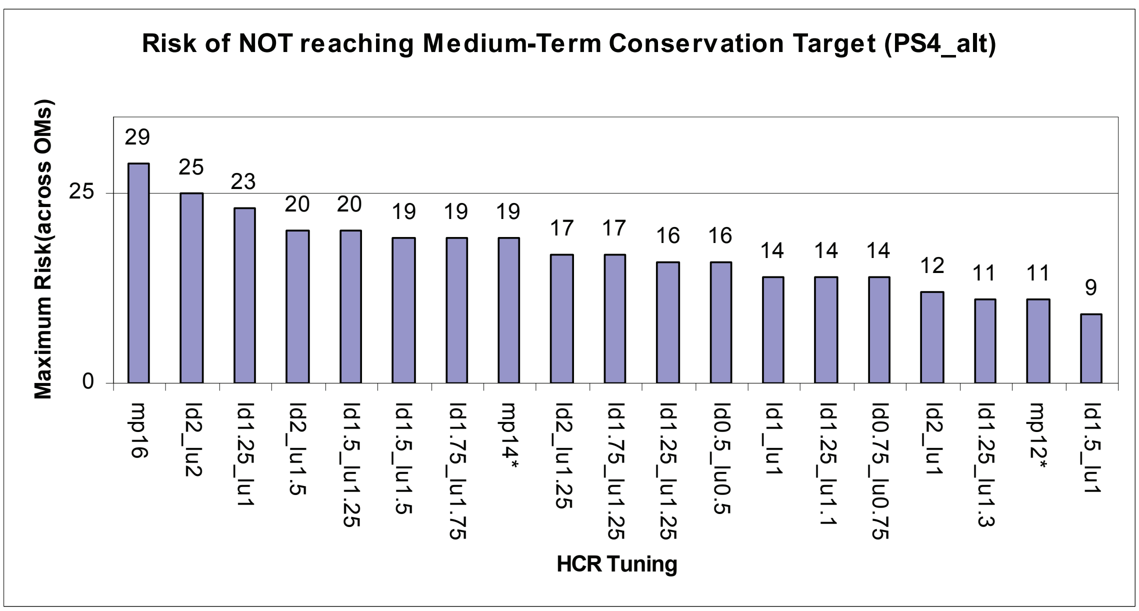


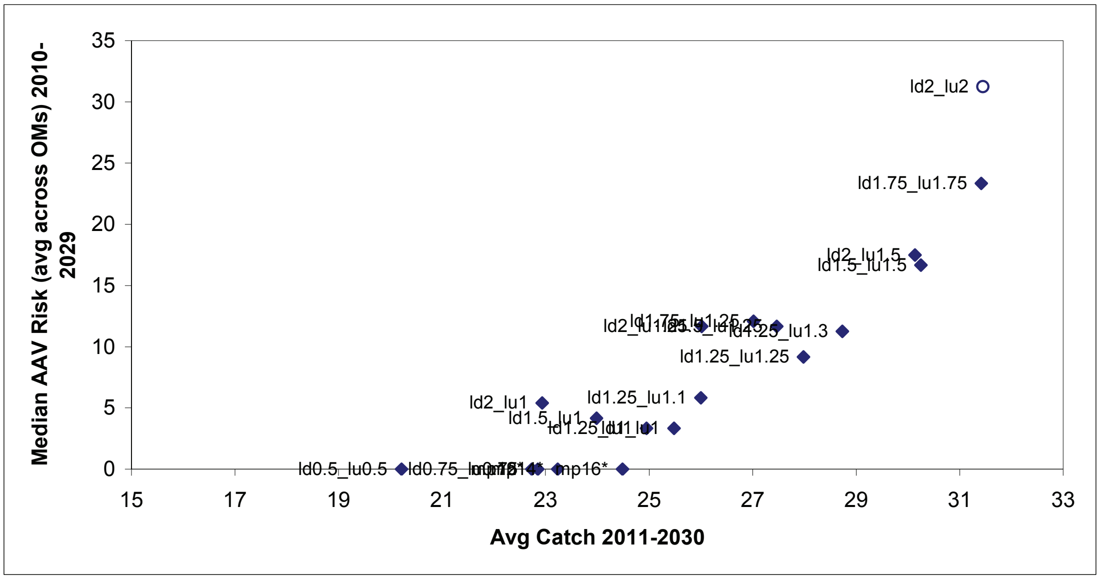
Fig. 6. Risk of not reaching the NAFO interim target or milestone by 2019 (PS4_alt). The maximum risk across OMs is plotted for each HCR tuning. The horizontal line indicates the risk tolerance specified by decision-makers with respect to the long-term meeting of the milestone.

With regard to "exploitation" PSs, there are three types of PSs: variation in catch (PS2a, PS2b), minimum catch (PS2c), and the average catch (PS3). The risk tolerance for PS2ai is met for all HCR tunings examined whereas for PSaii failure to meet the specified risk tolerance occurs for λ-up>1.5. It should be noted that this is associated with increases in TAC rather than reductions. The specified risk tolerance for PS2b is generally not met for most HCR tunings examined, except for tunings with λ<1 or those HCRs with forced constraints on the amount of TAC variation allowed (MP14* and MP16). The specified risk tolerance for PS2c is met by all HCR tunings examined.

To summarize the average catch, (PS3i, 3ii and 3iii) median catch across the 6 OMs is averaged. For the range of λ values considered, the short term catch (2011-2015; PS3i) ranges from 13.7 to 16.3kt. Average catches over 2016-2020 (PS3ii) range from 18.3 to 26.2kt and for 2011-2030 (PS3iii) the average catch ranges from 22.9 to 31.5kt.

The trade-off between annual catch variation (PS2aii) and the average catch (PS3iii) is clearly illustrated in Fig. 7 (average catch variation across OMs) and Fig. 8 (maximum catch variation across OMs). The greater the long-term average catch, the greater the year-to-year catch variation that has to be accommodated. These trade-offs are less evident in short-term data (PS2ai vs PS3i; Fig. 9).

Average across Oms



Same plot as above, but zoom in for greater clarity

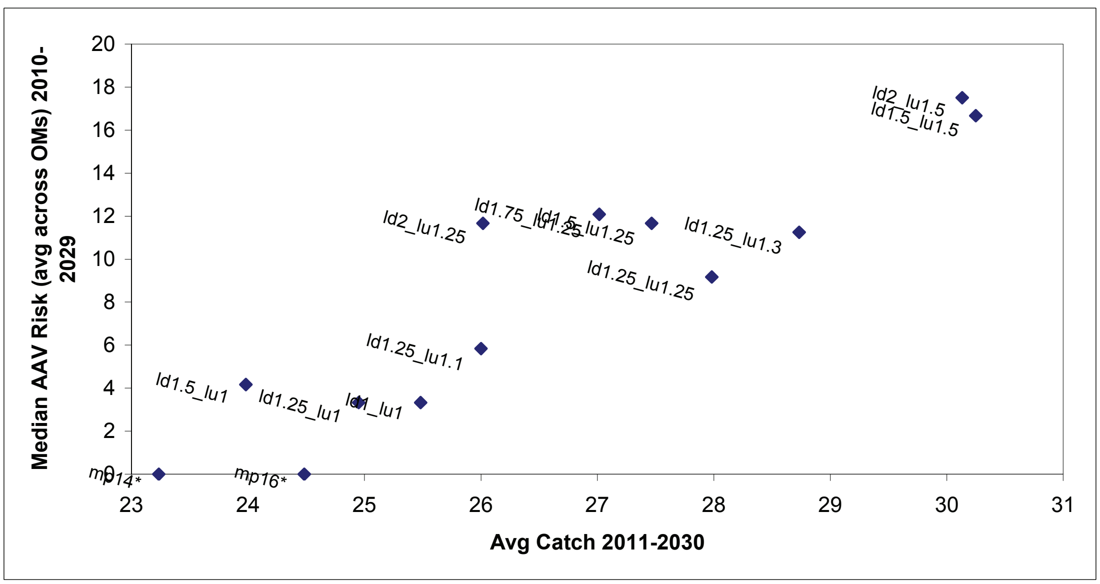
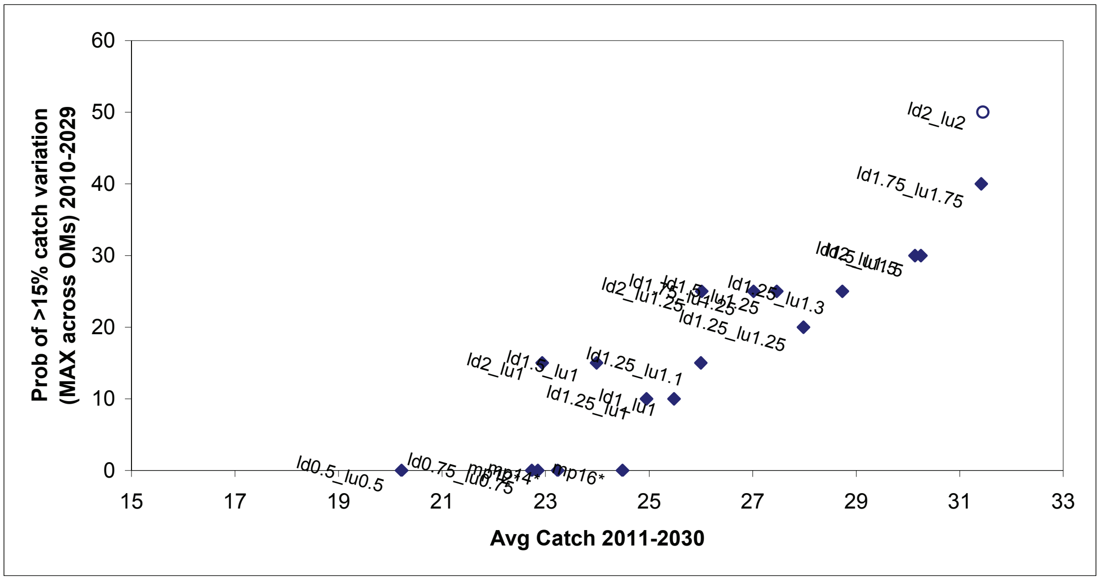


Fig. 7. Trade-off in the long-term between catch variation (average across OMs of the median risk of a greater than 15% annual catch variation ;PS2aii) on the y-axis plotted against the average of the median catches across OMs (PS3iii) on the x-axis for a range of HCR tunings.

Maximum across Oms



Same plot as above, but zoom in for greater clarity

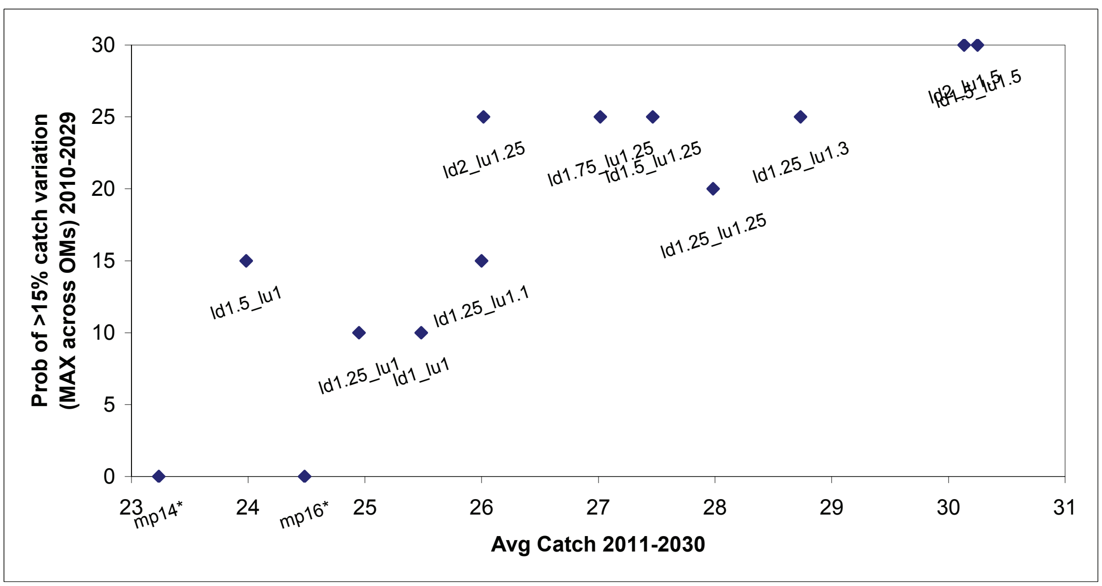
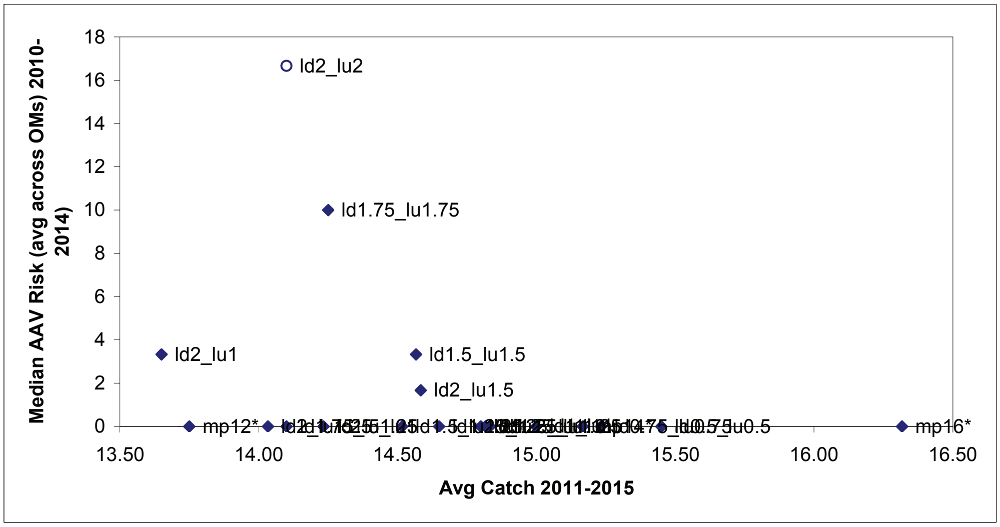


Fig. 8. Trade-off in the long-term between catch variation (maximum across OMs of the median risk of a greater than 15% annual catch variation ;PS2aii) on the y-axis plotted against the average of the median catches across OMs (PS3iii) on the x-axis for a range of HCR tunings.

Average



Maximum

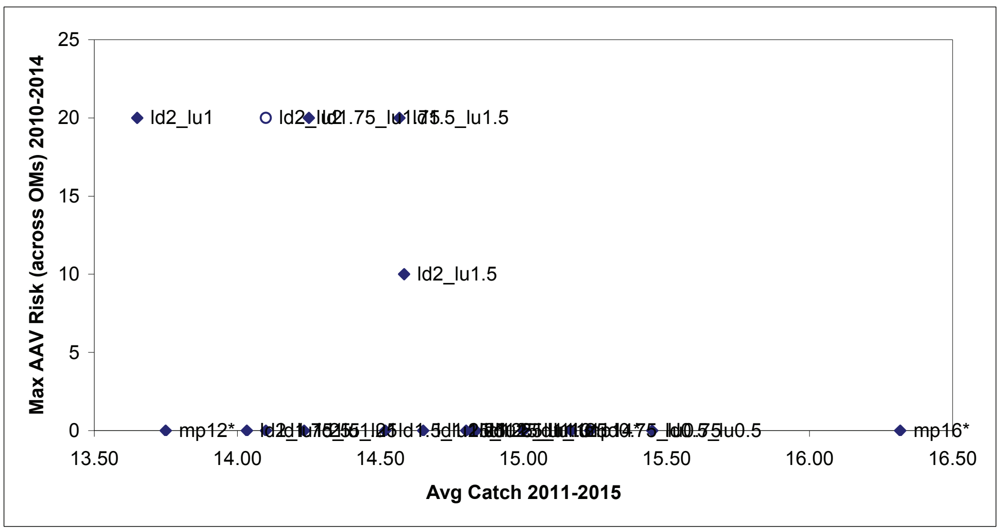


Fig. 9. Trade-off in the short-term between catch variation (average (top) and maximum (bottom) across OMs of the median risk of a greater than 15% annual catch variation ;PS2ai) on the y-axis plotted against the average of the median catches across OMs (PS3i) on the x-axis for a range of HCR tunings.

Appendix Table 1. Performance statistics results from the Greenland halibut MSE applied to operating models conditioned on XSA for a range of alternative tunings of the HCR. Shading indicates outcomes that don't meet the risk tolerances. Note that MS 12, 14 and 16 refer to the specific tunings in FCWGMSE WP 10/13 modified (as denoted by the star) such that MS12 has a 15% constraint both up and down, MS14 has a 10% constraint up and down.

