



FC Working Group on Greenland Halibut Management
Strategy Evaluation (WGMSE) – September 2010

Candidate Management Procedures Testing Methodology

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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 ($N_{2010,a} : a = 1, \dots, m$) 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.:

$$N_{2010,a} \rightarrow N_{2010,a} e^{\varepsilon_a} \quad \varepsilon_a \text{ from } N(0, (\sigma_R)^2) \quad (1)$$

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:

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

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:

$$S_{y,a} = S_a e^{\Omega_{y,a}} \quad (3)$$

where

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

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

$\sigma_\Omega = 2.0$.

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:

$$S_{y,a} = F_{y,a} / \max(F_{y,a}) \quad (4)$$

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

From this it follows that:

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

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:

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

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

$$N_{y+1,1} = R_{y+1} \quad (7)$$

$$N_{y+1,a+1} = (N_{y,a} e^{-M_a/2} - C_{y,a}) e^{-M_a/2} \quad \text{for } 1 \leq a \leq m-2 \quad (8)$$

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

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.

Step 4: Recruitment

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

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

Log-normal fluctuations are introduced by generating ζ_y factors from $N(0, \sigma_R^2)$ 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).

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

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:

$$\sigma_R = \sqrt{1/32 \sum_{y=1975}^{2006} (\ln(N_{y,0}) - \ln(R_y))^2} \quad (11)$$

where the recruitment is assumed to follow a segmented regression:

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

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.:

$$I_y^i = q^i B_y^i e^{\lambda_y^i} \quad (13)$$

$$\varepsilon_y^i = \lambda_y^i - \rho^i \lambda_{y-1}^i \quad (14)$$

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

where

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

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

for spring surveys,

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

for summer surveys, and

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

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:

$$S_{y,a}^{surv} = S_a^{surv} e^{\Omega_{y,a}^{surv}} \quad (19)$$

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:

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

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

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,

$$\varepsilon_y^i = \lambda_y^i - \rho^i \lambda_{y-1}^i \quad (22)$$

$$\lambda_y^i = \ln(I_y^i) - \ln(q^i \hat{B}_y^i) \quad (23)$$

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

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.

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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:

$$\lambda_{2009}^i = \ln(I_{2009}^i) - \ln(q^i B_{2009}^i) \quad (25)$$

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) $\frac{P_{2031}}{P_{target}}$, 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:

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

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

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

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

B_y^{surv} : equations 16 to 18

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

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

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

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

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

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

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

$P(> 15\%)$ 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):

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

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

Performance Statistic for Performance Target II b):

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

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

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^{5-9} 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”).

APPENDIX + - Index-based Management strategy (base case)

David Miller

modFree - Model-free, index-based TAC adjustment strategy

This is a variable TAC-based strategy. It constitutes a simple TAC adjustment strategy that uses the change in perceived status of the stock (from research surveys) to adjust the TAC according to:

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

Where:

$slope$ = unweighted average slope of log-linear regression lines fit to the last five years of each index (all ages combined), i.e. $y-5$ to $y-1$

λ_u and λ_d = adjustment variables for the relative change in TAC to the perceived change in stock size.

In the calculation of $slope$, missing data is ignored i.e. only data available since year $y-1$ are used. For each index I , annual CPUE values I_y are calculated by summing all ages in the age range of each index for each year. Linear models ($\ln(I_y) = ay + b$) are fit by minimising the sum of squared residuals.

Then $slope = (a_1 + a_2 + a_3)/3$, intercept values are not considered.

Various λ values were examined in deterministic simulations. In the case of a declining stock $\lambda_d = 1.25$ (allows for adequate adjustment of the TAC without having excessively large fluctuations from year to year) and in the case of an increasing stock $\lambda_u = 1$.

$\lambda > 1$ is required in the case of a perceived decline in stock size ($slope < 0$) but this value of λ could hamper stock recovery in the case of a perceived increase in stock size ($slope > 0$). A variable λ approach with $\lambda < 1$ when $slope > 0$ will allow for more rapid recovery of the stock.