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# Initial Applications of Statistical Catch-at-Age Assessment Methodology to the Greenland Halibut Resource

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**Summary**

Statistical Catch-at-Age (SCAA) assessment methodology is applied to the Greenland halibut resource, with full algebraic specifications of the approach provided in an Appendix. Results are reported for a baseline run and eight sensitivities. These are all duplicated given that the estimates of historical biomass are very sensitive to whether or not the commercial catch-at-age data for the first two years are included in fitting the assessment model. In most cases current biomasses are estimated to be above $B_{MSY}$ and increasing, with MSY estimates typically close to 25000t.

## Introduction

This document provides baseline Statistical-Catch-at-Age (SCAA) assessments of the Greenland halibut resource based on data provided following NAFO WebEx meetings to discuss appropriate choices. A number of sensitivity results are also reported, related to different choices for biological parameter inputs and fitting to different combinations of survey series.

## Data and Methodology

The catch and survey based data (including catch-at-age information) and some biological data are listed in Tables in Appendix A. Table 1 lists the different combinations of survey series considered for the various assessments.

The details of the SCAA assessment methodology are provided in Appendix B.

**Results**

Historical biomass estimates were found to be very sensitive to which commercial catch-at-age (CAA) data were included in the assessment model fit, so that two baseline assessments were specified for which the historical levels of biomass differed substantially:

a) Baseline StartA:14+ for the plus group, $M$=0.2, $h$=0.9,$W_{CAA}$=0.1 for both survey and commercial CAA. Survey series, see Table 1.

b) Baseline StartB: As baseline StartA but omitting 1975 and 1976 commercial CAA from the fit.

Results are given in Table 2 and Figures 1 and 2.

All sensitivities are carried out for both StartA and StartB baseline specifications:

c) 10+ instead of 14+ for the plus group: Tables 3a and 3b, Figures 3a and 3b

d) $M$=0.12 instead of 0.2: Tables 3a and 3b, Figures 3a and 3b

e) 10+ for the plus group and $M$=0.12 instead of 0.2: Tables 3a and 3b, Figures 3a and 3b

f) O1, O2 and O3: different survey series used, see Table 1: Tables 3a and 3b, Figures 4a and 4b and Figures 5-7

g) $h$=0.5 instead of $h$=0.9: Tables 3a and 3b, Figures 8a and 8b

h) $M$ increase: M is 0.2 for ages 0 to 10 then increase linearly to 0.5 at age 14+ Tables 3a and 3b, Figures 8a and 8b

Table 4 gives MSY-related estimates for the various assessments, together with Hessian-based 95% CIs. $F_{MSY}$ is in terms of the apical $F$ – the fishing mortality on the age class with a maximum selectivity of 1. The computation of $F_{MSY}$ requires the iterative solution of a non-linear equation; hence no Hessian-based CI is available, and other MSY-related values are conditional on the MLE of $F_{MSY}$.

**Discussion**

Some notable features of the results are as follows.

- Unsurprisingly, given the wide differences in historical estimates of abundances for the StartA and StartB assessments, CI estimates for biomasses early in the period of the assessment are much higher than for more recent years
- Estimates of current biomasses are generally somewhat above $B_{MSY}$, but drop below this for lower steepness values and the O1 and O2 choices of abundance indices.
- There is a lack of fit of the two baseline runs to the EU 3M 0-700m catch-at-age data: there is a clear pattern in the residuals and the models predict too many 8 year olds on average.
- There are no other obvious indications of lack of fit for the baseline runs (we have yet to fully check all the sensitivities).
- Recent spawning and exploitable biomasses are increasing except for the sensitivity with a 10+ plus group and $M$=0.12 (both StartA and StartB baselines) and for the sensitivity with the O2 choices of abundance indices.
- MSY estimates are typically close to 25000 tons, unless steepness $h$ is set lower than 0.9. However note that the model fit for this lower value of his notably worse in terms of the (penalised) log likelihood (see Tables 3a and 3b).

**Table 1**: Survey data series used in the various sensitivity runs, showing the period covered by each survey.

| Survey | Baseline | O1 | O2 | O3 |
|---|---|---|---|---|
| Can. Fall 2J3K | 1996-2015 | 1996-2015 | 1996-2015 | 1996-2015 |
| Can. Spring 3LNO | 1996-2014 | 1996-2014 | 1996-2014 | 1996-2014 |
| EU 3M 0-700m | 1995-2003 | 1995-2015 | 1995-2015 | 1995-2003 |
| EU 3M 0-1400m | 2004-2015 | | | 2004-2015 |
| EU 3m 700-1400m | | 2004-2015 | 2004-2015 | |
| EU 3L | | 2006-2015 | | |
| EU 3NO | | 1997-2015 | 1997-2015 | 1997-2015 |
| Can. Fall 3LNO | | 1996-2015 | 1996-2015 | 1996-2015 |

**Table 2**: Results of SCAA baseline runs StartA and StartB; values shown in **bold** are fixed on input. Hessian-based CVs are shown in parentheses.

| | StartA | | StartB | |
|---|---|---|---|---|
| -lnL:Overall | -104.50 | | -104.42 | |
| | -lnL:Index | -lnL:CAA | -lnL: index | -lnL: CAA |
| Can. Fall 2J3K | -7.56 | -3.96 | -7.73 | -3.88 |
| EU 3M 0-700m | -5.09 | 0.97 | -5.11 | 0.95 |
| EU 3M 0-1400m | -0.25 | -4.21 | -0.11 | -4.20 |
| EU 3m 700-1400m | - | - | - | - |
| Can. Spring 3LNO | 14.62 | -1.10 | 14.66 | -1.11 |
| EU 3L | - | - | - | - |
| EU 3NO | - | - | - | - |
| Can. Fall 3LNO | - | - | - | - |
| Commercial | | -9.15 | | -8.91 |
| | | | | |
| -lnL:RecRes | -33.10 | | -33.19 | |
| -lnL:CatchPen | -55.69 | | -55.80 | |
| | | | | |
| $h$ | **0.90** | | **0.90** | |
| $M$ | **0.20** | | **0.20** | |
| $\vartheta$ | 0.09 | (2.93) | 0.46 | (0.63) |
| $K^{sp}$ | 597 | (0.09) | 625 | (0.14) |
| $B^{sp}{}_{1975}$ | 362 | (1.49) | 46 | (2.06) |
| $B^{sp}{}_{2015}$ | 131 | (0.41) | 138 | (0.43) |
| $B^{sp}{}_{2015}/K^{sp}$ | 0.22 | (0.35) | 0.22 | (0.34) |
| $B^{sp}{}_{2015}/B^{sp}{}_{1975}$ | 0.36 | (1.52) | 3.01 | (2.23) |
| $B^{5\text{-}9}{}_{1975}$ | 196 | (0.60) | 167 | (0.36) |
| $B^{5\text{-}9}{}_{2015}$ | 127 | (0.19) | 132 | (0.21) |
| $B^{5\text{-}9}{}_{2015}/B^{5\text{-}9}{}_{1975}$ | 0.65 | (0.63) | 0.79 | (0.47) |
| | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA |
| Can. Fall 2J3K | 0.16 | 0.15 | 0.16 | 0.15 |
| EU 3M 0-700m | 0.15 | 0.23 | 0.15 | 0.22 |
| EU 3M 0-1400m | 0.24 | 0.11 | 0.24 | 0.11 |
| EU 3m 700-1400m | - | - | - | - |
| Can. Spring 3LNO | 0.55 | 0.19 | 0.55 | 0.19 |
| EU 3L | - | - | - | - |
| EU 3NO | - | - | - | - |
| Can. Fall 3LNO | - | - | - | - |
| Commercial | | 0.15 | | 0.14 |

**Table 3a**: Results of various SCAA variants based on baseline run StartA. Hessian-based CVs are shown in parentheses.

| | StartA | | 10+ plus group | | *M*=0.12 | | 10+ plus group, *M*=0.12 | | O1* | | O2 | | O3 | | *h*=0.5 | | *M* increase (linear from 0.2 age 10 to 0.5 age 14+) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -lnL:Overall | -104.50 | | -106.22 | | -104.32 | | -107.75 | | -75.43 | | -71.08 | | -92.04 | | -101.86 | | -104.72 | |
| | -lnL:Index | -lnL:CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA |
| Can. Fall 2J3K | -7.56 | -3.96 | -7.31 | -3.66 | -7.80 | -3.72 | -7.83 | -4.05 | -6.13 | -4.53 | -6.16 | -4.45 | -7.42 | -4.08 | -7.19 | -3.33 | -7.74 | -3.67 |
| EU 3M 0-700m | -5.09 | 0.97 | -5.21 | 1.13 | -5.18 | 1.05 | -6.00 | 0.63 | 13.19 | -0.04 | 12.65 | -0.18 | -5.20 | 0.55 | -2.04 | -0.52 | -4.72 | 0.76 |
| EU 3M 0-1400m | -0.25 | -4.21 | -0.16 | -4.22 | -0.28 | -4.39 | -1.24 | -3.90 | - | - | - | - | -0.43 | -4.26 | 0.27 | -4.26 | -0.07 | -4.06 |
| EU 3m 700-1400m | - | - | - | - | - | - | - | - | 1.77 | -5.45 | 2.25 | -5.03 | - | - | - | - | - | - |
| Can. Spring 3LNO | 14.62 | -1.10 | 14.32 | -1.23 | 14.80 | -1.06 | 13.29 | -0.86 | 14.03 | -1.68 | 13.74 | -1.74 | 14.14 | -1.36 | 14.11 | -1.06 | 14.45 | -1.19 |
| EU 3L | - | - | - | - | - | - | - | - | -4.16 | -0.71 | - | - | - | - | - | - | - | - |
| EU 3NO | - | - | - | - | - | - | - | - | 8.66 | 1.39 | 9.00 | 1.15 | 6.88 | 1.91 | - | - | - | - |
| Can. Fall 3LNO | - | - | - | - | - | - | - | - | 3.81 | -1.34 | 3.26 | -1.18 | 3.54 | -0.93 | - | - | - | - |
| Commercial | | -9.15 | | -10.79 | | -9.10 | | -9.61 | | -8.40 | | -8.05 | | -8.67 | | -8.66 | | -9.08 |
| | | | | | | | | | | | | | | | | | | |
| -lnL:RecRes | -33.10 | | -33.17 | | -33.06 | | -32.62 | | -31.18 | | -31.45 | | -31.65 | | -32.80 | | -33.51 | |
| -lnL:CatchPen | -55.69 | | -55.93 | | -55.57 | | -55.57 | | -54.67 | | -54.86 | | -55.07 | | -56.38 | | -55.89 | |
| | | | | | | | | | | | | | | | | | | |
| *h* | **0.90** | | **0.90** | | **0.90** | | **0.90** | | **0.90** | | **0.90** | | **0.90** | | **0.90** | | **0.90** | |
| *M* | **0.20** | | **0.20** | | **0.20** | | **0.20** | | **0.20** | | **0.20** | | **0.20** | | **0.20** | | **0.20** | |
| $\vartheta$ | 0.09 | (2.93) | 0.06 | (28.18) | 0.01 | (43.29) | 0.00 | (1000.00) | 0.00 | - | 0.00 | (53.91) | 0.09 | (3.12) | 0.19 | (0.76) | 0.07 | (3.94) |
| $K^{sp}$ | 597 | (0.09) | 544 | (0.08) | 1210 | (0.10) | 881 | (0.10) | 531 | - | 520 | (0.07) | 585 | (0.08) | 2171 | (0.46) | 366 | (0.07) |
| $B^{sp}_{1975}$ | 362 | (1.49) | 444 | (1.67) | 1312 | (1.50) | 1479 | (0.61) | 919 | - | 826 | (1.38) | 386 | (1.41) | 252 | (0.46) | 232 | (1.35) |
| $B^{sp}_{2015}$ | 131 | (0.41) | 107 | (0.36) | 278 | (0.41) | 109 | (0.44) | 70 | - | 59 | (0.45) | 131 | (0.34) | 310 | (0.28) | 109 | (0.30) |
| $B^{sp}_{2015}/K^{sp}$ | 0.22 | (0.35) | 0.20 | (0.33) | 0.23 | (0.35) | 0.12 | (0.40) | 0.13 | - | 0.11 | (0.45) | 0.22 | (0.29) | 0.14 | (0.61) | 0.30 | (0.25) |
| $B^{sp}_{2015}/B^{sp}_{1975}$ | 0.36 | (1.52) | 0.24 | (1.68) | 0.21 | (1.36) | 0.07 | (0.76) | 0.08 | - | 0.07 | (1.31) | 0.34 | (1.42) | 1.23 | (0.43) | 0.47 | (1.37) |
| $B^{5\text{-}9}_{1975}$ | 196 | (0.60) | 174 | (0.83) | 226 | (0.76) | 277 | (0.61) | 350 | - | 320 | (0.71) | 203 | (0.58) | 187 | (0.22) | 209 | (0.55) |
| $B^{5\text{-}9}_{2015}$ | 127 | (0.19) | 109 | (0.17) | 121 | (0.18) | 82 | (0.15) | 98 | - | 88 | (0.16) | 118 | (0.16) | 181 | (0.24) | 136 | (0.17) |
| $B^{5\text{-}9}_{2015}/B^{5\text{-}9}_{1975}$ | 0.65 | (0.63) | 0.63 | (0.85) | 0.53 | (0.74) | 0.29 | (0.64) | 0.28 | - | 0.27 | (0.68) | 0.58 | (0.61) | 0.97 | (0.32) | 0.65 | (0.58) |
| | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA |
| Can. Fall 2J3K | 0.16 | 0.15 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.15 | 0.18 | 0.15 | 0.17 | 0.15 | 0.16 | 0.15 | 0.17 | 0.16 | 0.16 | 0.16 |
| EU 3M 0-700m | 0.15 | 0.23 | 0.15 | 0.23 | 0.15 | 0.23 | 0.15 | 0.21 | 0.45 | 0.20 | 0.44 | 0.20 | 0.15 | 0.21 | 0.19 | 0.18 | 0.15 | 0.22 |
| EU 3M 0-1400m | 0.24 | 0.11 | 0.24 | 0.12 | 0.24 | 0.11 | 0.22 | 0.12 | - | - | - | - | 0.23 | 0.11 | 0.25 | 0.11 | 0.24 | 0.12 |
| EU 3m 700-1400m | - | - | - | - | - | - | - | - | 0.28 | 0.10 | 0.29 | 0.10 | | | - | - | - | - |
| Can. Spring 3LNO | 0.55 | 0.19 | 0.54 | 0.19 | 0.55 | 0.19 | 0.51 | 0.20 | 0.53 | 0.18 | 0.52 | 0.18 | 0.53 | 0.19 | 0.53 | 0.19 | 0.54 | 0.19 |
| EU 3L | - | - | - | - | - | - | - | - | 0.16 | 0.17 | - | - | - | - | - | - | - | - |
| EU 3NO | - | - | - | - | - | - | - | - | 0.38 | 0.20 | 0.39 | 0.20 | 0.35 | 0.21 | - | - | - | - |
| Can. Fall 3LNO | - | - | - | - | - | - | - | - | 0.30 | 0.18 | 0.29 | 0.18 | 0.29 | 0.18 | - | - | - | - |
| Commercial | | 0.15 | | 0.14 | | 0.15 | | 0.15 | | 0.15 | | 0.15 | | 0.15 | | 0.15 | | 0.15 |