label	PS	Description	Percentile_examined	CAV	LMV	CAV_domed	CAV_varM	CAV_dep	LMV_dep	Criterion	Pass%
Id1_lu1	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id1_lu1	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
Id1_lu1	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	0	0	0	0	10	10	<25%	Pass
Id1_lu1	2b	P(3yr Catch variation >25% for 2010-2027)	50%	15.1	17.3	14.2	14	23.3	25.5	<25%	Fail
Id1_lu1	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id1_lu1	3_i	Avg. Catch 2011-2015	50%	14.5	15.6	14.5	14.4	14.9	16.1	(mean:)	15
Id1_lu1	3_ii	Avg. Catch 2016-2020	50%	19.3	22.4	18.4	18	22.1	26.1	(mean:)	21.1
Id1_lu1	3_iii	Avg. Catch 2011-2030	50%	21.7	25.7	20.8	20.7	29.5	34.5	(mean:)	25.5
Id1_lu1	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	1	0	7	7	0	0	<25%	Pass
Id1_lu1	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	4	1	14	9	0	0	<25%	Pass
Id1_lu1	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
Id2_lu2	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	1	0	0	<10%	Pass
Id2_lu2	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	20	20	0	20	20	20	<25%	Pass
Id2_lu2	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	25	25	20	25	42.5	50	<25%	Fail
Id2_lu2	2b	P(3yr Catch variation >25% for 2010-2027)	50%	30.2	32.6	29	30.8	46.6	53.3	<25%	Fail
Id2_lu2	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id2_lu2	3_i	Avg. Catch 2011-2015	50%	13.8	15.4	13.5	12.5	13.9	15.5	(mean:)	14.1
Id2_lu2	3_ii	Avg. Catch 2016-2020	50%	23.4	30	22	20.9	30	40.2	(mean:)	27.8
Id2_lu2	3_iii	Avg. Catch 2011-2030	50%	25.7	32.7	24.9	23.6	37.9	43.9	(mean:)	31.4
Id2_lu2	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	15	7	30	21	0	1	<25%	Fail
Id2_lu2	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	7	1	25	11	0	0	<25%	Pass
Id2_lu2	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
Id2_lu1.5	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id2_lu1.5	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	10	<25%	Pass
Id2_lu1.5	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	10	15	10	10	30	30	<25%	Fail
Id2_lu1.5	2b	P(3yr Catch variation >25% for 2010-2027)	50%	20.6	24	21.3	22.2	35.3	37.1	<25%	Fail
Id2_lu1.5	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id2_lu1.5	3_i	Avg. Catch 2011-2015	50%	14.3	15.7	14	13.6	14.1	15.8	(mean:)	14.6
Id2_lu1.5	3_ii	Avg. Catch 2016-2020	50%	20.7	26.9	20.2	19.7	26.1	32.4	(mean:)	24.3
Id2_lu1.5	3_iii	Avg. Catch 2011-2030	50%	24.1	31	23.2	22.6	35.6	44.3	(mean:)	30.1
Id2_lu1.5	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	8	0	17	13	0	0	<25%	Pass
Id2_lu1.5	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	10	2	20	7	0	0	<25%	Pass
Id2_lu1.5	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
Id2_lu1.25	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id2_lu1.25	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
Id2_lu1.25	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	5	10	5	5	20	25	<25%	Pass
Id2_lu1.25	2b	P(3yr Catch variation >25% for 2010-2027)	50%	19.6	22.4	19.3	20	29.4	33.1	<25%	Fail
Id2_lu1.25	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id2_lu1.25	3_i	Avg. Catch 2011-2015	50%	13.7	15.3	13.3	12.9	13.5	15.5	(mean:)	14
Id2_lu1.25	3_ii	Avg. Catch 2016-2020	50%	18.7	23.9	17.6	17	22.7	29	(mean:)	21.5
Id2_lu1.25	3_iii	Avg. Catch 2011-2030	50%	21.5	27.1	20.4	19.4	29.4	38.3	(mean:)	26
Id2_lu1.25	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	2	0	6	3	0	0	<25%	Pass
Id2_lu1.25	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	3	1	17	1	0	0	<25%	Pass
Id2_lu1.25	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
Id1.5_lu1	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id1.5_lu1	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
Id1.5_lu1	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	0	0	0	0	10	15	<25%	Pass
Id1.5_lu1	2b	P(3yr Catch variation >25% for 2010-2027)	50%	15.5	17.9	15.5	15	24.7	27.1	<25%	Fail
Id1.5_lu1	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id1.5_lu1	3_i	Avg. Catch 2011-2015	50%	14	15	13.8	13.6	14	15	(mean:)	14.2
Id1.5_lu1	3_ii	Avg. Catch 2016-2020	50%	18.1	21.3	17.5	17.1	20.3	25.2	(mean:)	19.9
Id1.5_lu1	3_iii	Avg. Catch 2011-2030	50%	20.4	25.1	19.5	18.8	27	33.1	(mean:)	24
Id1.5_lu1	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	2	0	1	1	0	0	<25%	Pass
Id1.5_lu1	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	4	2	9	3	0	0	<25%	Pass
Id1.5_lu1	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
Id1.5_lu1.5	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id1.5_lu1.5	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	20	<25%	Pass
Id1.5_lu1.5	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	10	15	10	10	25	30	<25%	Fail
Id1.5_lu1.5	2b	P(3yr Catch variation >25% for 2010-2027)	50%	21.7	24.6	21.4	21.4	34	37.2	<25%	Fail
Id1.5_lu1.5	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id1.5_lu1.5	3_i	Avg. Catch 2011-2015	50%	14	15.8	13.9	13.6	14.5	15.6	(mean:)	14.6
Id1.5_lu1.5	3_ii	Avg. Catch 2016-2020	50%	20.7	26.5	20.2	20	26.4	32.6	(mean:)	24.4
Id1.5_lu1.5	3_iii	Avg. Catch 2011-2030	50%	24.3	30.5	23	22.6	36.5	44.6	(mean:)	30.2
Id1.5_lu1.5	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	7	0	19	18	0	0	<25%	Pass
Id1.5_lu1.5	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	8	0	19	9	0	0	<25%	Pass
Id1.5_lu1.5	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
Id1.5_lu1.25	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id1.5_lu1.25	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
Id1.5_lu1.25	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	5	10	5	5	20	25	<25%	Pass
Id1.5_lu1.25	2b	P(3yr Catch variation >25% for 2010-2027)	50%	18.7	21.2	18.4	18.6	29.5	32	<25%	Fail
Id1.5_lu1.25	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id1.5_lu1.25	3_i	Avg. Catch 2011-2015	50%	14.2	15.5	14	13.8	14.1	15.5	(mean:)	14.5
Id1.5_lu1.25	3_ii	Avg. Catch 2016-2020	50%	19.7	24.3	18.7	18.4	23.2	28.8	(mean:)	22.2
Id1.5_lu1.25	3_iii	Avg. Catch 2011-2030	50%	22.5	28.5	21.8	20.9	30.8	40.3	(mean:)	27.5
Id1.5_lu1.25	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	2	0	8	4	0	0	<25%	Pass
Id1.5_lu1.25	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	0	0	20	9	0	0	<25%	Pass
Id1.5_lu1.25	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
Id1.25_lu1	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id1.25_lu1	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
Id1.25_lu1	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	0	0	0	0	10	10	<25%	Pass
Id1.25_lu1	2b	P(3yr Catch variation >25% for 2010-2027)	50%	15.1	17.2	15.2	14.2	24	26.4	<25%	Fail
Id1.25_lu1	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id1.25_lu1	3_i	Avg. Catch 2011-2015	50%	14.5	15.6	14	13.9	14.4	15.5	(mean:)	14.7
Id1.25_lu1	3_ii	Avg. Catch 2016-2020	50%	18.6	22.2	17.6	17.6	21.9	25.4	(mean:)	20.6
Id1.25_lu1	3_iii	Avg. Catch 2011-2030	50%	21.3	25.6	20.2	19.9	28.6	34.1	(mean:)	24.9
Id1.25_lu1	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	1	0	4	2	0	0	<25%	Pass
Id1.25_lu1	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	8	0	23	7	0	0	<25%	Pass
Id1.25_lu1	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail

Id1.25_Iu1.1	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id1.25_Iu1.1	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
Id1.25_Iu1.1	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	0	5	0	0	15	15	<25%	Pass
Id1.25_Iu1.1	2b	P(3yr Catch variation >25% for 2010-2027)	50%	16.3	18.8	15.9	16.3	25.5	28.3	<25%	Fail
Id1.25_Iu1.1	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id1.25_Iu1.1	3_i	Avg. Catch 2011-2015	50%	14.4	15.6	14.4	14	14.5	15.9	(mean:)	14.8
Id1.25_Iu1.1	3_ii	Avg. Catch 2016-2020	50%	19.2	22.8	18.9	18.5	22.1	27.4	(mean:)	21.5
Id1.25_Iu1.1	3_iii	Avg. Catch 2011-2030	50%	21.8	26.7	21.3	20.2	28.9	37.1	(mean:)	26
Id1.25_Iu1.1	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	0	0	2	7	0	0	<25%	Pass
Id1.25_Iu1.1	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	12	0	14	9	0	0	<25%	Pass
Id1.25_Iu1.1	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
Id1.25_Iu1.3	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id1.25_Iu1.3	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
Id1.25_Iu1.3	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	5	10	5	2.5	20	25	<25%	Pass
Id1.25_Iu1.3	2b	P(3yr Catch variation >25% for 2010-2027)	50%	18.2	21.2	18.6	18.1	29.4	33	<25%	Fail
Id1.25_Iu1.3	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id1.25_Iu1.3	3_i	Avg. Catch 2011-2015	50%	14.6	15.7	14.2	14	14.7	15.7	(mean:)	14.8
Id1.25_Iu1.3	3_ii	Avg. Catch 2016-2020	50%	20.5	24.9	19.5	19.6	25	29.7	(mean:)	23.2
Id1.25_Iu1.3	3_iii	Avg. Catch 2011-2030	50%	23.5	28.9	22.7	22.1	34	41.2	(mean:)	28.7
Id1.25_Iu1.3	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	4	0	10	15	0	0	<25%	Pass
Id1.25_Iu1.3	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	8	0	11	8	0	0	<25%	Pass
Id1.25_Iu1.3	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
Id1.25_Iu1.25	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id1.25_Iu1.25	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
Id1.25_Iu1.25	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	5	5	0	5	20	20	<25%	Pass
Id1.25_Iu1.25	2b	P(3yr Catch variation >25% for 2010-2027)	50%	18.1	21.1	17.6	18.2	28.3	31.2	<25%	Fail
Id1.25_Iu1.25	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id1.25_Iu1.25	3_i	Avg. Catch 2011-2015	50%	14.6	15.7	14.3	13.9	14.7	15.8	(mean:)	14.8
Id1.25_Iu1.25	3_ii	Avg. Catch 2016-2020	50%	20.5	24.4	18.8	18.7	24	29	(mean:)	22.6
Id1.25_Iu1.25	3_iii	Avg. Catch 2011-2030	50%	23.1	28.6	21.9	21.7	32.3	40.3	(mean:)	28
Id1.25_Iu1.25	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	4	0	14	8	0	0	<25%	Pass
Id1.25_Iu1.25	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	5	0	16	2	0	0	<25%	Pass
Id1.25_Iu1.25	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
Id1.75_Iu1.25	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id1.75_Iu1.25	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
Id1.75_Iu1.25	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	5	10	5	5	22.5	25	<25%	Pass
Id1.75_Iu1.25	2b	P(3yr Catch variation >25% for 2010-2027)	50%	19.5	22.2	18.4	18.9	30.5	33.2	<25%	Fail
Id1.75_Iu1.25	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id1.75_Iu1.25	3_i	Avg. Catch 2011-2015	50%	13.8	15	13.4	13.2	13.6	15.6	(mean:)	14.1
Id1.75_Iu1.25	3_ii	Avg. Catch 2016-2020	50%	19	23.7	18	18	22.1	28.7	(mean:)	21.6
Id1.75_Iu1.25	3_iii	Avg. Catch 2011-2030	50%	22.1	28	21.1	20.1	30.7	40.1	(mean:)	27
Id1.75_Iu1.25	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	1	0	7	2	0	0	<25%	Pass
Id1.75_Iu1.25	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	6	0	17	3	0	0	<25%	Pass
Id1.75_Iu1.25	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
Id0.5_Iu0.5	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id0.5_Iu0.5	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
Id0.5_Iu0.5	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	0	0	0	0	0	0	<25%	Pass
Id0.5_Iu0.5	2b	P(3yr Catch variation >25% for 2010-2027)	50%	7.7	9	7.3	7.2	11.9	13.3	<25%	Pass
Id0.5_Iu0.5	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id0.5_Iu0.5	3_i	Avg. Catch 2011-2015	50%	15.3	15.7	15.3	15.2	15.3	15.9	(mean:)	15.4
Id0.5_Iu0.5	3_ii	Avg. Catch 2016-2020	50%	17.4	18.8	17.1	17.1	18.7	20.4	(mean:)	18.2
Id0.5_Iu0.5	3_iii	Avg. Catch 2011-2030	50%	18.8	20.6	18.5	18.2	21.6	23.6	(mean:)	20.2
Id0.5_Iu0.5	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	0	0	0	1	0	0	<25%	Pass
Id0.5_Iu0.5	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	7	0	16	10	0	0	<25%	Pass
Id0.5_Iu0.5	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Pass
Id0.75_Iu0.75	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id0.75_Iu0.75	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
Id0.75_Iu0.75	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	0	0	0	0	0	0	<25%	Pass
Id0.75_Iu0.75	2b	P(3yr Catch variation >25% for 2010-2027)	50%	11.1	13.3	10.5	10.7	17.6	20.1	<25%	Pass
Id0.75_Iu0.75	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id0.75_Iu0.75	3_i	Avg. Catch 2011-2015	50%	14.9	15.9	14.9	14.7	15.2	15.8	(mean:)	15.2
Id0.75_Iu0.75	3_ii	Avg. Catch 2016-2020	50%	18.3	20.9	17.8	17.7	20.8	22.9	(mean:)	19.7
Id0.75_Iu0.75	3_iii	Avg. Catch 2011-2030	50%	20.2	23.4	19.6	19.3	25.1	28.8	(mean:)	22.7
Id0.75_Iu0.75	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	0	0	4	1	0	0	<25%	Pass
Id0.75_Iu0.75	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	7	1	14	10	0	0	<25%	Pass
Id0.75_Iu0.75	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Pass
Id2_Iu1	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id2_Iu1	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	20	0	0	<25%	Pass
Id2_Iu1	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	0	0	2.5	5	10	15	<25%	Pass
Id2_Iu1	2b	P(3yr Catch variation >25% for 2010-2027)	50%	16.1	18.3	16.6	17.7	25.3	27.4	<25%	Fail
Id2_Iu1	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id2_Iu1	3_i	Avg. Catch 2011-2015	50%	13.8	14.9	12.7	12.2	13.4	14.9	(mean:)	13.7
Id2_Iu1	3_ii	Avg. Catch 2016-2020	50%	17.5	20.7	16.1	15.6	19.6	24.5	(mean:)	19
Id2_Iu1	3_iii	Avg. Catch 2011-2030	50%	19.4	24.3	18.1	17.4	25.5	32.9	(mean:)	22.9
Id2_Iu1	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	1	0	1	0	0	0	<25%	Pass
Id2_Iu1	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	2	0	12	0	0	0	<25%	Pass
Id2_Iu1	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
Id1.75_Iu1.75	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
Id1.75_Iu1.75	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	20	0	0	20	20	<25%	Pass
Id1.75_Iu1.75	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	15	20	15	15	35	40	<25%	Fail
Id1.75_Iu1.75	2b	P(3yr Catch variation >25% for 2010-2027)	50%	26	28.2	24	25.9	40.3	44.9	<25%	Fail
Id1.75_Iu1.75	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
Id1.75_Iu1.75	3_i	Avg. Catch 2011-2015	50%	13.6	15.5	13.7	13.3	13.9	15.5	(mean:)	14.2
Id1.75_Iu1.75	3_ii	Avg. Catch 2016-2020	50%	21.6	28.8	20.7	20.6	28.6	37	(mean:)	26.2
Id1.75_Iu1.75	3_iii	Avg. Catch 2011-2030	50%	24.7	32.2	23.6	23	38.3	46.7	(mean:)	31.4
Id1.75_Iu1.75	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	14	6	20	18	0	3	<25%	Pass
Id1.75_Iu1.75	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	8	2	19	8	0	0	<25%	Pass
Id1.75_Iu1.75	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
mp14*	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
mp14*	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
mp14*	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	0	0	0	0	0	0	<25%	Pass
mp14*	2b	P(3yr Catch variation >25% for 2010-2027)	50%	15.6	16.7	15.1	14.6	20.3	22	<25%	Pass
mp14*	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
mp14*	3_i	Avg. Catch 2011-2015	50%	14.7	15.8	14.8	14.6	15.1	16	(mean:)	15.2
mp14*	3_ii	Avg. Catch 2016-2020	50%	18	21.1	17.7	17.4	19.9	22.4	(mean:)	19.4
mp14*	3_iii	Avg. Catch 2011-2030	50%	20.5	24.7	20.4	19.5	25.2	29.1	(mean:)	23.2
mp14*	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	2	0	3	1	0	0	<25%	Pass
mp14*	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	9	1	19	7	0	0	<25%	Pass
mp14*	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Pass
mp16	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
mp16	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
mp16	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	0	0	0	0	0	0	<25%	Pass
mp16	2b	P(3yr Catch variation >25% for 2010-2027)	50%	15.1	16.3	15	15.2	20.4	21.6	<25%	Pass
mp16	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
mp16	3_i	Avg. Catch 2011-2015	50%	16	17.5	16.1	15.3	16	17	(mean:)	16.3
mp16	3_ii	Avg. Catch 2016-2020	50%	19.2	22.2	19	18.6	21	23.2	(mean:)	20.5
mp16	3_iii	Avg. Catch 2011-2030	50%	21.9	26	21.6	20.8	26.4	30.2	(mean:)	24.5
mp16	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	2	0	6	2	0	0	<25%	Pass
mp16	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	17	2	29	10	0	0	<25%	Fail
mp16	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail
mp12*	1	P(>=25% decline in expl bio from 2011 to 2016)	All	0	0	0	0	0	0	<10%	Pass
mp12*	2a_i	P(annual Catch variation >15% for 2010-2014)	50%	0	0	0	0	0	0	<25%	Pass
mp12*	2a_ii	P(annual Catch variation >15% for 2010-2029)	50%	0	0	0	0	0	0	<25%	Pass
mp12*	2b	P(3yr Catch variation >25% for 2010-2027)	50%	17.1	19	16.7	16.7	23.7	26.5	<25%	Fail
mp12*	2c	P(TAC <10kt at least once 2011-2015)	50%	0	0	0	0	0	0	<25%	Pass
mp12*	3_i	Avg. Catch 2011-2015	50%	13.3	14.7	13.3	12.6	13.8	14.8	(mean:)	13.8
mp12*	3_ii	Avg. Catch 2016-2020	50%	17.1	21	16.5	16.1	20	23.2	(mean:)	19
mp12*	3_iii	Avg. Catch 2011-2030	50%	19.2	24.8	18.7	17.9	25.8	30.7	(mean:)	22.9
mp12*	4	P(Expl bio in 2031 < 1985-1999 avg.)	All	1	0	0	2	0	0	<25%	Pass
mp12*	4_alt	P(Expl bio in 2019 < 1975-1999 avg.)	All	5	0	11	4	0	0	<25%	Pass
mp12*	Overall	Overall performance	NA	NA	NA	NA	NA	NA	NA	NA	Fail

FCWGMSE WP 10/13

Greenland Halibut MSE Results for Updated SCAA Reference Case and Robustness Test Operating Models

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ABSTRACT

This paper reports the results of the application of 18 potential Management Procedures (MPs) to the Base Case and seven robustness test operating models based on SCAA assessments of the Greenland halibut resource. One of these MPs is selected as a preferred candidate (subject to its performance for XSA-based operating models) on the basis of satisfying virtually all performance targets identified at the May NAFO WGMSE meeting and achieving relatively high catches. The one drawback for this MP (and also all others considered) is failure to meet the specified resource recovery target under robustness test SCAA5 (a lower stock-recruitment steepness), and suggestions are made in that regard. Suggestions are also made in relation to "exceptional circumstances" provisions where over-riding the TAC recommendation output by the MP becomes scientifically justified, and for catering for possible future TAC over-runs. Following discussions of these analyses with our EU principals, results for four further variants of these MPs have been added for consideration.

INTRODUCTION

This document reports results of testing of candidate Management Procedures (MPs) for Greenland halibut for a set of SCAA operating models for the population dynamics which have been updated using the most recent data for the resource as considered at the 2010 NAFO SC meeting (Butterworth and Rademeyer, 2010a). This set includes a Reference Case (SCAA0) and seven robustness tests (SCAA1 to SCAA7).

The projection methodology utilised for these tests is detailed in Butterworth and Rademeyer (2010b), which also lists the performance statistics agreed at the May NAFO WGMSE meeting (NAFO, 2010). Results for 18 alternative MPs are contrasted below in terms in line with the forms and the performance targets and statistics agreed at that meeting.

RESULTS AND DISCUSSION

All the MPs follow the form of the NAFO (2010) default control rule:

$$TAC_{y+1} = \begin{cases} TAC_y \times \left(1 + \lambda_u \times slope\right) & if \quad slope \geq 0 \\ TAC_y \times \left(1 + \lambda_d \times slope\right) & if \quad slope < 0 \end{cases} \tag{1}$$

Three factors/tuning parameters are varied, with the alternatives reflected here culled from a wider set investigated:

1) the λ_u and λ_d control parameters: a) λ_u=1.0 and λ_d=1.25; b) λ_u=1.0 and λ_d=2.0;

2) the starting TAC control parameter: a) 16 000t; b) 17 500t; c) 19 000t;

3) the inter-annual TAC change constraints: a) +10%, -10%; b) +10%; -5%; c)+15%,-5%.

Note that our earlier Greenland halibut MSE analyses (e.g. Rademeyer and Butterworth, 2010) had imposed inter-annual TAC constraints of 20% and later 15%. These relatively large values were necessitated by the poor status of the resource indicated by earlier XSA assessments, so that sufficient adaptive TAC adjustment could be achieved if these reflected the actual underlying resource situation. However the updated XSA assessment from the 2010 NAFO

SC meeting reflects notably improved results as regards resource status (which is now also closer to SCAA results), motivating consideration of tighter constraints in the interests of enhanced industrial stability.

A full cross of the factors/parameters listed above is reported, yielding 18 candidate MPs (mp01 to mp18) in all. The linkage between MP names and factor/parameter values is provided in Table 1a, which lists results in terms of a format corresponding to the performance targets agreed in NAFO (2010), with results for a 16 000 t constant catch MP also add to provide a convenient benchmark for comparisons. Note that in this Table, statistics that do not meet the targets specified in NAFO (2010) are shown shaded.

These same results are shown in Fig. 1 in the form of graphical projections for the annual catch (assumed equal to the TAC in projections under MPs) and exploitable biomass (*B*5-9), with both medians and lower 2.5%iles of probability distributions plotted. In this Figure, the 18 MPs are grouped by the starting TAC control parameter value.

