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 2009 ($N_{2009,a}$: a = 1,…, m) are obtained from the MLE of an assessment of the resource (SCAA or XSA). For SCAA the 2008 catch-at-age data are used in the assessment, whereas for XSA the estimated numbers-at-age at the start of 2008 are projected forward one year using these data. For XSA, the 2008 recruitment ($N_{2008,1}$) 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.:

$$N_{2009,a} \rightarrow N_{2009,a}e^{\varepsilon_a} \qquad \varepsilon_a \text{ from } N\left(0,(\sigma_R)^2\right) \tag{1}$$

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 2009 and 2010:

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

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, $S_{2009,a}$ is generated from the random process above.

For XSA, the selectivity each year is selected randomly from the selectivity vectors for the last 10 years (1996 to 2005) estimated in the assessment. The selectivity vectors for 1996 to 2005 are computed as follows:

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

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

From this it follows that:

$$F_{y}=C_{y}/\sum_{a} w_{y,a}^{mid} N_{y,a}\, e^{-M_a/2} S_a \tag{5}$$

where $w_{y,a}^{mid}$ is each year selected randomly from the weight-at-age vectors for the last 10 years (1998 to 2007) 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:

$$R_y=\frac{4hR_0B_y^{sp}}{K^{sp}(1-h)+(5h-1)B_y^{sp}}\,e^{(\varsigma_y-\sigma_R^2/2)} \tag{10}$$

Log-normal fluctuations are introduced by generating ς_y factors from $N(0,\sigma_R^2)$ where σ_R is estimated from the residuals of the model fit for years 1976 to 2004. 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 (1998 to 2007) used in the assessment (Table 2).

For XSA, σ_R is computed as follow:

$$\sigma_R = \sqrt{1/30 \sum_{y=1975}^{2004} \left(\ell n\left(N_{y,0}\right) - \ell n\left(R_y\right)\right)^2} \tag{11}$$

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.

<u>Step5</u>:

The information obtained in Step 1 is used to generate values of the abundance indices I_{2009}^i (in terms of biomass or of numbers). 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 11 for the Canadian Fall and the EU surveys and for ages 1 to 8 for the Canadian Spring survey,

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

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

Since the selectivity function varies by 2-year block starting in 1996 for the Canadian surveys and 1995 for the EU survey, $S_{2008,a}^{surv}$ and $S_{2009,a}^{surv}$ are equal and generated from the random process described above for the Canadian surveys. For the EU survey, $S_{2008,a}^{surv}$ is already specified, while $S_{2009,a}^{surv}$ 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 and 8 for the Canadian Fall, EU 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:

$$\ell n\, \hat{q}^i = 1/n_i \sum_{y=y1}^{2007}\left(\ln I_y^i - \ln \hat{B}_y^i\right) \tag{20}$$

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_{y=y1}^{2007}\left(\varepsilon_y^i\right)^2} \tag{21}$$

where y1=1996 for the Canadian surveys and 1995 for the EU survey,

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

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

$$\rho^i = \frac{\sum_{y1}^{2006} \lambda_{y+1}^i \lambda_y^i}{\sum_{y1}^{2006}\left(\lambda_y^i\right)^2} \tag{24}$$

where y1=1996 for the Canadian surveys and 1995 for the EU survey.

To commence this data generation process and compute I_{2009}^i , a value for λ_{2008}^i is required. For the Canadian Spring and EU surveys, this is given by:

$$\lambda_{2008}^i = \ell\text{n}\left(I_{2008}^i\right) - \ell\text{n}\left(q^i B_{2008}^i\right) \tag{25}$$

for the assessment concerned, using the known values for the outputs from these surveys for 2008.

For the Canadian Fall survey, the 2008 survey estimate is not comparable with the other years. For simplicity, we assume $\varepsilon^i_{2008} = 0$ and therefore $\lambda^i_{2008} = \rho^i \lambda^i_{2007}$.

Note however, that in the Canadian Fall survey case, the CMP will not take the I^i_{2008} value into account; this is generated only so that the serial correlation can influence the simulated survey results from 2009 onwards.

Step 6:

Given the new survey indices I^i_y 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.