* Not converged

**Table 3b**: Results of various SCAA variants based on baseline run StartB. Hessian-based CVs are shown in parentheses.

| | StartB | | 10+ plus group | | $M$=0.12 | | 10+ plus group, $M$=0.12 | | O1* | | O2* | | O3 | | $h$=0.5 | | $M$ increase (linear from 0.2 age 10 to 0.5 age 14+) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -lnL:Overall | -104.42 | | -106.17 | | -103.94 | | -107.89 | | -75.09 | | -70.71 | | -91.85 | | -101.94 | | -104.59 | |
| | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA | -lnL: index | -lnL: CAA |
| Can. Fall 2J3K | -7.73 | -3.88 | -7.53 | -3.51 | -7.75 | -3.71 | -7.96 | -4.14 | -6.06 | -4.53 | -6.02 | -4.27 | -7.47 | -4.05 | -7.24 | -3.32 | -7.86 | -3.59 |
| EU 3M 0-700m | -5.11 | 0.95 | -5.36 | 1.15 | -5.24 | 1.07 | -6.03 | 0.51 | 13.10 | -0.06 | 10.74 | -0.99 | -5.24 | 0.55 | -2.00 | -0.59 | -4.82 | 0.78 |
| EU 3M 0-1400m | -0.11 | -4.20 | 0.02 | -4.27 | -0.20 | -4.36 | -1.43 | -3.75 | | | | | -0.40 | -4.23 | 0.30 | -4.25 | -0.03 | -4.05 |
| EU 3m 700-1400m | - | - | | | | | | | 1.77 | -5.39 | 3.06 | -4.58 | - | - | | | | |
| Can. Spring 3LNO | 14.66 | -1.11 | 14.34 | -1.25 | 14.79 | -1.08 | 13.06 | -0.80 | 13.99 | -1.70 | 13.24 | -2.06 | 14.15 | -1.37 | 14.13 | -1.10 | 14.49 | -1.19 |
| EU 3L | - | - | - | - | - | - | - | - | -4.10 | -0.73 | - | - | - | - | - | - | - | - |
| EU 3NO | - | - | - | - | - | - | - | - | 8.69 | 1.37 | 10.13 | 0.78 | 6.86 | 1.94 | - | - | - | - |
| Can. Fall 3LNO | - | - | - | - | - | - | - | - | 3.76 | -1.33 | 1.62 | -1.11 | 3.58 | -0.92 | - | - | - | - |
| Commercial | | -8.91 | | -10.42 | | -8.77 | | -9.18 | | -8.03 | | -5.83 | | -8.44 | | -8.72 | | -8.86 |
| | | | | | | | | | | | | | | | | | | |
| -lnL:RecRes | -33.19 | | -33.31 | | -33.10 | | -32.63 | | -31.19 | | -30.78 | | -31.69 | | -32.80 | | -33.51 | |
| -lnL:CatchPen | -55.80 | | -56.05 | | -55.59 | | -55.54 | | -54.65 | | -54.63 | | -55.13 | | -56.34 | | -55.95 | |
| | | | | | | | | | | | | | | | | | | |
| $h$ | **0.90** | | **0.90** | | **0.90** | | **0.90** | | **0.90** | | **0.90** | | **0.90** | | **0.90** | | **0.90** | |
| $M$ | **0.20** | | **0.20** | | **0.20** | | **0.20** | | **0.20** | | **0.20** | | **0.20** | | **0.20** | | **0.20** | |
| $\vartheta$ | 0.46 | (0.63) | 0.53 | (0.90) | 0.25 | (1.76) | 0.00 | (1000.00) | 0.16 | - | 0.02 | - | 0.37 | (1.05) | 0.28 | (0.53) | 0.46 | (0.73) |
| $K^{sp}$ | 625 | (0.14) | 561 | (0.12) | 1225 | (0.11) | 860 | (0.11) | 530 | - | 486 | - | 594 | (0.10) | 2413 | (0.57) | 373 | (0.09) |
| $B^{sp}_{1975}$ | 46 | (2.06) | 53 | (2.87) | 447 | (2.32) | 2068 | (0.68) | 455 | - | 1227 | - | 91 | (2.41) | 190 | (0.53) | 33 | (2.10) |
| $B^{sp}_{2015}$ | 138 | (0.43) | 108 | (0.37) | 263 | (0.41) | 116 | (0.47) | 66 | - | 32 | - | 130 | (0.35) | 297 | (0.28) | 112 | (0.31) |
| $B^{sp}_{2015}/K^{sp}$ | 0.22 | (0.34) | 0.19 | (0.32) | 0.21 | (0.35) | 0.13 | (0.44) | 0.13 | - | 0.07 | - | 0.22 | (0.30) | 0.12 | (0.73) | 0.30 | (0.25) |
| $B^{sp}_{2015}/B^{sp}_{1975}$ | 3.01 | (2.23) | 2.02 | (2.97) | 0.59 | (2.26) | 0.06 | (0.71) | 0.15 | - | 0.03 | - | 1.43 | (2.47) | 1.56 | (0.47) | 3.33 | (2.18) |
| $B^{5\text{-}9}_{1975}$ | 167 | (0.36) | 153 | (0.40) | 192 | (0.66) | 388 | (0.68) | 326 | - | 505 | - | 187 | (0.46) | 206 | (0.22) | 179 | (0.37) |
| $B^{5\text{-}9}_{2015}$ | 132 | (0.21) | 110 | (0.18) | 120 | (0.18) | 82 | (0.16) | 96 | - | 68 | - | 119 | (0.17) | 176 | (0.24) | 138 | (0.18) |
| $B^{5\text{-}9}_{2015}/B^{5\text{-}9}_{1975}$ | 0.79 | (0.47) | 0.72 | (0.47) | 0.62 | (0.67) | 0.21 | (0.69) | 0.29 | - | 0.14 | #DIV/0! | 0.64 | (0.52) | 0.85 | (0.32) | 0.77 | (0.45) |
| | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA | $\sigma$ index | $\sigma$ CAA |
| Can. Fall 2J3K | 0.16 | 0.15 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.15 | 0.18 | 0.15 | 0.18 | 0.15 | 0.16 | 0.15 | 0.17 | 0.16 | 0.16 | 0.16 |
| EU 3M 0-700m | 0.15 | 0.22 | 0.15 | 0.23 | 0.15 | 0.23 | 0.15 | 0.21 | 0.45 | 0.20 | 0.40 | 0.19 | 0.15 | 0.21 | 0.19 | 0.18 | 0.15 | 0.22 |
| EU 3M 0-1400m | 0.24 | 0.11 | 0.24 | 0.12 | 0.24 | 0.11 | 0.21 | 0.13 | - | - | - | - | 0.23 | 0.11 | 0.25 | 0.11 | 0.24 | 0.12 |
| EU 3m 700-1400m | - | - | - | - | - | - | - | - | 0.28 | 0.10 | 0.31 | 0.11 | | | - | - | - | - |
| Can. Spring 3LNO | 0.55 | 0.19 | 0.54 | 0.19 | 0.55 | 0.19 | 0.50 | 0.20 | 0.53 | 0.18 | 0.50 | 0.18 | 0.53 | 0.19 | 0.53 | 0.19 | 0.54 | 0.19 |
| EU 3L | - | - | - | - | - | - | - | - | 0.16 | 0.17 | - | - | - | - | - | - | - | - |
| EU 3NO | - | - | - | - | - | - | - | - | 0.38 | 0.20 | 0.41 | 0.20 | 0.35 | 0.21 | - | - | - | - |
| Can. Fall 3LNO | - | - | - | - | - | - | - | - | 0.29 | 0.18 | 0.26 | 0.18 | 0.29 | 0.18 | - | - | - | - |
| Commercial | | 0.14 | | 0.14 | | 0.15 | | 0.14 | | 0.15 | | 0.16 | | 0.15 | | 0.15 | | 0.14 |

* Not converged

**Table 4**: MSY and related quantities for the various SCAA variants based on baseline run StartA (top two rows) and baseline run StartB (bottom two rows).