In the authors' view, mp14 provides the best trade-off amongst the performance statistics under SCAA0, satisfying all performance targets, and yielding the highest catches amongst the other MPs which do likewise. It is thus used as a "baseline" MP in Figure 2, which illustrates the sensitivity of the results for mp14 to single factor variations of the starting TAC control parameter (Fig. 2a), the inter-annual TAC change constraints (Fig. 2b) and the λ control parameters (Fig. 2c). Note that the impact of variation of the first two of these factors on results is much greater than the third. It is possible to "mimic" TAC change constraints by decreasing λ values, but for reasons of longer-term stability of abundance projections (i.e. adequate feedback), λ_d values in particular should preferably not be set less than 1.

The performance of the Baseline mp14 across the SCAA Base Case and robustness tests is shown in Table 1b and Fig. 3. Performance targets are met in all cases except for a marginal failure for $P_{\text{achieved}}/P_{\text{milestone}}$ (resource recovery) for SCAA4 (increasing natural mortality at larger ages), and a much greater extent of failure for SCAA5 (stock-recruitment steepness h = 0.6 in contrast to the h = 0.9 preferred for SCAA0 because of a much better fit to the data). Fig. 3 shows that behavior for SCAA5 is qualitatively different to that for the other robustness tests which manifest quite similar behavior to that of the Base Case SCAA0. In contrast to increases in both catches and exploitable biomasses for these other scenarios, for SCAA5 these both remain fairly steady into the future. Table 1c shows results for SCAA5 across all 18 of the MPs considered, and demonstrates that the failure to meet recovery targets for this scenario is general and not peculiar to mp14. Further comments on this are made below.

In response to a suggestion from Canadian scientists for selection of the three best performing MPs, our selections in addition to the Baseline mp14 are mp12 and mp16 (it must be stressed that these constitute the authors' selections, and do not necessarily reflect the views of the EU). These choices are seen by the authors to provide the best balances between achieving recovery targets, maximizing catches, and minimising TAC variations. We do not consider the marginal failure of mp16 to meet certain TAC change performance targets to be critical, both because these particular targets were chosen primarily with TAC decrease being the concern whereas it is TAC increases that are resulting in these "failures", and further because if such targets are considered critical, they could readily be hard-wired into the control rules without any great impact on other performance statistics. Results for these three MPs applied to the Base Case SCAA operating model (SCAA0) are given in Table 2 in a format different from Table 1, with the statistics for mp14 under robustness test SCAA5 also added there. Graphical comparisons are shown in Figs 4 and 5. Except for the earliest years mp14 achieves the highest catches for only marginal lesser recovery, and also shows appreciably less TAC variation.

An alternative graphical form for contrasting performance statistics for the various MPs applied to SCAA0 is shown in Fig 6a, with comparisons restricted to the authors' three preferred MP choices shown in Fig. 6b.

SUMMARY AND RELATED CONSIDERATIONS

Subject to showing satisfactory performance also under the various XSA based operating models, mp14 appears to the authors to be a strong candidate for adoption as the MP to provide TAC recommendations for Greenland halibut. It meets all the performance targets set at the May WGMSE meeting (NAFO, 2010) while also being likely to achieve relatively high catches. It provides a good example of a major strength of the MSE approach that has been evident in its application to other fisheries, *viz.* that of being able to provide a scientifically defensible basis to constrain inter-annual TAC variation in a manner that nevertheless secures adequate safeguards for the risk of unintended resource depletion. Thus in the first few future years in this case, the TAC change constraints imposed prevent unnecessary reduction of the TAC as a consequence of following more of the noise than the signal in the survey data (nearly all recent residuals in the assessment fits to the survey indices of abundance are positive), and in a manner which does not compromise resource recovery.

The one concern is the failure of mp14 (or indeed any of the other MPs considered) to secure the desired level of resource recovery under robustness test SCAA5 (lower steepness). The lower 2.5%ile plot for exploitable biomass shown in Fig. 3 for this situation does at least indicate that application of mp14 would prevent any continuing deterioration. This is a manifestation of a potential problem with derivative-control-based MP approaches such as that of equation (1), which arises because their targets are emergent properties which cannot be pre-specified and therefore may turn out to be different to what is desired. The simplest solution to this problem is to include a target-based term as an extension of equation (1). This might better secure some recovery under SCAA5 while not compromising the desirable performance achieved under mp14 for the other SCAA scenarios.

Two other more general issues merit attention in moving towards agreement of an MSE approach for Greenland halibut with its associated decision rule in the form of a TAC formula. The first is that it is usual to pre-agree some guidance concerning "exceptional circumstances" – unexpected future events which provide scientific justification for over-riding the TAC recommendation provided by an MP's control rule. A customary criterion for what need to be compelling reasons to take such action is future data falling outside the range considered in the MSE process, thus indicating that circumstances have arisen outside the range for which the control rule has been tested to show adequate robustness. To aid consideration of this possible approach, Fig. 7 shows probabilistic projections of future survey results expected under SCAA0 (and implementation of mp14).

A second concern is TAC over-runs, given an empirical MP (equation 1) which takes no explicit account of any mismatch between the TAC set and the catch subsequently taken (as, in contrast, a population model based MP would do). The feedback nature of MPs ensures that they do react to this, but typically slower than needed to make fully compensatory TAC adjustments in the short term. Furthermore, none of the robustness tests considered for these evaluations have considered the impact of possible future catch over-runs. Ideally there should be pre-agreement, as part of any Management Procedure of this type that is adopted, on how to make appropriate adjustments for such over-runs to recommendations output by an MP for TACs.

ADDENDUM

In discussion of the above with our EU principals, suggestions were made that the following further options warranted analysis to allow consideration of the results:

mp14*: this MP is as mp14 (i.e. starting TAC control parameter of 17 500t; λ_u=1 and λ_d =2; and constraints on the inter-annual TAC changes of +10% and -5%), but the 2011 MP output is over-ridden by a pre-set TAC of 16 000t. To compute the TAC in 2012 the original 2011 MP output (17 182t) is used in the control rule (equation 1).

mp14**: as mp14*, but the 2012 MP output is also over-ridden by a pre-set TAC of 16 000t.

mp14***: as mp14* but with a pre-set TAC of 14 500t instead of 16 000t in 2011.

mp19: starting TAC control parameter of 14 500t; λ_u=1 and λ_d =2; and constraints on the inter-annual TAC changes of +10% and -5%.

Results for these four further MPs are compared to mp14 and mp11 (starting TAC of 16 000t) in Tables 3 and 4, while the exploitable biomass and TAC are plotted in Fig. 8. In terms of the biomass projections (Fig. 8), the original mp14 and its three variants are virtually indistinguishable. The catches over time for all the mp14's (starting TAC control parameter of 17 500t) are appreciably higher than for mp11 (starting TAC control parameter of 16 000t) and mp19 (starting TAC control parameter of 14 500t) without compromising mp14 reaching the specified biomass recovery targets.

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Table 1a: Performance statistics for a series of MPs for the Base Case SCAA operating model (SCAA0), where these are reported in a format that relates to specified targets in NAFO (2010). Instances where those targets are not met are shown shaded.

SCAA0				1	2a				2b			2c				3		4
				Prob	Prob*	Prob*	Prob	Prob	Prob	Prob	Prob	Prob	Prob	Prob	$C_{2011-2015}$	$C_{2016-2020}$	$C_{2011-2030}$	Prob
	λ_{up}; λ_{down}	starting TAC	bounds	B^{5-9}	(2011-2015)	(2010-2014)	(2011-2030)	(2010-2029)	(2010-2027)	2011	2012	2013	2014	2015				$P_{achieved}$ / $P_{milestone}$
cteC	1; 1.25	16000t		3%	0%	20%	0%	5%	0%	0%	0%	0%	0%	0%	16000	16000	16000	4%
mp01	1; 1.25	16000t	+10%; -10%	0%	0%	20%	0%	5%	25%	0%	0%	0%	0%	0%	13413	13800	14329	2%
mp02	1; 1.25	16000t	+10%; -5%	2%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	14628	16093	16882	12%
mp03	1; 1.25	16000t	+15%; -5%	2%	0%	20%	0%	5%	22%	0%	0%	0%	0%	0%	14628	16425	17795	19%
mp04	1; 1.25	17500t	+10%; -10%	1%	0%	0%	0%	0%	28%	0%	0%	0%	0%	0%	14638	14953	15497	2%
mp05	1; 1.25	17500t	+10%; -5%	2%	0%	0%	0%	0%	17%	0%	0%	0%	0%	0%	15988	17461	18367	21%
mp06	1; 1.25	17500t	+15%; -5%	2%	0%	0%	0%	0%	22%	0%	0%	0%	0%	0%	15988	17726	19180	30%
mp07	1; 1.25	19000t	+10%; -10%	2%	0%	0%	0%	0%	22%	0%	0%	0%	0%	0%	15884	16079	16634	8%
mp08	1; 1.25	19000t	+10%; -5%	4%	0%	0%	0%	0%	11%	0%	0%	0%	0%	0%	17333	18717	19736	31%
mp09	1; 1.25	19000t	+15%; -5%	4%	0%	0%	0%	0%	17%	0%	0%	0%	0%	0%	17333	18959	20579	33%
mp10	1; 2	16000t	+10%; -10%	0%	0%	20%	0%	5%	28%	0%	0%	0%	0%	0%	13283	13437	13713	1%
mp11	1; 2	16000t	+10%; -5%	1%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	14513	15855	16674	11%
mp12	1; 2	16000t	+15%; -5%	1%	0%	20%	0%	5%	22%	0%	0%	0%	0%	0%	14513	16211	17485	17%
mp13	1; 2	17500t	+10%; -10%	1%	0%	20%	0%	5%	28%	0%	0%	0%	0%	0%	14517	14511	14869	2%
mp14	1; 2	17500t	+10%; -5%	2%	0%	20%	0%	5%	14%	0%	0%	0%	0%	0%	15857	17218	18102	20%
mp15	1; 2	17500t	+15%; -5%	2%	0%	20%	0%	5%	22%	0%	0%	0%	0%	0%	15857	17545	18916	28%
mp16	1; 2	19000t	+10%; -10%	2%	0%	0%	0%	0%	28%	0%	0%	0%	0%	0%	15746	15561	15930	3%
mp17	1; 2	19000t	+10%; -5%	4%	0%	0%	0%	0%	11%	0%	0%	0%	0%	0%	17203	18570	19466	27%
mp18	1; 2	19000t	+15%; -5%	4%	0%	0%	0%	0%	17%	0%	0%	0%	0%	0%	17203	18797	20240	33%

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Table 1b: Performance statistics formulated as in Table 1a for mp14 for the Base Case SCAA operating model (SCAA0) and its associated robustness tests.

	1	2a				2b	2c					3			4
mp14	Prob	Prob*	Prob*	Prob	Prob	Prob	Prob	Prob	Prob	Prob	Prob	$C_{2011\text{-}2015}$	$C_{2016\text{-}2020}$	$C_{2011\text{-}2030}$	Prob
	$B^{5\text{-}9}$	(2011-2015)	(2010-2014)	(2011-2030)	(2010-2029)	(2010-2027)	2011	2012	2013	2014	2015				$P_{achieved}/P_{milestone}$
SCAA0	2%	0%	20%	0%	5%	14%	0%	0%	0%	0%	0%	15857	17218	18102	20%
SCAA1	4%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	15756	16314	17816	22%
SCAA2	2%	0%	20%	0%	5%	22%	0%	0%	0%	0%	0%	15765	16676	19198	1%
SCAA3	2%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	16016	18306	18329	17%
SCAA4	2%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	15812	17310	18776	27%
SCAA5	14%	0%	20%	0%	5%	11%	0%	0%	0%	0%	0%	15579	14355	15366	100%
SCAA6	2%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	15923	17636	18598	6%
SCAA7	2%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	15847	17450	18849	16%

Table 1c: Performance statistics formulated as in Table 1a for a series of MPs for SCAA5.

				1	2a				2b	2c					3			4
SCAA5				Prob	Prob*	Prob*	Prob	Prob	Prob	Prob	Prob	Prob	Prob	Prob	$C_{2011\text{-}2015}$	$C_{2016\text{-}2020}$	$C_{2011\text{-}2030}$	Prob
	$\lambda_{up}; \lambda_{down}$	starting TAC	bounds	$B^{5\text{-}9}$	(2011-2015)	(2010-2014)	(2011-2030)	(2010-2029)	(2010-2027)	2011	2012	2013	2014	2015				$P_{achieved}/P_{milestone}$
cteC	1; 1.25	16000t		16%	0%	20%	0%	5%	0%	0%	0%	0%	0%	0%	16000	16000	16000	100%
mp01	1; 1.25	16000t	+10%; -10%	5%	0%	20%	0%	5%	28%	0%	0%	0%	0%	0%	13153	11020	11820	97%
mp02	1; 1.25	16000t	+10%; -5%	11%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	14381	13448	14465	100%
mp03	1; 1.25	16000t	+15%; -5%	11%	0%	20%	0%	5%	19%	0%	0%	0%	0%	0%	14381	13596	14801	100%
mp04	1; 1.25	17500t	+10%; -10%	8%	0%	0%	0%	0%	28%	0%	0%	0%	0%	0%	14364	11891	12687	99%
mp05	1; 1.25	17500t	+10%; -5%	14%	0%	0%	0%	0%	11%	0%	0%	0%	0%	0%	15715	14564	15597	100%
mp06	1; 1.25	17500t	+15%; -5%	14%	0%	0%	0%	0%	17%	0%	0%	0%	0%	0%	15715	14594	15950	100%
mp07	1; 1.25	19000t	+10%; -10%	13%	0%	0%	0%	0%	22%	0%	0%	0%	0%	0%	15574	12816	13596	100%
mp08	1; 1.25	19000t	+10%; -5%	21%	0%	0%	0%	0%	11%	0%	0%	0%	0%	0%	17039	15672	16714	100%
mp09	1; 1.25	19000t	+15%; -5%	21%	0%	0%	0%	0%	11%	0%	0%	0%	0%	0%	17039	15680	17116	100%
mp10	1; 2	16000t	+10%; -10%	4%	0%	20%	0%	5%	33%	0%	0%	0%	0%	0%	13025	10706	11273	94%
mp11	1; 2	16000t	+10%; -5%	11%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	14243	13281	14239	100%
mp12	1; 2	16000t	+15%; -5%	11%	0%	20%	0%	5%	19%	0%	0%	0%	0%	0%	14243	13288	14590	100%
mp13	1; 2	17500t	+10%; -10%	8%	0%	20%	0%	5%	33%	0%	0%	0%	0%	0%	14209	11568	12130	98%
mp14	1; 2	17500t	+10%; -5%	14%	0%	20%	0%	5%	11%	0%	0%	0%	0%	0%	15579	14355	15366	100%
mp15	1; 2	17500t	+15%; -5%	14%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	15579	14394	15752	100%
mp16	1; 2	19000t	+10%; -10%	12%	0%	0%	0%	0%	33%	0%	0%	0%	0%	0%	15398	12329	12990	100%
mp17	1; 2	19000t	+10%; -5%	20%	0%	0%	0%	0%	11%	0%	0%	0%	0%	0%	16914	15420	16472	100%
mp18	1; 2	19000t	+15%; -5%	20%	0%	0%	0%	0%	14%	0%	0%	0%	0%	0%	16914	15420	16772	100%

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Table 2: Performance statistics for mp12, mp14 and mp16 for the Base Case SCAA operating model (SCAA0) and for mp14 for SCAA5.

Performance target:		1	2a				2b		2c						3			4
		B^{5-9}	Prob*	Prob*	Prob	Prob	Prob	Prob										B^{5-9}
SCAA0		P_{2016}/P_{2011}	(2010-2014)	(2011-2015)	(2010-2029)	(2011-2030)	(2010-2027)	(2011-2028)	C_{2011}	C_{2012}	C_{2013}	C_{2014}	C_{2015}	$C_{2011-2015}$	$C_{2016-2020}$	$C_{2011-2030}$	AAV_{2011_2029}	$P_{achieved}/P_{milestone}$
constant catch	median	1.15	20%	0%	5%	0%	0%	0%	16000	16000	16000	16000	16000	16000	16000	16000	1.1%	1.22
	low 2.5%	0.75	20%	0%	5%	0%	0%	0%	16000	16000	16000	16000	16000	16000	16000	16000	0.9%	0.98
	high 2.5%	1.52	20%	0%	5%	0%	6%	0%	16000	16000	16000	16000	16000	16000	16000	16000	1.6%	1.53
mp12	median	1.18	20%	0%	5%	0%	22%	17%	15709	14939	14207	13511	14165	14513	16211	17485	6.8%	1.17
	low 2.5%	0.81	20%	0%	5%	0%	6%	0%	15709	14939	14207	13511	12849	14243	12249	14993	5.1%	0.81
	high 2.5%	1.54	20%	0%	5%	0%	42%	36%	15709	14939	14207	15043	16767	15303	21124	22118	8.5%	1.48
mp14	median	1.16	20%	0%	5%	0%	14%	11%	17182	16340	15539	14778	15420	15857	17218	18102	5.9%	1.17
	low 2.5%	0.78	0%	0%	0%	0%	0%	0%	17182	16340	15539	14778	14054	15579	13253	15683	4.6%	0.85
	high 2.5%	1.53	20%	0%	5%	0%	33%	28%	17182	16340	15539	16407	17840	16627	20785	21741	7.1%	1.46
mp16	median	1.17	0%	0%	0%	0%	28%	22%	18655	16808	15144	13645	14279	15746	15561	15930	7.2%	1.23
	low 2.5%	0.80	0%	0%	0%	0%	6%	3%	18655	16808	15144	13645	12294	15309	11197	13422	5.5%	1.00
	high 2.5%	1.53	20%	0%	5%	0%	53%	47%	18655	16808	15325	16015	17510	16837	19399	19696	8.6%	1.51
SCAA5																		
mp14	median	0.96	20%	0%	5%	0%	11%	11%	17182	16340	15539	14778	14054	15579	14355	15366	5.7%	0.61
	low 2.5%	0.57	0%	0%	0%	0%	0%	0%	17182	16340	15539	14778	14054	15579	12118	12880	4.6%	0.39
	high 2.5%	1.34	20%	0%	5%	0%	25%	22%	17182	16340	15539	14868	15658	15937	18261	19299	6.7%	0.86

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Table 3: Performance statistics for a series of further MPs for the Base Case SCAA operating model (SCAA0) requested for addition by our EU principals, where these are reported in a format that relates to specified targets in NAFO (2010). All MP options shown meet all the NAFO (2010) performance targets.

SCAA0			1	2a				2b	2c						3		4
			Prob	Prob*	Prob*	Prob	Prob	Prob	Prob	Prob	Prob	Prob	Prob	$C_{2011-2015}$	$C_{2016-2020}$	$C_{2011-2030}$	Prob
	starting TAC	override of MP recommendation	B^{5-9}	(2011-2015)	(2010-2014)	(2011-2030)	(2010-2029)	(2010-2027)	2011	2012	2013	2014	2015				$P_{achieved}/P_{milestone}$
mp11	16000t		1%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	14513	15855	16674	11%
mp14	17500t		2%	0%	20%	0%	5%	14%	0%	0%	0%	0%	0%	15857	17218	18102	20%
mp14*	17500t	C_{2011}=16000t	2%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	15625	17252	18045	20%
mp14**	17500t	C_{2011} and C_{2012}=16000t	2%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	15559	17260	18026	20%
mp14***	17500t	C_{2011}=14500t	2%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	15334	17295	17960	20%
mp19	14500		0%	0%	20%	0%	5%	17%	0%	0%	0%	0%	0%	13405	14765	15520	5%

Table 4: Performance statistics for a series of further MPs (as in Table 3) for the Base Case SCAA operating model (SCAA0).