Note: At a later stage in the process, both the catches and the survey estimates generated for 2008 and 2009 should be replaced by the actual values that are now or may be available by then.

Performance Statistics

During the 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

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 were proposed to capture PS (I) and (IV):

(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 $\left| \frac{C_y - C_{y-1}}{C_{y-1}} \right| > 0.15$

A total of 100 forward projections such 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 $B^{5\text{-}9}$ should be produced for each trial, the first showing the median and 90% probability envelopes, and the second showing the first 5 realisations (“worm plots”).

Projections check

The developers will run a constant catch (16 000t) and one common procedure (Appendix I) as a check on comparability of output statistics produced for the baseline XSA operating model.

Table 1: Catch weights-at-age (kg) matrix for Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO (Healy and Mahé, 2008 for ages 1 to 14; Miller, pers. commn, for ages 15+).

Year	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	9.451	10.301	10.816
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	7.996	8.716	9.152
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	10.810	11.782	12.372
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	8.175	8.583
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	7.461	8.133	8.540
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

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

Year	0	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	0.000	0.001	0.001	0.004	0.007	0.013	0.023	0.047	0.067	0.119	0.205	0.335	0.501	0.666	0.797	0.883	0.934	1.000	1.000
1976	0.000	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	0.797	0.883	0.934	1.000	1.000
1977	0.000	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	0.797	0.883	0.934	1.000	1.000
1978	0.000	0.000	0.000	0.001	0.002	0.002	0.005	0.022	0.014	0.041	0.107	0.117	0.143	0.335	0.501	0.666	0.797	0.883	0.934	1.000	1.000
1979	0.000	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	0.797	0.883	0.934	1.000	1.000
1980	0.000	0.000	0.000	0.000	0.001	0.002	0.007	0.009	0.018	0.064	0.061	0.158	0.277	0.310	0.499	0.666	0.797	0.883	0.934	1.000	1.000
1981	0.000	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	0.797	0.883	0.934	1.000	1.000
1982	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.021	0.034	0.070	0.177	0.233	0.451	0.549	0.604	0.856	0.883	0.934	1.000	1.000
1983	0.000	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	1.000	1.000
1984	0.000	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	1.000	1.000
1985	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.016	0.039	0.115	0.211	0.384	0.542	0.756	0.883	0.874	0.906	1.000	1.000
1986	0.000	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	1.000	1.000
1987	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.023	0.054	0.126	0.298	0.509	0.719	0.787	0.936	0.970	1.000	1.000
1988	0.000	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	1.000	1.000
1989	0.000	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	1.000	1.000
1990	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.015	0.001	0.023	0.092	0.332	0.285	0.498	0.715	0.888	0.955	1.000	1.000
1991	0.000	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	1.000	1.000
1992	0.000	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	0.407	0.794	0.592	0.781	0.892	1.000	1.000
1993	0.000	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	1.000	1.000
1994	0.000	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	1.000	1.000
1995	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.007	0.010	0.063	0.257	0.250	0.879	1.000	0.947	0.923	0.988	1.000	1.000
1996	0.000	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	1.000	1.000
1997	0.000	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	1.000	1.000
1998	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.015	0.039	0.097	0.203	0.606	0.920	0.864	0.997	1.000	1.000	1.000
1999	0.000	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
2000	0.000	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
2001	0.000	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	1.000	1.000
2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.009	0.028	0.069	0.181	0.533	0.412	0.640	0.812	0.952	0.990	1.000	1.000
2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.007	0.026	0.070	0.364	0.530	0.902	0.648	0.821	0.916	0.983	1.000	1.000
2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.009	0.024	0.072	0.166	0.817	0.851	0.987	0.829	0.922	0.965	1.000	1.000
2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.009	0.026	0.074	0.188	0.346	0.972	0.967	0.998	0.927	0.968	1.000	1.000
2006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.009	0.026	0.072	0.209	0.406	0.584	0.996	0.993	1.000	0.971	1.000	1.000
2007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.009	0.026	0.072	0.188	0.466	0.663	0.788	1.000	0.999	1.000	1.000	1.000
2008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.009	0.026	0.072	0.188	0.406	0.742	0.846	0.908	1.000	1.000	1.000	1.000

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:

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

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 λ_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.