| | StartA | 10+ plus group | $M$=0.12 | 10+ plus group, $M$=0.12 | O1* | O2 | O3 | $h$=0.5 | $M$ increase (linear from 0.2 age 10 to 0.5 age 14+) |
|---|---|---|---|---|---|---|---|---|---|
| MSY | 26.58 (0.08) | 25.47 (0.08) | 25.51 (0.08) | 22.05 (0.09) | 24.46 - | 24.41 (0.07) | 26.10 (0.07) | 43.56 (0.46) | 28.23 (0.06) |
| $F_{MSY}$ | 0.60 | 0.58 | 0.58 | 0.60 | 0.56 | 0.52 | 0.62 | 0.21 | 0.58 |
| $B^{sp}_{MSY}$ | 90.16 (0.25) | 88.63 (0.23) | 194.57 (0.24) | 149.57 (0.18) | 80.82 - | 79.75 (0.39) | 88.17 (0.22) | 695.25 (0.51) | 54.65 (0.26) |
| $B^{sp}_{MSY}/K^{sp}$ | 0.15 (0.23) | 0.16 (0.21) | 0.16 (0.24) | 0.17 (0.14) | 0.15 - | 0.15 (0.38) | 0.15 (0.21) | 0.32 (0.20) | 0.15 (0.25) |
| $B^{sp}_{2015}/B^{sp}_{MSY}$ | 1.45 (0.43) | 1.21 (0.39) | 1.43 (0.47) | 0.73 (0.37) | 0.87 - | 0.74 (0.35) | 1.48 (0.35) | 0.45 (0.67) | 1.99 (0.37) |
| $B^{5\text{-}9}_{MSY}$ | 110.89 (0.11) | 103.39 (0.10) | 98.70 (0.12) | 84.13 (0.10) | 104.70 - | 105.59 (0.12) | 109.10 (0.10) | 377.99 (0.49) | 117.15 (0.11) |
| $B^{5\text{-}9}_{2015}/B^{5\text{-}9}_{MSY}$ | 1.14 (0.18) | 1.06 (0.17) | 1.22 (0.19) | 0.97 (0.13) | 0.93 - | 0.83 (0.15) | 1.08 (0.16) | 0.48 (0.61) | 1.16 (0.18) |
| | StartB | 10+ plus group | $M$=0.12 | 10+ plus group, $M$=0.12 | O1* | O2* | O3 | $h$=0.5 | $M$ increase (linear from 0.2 age 10 to 0.5 age 14+) |
| MSY | 27.78 (0.12) | 26.53 (0.12) | 25.86 (0.09) | 21.27 (0.10) | 24.48 - | 24.70 - | 26.48 (0.09) | 48.49 (0.57) | 28.75 (0.08) |
| $F_{MSY}$ | 0.60 | 0.56 | 0.58 | 0.62 | 0.55 | 0.39 | 0.62 | 0.21 | 0.58 |
| $B^{sp}_{MSY}$ | 94.46 (0.26) | 92.55 (0.24) | 196.93 (0.25) | 143.97 (0.19) | 80.70 - | 79.13 - | 89.44 (0.23) | 772.64 (0.61) | 55.71 (0.26) |
| $B^{sp}_{MSY}/K^{sp}$ | 0.15 (0.24) | 0.16 (0.23) | 0.16 (0.24) | 0.17 (0.15) | 0.15 - | 0.16 - | 0.15 (0.21) | 0.32 (0.19) | 0.15 (0.25) |
| $B^{sp}_{2015}/B^{sp}_{MSY}$ | 1.46 (0.43) | 1.17 (0.39) | 1.33 (0.46) | 0.80 (0.38) | 0.82 - | 0.40 - | 1.46 (0.35) | 0.38 (0.78) | 2.00 (0.37) |
| $B^{5\text{-}9}_{MSY}$ | 115.79 (0.14) | 107.47 (0.12) | 100.11 (0.12) | 81.55 (0.10) | 105.02 - | 106.40 - | 110.77 (0.11) | 420.65 (0.60) | 119.30 (0.12) |
| $B^{5\text{-}9}_{2015}/B^{5\text{-}9}_{MSY}$ | 1.14 (0.18) | 1.03 (0.17) | 1.20 (0.19) | 1.01 (0.13) | 0.91 - | 0.64 - | 1.07 (0.16) | 0.42 (0.72) | 1.16 (0.18) |

* Not converged

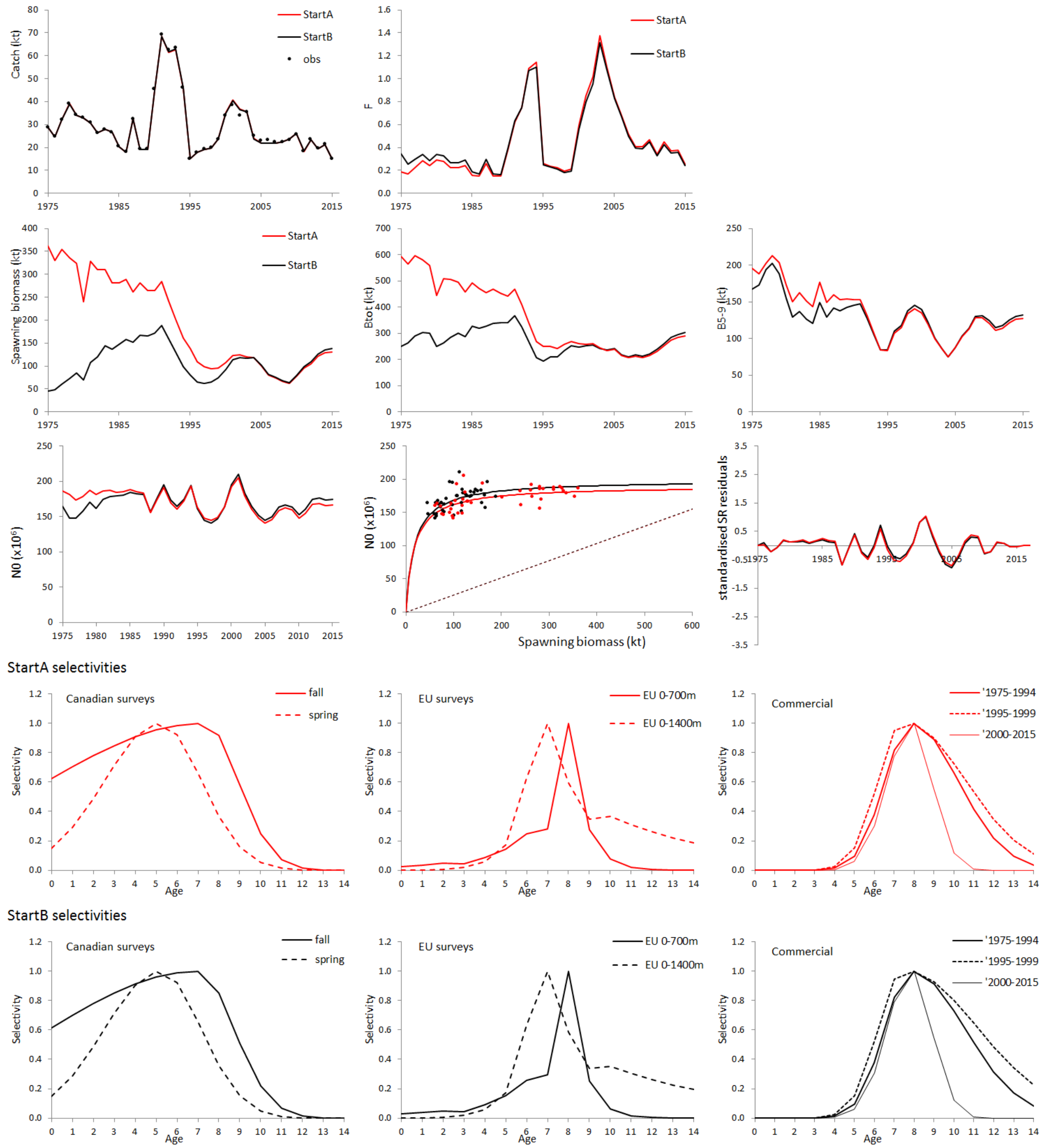


**Fig. 1.** Results for SCAA baseline variants StartA and StartB.


**Fig. 2.** Fits to the survey data for SCAA baseline variants StartA and StartB.

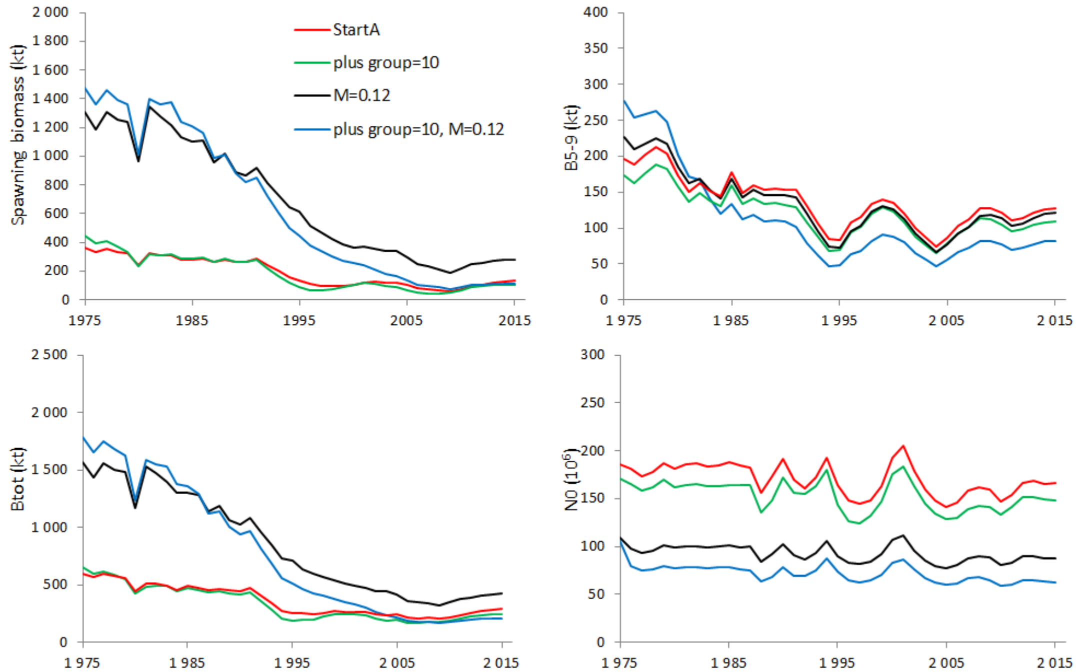


**Fig. 3a.** Biomass (spawning, 5-9 and total) and recruitment trajectories for baseline run StartA and the three variants: 10 instead of 14 plus-group, M=0.12 instead of M=0.2 and a combination of the two: M=0.12 and 10+.

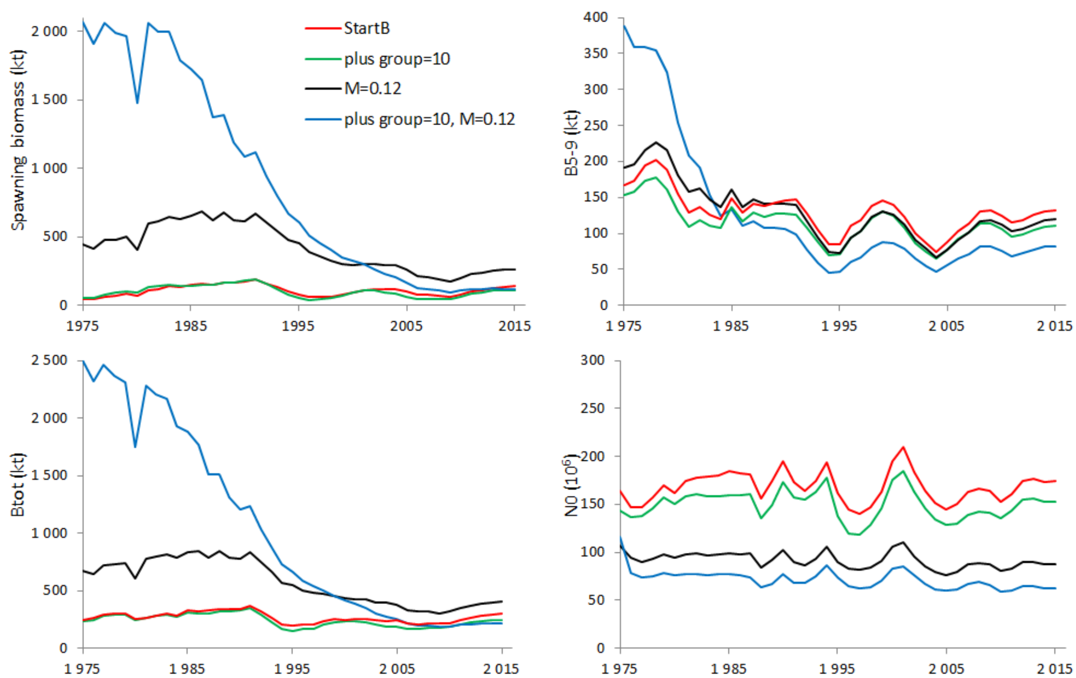


**Fig. 3b.** Biomass (spawning, 5-9 and total) and recruitment trajectories for baseline run StartB and the three variants: 10 instead of 14 plus-group, M=0.12 instead of M=0.2 and a combination of the two: M=0.12 and 10+.