SCAA0			Performance target	1	2a				2b		2c						3			4
				B^{5-9}	Prob*	Prob*	Prob	Prob	Prob	Prob										B^{5-9}
	starting TAC	override of MP recommendation		P_{2016}/P_{2011}	(2010-2014)	(2011-2015)	(2010-2029)	(2011-2030)	(2010-2027)	(2011-2028)	C_{2011}	C_{2012}	C_{2013}	C_{2014}	C_{2015}	$C_{2011-2015}$	$C_{2016-2020}$	$C_{2011-2030}$	AAV_{2011_2029}	$P_{achieved}/P_{milestone}$
			median	1.18	0.20	0.00	0.05	0.00	0.17	0.11	15709	14939	14207	13511	14165	14513	15855	16674	6.3%	1.21
mp11	16000t		low 2.5%	0.81	0.20	0.00	0.05	0.00	0.06	0.00	15709	14939	14207	13511	12849	14243	12249	14532	5.1%	0.91
			high 2.5%	1.54	0.20	0.00	0.05	0.00	0.33	0.28	15709	14939	14207	15043	16359	15221	19038	20096	7.4%	1.48
			median	1.16	0.20	0.00	0.05	0.00	0.14	0.11	17182	16340	15539	14778	15420	15857	17218	18102	5.9%	1.17
mp14	17500t		low 2.5%	0.78	0.00	0.00	0.00	0.00	0.00	0.00	17182	16340	15539	14778	14054	15579	13253	15683	4.6%	0.85
			high 2.5%	1.53	0.20	0.00	0.05	0.00	0.33	0.28	17182	16340	15539	16407	17840	16627	20785	21741	7.1%	1.46
			median	1.16	0.20	0.00	0.05	0.00	0.17	0.11	16000	16340	15539	14778	15443	15625	17252	18045	6.0%	1.17
mp14*	17500t	C_{2011}=16000t	low 2.5%	0.78	0.20	0.00	0.05	0.00	0.00	0.00	16000	16340	15539	14778	14054	15342	13273	15615	4.8%	0.85
			high 2.5%	1.53	0.20	0.00	0.05	0.00	0.33	0.28	16000	16340	15539	16435	17876	16403	20791	21686	7.2%	1.46
			median	1.16	0.20	0.00	0.05	0.00	0.17	0.11	16000	16000	15539	14778	15449	15559	17260	18026	5.8%	1.17
mp14**	17500t	C_{2011}=16000t	low 2.5%	0.78	0.20	0.00	0.05	0.00	0.00	0.00	16000	16000	15539	14778	14054	15274	13282	15605	4.6%	0.85
		C_{2012}=16000t	high 2.5%	1.53	0.20	0.00	0.05	0.00	0.33	0.28	16000	16000	15539	16436	17872	16335	20792	21669	7.0%	1.46
			median	1.16	0.20	0.00	0.05	0.00	0.17	0.11	14500	16340	15539	14778	15474	15334	17295	17960	6.9%	1.17
mp14***	17500t	C_{2011}=14500t	low 2.5%	0.78	0.20	0.00	0.05	0.00	0.00	0.00	14500	16340	15539	14778	14054	15042	13311	15583	5.7%	0.85
			high 2.5%	1.53	0.20	0.00	0.05	0.00	0.33	0.28	14500	16340	15539	16470	17911	16127	20799	21615	8.0%	1.46
			median	1.21	0.20	0.00	0.05	0.00	0.17	0.14	14500	13790	13114	12471	13128	13405	14765	15520	6.6%	1.23
mp19	14500t		low 2.5%	0.84	0.20	0.00	0.05	0.00	0.06	0.00	14500	13790	13114	12471	11860	13147	11458	13557	5.4%	0.96
			high 2.5%	1.56	0.20	0.00	0.05	0.00	0.33	0.28	14500	13790	13114	13918	15141	14082	17599	18712	7.7%	1.51

Starting TAC:

16 000t

Starting TAC:

17 500t

Starting TAC:

19 000t

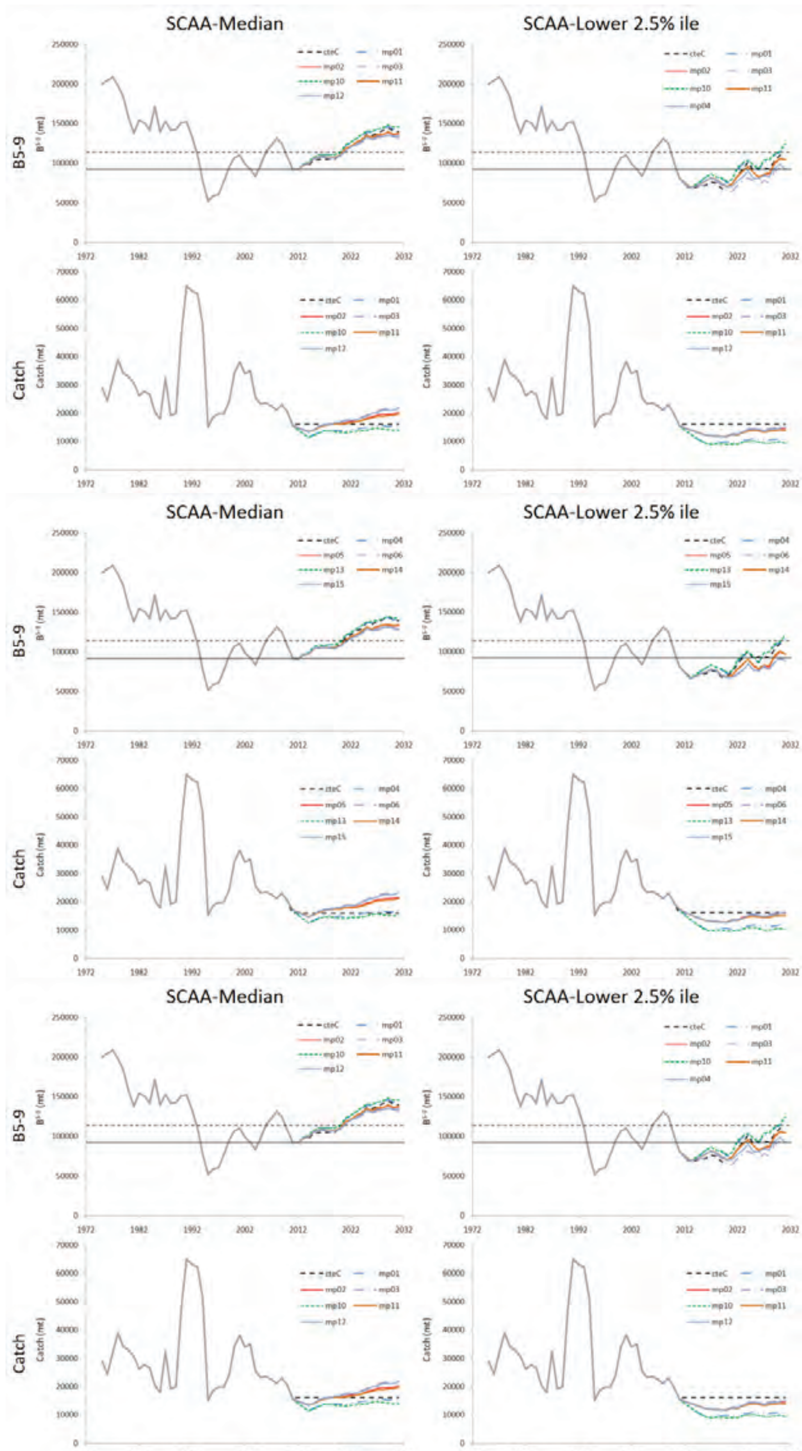

Fig. 1: Medians (left) and lower 2.5%iles (right) TAC and exploitable biomass for a series of MPs for the **Base Case SCAA** operating model (SCAA0). Here and in subsequent biomass plots the full horizontal line represents the 2011 median level while the dashed horizontal line represents the target level (1985-1999 average).

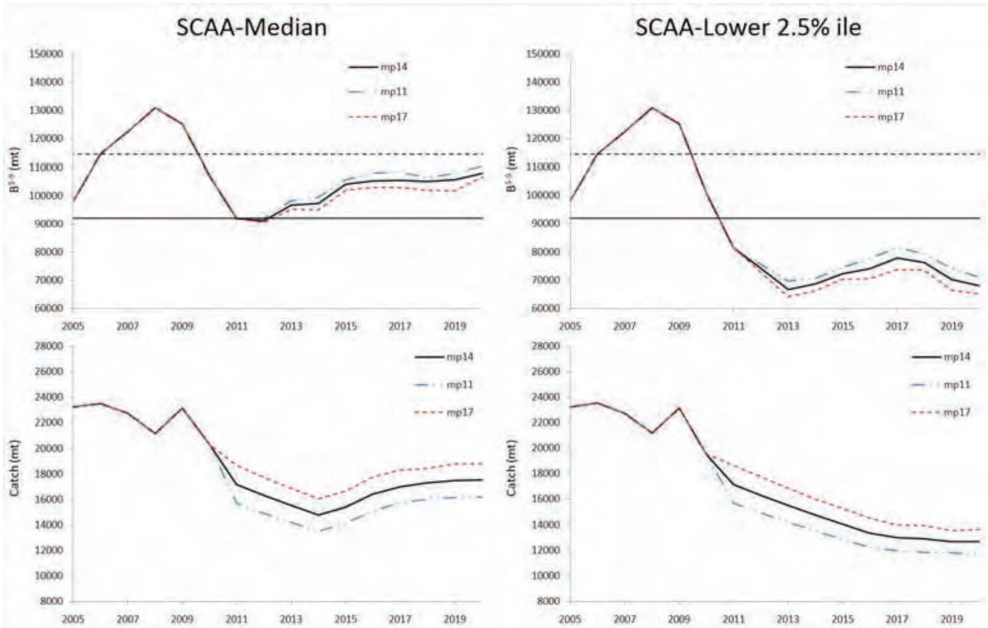

Fig. 2a: Medians (left) and lower 2.5%iles (right) TAC and exploitable biomass for three MPs with different starting TAC control parameters (mp14: 17 500t; mp11: 16 000t and mp17: 19 000t) for SCAA0. Note that here and below to magnify around where most differences are evident, the axes no longer intersect at a zero value on the vertical axis.

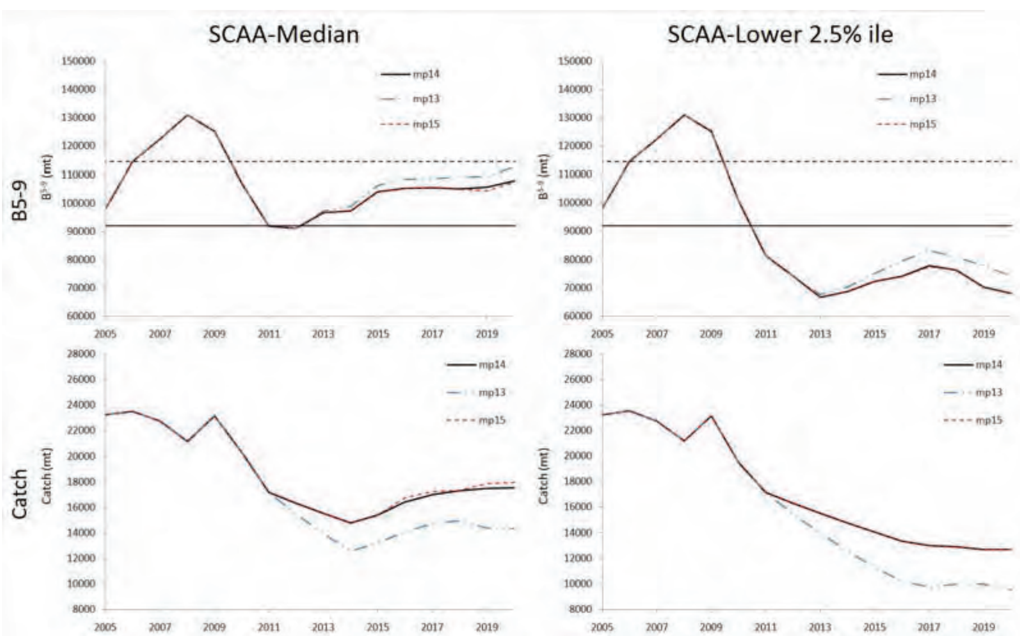

Fig. 2b: Medians (left) and lower 2.5%iles (right) TAC and biomass for three MPs with different bounds on maximum annual TAC change (mp14: +10%, -5%; mp13: +10%, -10% and mp15: +15%, -5%) for SCAA0.

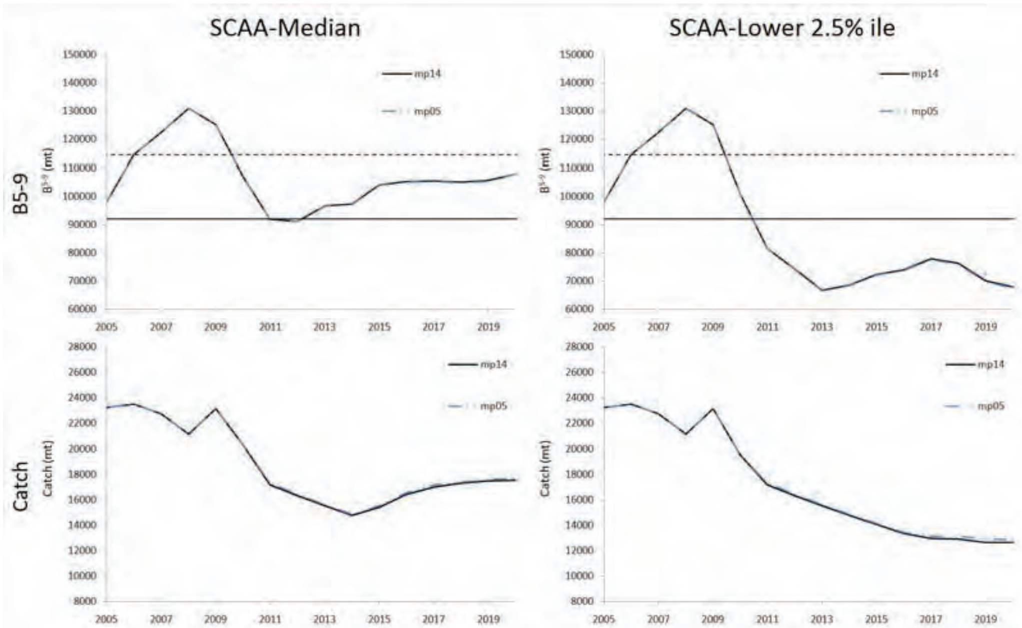

Fig. 2c: Medians (left) and lower 2.5%iles (right) TAC and exploitable biomass for three MPs with different values for $_{down}$ (mp14: 1.25 and mp05: 2.0) for SCAA0.

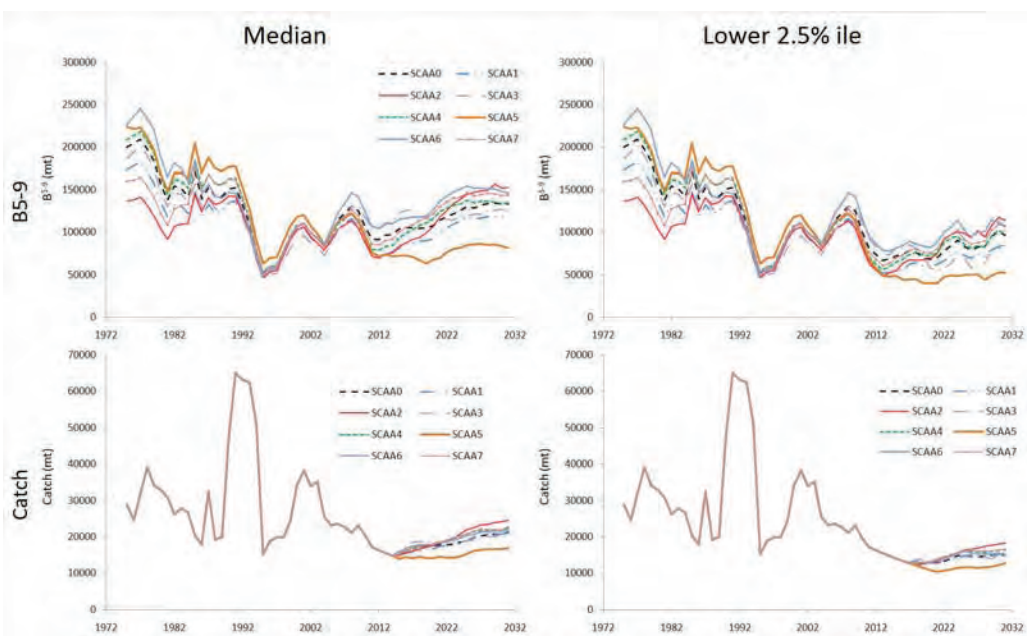

Fig. 3: Medians (left) and lower 2.5%iles (right) TAC and exploitable biomass for the SCAA Base Case operating model (SCAA0) and a series of robustness tests (SCAA1 – SCAA7) for mp14.

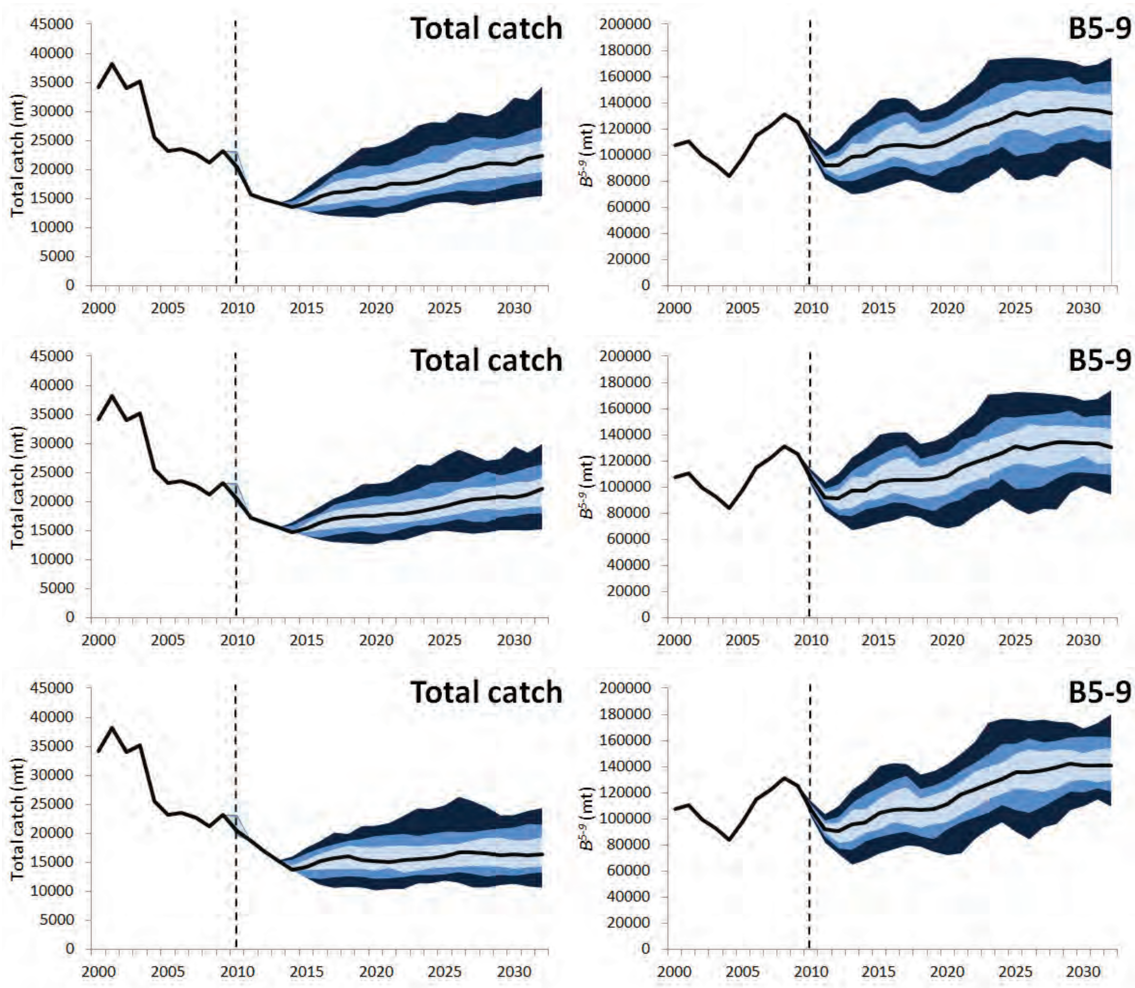

Fig. 4: 95, 75 and 50% PIs and medians for the total catch and exploitable biomass projections for mp12 (top), mp14 (middle) and mp16 (bottom) for SCAA0.