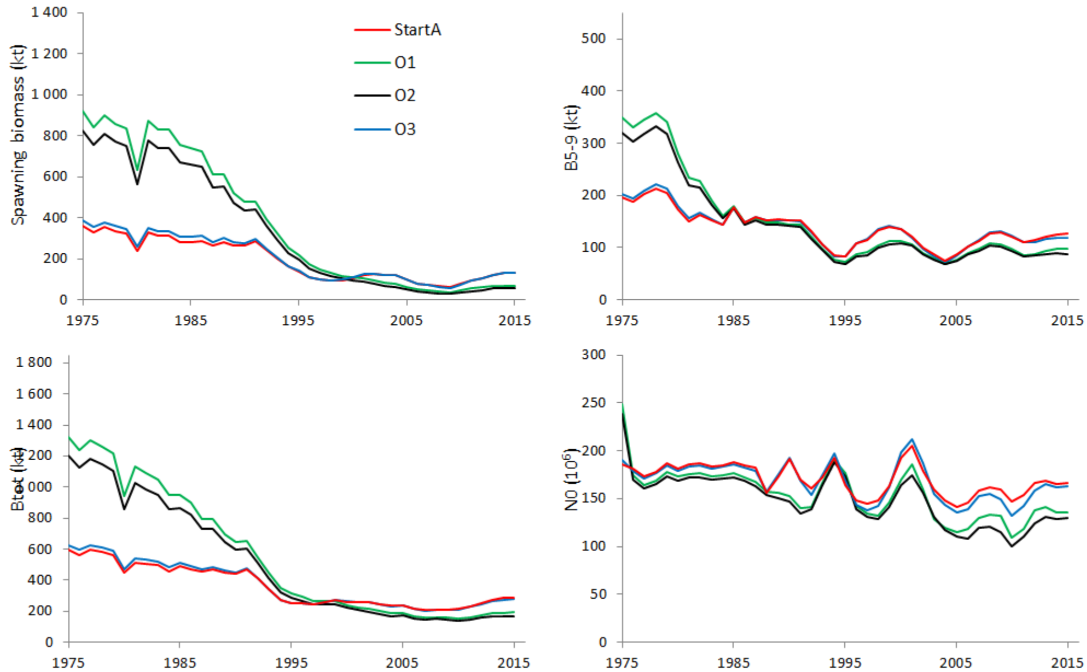


**Fig. 4a.** Biomass (spawning, 5-9 and total) and recruitment trajectories for baseline run StartA and the three variants based on different survey series.

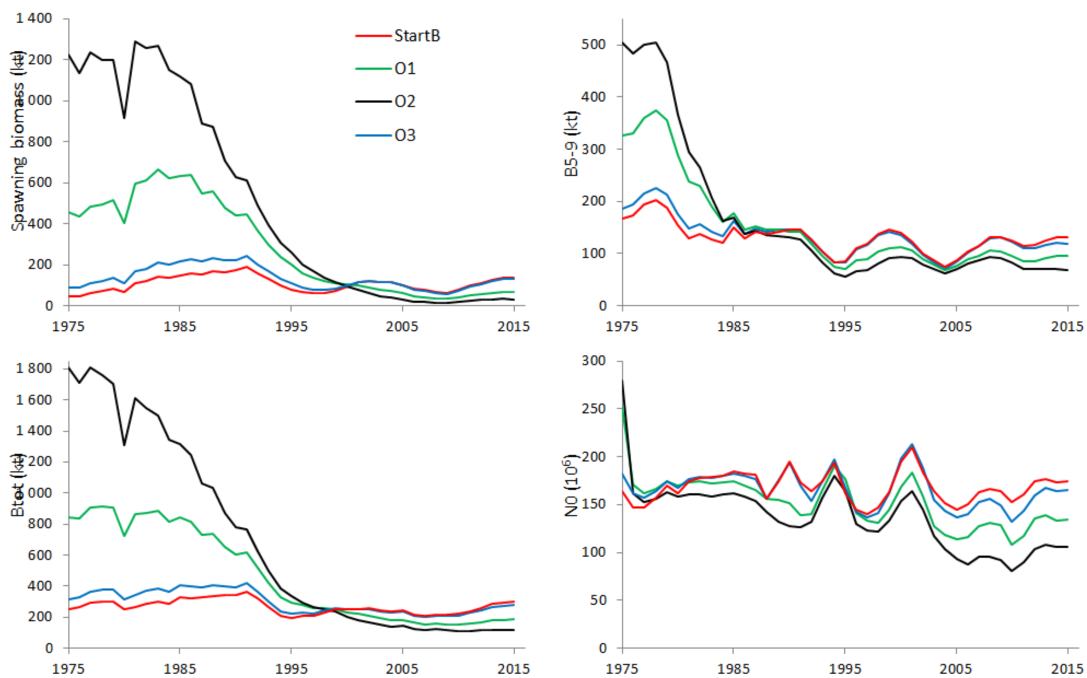


**Fig. 4b.** Biomass (spawning, 5-9 and total) and recruitment trajectories for baseline run StartB and the three variants based on different survey series.

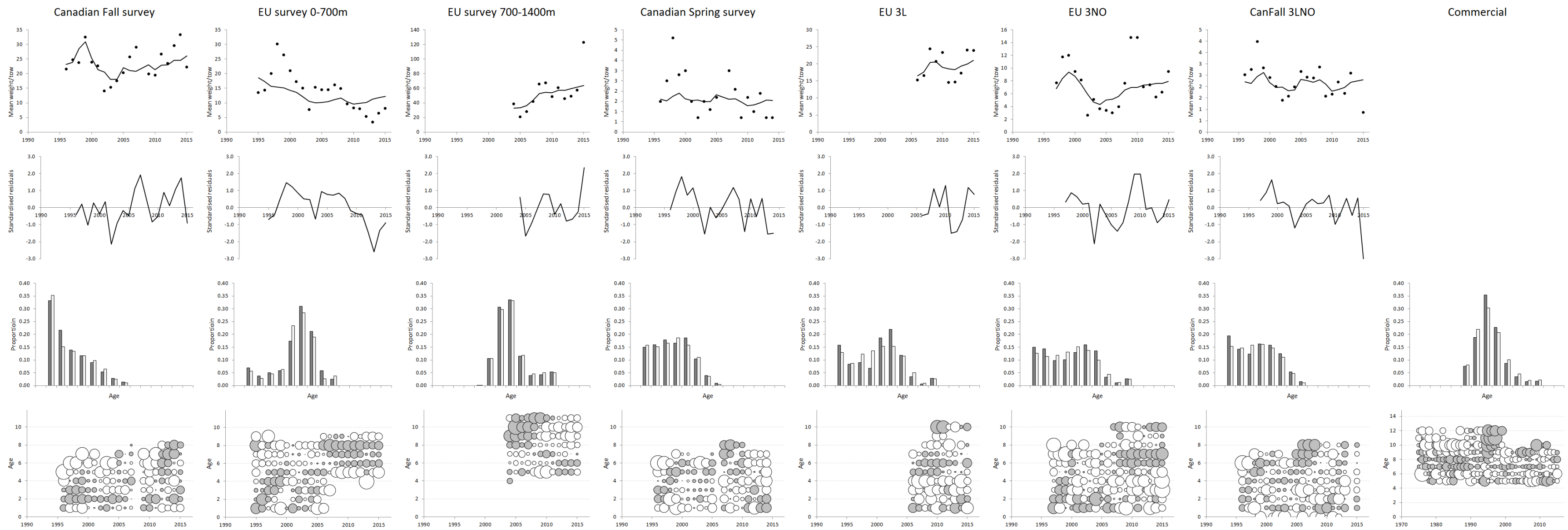


**Fig. 5.** Fits to the survey biomass indices and catch-at-age data for variant O1 based on StartA baseline run.

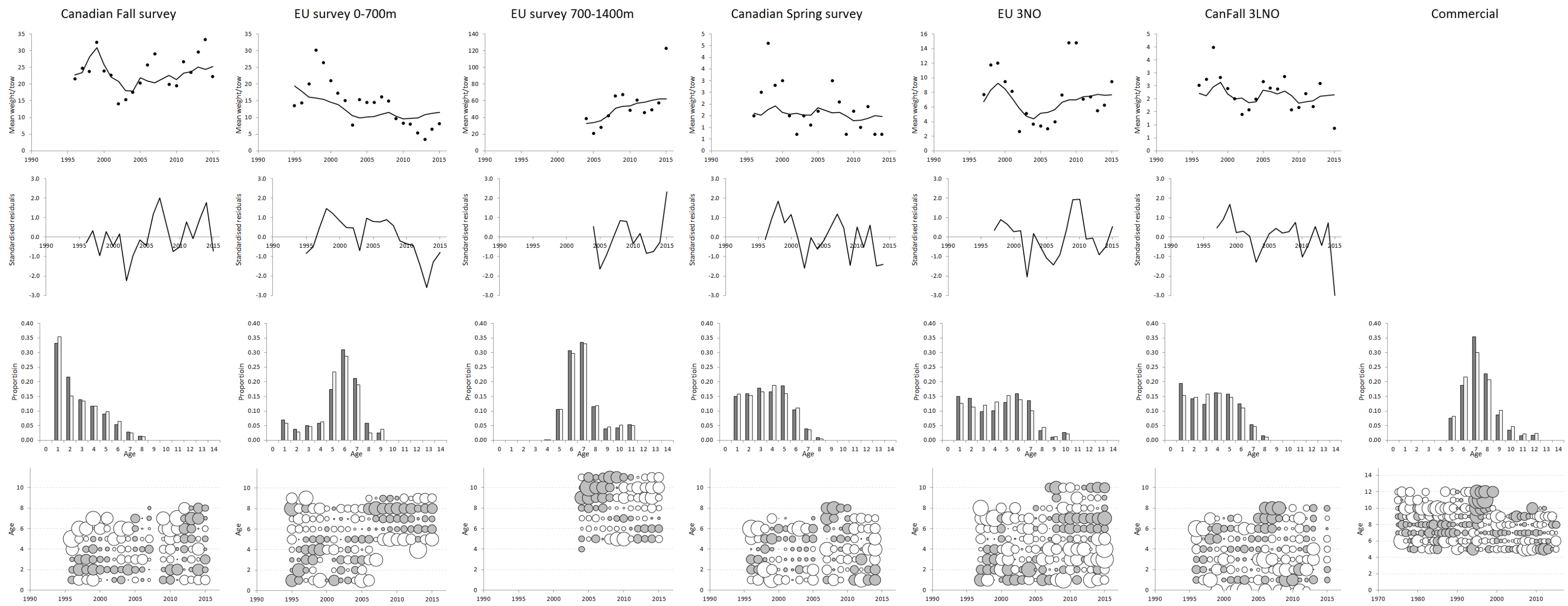


**Fig.6.** Fits to the survey biomass indices and catch-at-age data for variant O2 based on StartA baseline run.

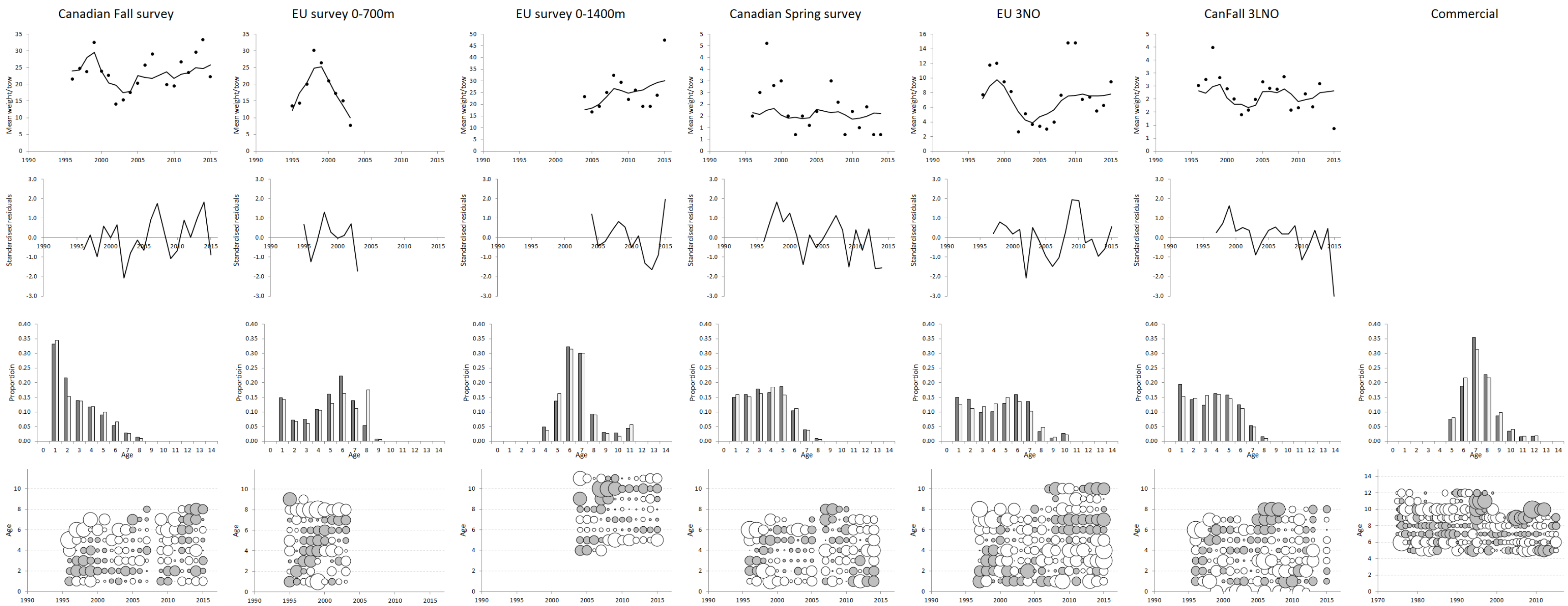


**Fig.7.** Fits to the survey biomass indices and catch-at-age data for variant O3 based on StartA baseline run.


**Fig. 8a.** Biomass (spawning, 5-9 and total) and recruitment trajectories for baseline run StartA and two variants.

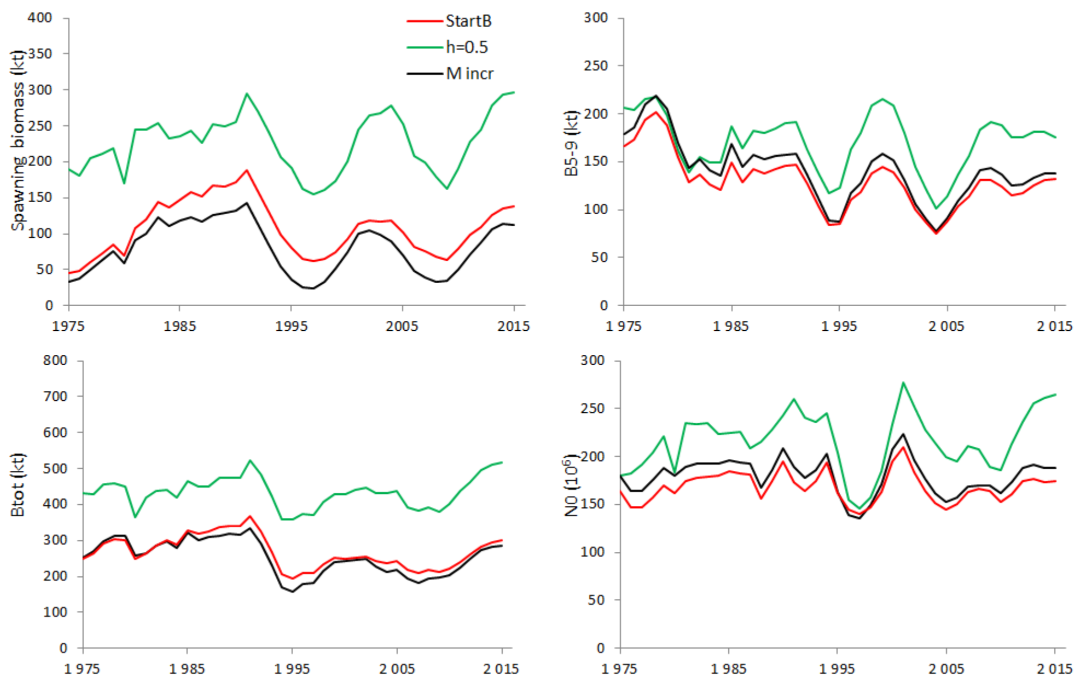


**Fig. 8b.** Biomass (spawning, 5-9 and total) and recruitment trajectories for baseline run StartB and two variants.

**APPENDIX A – Data**

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

| Year | Landings (t) | Year | Landings (t) |
|---|---|---|---|
| 1975 | 28817 | 1996 | 17715 |
| 1976 | 24608 | 1997 | 19201 |
| 1977 | 32047 | 1998 | 19863 |
| 1978 | 39069 | 1999 | 23488 |
| 1979 | 34102 | 2000 | 33850 |
| 1980 | 32867 | 2001 | 38425 |
| 1981 | 30756 | 2002 | 33975 |
| 1982 | 26277 | 2003 | 35432 |
| 1983 | 27863 | 2004 | 25126 |
| 1984 | 26711 | 2005 | 22866 |
| 1985 | 20347 | 2006 | 23075 |
| 1986 | 17981 | 2007 | 22229 |
| 1987 | 32447 | 2008 | 22191 |
| 1988 | 19219 | 2009 | 23281 |
| 1989 | 19229 | 2010 | 25681 |
| 1990 | 45416 | 2011 | 18290 |
| 1991 | 69197 | 2012 | 23385 |
| 1992 | 62372 | 2013 | 19659 |
| 1993 | 63545 | 2014 | 21353 |
| 1994 | 46040 | 2015 | 15080 |
| 1995 | 15087 | | |

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

| 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 | 37 | 479 | 1662 | 7239 | 17581 | 6607 | 1244 | 659 | 360 | 224 | 126 | 81 |
| 2003 | 0 | 0 | 203 | 1279 | 4491 | 10723 | 16764 | 6385 | 1614 | 516 | 290 | 144 | 76 | 85 |
| 2004 | 0 | 0 | 17 | 897 | 4062 | 8236 | 10542 | 4126 | 1307 | 529 | 289 | 184 | 87 | 75 |
| 2005 | 0 | 0 | 40 | 534 | 1652 | 5999 | 10313 | 3996 | 1410 | 444 | 244 | 114 | 64 | 46 |
| 2006 | 0 | 0 | 10 | 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 |
| 2010 | 0 | 0 | 0 | 146 | 825 | 5077 | 11202 | 6171 | 2134 | 520 | 214 | 64 | 22 | 21 |
| 2011 | 0 | 0 | 430 | 690 | 1385 | 4101 | 7257 | 3953 | 1255 | 455 | 155 | 66 | 21 | 18 |
| 2012 | 0 | 0 | 1216 | 706 | 1982 | 3422 | 7618 | 5529 | 1992 | 657 | 287 | 134 | 36 | 29 |
| 2013 | 0 | 0 | 127 | 481 | 1966 | 4850 | 5894 | 5370 | 1263 | 401 | 93 | 35 | 15 | 17 |
| 2014 | 0 | 0 | 119 | 263 | 1106 | 3818 | 5784 | 7441 | 1314 | 302 | 85 | 34 | 11 | 15 |
| 2015 | 0 | 0 | 59 | 89 | 429 | 1237 | 4037 | 5546 | 1571 | 223 | 58 | 22 | 9 | 19 |

**Table A3.** Catch weights-at-age (kg) matrix for Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO.

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 5.764 |
| 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 | 5.144 |
| 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 | 5.992 |
| 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 | 5.894 |
| 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 | 6.077 |
| 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 | 5.053 |
| 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 | 7.426 |
| 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 | 7.359 |
| 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 | 7.061 |
| 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 | 7.016 |
| 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 | 7.010 |
| 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 | 7.345 |
| 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 | 6.454 |
| 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 | 7.164 |
| 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 | 6.370 |
| 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 | 6.391 |
| 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 | 7.081 |
| 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 | 6.648 |
| 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 | 6.489 |
| 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 | 6.348 |
| 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 | 6.790 |
| 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 | 6.312 |
| 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 | 6.317 |
| 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 | 6.124 |
| 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 | 5.789 |
| 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 | 5.531 |
| 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 | 5.458 |
| 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 | 5.477 |
| 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 | 5.409 |
| 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 | 5.698 |
| 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 | 5.224 |
| 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 | 4.701 |
| 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 | 4.954 |
| 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 | 4.721 |
| 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 | 4.431 |
| 2010 | 0.000 | 0.000 | 0.000 | 0.250 | 0.350 | 0.570 | 0.840 | 1.210 | 1.650 | 2.100 | 2.610 | 3.310 | 4.180 | 5.220 |
| 2011 | 0.000 | 0.000 | 0.125 | 0.215 | 0.314 | 0.541 | 0.870 | 1.270 | 1.755 | 2.250 | 2.818 | 3.610 | 4.489 | 5.840 |
| 2012 | 0.000 | 0.000 | 0.170 | 0.240 | 0.300 | 0.570 | 0.890 | 1.280 | 1.750 | 2.290 | 2.810 | 3.620 | 4.400 | 5.730 |
| 2013 | 0.000 | 0.000 | 0.140 | 0.270 | 0.420 | 0.630 | 0.870 | 1.230 | 1.820 | 2.470 | 3.310 | 3.850 | 4.440 | 5.790 |
| 2014 | 0.000 | 0.000 | 0.150 | 0.240 | 0.400 | 0.613 | 0.890 | 1.280 | 1.900 | 2.550 | 3.360 | 3.930 | 4.600 | 5.530 |
| 2015 | 0.000 | 0.000 | 0.160 | 0.240 | 0.410 | 0.630 | 0.890 | 1.220 | 1.760 | 2.490 | 3.270 | 3.810 | 4.360 | 5.390 |

**Table A4**: Proportion mature-at-age for Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |

**Table A5**: Survey catch-at-age data (numbers) and biomass indices (mean weight (kg) per tow) for Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO.

Canadian Fall 3J3K

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Mean weight/tow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1996 | 4.92 | 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 | 0.01 | 21.60 |
| 1997 | 2.18 | 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 | 0.00 | 24.80 |
| 1998 | 1.52 | 23.35 | 25.07 | 31.19 | 21.87 | 10.86 | 4.45 | 2.07 | 0.57 | 0.13 | 0.06 | 0.03 | 0.02 | 0.01 | 0.00 | 23.80 |
| 1999 | 6.46 | 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 | 0.00 | 32.50 |
| 2000 | 3.08 | 38.60 | 22.09 | 16.48 | 13.29 | 13.90 | 7.27 | 2.17 | 0.50 | 0.06 | 0.03 | 0.02 | 0.00 | 0.00 | 0.01 | 23.90 |
| 2001 | 8.49 | 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 | 0.00 | 22.70 |
| 2002 | 8.30 | 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 | 0.00 | 14.10 |
| 2003 | 9.94 | 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 | 0.00 | 15.30 |
| 2004 | 4.15 | 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 | 0.00 | 17.50 |
| 2005 | 5.07 | 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 | 0.01 | 20.30 |
| 2006 | 3.75 | 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 | 0.00 | 25.70 |
| 2007 | 2.21 | 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 | 0.01 | 29.10 |
| 2009 | 5.49 | 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 | 0.01 | 19.90 |
| 2010 | 19.54 | 50.94 | 39.25 | 14.81 | 9.45 | 6.74 | 3.77 | 2.20 | 1.02 | 0.18 | 0.07 | 0.04 | 0.02 | 0.01 | 0.01 | 19.50 |
| 2011 | 4.81 | 44.14 | 42.06 | 20.97 | 18.79 | 10.32 | 5.50 | 3.15 | 1.26 | 0.33 | 0.13 | 0.06 | 0.02 | 0.00 | 0.01 | 26.70 |
| 2012 | 5.16 | 12.28 | 9.61 | 11.27 | 11.86 | 10.96 | 9.03 | 4.31 | 1.69 | 0.29 | 0.11 | 0.05 | 0.02 | 0.01 | 0.02 | 23.50 |
| 2013 | 0.10 | 24.32 | 12.92 | 6.74 | 7.40 | 10.91 | 9.09 | 7.76 | 3.96 | 0.50 | 0.15 | 0.04 | 0.02 | 0.02 | 0.01 | 29.60 |
| 2014 | 3.10 | 22.08 | 30.41 | 11.39 | 4.54 | 7.96 | 7.38 | 8.92 | 6.62 | 0.97 | 0.20 | 0.04 | 0.02 | 0.01 | 0.04 | 33.30 |
| 2015 | 0.50 | 17.17 | 13.98 | 15.14 | 7.77 | 6.82 | 4.18 | 3.91 | 3.92 | 0.65 | 0.14 | 0.06 | 0.01 | 0.01 | 0.02 | 22.30 |