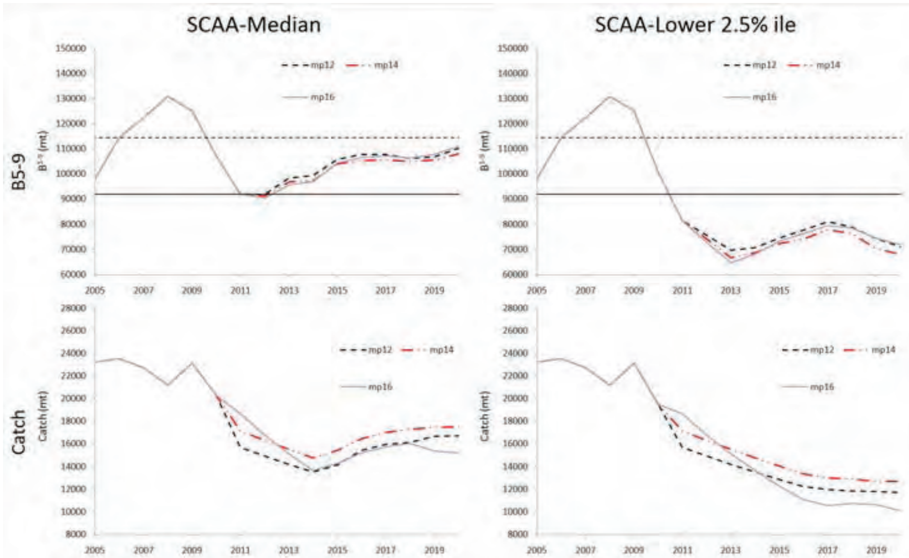

Fig. 5: Medians (left) and lower 2.5%iles (right) TAC and exploitable biomass for the SCAA Base Case for mp12, mp14 and mp16.

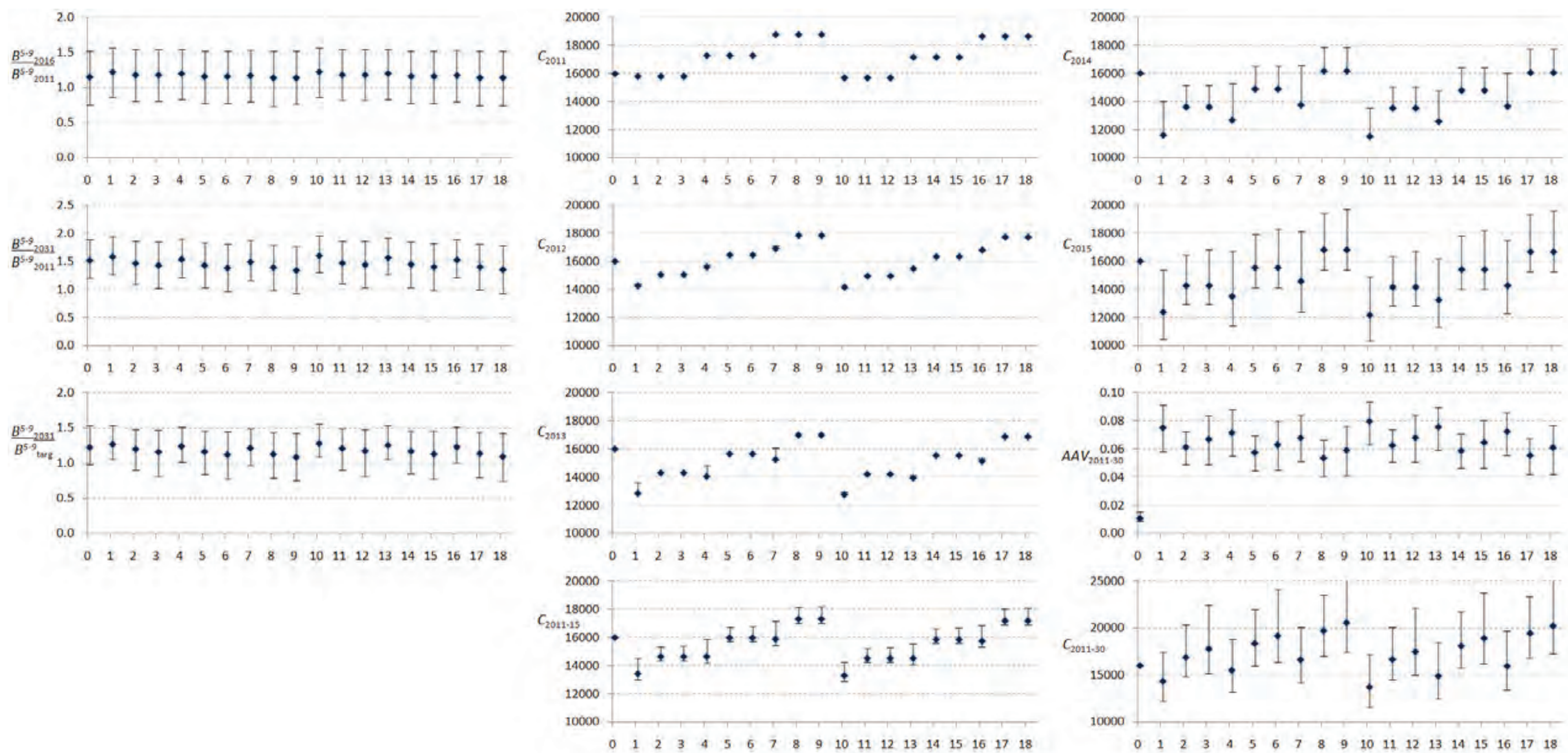

Fig. 6a: Median and 95%-iles for a series of performance statistics for the Base Case SCAA under a series of MPs (0=cteC; 1=mp1, 2=mp2...).

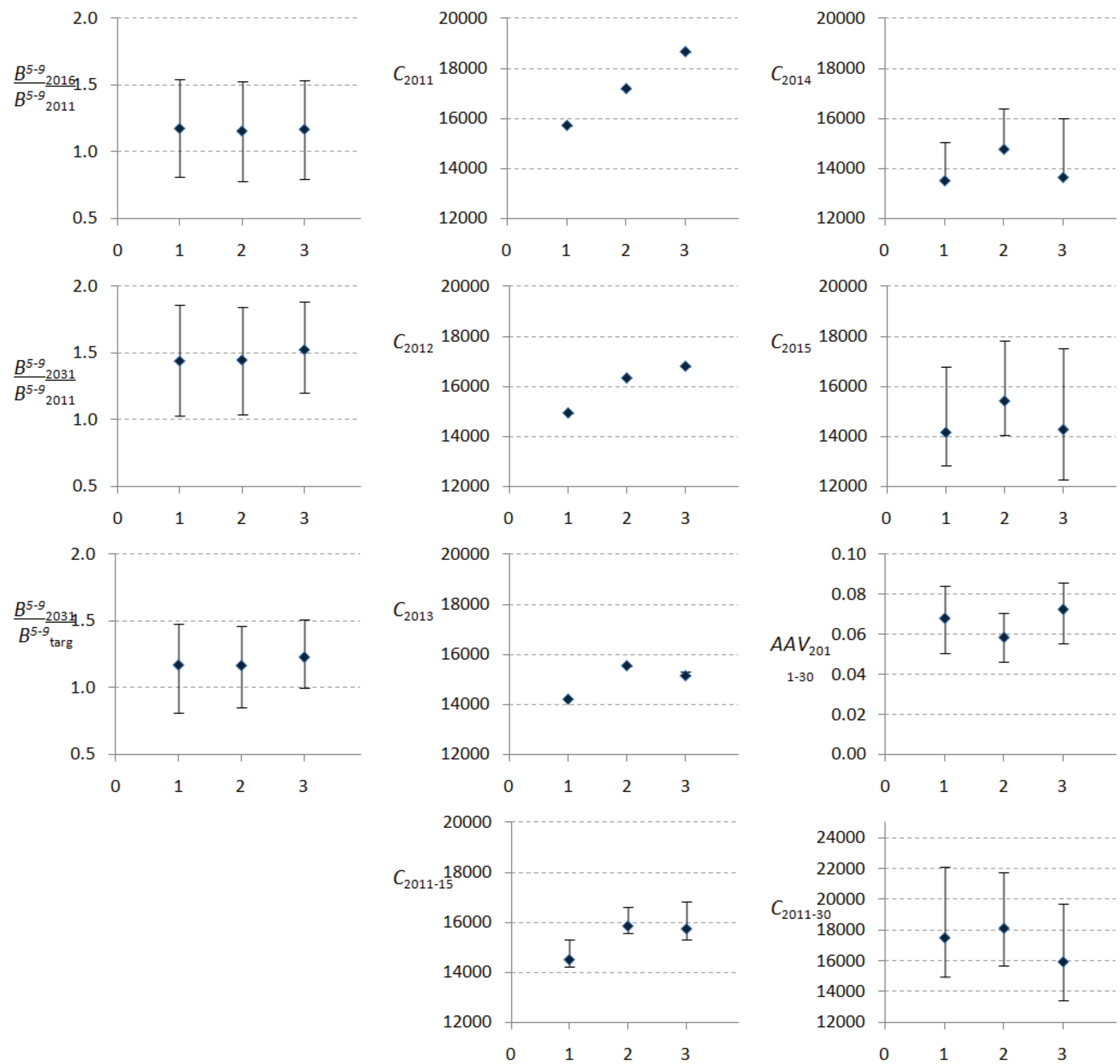

Fig. 6b: Median and 95%-iles for a series of performance statistics for the Base Case SCAA under mp12, mp14 and mp16 (in that order).

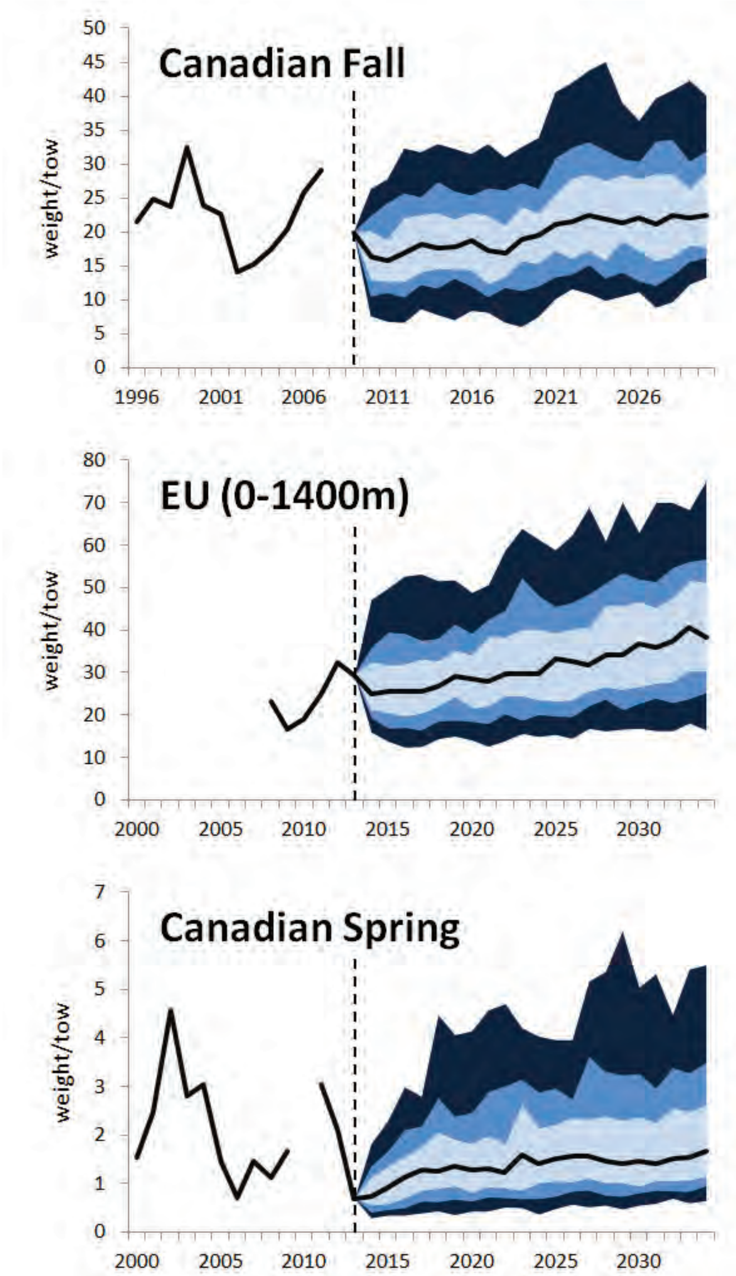

Fig. 7: 95, 75 and 50% PIs and medians for the survey projections for SCAA0 under implementation of mp14.

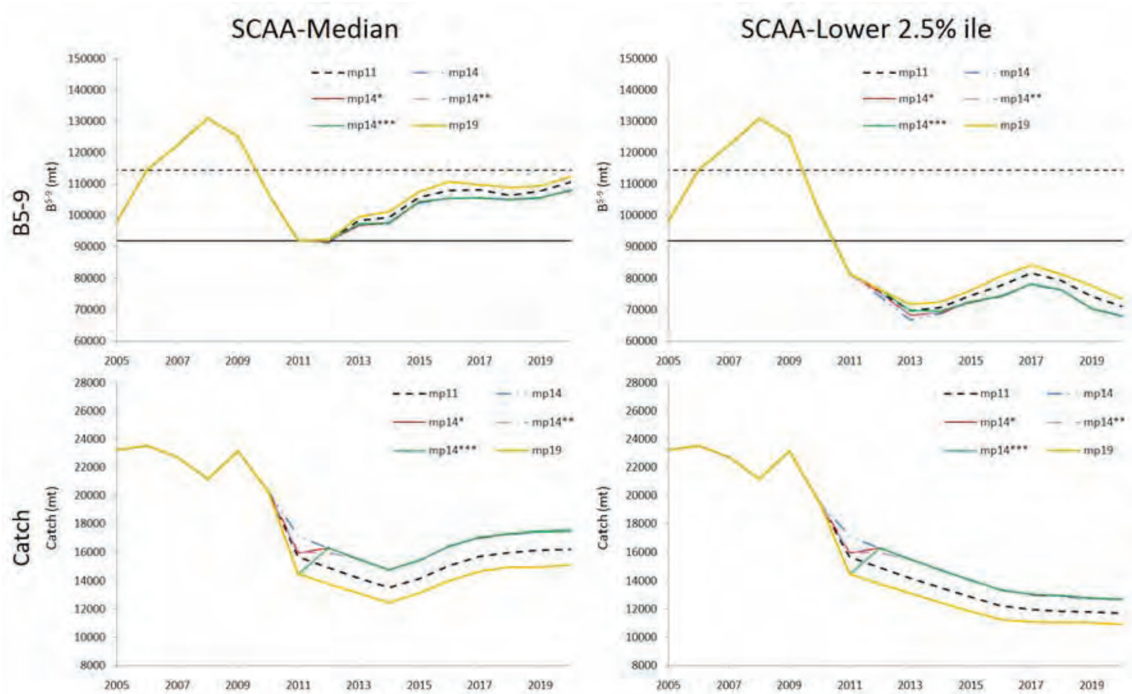

Fig. 8: Medians (left) and lower 2.5%iles (right) TAC and exploitable biomass for some further MPs (requested for addition by our EU principals) for the **Base Case SCAA** operating model (SCAA0). Here and in subsequent biomass plots the full horizontal line represents the 2011 median level while the dashed horizontal line represents the target level (1985-1999 average).

(FCWGMSE WP 10/14)

Greenland Halibut Updated SCAA Reference Case and Robustness Tests

DS Butterworth and RA Rademeyer
August 2010

INTRODUCTION

The Greenland halibut SCAA Reference Case (RC) and robustness test operating models (Butterworth and Rademeyer, 2010a) have been updated to take into account data now available up to 2009. The updated data (Appendix A) are:

1) 2008 and 2009 catches (Table A1) (Healey *et al*. 2010);
2) 2008 and 2009 commercial catches-at-age (Table A2) (Healey *et al.* 2010);
3) updated weights-at-age to age 20 (Table A3) (ages 1-13, Healey *et al.* 2010; ages 14-20+, Miller, pers. commn);
4) updated maturity-at-age to age 20 (Table A4) (Morgan, pers. commn);
5) 2008 and 2009 survey data: numbers-at-age (Table A5) and total weight per tow (Table A6).

The EU summer survey has been split into two series in order to make use of the deep-water portion (0-1400m) of the survey which has taken place since 2004. The model is therefore fit to four survey series: a) Canadian Fall survey (2J3K) (1996-2009), b) Canadian Spring survey (3LNO) (1996-2009), c) EU summer 0-700m survey (1995-2003) and d) EU summer 0-1400m survey (2004-2009).

In fitting the survey CAA, the plus and minus groups have been changed slightly compared to the assessments presented in Butterworth and Rademeyer (2010a). The table below compares the plus and minus groups used in each instance. The splitting of The EU survey series prompted the one change; the change for the Canadian Fall series was made because of the small proportions of fish in the age classes above 8.

	Butterworth and Rademeyer (2010a)		Updated assessment	
	minus	plus	minus	plus
Canadian Fall	1	13	1	8
EU (0-700m)	1	11	1	9
EU (0-1400m)	-	-	4	11
Canadian Spring	1	8	1	8

Furthermore a selectivity smoothing penalty has been included in the negative log likelihood:

$$PenS = \sum_i \sum_{a=a^-+1}^{a^+-1} 3\left(S_{a-1}^i - 2S_a^i + S_{a+1}^i\right)^2 + \sum_{a=a^-+1}^{a^+-1} 3\left(S_{a-1}^{com} - 2S_a^{com} + S_{a+1}^{com}\right)^2$$

where

S_a^i is the selectivity at age *a* for survey *i* (before adding variability);

S_a^{com} is the commercial selectivity at age *a* (before adding variability); and

a^- and a^+ are the minus and plus groups.

This addition was prompted by the large upward spike that otherwise occurs in selectivity at age 10 for the EU (0-1400m) survey. Introduction of this term hardly affects estimates of abundance trends.

In other respects the structure of these operating models remains identical to that detailed In Appendix B of Butterworth and Rademeyer (2009a), with two updates detailed in Butterworth and Rademeyer (2009b). In particular note that first order autocorrelation in time is estimated in fitting to the survey indices of abundance, and similarly in both time and age in fitting to the survey catch-at-age proportions. Fishing selectivity functions change at two-yearly intervals, with the extent of the change constrained by treating these as random effects with standard deviation σ_Ω = 2.0 for the commercial selectivity and σ_Ω = 0.5 for the survey selectivities.

RESULTS AND DISCUSSION

The following SCAA Reference Case (RC) and robustness test operating models for the Greenland Halibut, which are straightforward updates of those reported in Butterworth and Rademeyer (2010a), will be used in the MSE process.

0) Reference Case: Update of Case 2 of Butterworth and Rademeyer (2010b): Beverton-Holt, h=0.9, M=0.2, exponential decrease in selectivity for ages 11+;

1) RC with flat commercial selectivity (estimated in the fit to be 0.27) for ages 11+;

2) RC with flat commercial selectivity (fixed to 0.3, which is equal to the new XSA average value over 2005-2009) for ages 11+;

3) RC with M=0.1;

4) RC with M=0.2 for ages 0-10, linear increase to M=0.4 for age 14, and constant thereafter;

5) RC with h = 0.6 in the assessment, to simulate a stock that has a large maximum recruitment which has been severely recruitment-overfished;

6) RC with a modified Ricker stock-recruitment relationship: $R_y = \alpha B_y^{sp} \exp\left(-\beta \left(B_y^{sp}\right)^\gamma\right)$;

7) RC with fixed flat commercial selectivity (as in 2 above) and increasing M with age (as in 4 above).

The results of the SCAA variants explored are listed in Table 1, with corresponding biomass trajectories plotted in Fig. 1 and stock-recruitment relationships shown in Fig. 2. Results for the RC presented in Butterworth and Rademeyer (2010a) are shown in Table 1 and Fig. 1 for comparative purposes. The commercial and survey selectivities estimated in the RC are plotted in Fig. 3. The commercial selectivities of the two OMs with flat selectivity at older ages are also shown in Fig. 3. The RC stock-recruitment curve, and time series of recruitment and standardised recruitment residuals are shown in Fig. 4. The fit of the RC to the survey indices and the commercial and survey CAA are shown in Fig. 5. It is notable that these CAA residual plots (which are outputs after adjustment for auto-correlation) all now show few obvious and substantial patterns, and thus constitute a considerable improvement over results for this SCAA methodology (Butterworth and Rademeyer, 2009b) prior to this update of the data.