Canadian Spring 3LNO

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Mean weight/tow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1996 | 0.00 | 1.62 | 4.24 | 4.60 | 2.18 | 0.83 | 0.28 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.50 |
| 1997 | 0.00 | 1.16 | 3.92 | 5.16 | 3.23 | 1.46 | 0.51 | 0.10 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.50 |
| 1998 | 0.00 | 0.23 | 0.84 | 3.89 | 6.22 | 4.96 | 1.24 | 0.33 | 0.07 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.60 |
| 1999 | 0.00 | 0.29 | 0.55 | 1.15 | 1.98 | 3.39 | 1.09 | 0.24 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.80 |
| 2000 | 0.02 | 0.79 | 1.07 | 1.07 | 1.51 | 1.95 | 2.04 | 0.56 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 |
| 2001 | 0.00 | 0.57 | 0.71 | 0.74 | 0.68 | 0.80 | 0.72 | 0.28 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.50 |
| 2002 | 0.00 | 0.64 | 0.57 | 0.60 | 0.58 | 0.61 | 0.21 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.70 |
| 2003 | 0.00 | 0.93 | 2.14 | 1.66 | 1.57 | 1.06 | 0.21 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.50 |
| 2004 | 0.00 | 0.66 | 0.57 | 1.18 | 1.18 | 1.16 | 0.26 | 0.04 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.10 |
| 2005 | 0.00 | 0.35 | 0.31 | 1.09 | 0.95 | 1.37 | 0.82 | 0.21 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.70 |
| 2007 | 0.00 | 1.60 | 0.52 | 0.80 | 0.40 | 1.41 | 1.49 | 1.12 | 0.18 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 |
| 2008 | 0.00 | 0.44 | 0.77 | 0.96 | 0.71 | 1.25 | 0.75 | 0.64 | 0.28 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 2.10 |
| 2009 | 0.00 | 0.27 | 0.22 | 0.19 | 0.39 | 0.45 | 0.26 | 0.13 | 0.07 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.70 |
| 2010 | 0.00 | 0.77 | 0.66 | 0.52 | 0.40 | 0.84 | 1.08 | 0.35 | 0.14 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 1.70 |
| 2011 | 0.00 | 1.96 | 1.40 | 0.92 | 0.65 | 0.62 | 0.29 | 0.16 | 0.10 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 |
| 2012 | 0.02 | 0.32 | 0.80 | 2.48 | 1.40 | 1.16 | 0.50 | 0.18 | 0.06 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.90 |
| 2013 | 0.00 | 1.28 | 0.68 | 0.05 | 0.38 | 0.61 | 0.23 | 0.11 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.70 |
| 2014 | 0.00 | 1.62 | 1.19 | 0.32 | 0.20 | 0.24 | 0.24 | 0.14 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.70 |

Canadian Fall 3LNO

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Mean weight/tow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1996 | 0.25 | 5.27 | 4.92 | 3.84 | 1.41 | 1.00 | 0.40 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.52 |
| 1997 | 0.24 | 1.22 | 3.33 | 4.46 | 3.63 | 1.88 | 0.48 | 0.11 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.76 |
| 1998 | 0.06 | 0.53 | 1.76 | 1.86 | 2.99 | 4.10 | 1.50 | 0.32 | 0.08 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.98 |
| 1999 | 0.22 | 0.04 | 0.62 | 0.73 | 1.04 | 1.97 | 1.67 | 0.39 | 0.04 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 2.82 |
| 2000 | 0.12 | 1.76 | 1.24 | 0.39 | 0.78 | 1.21 | 1.35 | 0.47 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.39 |
| 2001 | 0.49 | 1.40 | 0.62 | 0.68 | 1.39 | 0.75 | 1.15 | 0.61 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.01 |
| 2002 | 0.13 | 1.28 | 0.90 | 1.04 | 1.01 | 0.91 | 0.39 | 0.17 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.40 |
| 2003 | 0.17 | 1.79 | 1.07 | 1.55 | 1.87 | 0.91 | 0.28 | 0.05 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.59 |
| 2004 | 0.06 | 1.18 | 1.32 | 1.56 | 1.69 | 1.51 | 0.39 | 0.10 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.99 |
| 2005 | 0.08 | 0.60 | 0.89 | 0.50 | 1.76 | 1.58 | 1.14 | 0.56 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.67 |
| 2006 | 0.16 | 0.85 | 0.49 | 0.12 | 0.68 | 1.33 | 1.35 | 0.59 | 0.13 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.42 |
| 2007 | 0.10 | 0.83 | 0.47 | 0.27 | 0.81 | 0.61 | 1.24 | 0.75 | 0.21 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 2.38 |
| 2008 | 0.26 | 0.95 | 0.28 | 0.82 | 1.13 | 0.90 | 1.00 | 0.76 | 0.44 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.87 |
| 2009 | 0.23 | 2.15 | 0.24 | 0.42 | 0.47 | 0.88 | 0.61 | 0.30 | 0.14 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 1.58 |
| 2010 | 0.44 | 1.95 | 0.62 | 0.86 | 0.68 | 0.68 | 0.67 | 0.31 | 0.11 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 1.66 |
| 2011 | 0.33 | 1.30 | 4.13 | 1.20 | 2.02 | 0.93 | 0.67 | 0.32 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 2.21 |
| 2012 | 0.33 | 0.62 | 0.20 | 0.45 | 1.19 | 0.93 | 0.70 | 0.27 | 0.08 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.71 |
| 2013 | 0.08 | 2.77 | 1.00 | 0.37 | 0.41 | 1.02 | 1.06 | 0.62 | 0.26 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 2.59 |
| 2015 | 0.05 | 0.78 | 0.60 | 0.33 | 0.31 | 0.25 | 0.34 | 0.17 | 0.10 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.87 |

**Table A5**: continued

EU 3M 0-700m

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Mean weight/tow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1995 | 0.00 | 12.41 | 2.54 | 2.23 | 1.91 | 2.66 | 5.10 | 3.77 | 2.12 | 1.31 | 0.26 | 0.07 | 0.02 | 0.00 | 0.01 | 13.52 |
| 1996 | 0.00 | 5.84 | 7.97 | 2.41 | 3.04 | 4.20 | 5.82 | 2.49 | 1.62 | 0.42 | 0.09 | 0.03 | 0.04 | 0.00 | 0.01 | 14.42 |
| 1997 | 0.00 | 3.33 | 3.78 | 6.00 | 6.50 | 7.11 | 8.46 | 4.99 | 2.15 | 0.66 | 0.22 | 0.03 | 0.02 | 0.02 | 0.02 | 20.01 |
| 1998 | 0.00 | 2.74 | 2.13 | 7.68 | 11.00 | 12.33 | 11.30 | 7.84 | 2.62 | 0.75 | 0.20 | 0.03 | 0.01 | 0.02 | 0.00 | 30.13 |
| 1999 | 0.00 | 1.06 | 0.70 | 3.01 | 10.47 | 13.41 | 12.58 | 5.55 | 1.82 | 0.35 | 0.10 | 0.01 | 0.00 | 0.00 | 0.01 | 26.37 |
| 2000 | 0.00 | 3.75 | 0.29 | 0.60 | 2.16 | 7.09 | 14.10 | 5.40 | 2.32 | 0.45 | 0.11 | 0.05 | 0.00 | 0.00 | 0.00 | 21.08 |
| 2001 | 0.00 | 8.03 | 1.43 | 1.81 | 0.99 | 2.79 | 7.79 | 6.63 | 3.21 | 0.18 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 | 17.25 |
| 2002 | 0.00 | 4.08 | 2.94 | 2.79 | 1.67 | 3.79 | 5.59 | 5.73 | 1.28 | 0.13 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 15.05 |
| 2003 | 0.00 | 2.20 | 1.00 | 0.61 | 1.51 | 2.48 | 2.94 | 1.93 | 0.47 | 0.13 | 0.10 | 0.02 | 0.00 | 0.00 | 0.00 | 7.73 |
| 2004 | 0.00 | 2.19 | 3.29 | 4.37 | 1.97 | 6.96 | 7.80 | 2.54 | 0.64 | 0.29 | 0.13 | 0.08 | 0.05 | 0.01 | 0.00 | 15.28 |
| 2005 | 0.00 | 0.54 | 0.81 | 3.18 | 2.50 | 6.89 | 7.59 | 2.92 | 0.61 | 0.11 | 0.12 | 0.06 | 0.02 | 0.00 | 0.00 | 14.55 |
| 2006 | 0.00 | 0.68 | 0.39 | 0.65 | 1.18 | 5.97 | 7.46 | 3.31 | 0.77 | 0.22 | 0.18 | 0.13 | 0.06 | 0.01 | 0.00 | 14.56 |
| 2007 | 0.00 | 0.37 | 0.08 | 0.57 | 0.34 | 3.44 | 7.37 | 5.76 | 1.51 | 0.31 | 0.21 | 0.08 | 0.05 | 0.01 | 0.00 | 16.22 |
| 2008 | 0.00 | 0.20 | 0.10 | 0.15 | 0.19 | 1.50 | 5.70 | 6.16 | 1.13 | 0.35 | 0.26 | 0.12 | 0.05 | 0.02 | 0.01 | 14.91 |
| 2009 | 0.00 | 0.08 | 0.01 | 0.04 | 0.10 | 0.75 | 3.61 | 4.05 | 0.89 | 0.19 | 0.27 | 0.08 | 0.06 | 0.04 | 0.02 | 9.67 |
| 2010 | 0.00 | 0.05 | 0.01 | 0.04 | 0.06 | 1.11 | 3.07 | 2.94 | 0.89 | 0.32 | 0.17 | 0.06 | 0.03 | 0.01 | 0.00 | 8.28 |
| 2011 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 1.08 | 3.58 | 3.46 | 0.68 | 0.21 | 0.11 | 0.02 | 0.01 | 0.01 | 0.01 | 8.05 |
| 2012 | 0.00 | 0.00 | 0.01 | 0.05 | 0.11 | 1.02 | 2.27 | 1.75 | 0.44 | 0.14 | 0.10 | 0.07 | 0.02 | 0.01 | 0.02 | 5.34 |
| 2013 | 0.00 | 0.01 | 0.00 | 0.01 | 0.14 | 0.80 | 2.16 | 0.89 | 0.20 | 0.05 | 0.06 | 0.02 | 0.01 | 0.01 | 0.01 | 3.48 |
| 2014 | 0.00 | 0.03 | 0.00 | 0.00 | 0.12 | 1.35 | 2.88 | 1.95 | 0.35 | 0.08 | 0.08 | 0.03 | 0.01 | 0.02 | 0.01 | 6.43 |
| 2015 | 0.00 | 0.05 | 0.02 | 0.00 | 0.06 | 0.89 | 4.28 | 2.60 | 0.61 | 0.15 | 0.14 | 0.06 | 0.02 | 0.00 | 0.00 | 8.18 |

EU 3M 0-1400m

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Mean weight/tow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | 0.00 | 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 | 0.17 | 23.33 |
| 2005 | 0.00 | 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 | 0.05 | 16.71 |
| 2006 | 0.00 | 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 | 0.04 | 19.17 |
| 2007 | 0.00 | 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 | 0.07 | 25.10 |
| 2008 | 0.00 | 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 | 0.22 | 32.35 |
| 2009 | 0.00 | 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 | 0.24 | 29.44 |
| 2010 | 0.00 | 0.03 | 0.01 | 0.02 | 0.11 | 2.00 | 6.01 | 7.83 | 2.50 | 0.98 | 0.83 | 0.31 | 0.17 | 0.12 | 0.19 | 22.13 |
| 2011 | 0.00 | 0.00 | 0.00 | 0.01 | 0.09 | 1.85 | 6.70 | 8.49 | 2.57 | 1.11 | 1.22 | 0.46 | 0.26 | 0.22 | 0.19 | 26.15 |
| 2012 | 0.00 | 0.00 | 0.01 | 0.04 | 0.16 | 2.42 | 5.78 | 5.00 | 1.92 | 0.75 | 0.74 | 0.48 | 0.19 | 0.10 | 0.27 | 19.20 |
| 2013 | 0.00 | 0.01 | 0.00 | 0.01 | 0.32 | 2.11 | 7.03 | 4.53 | 1.64 | 0.53 | 0.84 | 0.34 | 0.29 | 0.13 | 0.22 | 19.11 |
| 2014 | 0.00 | 0.02 | 0.00 | 0.01 | 0.16 | 2.78 | 8.04 | 6.87 | 1.62 | 0.45 | 0.64 | 0.33 | 0.15 | 0.19 | 0.22 | 23.92 |
| 2015 | 0.00 | 0.03 | 0.01 | 0.01 | 0.12 | 2.54 | 14.85 | 14.04 | 4.62 | 1.67 | 1.41 | 0.78 | 0.29 | 0.17 | 0.41 | 47.52 |