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Butterworth DS and Rademeyer RA. 2010b. A comparison between XSA and SCAA assessments of Greenland Halibut based on the same input data. (Report provided to the NAFO Secretariat and SC Chair)

Healey BP, Mahé J-C and Morgan MJ. 2010. An assessment of Greenland Halibut (*Reinhardtius hippoglossoides*) in NAFO Subarea 2 and Divisions 3KLMNO. NAFO SCR Doc. 10/40, Ser. No. N5799.

Table 1: Results of fits of SCAA Reference Case and the intended robustness test operating models to the commercial catch and survey data. Values fixed on input rather than estimated are shown in **bold**. Quantities shown in parenthesis are Hessian-based CVs. Where autocorrelation coefficients are shown for fits to the survey catch-at-age proportions, they correspond to the following order of the surveys: Canadian Fall, EU 0-700m, EU 0-1400m and Canadian spring

	0prev) Butterworth and Rademeyer (2010a) Reference Case	0) Reference Case	1) flat commercial selectivitiy for ages 11+ estimated	2) flat commercial selectivity for ages 11+ fixed to XSA value	3) M = 0.1	4) M_{10-}=0.2, M_{14+}=0.4, linear in between	5) h =0.6	6) Modified Ricker	7) fixed flat comm. sel. for ages 11+ (as in 2) and increasing M with age (as in 4)
'-lnL:overall	-630.8	-701.0	-694.4	-690.6	-698.4	-701.6	-697.7	-703.3	-693.8
'-lnL:Survey	-29.9	-36.0	-36.8	-36.5	-31.4	-36.8	-37.8	-34.2	-36.6
'-lnL:CAA	-222.8	-231.6	-230.1	-218.3	-231.8	-232.0	-230.7	-235.1	-222.4
'-lnL:CAAsurv	-462.8	-531.1	-530.7	-530.6	-532.8	-530.8	-528.3	-532.1	-531.3
'-lnL:RecRes	17.6	18.9	19.2	19.9	17.7	20.0	18.7	17.1	20.8
'-lnL:SelPen	67.0	73.2	77.2	69.6	73.8	72.7	74.7	75.2	70.2
SelSmoothing	-	5.6	-	-	-	-	-	-	-
h	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**	**0.60**	**1.43**	**0.90**
M	**0.20**	**0.20**	**0.20**	**0.20**	**0.10**	**0.20**	**0.20**	**0.20**	**0.20**
θ	0.31	0.24	0.13	0.05	0.26	0.25	0.45	0.22	0.14
ϕ	0.28	0.29	0.34	0.42	0.30	0.30	0.16	0.37	0.35
ρ - surveys	0.60	0.57	0.54	0.53	0.64	0.53	0.53	0.63	0.55
ρ_{CAAage}	0.28 0.35 0.35	0.48 0.31 0.31 0.23	0.48 0.30 0.32 0.23	0.48 0.31 0.32 0.22	0.48 0.30 0.32 0.24	0.48 0.31 0.32 0.23	0.48 0.31 0.31 0.23	0.48 0.31 0.31 0.22	0.48 0.31 0.32 0.23
ρ_{CAAyr}	-0.32 -0.49 -0.49	-0.68 -0.26 -0.91 -0.59	-0.68 -0.26 -0.90 -0.58	-0.68 -0.25 -0.91 -0.59	-0.68 -0.26 -0.90 -0.60	-0.68 -0.27 -0.90 -0.58	-0.68 -0.26 -0.87 -0.56	-0.68 -0.26 -0.91 -0.59	-0.68 -0.27 -0.91 -0.59
K^{sp}	340	439 (0.06)	422 (0.08)	535 (0.07)	1754 (0.07)	166 (0.05)	557 (0.19)	304 (0.21)	174 (0.05)
B^{sp}_{2009}	37	21 (0.34)	16 (0.33)	12 (0.18)	169 (0.40)	8 (0.30)	42 (0.27)	22 (0.46)	8 (0.20)
$B^{5\text{-}9}_{2009}$	128	126 (0.11)	109 (0.11)	106 (0.09)	131 (0.13)	115 (0.12)	114 (0.12)	142 (0.15)	120 (0.08)
B^{10+}_{2009}	53	46 (0.25)	38 (0.24)	32 (0.16)	206 (0.37)	30 (0.22)	68 (0.24)	51 (0.30)	31 (0.17)
$MSYL^{sp}$	0.18	0.15 (0.15)	0.16 (0.16)	0.17 (0.06)	0.17 (0.13)	0.16 (0.14)	0.28 (0.09)	0.24 (0.23)	0.16 (0.07)
B^{sp}_{MSY}	60	67 (0.17)	69 (0.16)	89 (0.09)	291 (0.17)	26 (0.15)	157 (0.20)	72 (0.20)	28 (0.09)
MSY	27	26 (0.06)	26 (0.09)	34 (0.07)	27 (0.06)	27 (0.05)	19 (0.19)	31 (0.10)	29 (0.05)
σ_{comCAA}	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Survey	q's x10^6 σ_{surv} $\sigma_{survCAA}$	q's x10^6 σ_{surv} $\sigma_{survCAA}$	q's x10^6 σ_{surv} $\sigma_{survCAA}$	q's x10^6 σ_{surv} $\sigma_{survCAA}$	q's x10^6 σ_{surv} $\sigma_{survCAA}$	q's x10^6 σ_{surv} $\sigma_{survCAA}$	q's x10^6 σ_{surv} $\sigma_{survCAA}$	q's x10^6 σ_{surv} $\sigma_{survCAA}$	q's x10^6 σ_{surv} $\sigma_{survCAA}$
CanFall	421 0.17 0.02	451 0.15 0.02	494 0.14 0.02	501 0.14 0.02	670 0.20 0.02	468 0.14 0.02	469 0.14 0.02	426 0.16 0.02	462 0.14 0.02
EU (0-700m)	219 0.28 0.05	349 0.28 0.05	365 0.28 0.05	375 0.29 0.05	366 0.29 0.05	349 0.28 0.05	291 0.24 0.05	359 0.30 0.05	347 0.28 0.05
EU (0-1400m)	- - -	347 0.22 0.02	386 0.23 0.02	398 0.23 0.02	318 0.25 0.02	371 0.23 0.02	345 0.24 0.02	317 0.22 0.02	363 0.22 0.02
CanSpr	22 0.41 0.05	27 0.46 0.05	29 0.45 0.05	29 0.45 0.05	34 0.47 0.05	28 0.45 0.05	27 0.44 0.05	26 0.47 0.05	28 0.45 0.05
σ_R_out	0.21	0.21	0.22	0.22	0.21	0.22	0.21	0.20	0.22

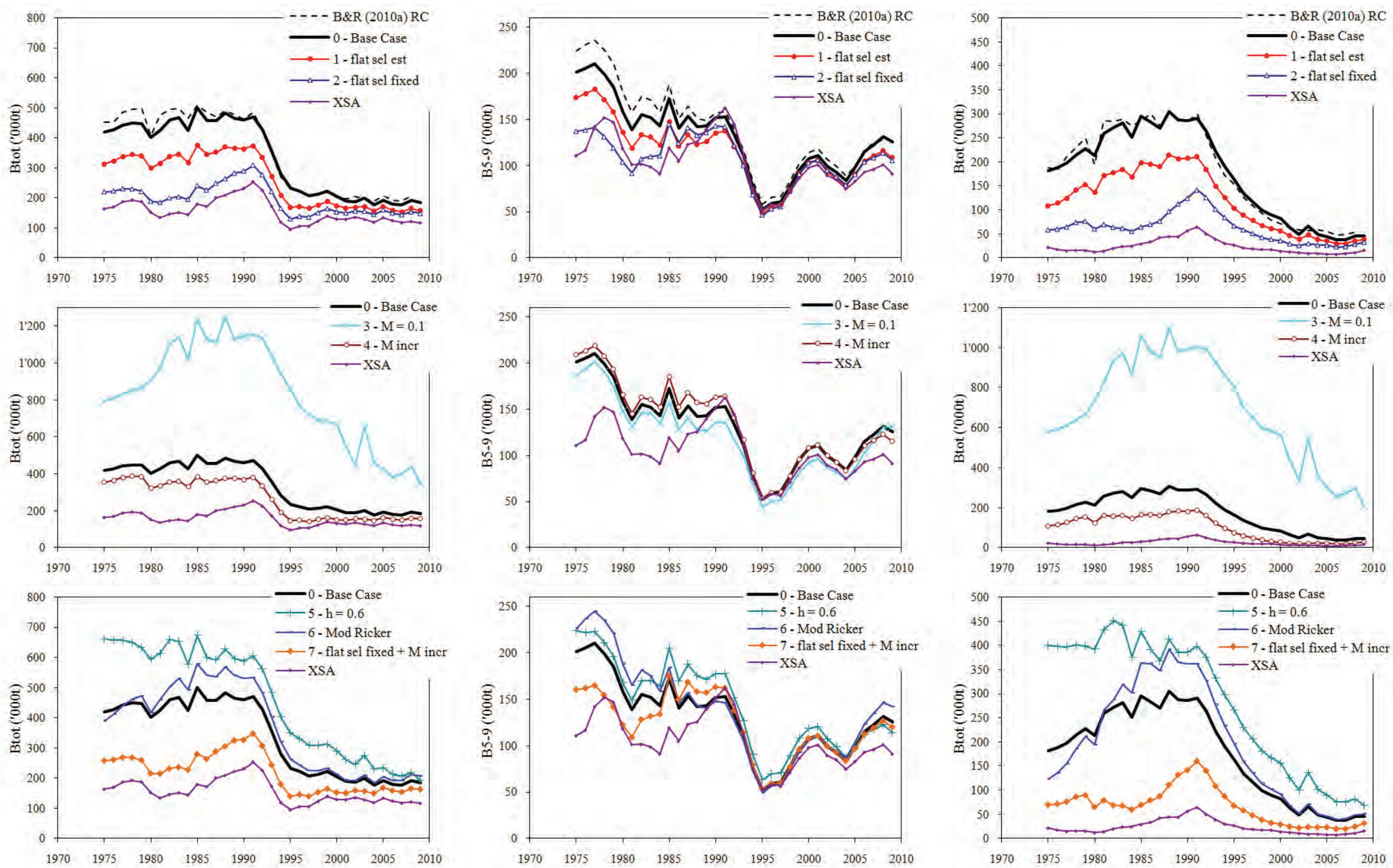

Fig. 1: Biomass trajectories for a series of SCAA variants and the 2009 XSA (Healey *et al*. 2010).

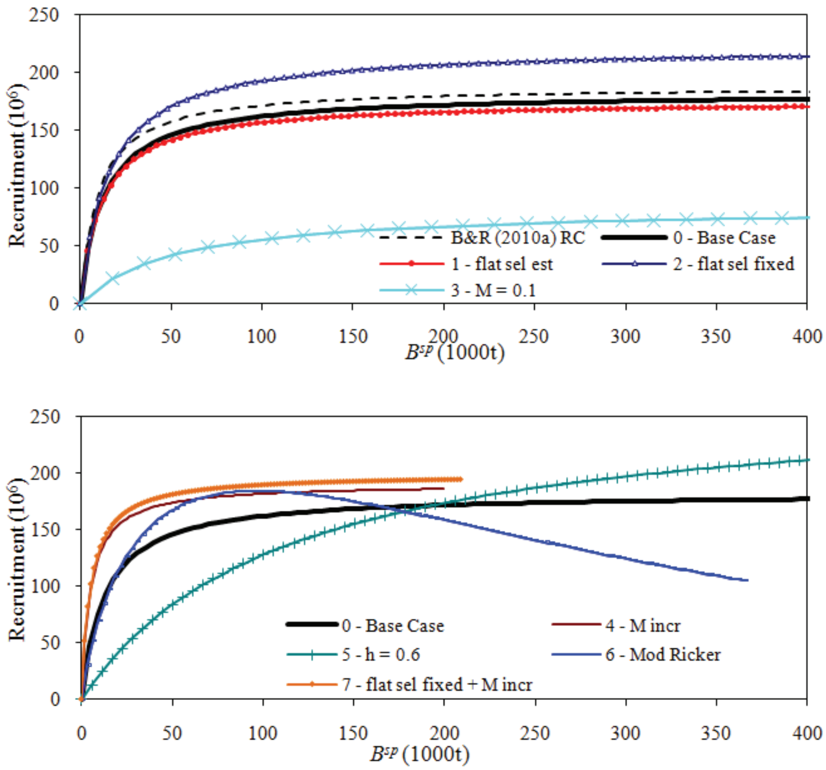

Fig. 2: Stock-recruitment relationships for a series of SCAA variants.

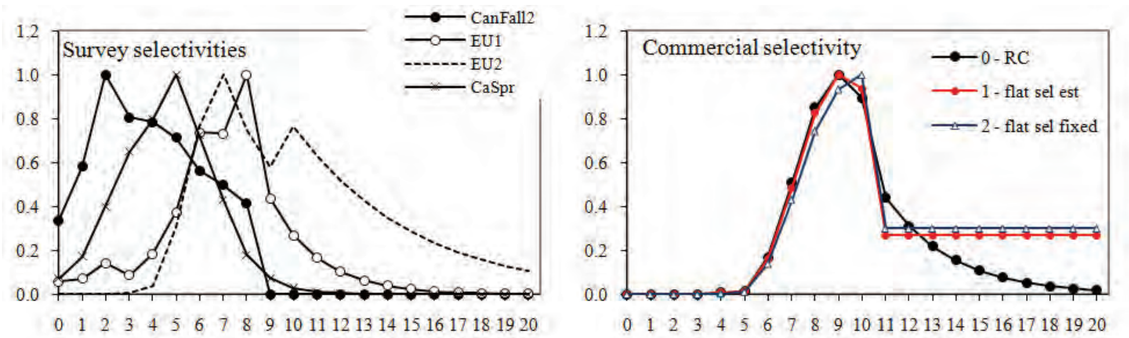

Fig. 3: Survey and commercial selectivities-at-age estimated for the RC. Commercial selectivity estimates are also shown for robustness tests 1) and 2) for which selectivity is flat for ages 11+.

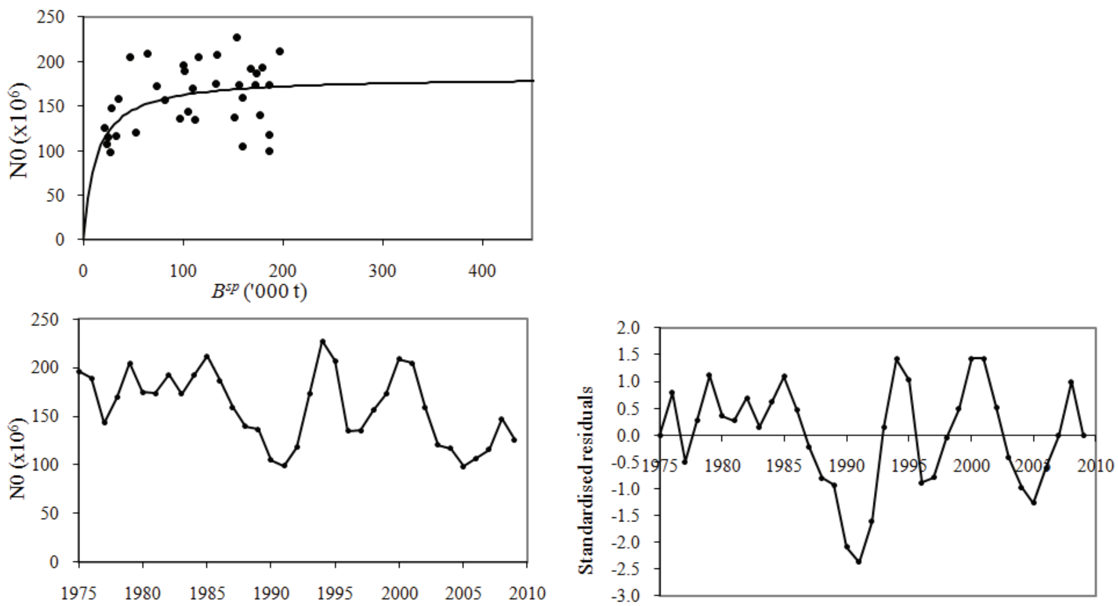

Fig. 4: Estimated stock-recruitment curve, and time series of recruitment and standardised residuals for the RC.

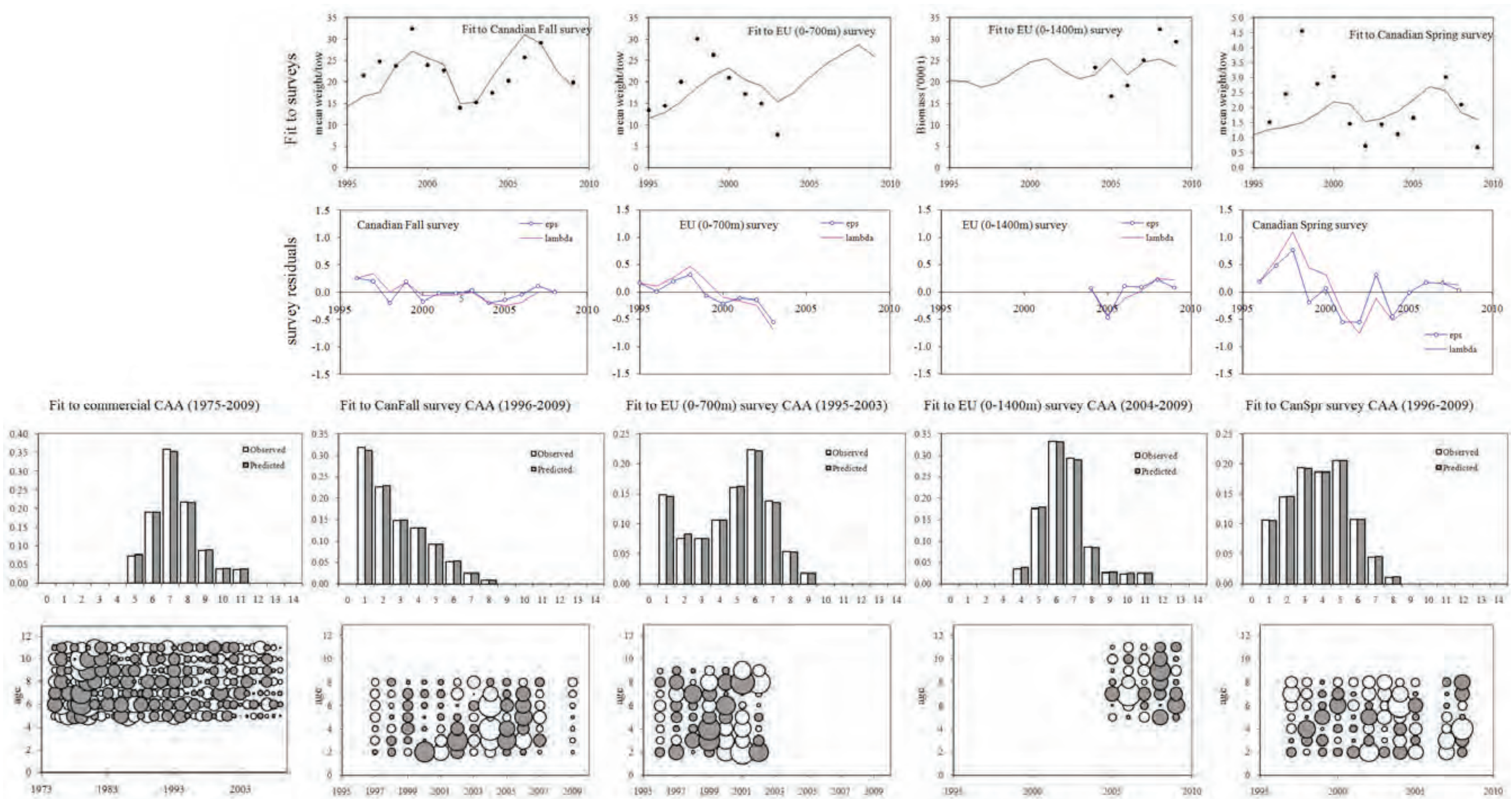

Fig. 5: Fit of the RC to the survey indices and the commercial and survey CAA. For the survey index residuals, lambda and eps refer respectively to before and after adjusting for the estimated autocorrelation. For the CAA bubble plots of residuals for the surveys, these also pertain to values after adjustment for estimated autocorrelation in both year and age. The size (area) of the bubbles are proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.