EU 3M 700-1400m

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Mean weight/tow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | 0.00 | 0.02 | 0.00 | 0.06 | 0.73 | 5.99 | 12.36 | 9.57 | 3.15 | 1.59 | 0.84 | 0.61 | 0.36 | 0.40 | 0.49 | 38.72 |
| 2005 | 0.00 | 0.00 | 0.00 | 0.02 | 0.26 | 2.22 | 5.26 | 4.37 | 1.70 | 0.55 | 0.96 | 0.57 | 0.35 | 0.18 | 0.16 | 20.85 |
| 2006 | 0.00 | 0.00 | 0.00 | 0.04 | 0.40 | 5.61 | 10.65 | 7.29 | 2.56 | 0.79 | 0.71 | 0.63 | 0.32 | 0.11 | 0.14 | 28.00 |
| 2007 | 0.00 | 0.03 | 0.00 | 0.05 | 0.20 | 4.60 | 12.39 | 13.93 | 5.51 | 1.51 | 1.31 | 0.72 | 0.40 | 0.17 | 0.21 | 42.10 |
| 2008 | 0.00 | 0.00 | 0.00 | 0.00 | 0.12 | 3.05 | 15.33 | 24.73 | 7.09 | 2.67 | 2.02 | 1.05 | 0.62 | 0.33 | 0.64 | 65.72 |
| 2009 | 0.00 | 0.00 | 0.00 | 0.02 | 0.05 | 1.83 | 12.90 | 25.56 | 8.64 | 2.33 | 2.48 | 0.88 | 0.69 | 0.64 | 0.67 | 67.28 |
| 2010 | 0.00 | 0.00 | 0.00 | 0.02 | 0.05 | 1.83 | 12.90 | 25.56 | 8.64 | 2.33 | 2.48 | 0.88 | 0.69 | 0.64 | 0.67 | 48.64 |
| 2011 | 0.00 | 0.00 | 0.00 | 0.03 | 0.11 | 3.33 | 12.66 | 18.09 | 6.15 | 2.85 | 3.34 | 1.29 | 0.75 | 0.63 | 0.53 | 60.79 |
| 2012 | 0.00 | 0.00 | 0.00 | 0.02 | 0.27 | 5.09 | 12.49 | 11.23 | 4.76 | 1.93 | 1.96 | 1.27 | 0.52 | 0.27 | 0.74 | 45.73 |
| 2013 | 0.00 | 0.00 | 0.00 | 0.02 | 0.67 | 4.62 | 16.38 | 11.47 | 4.40 | 1.44 | 2.34 | 0.95 | 0.81 | 0.35 | 0.63 | 49.00 |
| 2014 | 0.00 | 0.00 | 0.00 | 0.01 | 0.25 | 5.51 | 17.91 | 16.30 | 4.06 | 1.15 | 1.70 | 0.91 | 0.41 | 0.53 | 0.60 | 57.41 |
| 2015 | 0.00 | 0.00 | 0.00 | 0.02 | 0.24 | 5.69 | 35.08 | 35.94 | 12.28 | 4.57 | 3.86 | 2.17 | 0.83 | 0.50 | 1.19 | 122.81 |

**Table A5**: continued

EU 3L

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Mean weight/tow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2006 | 0.00 | 8.58 | 3.95 | 2.30 | 3.36 | 11.41 | 7.15 | 2.36 | 0.41 | 0.07 | 0.13 | 0.06 | 0.01 | 0.03 | 0.02 | 15.32 |
| 2007 | 0.00 | 5.56 | 1.33 | 2.16 | 0.82 | 9.22 | 8.58 | 4.16 | 0.63 | 0.18 | 0.15 | 0.06 | 0.01 | 0.01 | 0.03 | 16.64 |
| 2008 | 0.00 | 3.44 | 0.62 | 5.73 | 1.64 | 6.61 | 11.00 | 7.85 | 1.54 | 0.43 | 0.32 | 0.17 | 0.04 | 0.05 | 0.16 | 24.40 |
| 2009 | 0.00 | 7.11 | 1.48 | 1.16 | 2.50 | 7.54 | 8.20 | 5.77 | 1.63 | 0.37 | 0.40 | 0.09 | 0.07 | 0.03 | 0.11 | 20.75 |
| 2010 | 0.00 | 1.29 | 3.50 | 2.12 | 3.32 | 7.39 | 8.14 | 4.54 | 1.67 | 0.84 | 0.53 | 0.16 | 0.18 | 0.17 | 0.20 | 23.41 |
| 2011 | 0.00 | 4.60 | 1.57 | 1.80 | 1.57 | 3.54 | 5.26 | 2.37 | 1.46 | 0.69 | 0.32 | 0.33 | 0.13 | 0.06 | 0.11 | 14.61 |
| 2012 | 0.00 | 3.18 | 2.58 | 8.65 | 2.41 | 4.13 | 5.66 | 2.27 | 0.66 | 0.40 | 0.33 | 0.18 | 0.10 | 0.03 | 0.06 | 14.67 |
| 2013 | 0.00 | 13.05 | 1.72 | 1.11 | 4.00 | 6.19 | 6.92 | 3.30 | 0.66 | 0.37 | 0.31 | 0.13 | 0.13 | 0.09 | 0.14 | 17.31 |
| 2014 | 0.00 | 8.49 | 9.98 | 2.56 | 1.43 | 7.33 | 6.92 | 5.47 | 1.83 | 0.84 | 0.45 | 0.33 | 0.22 | 0.08 | 0.20 | 24.09 |
| 2015 | 0.00 | 1.51 | 4.71 | 2.58 | 2.62 | 2.99 | 8.86 | 3.89 | 2.62 | 0.62 | 0.81 | 0.25 | 0.27 | 0.12 | 0.23 | 23.90 |

EU 3NO

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Mean weight/tow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | 0.00 | 9.92 | 5.52 | 3.49 | 3.81 | 2.24 | 1.97 | 1.22 | 0.60 | 0.07 | 0.05 | 0.05 | 0.02 | 0.01 | 0.03 | 7.73 |
| 1998 | 0.00 | 1.71 | 5.24 | 9.09 | 8.47 | 5.06 | 2.77 | 1.10 | 0.66 | 0.21 | 0.08 | 0.03 | 0.03 | 0.02 | 0.03 | 11.73 |
| 1999 | 0.15 | 4.38 | 4.81 | 7.21 | 9.31 | 6.29 | 2.92 | 0.78 | 0.49 | 0.23 | 0.09 | 0.03 | 0.05 | 0.03 | 0.05 | 12.00 |
| 2000 | 0.00 | 2.92 | 0.49 | 0.80 | 1.39 | 3.84 | 4.42 | 2.56 | 0.71 | 0.28 | 0.08 | 0.06 | 0.04 | 0.05 | 0.12 | 9.48 |
| 2001 | 0.00 | 8.87 | 5.90 | 1.18 | 1.07 | 2.84 | 3.96 | 1.56 | 0.22 | 0.06 | 0.05 | 0.04 | 0.05 | 0.05 | 0.06 | 8.17 |
| 2002 | 0.00 | 2.91 | 0.64 | 1.02 | 0.70 | 1.14 | 0.92 | 0.44 | 0.23 | 0.02 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 2.64 |
| 2003 | 0.00 | 3.56 | 2.40 | 1.69 | 1.91 | 1.58 | 0.90 | 0.78 | 0.26 | 0.06 | 0.04 | 0.01 | 0.07 | 0.01 | 0.02 | 5.10 |
| 2004 | 0.00 | 1.22 | 6.96 | 2.09 | 2.06 | 1.24 | 0.85 | 0.51 | 0.21 | 0.05 | 0.03 | 0.01 | 0.03 | 0.02 | 0.02 | 3.68 |
| 2005 | 0.00 | 1.07 | 0.97 | 1.81 | 1.04 | 1.32 | 1.44 | 0.68 | 0.19 | 0.08 | 0.06 | 0.03 | 0.03 | 0.02 | 0.02 | 3.39 |
| 2006 | 0.00 | 2.31 | 1.12 | 0.41 | 1.55 | 1.38 | 0.82 | 0.52 | 0.23 | 0.05 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 3.03 |
| 2007 | 0.00 | 1.81 | 0.65 | 0.51 | 0.32 | 1.48 | 1.40 | 1.02 | 0.29 | 0.10 | 0.09 | 0.03 | 0.03 | 0.00 | 0.02 | 3.98 |
| 2008 | 0.00 | 0.62 | 0.99 | 0.90 | 0.69 | 0.94 | 2.70 | 2.50 | 0.74 | 0.40 | 0.15 | 0.10 | 0.03 | 0.02 | 0.04 | 7.66 |
| 2009 | 0.00 | 0.70 | 3.22 | 2.21 | 2.61 | 2.73 | 4.94 | 5.67 | 0.85 | 0.35 | 0.19 | 0.14 | 0.03 | 0.02 | 0.12 | 14.78 |
| 2010 | 0.00 | 0.37 | 2.21 | 0.94 | 0.73 | 3.42 | 5.58 | 5.16 | 1.24 | 0.39 | 0.26 | 0.24 | 0.04 | 0.02 | 0.05 | 14.80 |
| 2011 | 0.00 | 2.20 | 1.30 | 0.48 | 0.62 | 0.95 | 2.01 | 2.12 | 0.43 | 0.23 | 0.24 | 0.05 | 0.06 | 0.02 | 0.10 | 7.09 |
| 2012 | 0.00 | 0.08 | 1.80 | 1.34 | 0.44 | 1.09 | 1.71 | 2.00 | 0.54 | 0.40 | 0.34 | 0.11 | 0.05 | 0.06 | 0.12 | 7.37 |
| 2013 | 0.00 | 0.27 | 0.45 | 0.23 | 0.81 | 1.18 | 1.48 | 1.22 | 0.33 | 0.21 | 0.24 | 0.13 | 0.09 | 0.03 | 0.09 | 5.46 |
| 2014 | 0.00 | 0.51 | 1.28 | 0.26 | 0.15 | 0.54 | 1.65 | 1.75 | 0.45 | 0.21 | 0.23 | 0.18 | 0.11 | 0.05 | 0.10 | 6.24 |
| 2015 | 0.00 | 0.93 | 0.62 | 0.20 | 0.21 | 0.47 | 1.81 | 3.38 | 0.94 | 0.44 | 0.35 | 0.19 | 0.10 | 0.03 | 0.12 | 9.49 |

## Appendix B

### Algebraic details of the Statistical Catch-at-Age Model

The text following sets out the equations and other general specifications of the Statistical Catch-at-Age (SCAA) assessment model applied to Greenland halibut, followed by details of the contributions to the (penalised) log-likelihood function from the different sources of data available and assumptions concerning the stock-recruitment relationship. Quasi-Newton minimization is applied to minimize the total negative log-likelihood function to estimate parameter values (the package AD Model Builder™, Otter Research, Ltd is used for this purpose).

Where options are provided under a particular section, the section concludes with a statement in **bold** as to which option was selected for the baseline run selected.

**B.1. Population dynamics**

*B.1.1 Numbers-at-age*

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,0} = R_{y+1} \quad \text{(B.1)}$$

$$N_{y+1,a+1} = N_{y,a}e^{-Z_{y,a}} \quad \text{for } 0 \le a \le m-2 \quad \text{(B.2)}$$

$$N_{y+1,m} = N_{y,m-1}e^{-Z_{y,m-1}} + N_{y,m}e^{-Z_{y,m}} \quad \text{(B.3)}$$

where

$N_{y,a}$ is the number of fish of age $a$ at the start of year $y$,

$R_y$ is the recruitment (number of 0-year-old fish) at the start of year $y$,

$m$ is the maximum age considered (taken to be a plus-group).