APPENDIX A – Data

Table A1: Landings (tons) for Greenland Halibut in Sub-area 2 and Div. 3KLMNO (Healey *et al*. 2010).

Year	Landings (t)	Year	Landings (t)
1960	938	1985	20347
1961	741	1986	17976
1962	588	1987	32442
1963	1621	1988	19215
1964	4252	1989	20034
1965	10069	1990	47454
1966	19276	1991	65008
1967	26525	1992	63193
1968	32392	1993	62455
1969	37275	1994	51029
1970	36889	1995	15272
1971	24834	1996	18840
1972	30038	1997	19858
1973	29105	1998	19946
1974	27588	1999	24226
1975	28814	2000	34177
1976	24611	2001	38232
1977	32048	2002	34062
1978	39070	2003	35151
1979	34104	2004	25486
1980	32867	2005	23225
1981	30754	2006	23531
1982	26278	2007	22747
1983	27861	2008	21178
1984	26711	2009	23156

Table A2. Catch at age matrix (000s) for Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO (Healey *et al*. 2010).

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14+
1975	0	0	0	0	334	2819	5750	4956	3961	1688	702	135	279	288
1976	0	0	0	0	17	610	3231	5413	3769	2205	829	260	101	53
1977	0	0	0	0	534	5012	10798	7346	2933	1013	220	130	116	84
1978	0	0	0	0	2982	8415	8970	7576	2865	1438	723	367	222	258
1979	0	0	0	0	2386	8727	12824	6136	1169	481	287	149	143	284
1980	0	0	0	0	209	2086	9150	9679	5398	3828	1013	128	53	27
1981	0	0	0	0	863	4517	9806	11451	4307	890	256	142	43	69
1982	0	0	0	0	269	2299	6319	5763	3542	1684	596	256	163	191
1983	0	0	0	0	701	3557	9800	7514	2295	692	209	76	106	175
1984	0	0	0	0	902	2324	5844	7682	4087	1259	407	143	106	183
1985	0	0	0	0	1983	5309	5913	3500	1380	512	159	99	87	86
1986	0	0	0	0	280	2240	6411	5091	1469	471	244	140	70	117
1987	0	0	0	0	137	1902	11004	8935	2835	853	384	281	225	349
1988	0	0	0	0	296	3186	8136	4380	1288	465	201	105	107	129
1989	0	0	0	0	181	1988	7480	4273	1482	767	438	267	145	71
1990	0	0	0	95	1102	6758	12632	7557	4072	2692	1204	885	434	318
1991	0	0	0	220	2862	7756	13152	10796	7145	3721	1865	1216	558	422
1992	0	0	0	1064	4180	10922	20639	12205	4332	1762	1012	738	395	335
1993	0	0	0	1010	9570	15928	17716	11918	4642	1836	1055	964	401	182
1994	0	0	0	5395	16500	15815	11142	6739	3081	1103	811	422	320	215
1995	0	0	0	323	1352	2342	3201	2130	1183	540	345	273	251	201
1996	0	0	0	190	1659	5197	6387	1914	956	504	436	233	143	89
1997	0	0	0	335	1903	4169	7544	3215	1139	606	420	246	137	89
1998	0	0	0	552	3575	5407	5787	3653	1435	541	377	161	92	51
1999	0	0	0	297	2149	5625	8611	3793	1659	623	343	306	145	151
2000	0	0	0	271	2029	12583	21175	3299	973	528	368	203	129	104
2001	0	0	0	448	2239	12163	22122	5154	1010	495	439	203	156	75
2002	0	0	0	479	1662	7239	17581	6607	1244	659	360	224	126	81
2003	0	0	0	1279	4491	10723	16764	6385	1614	516	290	144	76	85
2004	0	0	0	897	4062	8236	10542	4126	1307	529	289	184	87	75
2005	0	0	0	534	1652	5999	10313	3996	1410	444	244	114	64	46
2006	0	0	0	216	1869	6450	12144	4902	1089	372	136	47	32	40
2007	0	0	0	88	570	3732	11912	5414	1230	472	163	80	41	29
2008	0	0	0	29	448	3312	10697	5558	1453	393	115	46	26	15
2009	0	0	0	61	476	3121	8801	7276	1949	508	206	67	31	34

Table A3. Catch weights-at-age (kg) matrix for Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO (ages 1-13: Healey *et al*. 2010; ages 14-20+: Miller pers. commn).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1975	0.000	0.000	0.126	0.244	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	4.560	5.920	7.140	7.890	8.916	9.718	10.204
1976	0.000	0.000	0.126	0.244	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	4.560	5.920	7.140	7.890	8.916	9.718	10.204
1977	0.000	0.000	0.126	0.244	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	4.560	5.920	7.140	7.890	8.916	9.718	10.204
1978	0.000	0.000	0.126	0.244	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	4.560	5.920	7.140	7.890	8.916	9.718	10.204
1979	0.000	0.000	0.126	0.244	0.609	0.760	0.955	1.190	1.580	2.210	2.700	3.370	3.880	4.560	5.920	7.140	7.890	8.916	9.718	10.204
1980	0.000	0.000	0.126	0.244	0.514	0.659	0.869	1.050	1.150	1.260	1.570	2.710	3.120	4.420	5.040	7.020	10.100	11.413	12.440	13.062
1981	0.000	0.000	0.126	0.244	0.392	0.598	0.789	0.985	1.240	1.700	2.460	3.510	4.790	5.940	8.060	8.710	9.580	10.825	11.800	12.390
1982	0.000	0.000	0.126	0.244	0.525	0.684	0.891	1.130	1.400	1.790	2.380	3.470	4.510	5.850	7.530	8.680	11.500	12.995	14.165	14.873
1983	0.000	0.000	0.126	0.244	0.412	0.629	0.861	1.180	1.650	2.230	3.010	3.960	5.060	6.060	7.310	8.600	11.300	12.769	13.918	14.614
1984	0.000	0.000	0.126	0.244	0.377	0.583	0.826	1.100	1.460	1.940	2.630	3.490	4.490	5.730	6.850	8.330	9.570	10.814	11.787	12.377
1985	0.000	0.000	0.126	0.244	0.568	0.749	0.941	1.240	1.690	2.240	2.950	3.710	4.850	6.130	7.160	8.920	11.800	13.334	14.534	15.261
1986	0.000	0.000	0.126	0.244	0.350	0.584	0.811	1.100	1.580	2.120	2.890	3.890	4.950	6.090	7.640	9.810	10.100	11.413	12.440	13.062
1987	0.000	0.000	0.126	0.244	0.364	0.589	0.836	1.160	1.590	2.130	2.820	3.600	4.630	5.480	6.670	7.850	9.840	11.119	12.120	12.726
1988	0.000	0.000	0.126	0.244	0.363	0.569	0.805	1.163	1.661	2.216	3.007	3.925	5.091	5.858	7.233	8.485	11.444	12.932	14.096	14.800
1989	0.000	0.000	0.126	0.244	0.400	0.561	0.767	1.082	1.657	2.237	2.997	3.862	4.919	5.812	7.002	7.547	9.659	10.915	11.897	12.492
1990	0.000	0.000	0.090	0.181	0.338	0.546	0.766	1.119	1.608	2.173	2.854	3.731	4.691	5.686	7.082	8.776	9.826	11.103	12.102	12.707
1991	0.000	0.000	0.126	0.244	0.383	0.592	0.831	1.228	1.811	2.461	3.309	4.142	5.333	6.189	7.301	9.363	9.546	10.787	11.758	12.346
1992	0.000	0.000	0.175	0.289	0.430	0.577	0.793	1.234	1.816	2.462	3.122	3.972	5.099	6.197	7.170	8.267	10.057	11.364	12.387	13.006
1993	0.000	0.000	0.134	0.232	0.368	0.547	0.809	1.207	1.728	2.309	2.999	3.965	4.816	5.917	7.151	8.487	9.793	11.066	12.062	12.665
1994	0.000	0.000	0.080	0.196	0.330	0.514	0.788	1.179	1.701	2.268	2.990	3.766	4.882	5.984	7.540	7.688	9.456	10.685	11.647	12.229
1995	0.000	0.000	0.080	0.288	0.363	0.531	0.808	1.202	1.759	2.446	3.122	3.813	4.893	5.957	6.928	7.471	9.311	10.521	11.468	12.042
1996	0.000	0.000	0.161	0.242	0.360	0.541	0.832	1.272	1.801	2.478	3.148	3.856	4.953	5.876	6.848	7.946	8.369	9.456	10.307	10.823
1997	0.000	0.000	0.120	0.206	0.336	0.489	0.771	1.159	1.727	2.355	3.053	3.953	5.108	5.914	6.633	8.280	8.290	9.368	10.211	10.721
1998	0.000	0.000	0.119	0.228	0.373	0.543	0.810	1.203	1.754	2.351	3.095	4.010	5.132	5.884	6.445	7.269	8.218	9.286	10.122	10.628
1999	0.000	0.000	0.176	0.253	0.358	0.533	0.825	1.253	1.675	2.287	2.888	3.509	4.456	5.195	6.131	7.481	8.623	9.744	10.621	11.152
2000	0.000	0.000	0.000	0.254	0.346	0.524	0.787	1.192	1.774	2.279	2.895	3.645	4.486	5.082	5.909	6.919	8.363	10.157	11.071	11.625
2001	0.000	0.000	0.000	0.249	0.376	0.570	0.830	1.168	1.794	2.367	2.950	3.715	4.585	5.075	6.129	7.196	7.433	8.400	9.156	9.613
2002	0.000	0.000	0.217	0.251	0.369	0.557	0.841	1.193	1.760	2.277	2.896	3.579	4.407	5.181	5.631	6.584	7.076	7.345	7.426	7.797
2003	0.000	0.000	0.188	0.247	0.389	0.564	0.822	1.199	1.651	2.166	2.700	3.404	4.377	5.296	5.913	6.737	9.566	11.462	12.494	14.408
2004	0.000	0.000	0.180	0.249	0.376	0.535	0.808	1.196	1.629	2.146	2.732	3.538	4.381	5.099	6.127	7.086	7.489	8.463	9.225	9.686
2005	0.000	0.000	0.252	0.301	0.396	0.564	0.849	1.247	1.691	2.177	2.705	3.464	4.264	4.726	5.745	6.576	6.637	7.500	8.328	8.744
2006	0.000	0.000	0.129	0.267	0.405	0.605	0.815	1.092	1.495	1.874	2.396	3.139	3.747	4.298	5.225	6.236	6.603	6.977	7.605	7.985
2007	0.000	0.000	0.000	0.276	0.389	0.581	0.833	1.137	1.500	1.948	2.607	3.057	3.869	4.579	5.294	5.437	7.088	8.009	8.730	9.167
2008	0.000	0.000	0.000	0.278	0.404	0.617	0.891	1.195	1.605	2.038	2.804	3.247	4.232	4.400	5.800	6.831	8.014	9.056	9.871	10.364
2009	0.000	0.000	0.000	0.279	0.390	0.599	0.862	1.158	1.611	2.099	2.549	3.118	3.432	3.856	4.776	5.596	5.089	5.751	6.268	6.582

Table A4: Proportion mature-at-age for Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO (Morgan pers. commn).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1975	0.000	0.001	0.001	0.001	0.007	0.003	0.010	0.036	0.037	0.027	0.119	0.205	0.335	0.501	0.666	0.796	0.883	0.934	0.964	0.980
1976	0.000	0.000	0.001	0.001	0.002	0.012	0.006	0.020	0.063	0.067	0.064	0.205	0.335	0.501	0.666	0.796	0.883	0.934	0.964	0.980
1977	0.000	0.000	0.000	0.002	0.002	0.004	0.022	0.013	0.041	0.107	0.117	0.143	0.335	0.501	0.666	0.796	0.883	0.934	0.964	0.980
1978	0.000	0.000	0.000	0.001	0.004	0.005	0.009	0.038	0.029	0.083	0.177	0.196	0.290	0.501	0.666	0.796	0.883	0.934	0.964	0.980
1979	0.000	0.000	0.000	0.001	0.002	0.007	0.009	0.018	0.064	0.060	0.158	0.277	0.310	0.499	0.666	0.796	0.883	0.934	0.964	0.980
1980	0.000	0.000	0.000	0.000	0.001	0.003	0.012	0.017	0.036	0.108	0.123	0.282	0.406	0.453	0.709	0.796	0.883	0.934	0.964	0.980
1981	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.021	0.034	0.070	0.177	0.232	0.451	0.549	0.604	0.856	0.883	0.934	0.964	0.980
1982	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.011	0.038	0.064	0.132	0.275	0.397	0.632	0.685	0.738	0.936	0.934	0.964	0.980
1983	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.008	0.021	0.067	0.119	0.236	0.401	0.588	0.782	0.795	0.839	0.973	0.964	0.980
1984	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.016	0.039	0.114	0.211	0.384	0.542	0.756	0.882	0.874	0.905	0.989	0.980
1985	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.008	0.029	0.071	0.190	0.345	0.558	0.676	0.870	0.940	0.925	0.946	0.995
1986	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.023	0.054	0.126	0.297	0.509	0.719	0.787	0.936	0.970	0.957	0.970
1987	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.002	0.015	0.060	0.099	0.215	0.434	0.672	0.838	0.867	0.969	0.986	0.975
1988	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.005	0.000	0.006	0.038	0.152	0.173	0.343	0.581	0.801	0.913	0.920	0.986	0.993
1989	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.015	0.001	0.023	0.092	0.332	0.285	0.498	0.715	0.888	0.955	0.953	0.993
1990	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.007	0.051	0.158	0.081	0.209	0.581	0.432	0.653	0.820	0.940	0.977	0.973
1991	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.010	0.017	0.154	0.971	0.249	0.406	0.794	0.592	0.781	0.892	0.969	0.989
1992	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.007	0.032	0.045	0.384	1.000	0.557	0.640	0.915	0.735	0.872	0.937	0.984
1993	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.003	0.021	0.097	0.111	0.680	1.000	0.826	0.822	0.968	0.841	0.928	0.964
1994	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.007	0.010	0.062	0.257	0.250	0.879	1.000	0.947	0.923	0.988	0.910	0.961
1995	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.017	0.028	0.168	0.526	0.471	0.961	1.000	0.986	0.969	0.996	0.951
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.016	0.041	0.079	0.364	0.781	0.703	0.988	1.000	0.996	0.988	0.998
1997	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.014	0.039	0.097	0.203	0.606	0.920	0.864	0.997	1.000	0.999	0.995
1998	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002	0.002	0.037	0.095	0.213	0.430	0.806	0.974	0.944	0.999	1.000	1.000
1999	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.004	0.001	0.009	0.017	0.092	0.212	0.405	0.692	0.922	0.992	0.978	1.000	1.000
2000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.011	0.009	0.042	0.124	0.211	0.409	0.632	0.870	0.972	0.997	0.992	1.000
2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.009	0.028	0.069	0.181	0.533	0.412	0.640	0.812	0.952	0.990	0.999	0.997
2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.007	0.026	0.070	0.364	0.529	0.902	0.648	0.820	0.916	0.983	0.997	1.000
2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.006	0.024	0.072	0.166	0.817	0.851	0.987	0.829	0.921	0.965	0.994	0.999
2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.005	0.022	0.074	0.188	0.346	0.972	0.967	0.998	0.927	0.968	0.986	0.998
2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.020	0.076	0.209	0.406	0.584	0.996	0.993	1.000	0.971	0.987	0.994
2006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.022	0.078	0.234	0.466	0.663	0.788	1.000	0.999	1.000	0.989	0.995
2007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.022	0.076	0.259	0.529	0.742	0.846	0.908	1.000	1.000	1.000	0.996
2008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.022	0.076	0.234	0.592	0.800	0.905	0.938	0.963	1.000	1.000	1.000
2009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.022	0.076	0.234	0.529	0.858	0.933	0.969	0.977	0.986	1.000	1.000

Table A5: Survey data (mean numbers per tow) of Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO (Healey *et al*. 2010)

2J3K Canadian Fall, 1995-2009

	1	2	3	4	5	6	7	8	9	10	11	12	13+
1996	98.68	47.82	32.01	9.54	6.28	2.47	0.84	0.19	0.18	0.04	0.02	0.01	0.02
1997	28.05	58.62	43.61	21.13	10.37	5.01	2.00	0.64	0.20	0.06	0.03	0.02	0.01
1998	23.35	25.07	31.19	21.87	10.86	4.45	2.07	0.57	0.13	0.06	0.03	0.02	0.02
1999	15.99	34.42	24.07	28.28	20.04	10.53	3.81	0.70	0.14	0.07	0.02	0.01	0.03
2000	38.57	21.94	16.43	13.20	13.76	7.21	2.16	0.50	0.06	0.03	0.02	0.00	0.01
2001	43.90	22.72	17.00	14.07	9.77	7.59	3.40	0.69	0.11	0.02	0.01	0.00	0.01
2002	40.67	24.08	12.50	9.68	6.03	1.97	0.72	0.19	0.04	0.01	0.00	0.00	0.00
2003	45.70	26.67	11.69	9.49	6.39	2.27	0.89	0.27	0.04	0.02	0.01	0.01	0.00
2004	32.49	32.93	13.89	12.31	9.21	2.68	1.20	0.36	0.08	0.03	0.01	0.00	0.01
2005	16.06	16.15	8.56	13.84	10.98	6.85	3.96	0.66	0.12	0.03	0.03	0.01	0.01
2006	32.34	17.98	8.50	17.60	13.03	9.11	4.18	1.15	0.18	0.03	0.02	0.01	0.00
2007	32.61	14.51	12.81	18.77	9.57	10.35	6.17	2.14	0.34	0.08	0.04	0.02	0.01
2008						Survey not completed							
2009	50.62	19.15	11.40	8.42	9.89	5.40	3.59	1.39	0.25	0.08	0.02	0.01	0.01

EU Summer 0-700m, 1995-2003

	1	2	3	4	5	6	7	8	9	10	11	12+
1995	12.41	2.54	2.23	1.91	2.66	5.10	3.77	2.12	1.31	0.26	0.07	0.02
1996	5.84	7.97	2.42	3.04	4.20	5.82	2.49	1.62	0.42	0.09	0.03	0.04
1997	3.33	3.78	6.00	6.50	7.11	8.46	4.99	2.15	0.66	0.22	0.03	0.02
1998	2.74	2.13	7.69	11.00	12.33	11.30	7.84	2.62	0.75	0.20	0.03	0.01
1999	1.06	0.70	3.01	10.47	13.41	12.58	5.55	1.82	0.35	0.10	0.01	0.00
2000	3.75	0.29	0.60	2.17	7.09	14.10	5.40	2.32	0.45	0.11	0.05	0.00
2001	8.03	1.43	1.81	0.99	2.79	7.79	6.63	3.21	0.18	0.05	0.01	0.00
2002	4.08	2.94	2.80	1.67	3.79	5.59	5.73	1.28	0.13	0.06	0.02	0.01
2003	2.20	1.00	0.61	1.51	2.48	2.94	1.93	0.47	0.13	0.10	0.02	0.01

EU Summer 0-1400m, 2004-2009

	1	2	3	4	5	6	7	8	9	10	11	12	13+
2004	1.40	2.19	2.92	1.54	6.80	9.16	4.95	1.46	0.73	0.37	0.26	0.16	0.15
2005	0.36	0.53	2.09	1.73	5.28	6.79	3.42	0.99	0.26	0.41	0.23	0.13	0.06
2006	0.45	0.26	0.44	0.91	5.85	8.56	4.68	1.39	0.42	0.36	0.30	0.15	0.05
2007	0.25	0.05	0.39	0.29	3.84	9.09	8.57	2.88	0.72	0.59	0.30	0.17	0.07
2008	0.13	0.07	0.10	0.16	2.03	9.00	12.53	3.18	1.14	0.87	0.44	0.25	0.13
2009	0.05	0.01	0.03	0.08	1.13	6.80	11.43	3.55	0.93	1.03	0.36	0.28	0.25

3LNO Canadian Spring, 1996-2009

	1	2	3	4	5	6	7	8+
1996	1.62	4.24	4.60	2.18	0.83	0.28	0.06	0.00
1997	1.16	3.92	5.16	3.23	1.46	0.51	0.10	0.01
1998	0.22	0.81	3.85	6.19	4.96	1.24	0.33	0.07
1999	0.29	0.55	1.15	1.98	3.39	1.09	0.24	0.05
2000	0.79	1.07	1.07	1.51	1.95	2.04	0.56	0.03
2001	0.57	0.71	0.74	0.68	0.80	0.72	0.28	0.02
2002	0.64	0.57	0.60	0.58	0.61	0.21	0.05	0.01
2003	0.93	2.14	1.66	1.57	1.06	0.21	0.05	0.01
2004	0.66	0.57	1.18	1.18	1.16	0.26	0.04	0.02
2005	0.35	0.31	1.09	0.95	1.37	0.82	0.21	0.03
2006				Survey not completed				
2007	1.60	0.52	0.80	0.40	1.41	1.49	1.12	0.18
2008	0.44	0.77	0.96	0.71	1.25	0.75	0.64	0.28
2009	0.27	0.22	0.19	0.39	0.45	0.26	0.13	0.07

Table A6: Survey data (kg per tow) for ages combined: 2J3K Fall and 3LNO Spr, and EU summer 0-700m and 0-1400m surveys (Healey pers. commn).