$Z_{y,a} = F_yS_{y,a} + M_a$ is the total mortality in year $y$ on fish of age $a$, where

$M_a$ denotes the natural mortality rate for fish of age $a$,

$F_y$ is the fishing mortality of a fully selected age class in year $y$, and

$S_{y,a}$ is the commercial selectivity at age $a$ for year $y$.

*B.1.2. Recruitment*

The number of recruits (i.e. new 0-year olds) at the start of year $y$ is assumed to be related to the spawning stock size (i.e. the biomass of mature fish) by Beverton-Holt stock-recruitment relationship, allowing for annual fluctuation about the deterministic relationship.

$$R_y = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{(\varphi_y - (\sigma_R)^2/2)} \quad \text{(B.4)}$$

where

$\alpha$ and $\beta$ are spawning biomass-recruitment relationship parameters,

$\varphi_y$ reflects fluctuation about the expected recruitment for year $y$, which is assumed to be normally distributed with standard deviation $\sigma_R$ (which is input in the applications considered here); these residuals are treated as estimable parameters in the model fitting process.

$B_y^{sp}$ is the spawning biomass at the start of year $y$, computed as:

$$B_y^{sp} = \sum_{a=1}^{m} f_a\, w_{y,a}^{strt} N_{y,a} \quad \text{(B.5)}$$

where

$w_{y,a}^{strt}$ is the mass of fish of age $a$ during spawning, and

$f_a$ is the proportion of fish of age $a$ that are mature.

In order to work with estimable parameters that are more biologically meaningful, the stock-recruitment relationship is re-parameterised in terms of the pre-exploitation (virgin) equilibrium spawning biomass $B_0$ and the steepness, $h$, of the stock-recruitment relationship, which is the proportion of the virgin recruitment $R_0$ that is realised at a spawning biomass level of 20% of the virgin spawning biomass:

$$\alpha = \frac{4hR_0}{5h-1} \tag{B.6}$$

and

$$\beta = \frac{B_0(1-h)}{5h-1} \tag{B.7}$$

where

$$R_0 = B_0 \Big/ \left[ \sum_{a=1}^{m-1} f_a w_{y_0,a}^{strt} exp\left(-\sum_{a'=0}^{a-1} M_{a'}\right) + f_m w_{y_0,m}^{strt} \frac{exp\left(-\sum_{a'=0}^{m-1} M_{a'}\right)}{1-exp(-M_m)} \right] \tag{B.8}$$

**For baseline run, $h$ is fixed to 0.9 and $\sigma_R$=0.2.**

*B.1.3. Total catch and catches-at-age*

The total catch by mass in year $y$ is given by:

$$C_y = \sum_{a=0}^{m} w_{y,a}^{mid} C_{y,a} = \sum_{a=0}^{m} w_{y,a}^{mid} N_{y,a} S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a} \tag{B.9}$$

where

$w_{y,a}^{mid}$ denotes the mass of fish of age $a$ landed in year $y$,

$C_{y,a}$ is the catch-at-age, i.e. the number of fish of age $a$, caught in year $y$.

*B.1.4. Initial conditions*

As the first year for which data are available for the Greenland halibut stock considered clearly does not correspond to the first year of (appreciable) exploitation, one cannot necessarily make the conventional assumption in the application of SCAA's that this initial year reflects a population (and its age-structure) at pre-exploitation equilibrium. For the first year ($y_0$) considered in the model therefore, the starting numbers-at-age are estimated directly for ages 0 to $a_m$, and an average fishing mortality is applied for ages $a_m$ +1 to $m$:

$$N_{y_0,a} = \begin{cases} \text{estimated} & \text{for } 0 \le a \le a_m \\ N_{y_0,a-1} e^{-M_{a-1}} \left(1 - \vartheta S_{y_0,a-1}\right) & \text{for } a_m < a < m \\ N_{y_0,m-1} e^{-M_{m-1}} \left(1 - \vartheta S_{y_0,m-1}\right) / \left(1 - e^{-M_m}\left(1 - \vartheta S_{y_0,m}\right)\right) & \text{for } a = m \end{cases} \tag{B.10}$$

where $\vartheta$ characterises the average fishing proportion over the years immediately preceding $y_0$.

**For baseline run, $\vartheta$ is estimated directly in the model fitting procedure and $a_m = 5$.**

***B.2. The (penalised) likelihood function***

The model can be fit to (a subset of) survey biomass indices, and commercial and survey catch-at-age and catch-at-age data to estimate model parameters (which may include residuals about the stock-recruitment function, facilitated through the incorporation of a penalty function described below). Contributions by each of these to the negative of the (penalised) log-likelihood (- $\ell nL$ ) are as follows.

*B.2.1. Survey biomass data*

The likelihood is calculated assuming that a survey biomass index is lognormally distributed about its expected value:

$$I_y^i = \hat{I}_y^i e^{\varepsilon_y^i} \quad \text{or} \quad \varepsilon_y^i = ln\left(I_y^i\right) - ln\left(\hat{I}_y^i\right) \tag{B.11}$$

where

$I_y^i$ is the survey index for survey $i$ in year $y$,

$\hat{I}_y^i = \hat{q}^i \hat{B}_y^i$ is the corresponding model estimate, where

$\hat{q}^i$ is the constant of proportionality (catchability) for the survey biomass series *i*, and

$\varepsilon_y^i$ from $N\left(0,\left(\sigma_y^i\right)^2\right)$.

The model estimate of survey biomass index is computed as:

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

where

$S_a^i$ is the survey selectivity for age *a*, which is taken to be year-independent.

$T^i$ is the month in which the survey is taking place (see Table B1), and

$w_{y,a}^i$ denotes the mass of fish of age *a* from survey *i* in year *y*.

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

$$-lnL^{\text{survey}} = \sum_i \sum_y \left\{ ln\left(\sqrt{\left(\sigma_y^i\right)^2 + \left(\sigma_{Add}^i\right)^2}\right) + \frac{\left(\varepsilon_y^i\right)^2}{2\left(\left(\sigma_y^i\right)^2 + \left(\sigma_{Add}^i\right)^2\right)} \right\} \quad \text{(B.13)}$$

where

$\sigma_y^i$ is the standard deviation of the residuals for the logarithm of index *i* in year *y,* and

$\sigma_{Add}^i$ is the square root of the additional variance for survey biomass series *i*, which is estimated in the model fitting procedure, with an upper bound of 0.5.

In this case, however, external estimates of $\sigma_y^i$ (from survey sampling variance) are not available. So homoscedasticity of residuals is assumed, so that estimation of additional variance falls away and $\sigma_y^i = \sigma^i$ is estimated in the fitting procedure by its maximum likelihood value (with a minimum estimate of 0.15 imposed to prevent overweighting through overfitting):

$$\sigma^i = \sqrt{\frac{1}{n^i} \sum_y \left(lnI_y^i - ln\left(q^i B_y^i\right)\right)^2} \quad \text{(B.14)}$$

The constant of proportionality $q^i$ for survey biomass index *i* is estimated by its maximum likelihood value:

$$lnq^i = \frac{1}{n^i} \sum_y \left(lnI_y^i - lnB_y^i\right) \quad \text{(B.15)}$$

*B.2.3. Commercial catches-at-age*

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of an "adjusted" lognormal error distribution is given by:

$$-lnL^{CAA} = w^{CAA} \sum_y \sum_a \left[ ln\left(\frac{\sigma_a^{com}}{\sqrt{p_{y,a}}}\right) + p_{y,a}\left(lnp_{y,a} - ln\hat{p}_{y,a}\right)^2 / 2(\sigma_a^{com})^2 \right] \quad \text{(B.16)}$$

where

$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of fish caught in year *y* that are of age *a*,

$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model-predicted proportion of fish caught in year *y* that are of age *a*,

with

$$\hat{C}_{y,a} = N_{y,a} S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a} \quad \text{(B.17)}$$

and

$\sigma_a^{com}$ is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_a^{com} = \sqrt{\sum_y p_{y,a}\left(lnp_{y,a} - ln\hat{p}_{y,a}\right)^2 / \sum_y 1} \quad \text{(B.18)}$$

The $w^{CAA}$ weighting factor in equation B.16 may be set to a value less than 1 to downweight the contribution of the catch-at-lage data (which tend to be positively correlated between adjacent age groups) to the overall negative log-likelihood compared to that of the survey biomass data.

Commercial catches-at-age are incorporated in the likelihood function using equation (B.16), for which the summation over age $a$ is taken from age $a_{\text{minus}}$ (considered as a minus group) to $a_{\text{plus}}$ (a plus group).

**For the baseline run, $w^{CAA} = 0.1$.**

*B.2.4. Survey catches-at-age*

The survey catches-at-age are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age, assuming an "adjusted" lognormal error distribution (equation (B.16)) where:

$p_{y,a}^{i} = C_{y,a}^{i}/\sum_{a'} C_{y,a'}^{i}$ is the observed proportion of fish of age $a$ in year $y$ for survey $i$,

$\hat{p}_{y,a}^{i}$ is the expected proportion of fish of age $a$ in year $y$ in the survey $i$, given by:

$$\hat{p}_{y,a}^{i} = S_{a}^{i} N_{y,a} e^{-Z_{y,a} T^{i}/12} / \sum_{a'} S_{a'}^{i} N_{y,a'} e^{-Z_{y,a'} T^{i}/12} \quad \text{(B.19)}$$

*B.2.5. Stock-recruitment function residuals*

The stock-recruitment residuals are assumed to be lognormally distributed. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-lnL^{pen} = \sum_{y=y_1}^{y_2} \left(\varphi_y^2 / 2\sigma_R^2\right) \quad \text{(B.20)}$$

where

$\varphi_y$ from $N(0, \sigma_R^2)$,

$\sigma_R$ is the standard deviation of the log-residuals, which is input.

*B.2.7. Catches*

$$-lnL^{Catch} = \sum_y \frac{lnC_y - ln\hat{C}_y}{2\sigma_C^2} \quad \text{(B.21)}$$

where

$C_y$ is the observed catch in year $y$,

$\hat{C}_y$ is the predicted catch in year $y$ (equation B.9), and

$\sigma_C = 0.1$ is the input CV input.

***B.3. Estimation of precision***

Where quoted, CV's or 95% probability interval estimates are based on the Hessian.

***B.4. Model parameters***

B.4.1. Fishing selectivity-at-age:

For the surveys, the fishing selectivities are either estimated separately for ages $a_1$ to age $a_2$ or are modelled by a double normal shape:

$$S_a = \begin{cases} exp\left(-\frac{(a-a_{max})^2}{2\sigma_{left}^2}\right) & \text{for } a \le a_{max} \\ exp\left(-\frac{(a-a_{max})^2}{2\sigma_{right}^2}\right) & \text{for } a > a_{max} \end{cases} \quad \text{(B.22)}$$

where $\sigma_{left}$, $\sigma_{right}$ and $a_{max}$ are estimable parameters.

B.4.2. Other parameters

b: Model parameters

| | | | |
|---|---|---|---|
| Stock-recruit standard dev. | | | |
| $\sigma_R$ | 0.2 | | |
| Model plus group | | | |
| $m$ | 14 | | |
| CAA minus and plus groups | $a_{minus}$ | $a_{plus}$ | $T^i$ |
| Can. Fall 2J3K | 1 | 8 | 9 |
| Can. Spring 3LNO | 1 | 8 | 3 |
| EU 3M 0-700m | 1 | 9 | 6 |
| EU 3M 0-1400m | 4 | 11 | 6 |
| EU 3m 700-1400m | 4 | 11 | 6 |
| EU 3L | 1 | 10 | 6 |
| EU 3NO | 1 | 10 | 6 |
| Can. Fall 3LNO | 0 | 8 | 9 |
| Commercial | 5 | 12 | |
| Natural mortality: | | | |
| $M$ | 0.2, age-independent | | |
| Proportion mature-at-age: | | | |
| $f_a$ | input, see Table A4 | | |
| Weight-at-age: | | | |
| $w_{y,a}^{strt}$ | input, see Table A3 | | |
| $w_{y,a}^{mid}$ | input, see Table A3 | | |
| $w_{y,a}^{i}$ | input, see Table A3 | | |