	Canadian Fall 2J3K	EU summer (0-700m)	EU summer (0-1400m)	Canadian Spring 3LNO
1995		13.52		
1996	21.58	14.42		1.53
1997	24.80	20.01		2.46
1998	23.83	30.13		4.56
1999	32.48	26.37		2.81
2000	23.89	21.08		3.04
2001	22.69	17.25		1.46
2002	14.07	15.05		0.72
2003	15.31	7.73		1.45
2004	17.45		23.33	1.12
2005	20.34		16.71	1.67
2006	25.73		19.17	
2007	29.12		25.10	3.03
2008			32.35	2.10
2009	19.88		29.44	0.68

(FCWGMSE WP 10/15)

Candidate Management Procedures Testing Methodology

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August 2010

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 2010 ($N_{2010,a}$: a = 1,…, m) are obtained from the MLE of an assessment of the resource (SCAA or XSA). For SCAA the 2009 catch-at-age data are used in the assessment, whereas for XSA the estimated numbers-at-age at the start of 2009 are projected forward one year using these data. For XSA, the 2009 recruitment ($N_{2009,1}$) is generated deterministically from the estimated stock-recruitment relationship. Error is included for ages 0 to 5 (1 to 5 for XSA) because these are poorly estimated in the assessment given limited information on these year-classes, i.e.:

$$N_{2010,a} \to N_{2010,a} e^{\varepsilon_a} \qquad \varepsilon_a \text{ from } N\left(0,(\sigma_R)^2\right) \tag{1}$$

where σ_R is the standard deviation of the stock-recruitment residuals estimated by the SCAA, and for XSA is estimated in the process of fitting a stock-recruitment relationship to the outputs from that assessment as described below. 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 2010:

$$C_y = 16000\chi_y \qquad \chi_y \text{ from } U(1.27;1.22;1.27;1.42;1.32;1.45) \tag{2}$$

From 2011 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

For SCAA the $C_{y,a}$ values are obtained under the assumption that the commercial selectivity function estimated continues to vary by 2-year block, as assumed in the assessment:

$$S_{y,a} = S_a e^{\Omega_{y,a}} \tag{3}$$

where

$\Omega_{y,a}$ from $N\left(0,(\sigma_\Omega)^2\right)$ for ages 5 to 10,

$\Omega_{y,a} = 0$ for ages 4- and 11+, and

σ_Ω =2.0.

Since the selectivity function varies by 2-year block starting in 1975, $S_{2009,a}$ and $S_{2010,a}$ are equal and already specified and $S_{y,a}$ is generated from the random process above from 2011 onwards.
For XSA, the selectivity each year is selected randomly from the selectivity vectors for the last 10 years (1997 to 2006) estimated in the assessment. The selectivity vectors for 1997 to 2006 are computed as follows:

$$S_{y,a} = F_{y,a} \big/ \max\left(F_{y,a}\right) \tag{4}$$

where the maximum is taken across the ages for that year.

From this it follows that:

$$F_y = C_y \Big/ \sum_a w_{y,a}^{mid} N_{y,a}\, e^{-M_a/2} S_a \tag{5}$$

where $w_{y,a}^{mid}$ is each year selected randomly from the weight-at-age vectors for the last 10 years (2000 to 2009) used in the assessment (Table 1), and hence that:

$$C_{y,a} = N_{y,a}\, e^{-M_a/2} S_a F_y \tag{6}$$

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

$$N_{y+1,1} = R_{y+1} \tag{7}$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_a/2} - C_{y,a}\right) e^{-M_a/2} \qquad \text{for } 1 \le a \le m-2 \tag{8}$$

$$N_{y+1,m} = \left(N_{y,m-1}\, e^{-M_{m-1}/2} - C_{y,m-1}\right) e^{-M_{m-1}/2} + \left(N_{y,m}\, e^{-M_m/2} - C_{y,m}\right) e^{-M_m/2} \tag{9}$$

These equations reflect Pope's approximation. The XSA uses the Baranov equations rather than Pope's approximation; these equations can be adjusted accordingly for XSA projections.
The plus-group *m* is 20 for both the SCAA and XSA.

<u>Step 4</u>: Recruitment

Future recruitments for the reference case SCAA operating model (RC) are provided by a Beverton-Holt stock-recruitment relationship:

$$R_y = \frac{4hR_0 B_y^{sp}}{K^{sp}(1-h) + (5h-1)B_y^{sp}}\, e^{(\varsigma_y - \sigma_R^2/2)} \tag{10}$$

Log-normal fluctuations are introduced by generating ς_y factors from $N\left(0, \sigma_R^2\right)$ where σ_R is estimated from the residuals of the model fit for years 1976 to 2006. K^{sp} is as estimated for that RC assessment. For the Reference Case SCAA, *h* is fixed (0.9).

$$B_y^{sp} = \sum_{a=1}^{m} f_{y,a} w_{y,a}^{mid} N_{y,a} \tag{11}$$

where

$f_{y,a}$ is each year selected randomly from the maturity-at-age vectors for the last 10 years (2000 to 2009) used in the assessment (Table 2).

For XSA, σ_R is computed as follow:

$$\sigma_R = \sqrt{1/32 \sum_{y=1975}^{2006} \left(\ell n\left(N_{y,0}\right) - \ell n\left(R_y\right)\right)^2} \tag{11}$$

where the recruitment is assumed to follow a segmented regression:

$$R_{y+1} = \begin{cases} \alpha B_y^{sp} & if \quad B_y^{sp} < \beta \\ \alpha\beta & if \quad B_y^{sp} \geq \beta \end{cases} \tag{12}$$

with the α and β parameters as estimated from the results of that assessment and provided by D Miller.

At a later stage in the process, these approaches should be extended to take account of first order serial correlation in recruitment residuals.

Step5:

The information obtained in Step 1 is used to generate values of the abundance indices I_{2010}^i (in terms of biomass or of numbers). 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, taking account of the serial correlation i.e.:

$$I_y^i = q^i B_y^i e^{\lambda_y^i} \tag{13}$$

$$\varepsilon_y^i = \lambda_y^i - \rho^i \lambda_{y-1}^i \tag{14}$$

$$\varepsilon_y^i \quad \text{from } N\left(0, \left(\sigma^i\right)^2\right) \tag{15}$$

where B_y^i is the biomass (or numbers) available to the survey:

$$B_y^{surv,spring} = \sum_{a=1}^{m} w_{y,a}^{mid} S_{y,a}^{surv} N_{y,a} e^{-M_a/4} \left(1 - S_{y,a} F_y / 4\right) \tag{16}$$

for spring surveys,

$$B_y^{surv,summer} = \sum_{a=1}^{m} w_{y,a}^{mid} S_{y,a}^{surv} N_{y,a} e^{-M_a/2} \left(1 - S_{y,a} F_y / 2\right) \tag{17}$$

for summer surveys, and

$$B_y^{surv,fall} = \sum_{a=1}^{m} w_{y,a}^{mid} S_{y,a}^{surv} N_{y,a} e^{-M_a 3/4} \left(1 - S_{y,a} F_y 3/4\right) \tag{18}$$

for fall surveys.

As for the commercial selectivity, the survey selectivities for the SCAA are obtained under the assumption that the selectivity functions estimated in that assessment continue to vary by 2-year block, as assumed for the assessment:

$$S_{y,a}^{surv} = S_a^{surv} e^{\Omega_{y,a}^{surv}} \tag{19}$$

where

$\Omega_{y,a}^{surv}$ from $N\left(0, \left(\sigma_{\Omega^{surv}}\right)^2\right)$ for ages 1 to 8 for the Canadian Fall and Spring surveys, and for ages 4 to 11 for the EU 0-1400m survey,

$\Omega_{y,a}^{surv} = 0$ for ages 9+ for the Canadian Fall and Spring surveys, and 12+ for the EU 0-1400m survey, and

$\sigma_{\Omega^{surv}} = 0.5$

For the Canadian and the EU 0-1400m surveys, $S_{2009,a}^{surv}$ is already specified, while $S_{2010,a}^{surv}$ is generated from the random process above.

For the XSA, the survey selectivities are taken as the catchabilities (q_a^i) estimated in that assessment, renormalized so that $\max(q_a^i) = 1$. For each survey, the selectivity is assumed to be zero after the last age for which data are specified (13,12, 13 and 8 for the Canadian Fall, EU 0-700m, EU 0-1400m and Canadian Spring surveys respectively) to the plus group (age 20).

For the SCAA, for the indices related to biomass, the constant of proportionality q^i, the σ^i and ρ^i are estimated directly in the assessment. For other cases, the following procedure is used.

The constant of proportionality q^i is as estimated for the assessment in question by:

$$\ell n\, \hat{q}^i = 1/n_i \sum_{y=y1}^{2009} \left(\ln I_y^i - \ln \hat{B}_y^i \right) \tag{20}$$

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_{y=y1}^{2009} \left(\varepsilon_y^i \right)^2} \tag{21}$$

where n_i is the number of data points in the series, $y1$=1996 for the Canadian surveys, and 2004 for the EU 0-1400m survey,

$$\varepsilon_y^i = \lambda_y^i - \rho^i \lambda_{y-1}^i \tag{22}$$

$$\lambda_y^i = \ell n(I_y^i) - \ell n(q^i \widehat{B}_y^i) \tag{23}$$

$$\rho^i = \frac{\sum_{y1}^{y2} \lambda_{y+1}^i \lambda_y^i}{\sum_{y1}^{y2} \left(\lambda_y^i \right)^2} \tag{24}$$

where $y1$=1996 for the Canadian surveys, and 2004 for the EU 0-1400m survey; and y2=2008 for the EU 0-1400m and Canadian spring surveys, but 2006 for the Canadian Fall survey because of the missing data in 2008.

To commence this data generation process and compute I_{2010}^i, a value for λ_{2009}^i is required. For each of the three surveys, this is given by:

$$\lambda_{2009}^i = \ell n\left(I_{2009}^i \right) - \ell n\left(q^i B_{2009}^i \right) \tag{25}$$

for the assessment concerned, using the known values for the outputs from these surveys for 2009.

Step 6:

Given the new survey indices I_y^i compute TAC_{y+1} using the CMP.

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

During the January 2010 Brussels meeting it was agreed that four properties would be evaluated in a risk management context:

I) the risk of steep decline be kept moderately low;

II) the risk of annual average catch variation of greater than 15% be kept moderately low;

III) the magnitude of the average catch in the short, medium term and long term be maximized; and

IV) the risk of failure to meet an interim target within a prescribed period of time should be kept moderately low.

A number of mathematical expressions (Performance Statistics) were then proposed to capture these four properties:

(a) $\frac{P_{2031}}{P_{2011}}$, where P_y is the population size in year *y*;

(b) $\frac{P_{2016}}{P_{2011}}$;

(c) $\frac{P_{lowest}}{P_{2011}}$, where P_{lowest} is the lowest population size during evaluation period (2011-2031);

(d) $\frac{P_{lowest}}{P_{\min}}$, where $P_{\min}$ is the lowest population size during the assessment period (1975-2010);

(e) $\frac{P_{2031}}{P_{\text{target}}}$, 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;

(f) $\frac{P_{2031}}{P_{MSY}}$ where P_{MSY} is the population level when maximum sustainable yield is achieved; this will be pursued only after the next meeting at which methods to compute P_{MSY} will be discussed.

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^{surv}) or spawning biomass (B_y^{sp}), (though with primary focus on exploitable biomass for P_{target}) where:

$$N_y^{tot} = \sum_{a=0}^{m} N_{y,a} \tag{26}$$

$$B_y^{tot} = \sum_{a=0}^{m} w_{y,a}^{mid} N_{y,a} \tag{27}$$

$$N_y^{5-9} = \sum_{a=5}^{9} N_{y,a} \tag{28}$$

$$B_y^{5-9} = \sum_{a=5}^{9} w_{y,a}^{mid} N_{y,a} \tag{29}$$

B_y^{surv} : equations 16 to 18

$$B_y^{sp} = \sum_{a=1}^{m} f_{y,a} w_{y,a}^{mid} N_{y,a} \tag{30}$$

The primary PS (I) and (III) above can be captured by:

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

$$C_{2011},\ C_{2012},\ \sum_{y=2011}^{2015} C_y \Big/ 5,\ \sum_{y=2016}^{2020} C_y \Big/ 5 \text{ and } \sum_{y=2011}^{2030} C_y \Big/ 20$$

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

$$AAV_{2011-2015} = \frac{1}{5}\sum_{y=2011}^{2015} \left|C_y - C_{y-1}\right| / C_{y-1} \text{ and}$$

$$AAV_{2011-2030} = \frac{1}{20}\sum_{y=2011}^{2030} \left|C_y - C_{y-1}\right| / C_{y-1}$$

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

Subsequently, at the May 2010 Halifax meeting, the four properties (or Performance Targets) were refined as follows:

I) The probability of the decline of 25% or more in terms of exploitable biomass from 2011 to 2016 is kept at 10%* or lower.

II) a) The probability of annual TAC variation of greater than 15% be kept at 25% or lower and

b) The probability of variation of TAC more than 25% over any period of 3 years should be kept at 25% or lower.

If the conditions a) **and** b) are not met, then an alternate performance target should be considered as follows:

c) The TAC should not be below 10 000 t for the period 2011-2015 in any one year with a probability of 25% on a year by year basis.

III) The magnitude of the average TAC in the short, medium and long term should be maximized.

IV) The probability of failure to meet or exceed a milestone within a prescribed period of time should be kept at 25% or lower. *Milestone* means the average exploitable biomass for the period 1985-1999 to be compared with the exploitable biomass in 2031.

The following corresponding Performance Statistics were then also agreed:

Performance Statistic for Performance Target I:

$$\frac{P_{2016}}{P_{2011}},$$

where P_y is the exploitable biomass computed at the start of the year indicated.

Performance Statistics for Performance Target II a):

$$\left\{\sum_{y=2010}^{y=2029} \frac{\left|C_{y+1} - C_y\right|}{C_y}\right\} \Big/ 20; \qquad X_y = \frac{\left|C_{y+1} - C_y\right|}{C_y} - 0.15;$$

$$I_y = \begin{Bmatrix} 1 & \text{if } X_y > 0 \\ 0 & \text{if } X_y \le 0 \end{Bmatrix}; \qquad \begin{Bmatrix} \text{Prob*} = \frac{1}{5}\sum_{y=2010}^{2014} I_y \\ \text{Prob} = \frac{1}{20}\sum_{y=2011}^{2030} I_y \end{Bmatrix}$$

Performance Statistic for Performance Target II b):

$$\left\{\sum_{y=2010}^{y=2027}\frac{\left|C_{y+3}-C_y\right|}{C_y}\right\}\Big/18; \qquad X_y = \frac{\left|C_{y+3}-C_y\right|}{C_y} - 0.25;$$

$$I_y = \begin{Bmatrix} 1 & \text{if } X_y > 0 \\ 0 & \text{if } X_y \le 0 \end{Bmatrix}; \qquad \text{Prob} = \frac{1}{18}\sum_{y=2010}^{2027} I_y$$

where C_y is the TAC for the year indicated.

Performance Statistics for Performance Target IIc):

$$C_{2011};\ C_{2012};\ C_{2013};\ C_{2014};\ C_{2015}$$

Performance Statistics for Performance Target III:

$$\frac{1}{5}\sum_{y=2011}^{2015} C_y\ ;\ \frac{1}{5}\sum_{y=2016}^{2020} C_y\ ;\ \frac{1}{20}\sum_{y=2011}^{2030} C_y$$

Performance Statistic for Performance Target IV:

$$\frac{P_{achieved}}{P_{milestone}} \text{ where } P_{achieved} = P_{2031} \text{ and } P_{milestone} = \frac{1}{15}\sum_{y=1985}^{1999} P_y$$

A total of 100 forward projections will be run for each trial, with results presented as the 5th, average of 50th and 51st and 96th 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").

Annex 4. Application of the Management Strategies

The management strategy to calculate the TAC for year *y*+1 is defined by the following formulae:

$$TAC^*_{y+1} = Z_y\left(1 + \lambda_y slope_y\right)$$

where $Z_y = \begin{cases} Z & y = 2010 \\ TAC^*_y & y \geq 2011 \end{cases}$

$\lambda_y = \begin{cases} \lambda_u & slope_y > 0 \\ \lambda_d & slope_y \leq 0 \end{cases}$

and where

if $TAC_{y+1} - TAC_y > TAC_y\left(1 + x\%\right)$ then $TAC_{y+1} = TAC_y\left(1 + x\%\right)$

if $TAC_{y+1} - TAC_y < TAC_y\left(1 - y\%\right)$ then $TAC_{y+1} = TAC_y\left(1 - y\%\right)$

where Z, λ_u, λ_d, x and y are control parameters to be selected.

For the MP selected the values of the control parameters are:

Z	16 000 t	or	17 500 t
λ_u	1.00	or	1.00
λ_d	1.25	or	2.00
x	0.10	or	0.05
y	0.10	or	0.05

The quantity $slope_y$ is calculated as follows:

For each survey, linearly regress $\ln I^i_y$ *vs* year *y*' for $y' = y - 5$ to $y' = y - 1$, to yield a regression slope value $slope^i_y$, an average of the slopes is taken to provide a composite value:

$$slope_y = \left(slope^{CanFall}_y + slope^{CanSpring}_y + slope^{EU(0-1400m)}_y\right) / 3$$

where I_y is the survey biomass result in terms of mean weight per tow of fish for all ages.

Annex 5. Results of the MSE Application

Performance statistics (medians) for two Management Strategies as averaged over the SCAA- and the XSA-conditioned operating models.

	SCAA average		XSA average	
	MS 1 (mp01)	MS 2 (mp14 (+-5%))	MS 1 (mp01)	MS 2 (mp14 (+-5%))
$C_{2011-2015}$	13374	15766	14800	16400
$C_{2016-2020}$	13566	15827	19600	19100
$C_{2011-2030}$	14335	16195	23100	21400
$B_{2011-2015}$	91530	89361	69446	66588
$B_{2016-2020}$	107715	103211	131854	128102
$B_{2011-2030}$	117766	113381	127975	127612
$B_{2011-2015}/B_{2011}$	1.05	1.03	1.04	1.02
$B_{2016-2020}/B_{2011}$	1.26	1.20	1.98	1.98
$B_{2011-2030}/B_{2011}$	1.36	1.31	1.93	1.97