Applications of Statistical Catch-at-Age Assessment Methodology to Gulf of Maine cod, October 2012

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Summary

The Statistical Catch-at-Age assessment conducted by the authors earlier in 2012 is updated to take account of more recent data, and refined by introducing two new features: fitting to length distribution data for the NEFSC surveys in the 1960s for which age information is not available, and adjusting the externally provided estimates of the *Bigelow-Albatross* calibration function through adding the calibration information contained in cohorts present both before and after the survey vessel change to the model fitting process. The options selected for the Base Case assessment are those motivated in the assessment conducted earlier in the year. The resultant estimate of the 2011 spawning biomass is 12.0 thousand tons with a CV of 13%. The survey calibration function is slightly modified, resulting in an increase of about 3% in the 2011 spawning biomass. The survey catch-at-length data are consistent with previous estimates of poor recruitments from relatively large spawning biomasses in the 1960s. This last result is robust under a range of sensitivity tests, and is suggestive of a Ricker-like stock-recruitment relationship for the stock. These sensitivity tests also suggest that the 2011 spawning biomass estimate of 12.0 thousand tons is robustly determined. The range of this estimate across these sensitivities is 9.9 to 16.6 thousand tons, with lower values arising from the sqrt(p) weighting approach for proportions data and from forcing selectivities above age 6 to be flat, and the higher values coming from inclusion of the stock-recruitment function in the assessment and increasing the value of *M.* The evidence for commercial selectivities to be domed relative to the NEFSC surveys appears reasonably strong, but less so that for the selectivities for these surveys themselves to be domed.

Introduction

This paper is an extension of the Statistical Catch-at-Age (SCAA) assessment advocated in Butterworth and Rademeyer (2012) which was presented to a meeting of the NEFMC SSC in March earlier this year (2012). The NBC2 variant selected there is extended here to incorporate one further year's data, and refined to also take account of length distribution data available for the un-aged pre-1970 NEFSC surveys, and to use the population model fit to improve estimates of the *Bigelow-Albatross* survey calibration relationship.

The paper also checks the sensitivity of results for its Base Case assessment to some of the factors on which discussions at the SSC indicated an absence of unanimity. For the most part, only single factor changes to the Base Case have been run. Further runs combining more than one change to such factors could be specified by the coming October assessment meeting, and run during its duration, if required.

This paper focuses on assessment aspects, with a further paper on the estimation of reference points to follow shortly.

Data and Methodology

The catch and survey based data (including catch-at-length information) and some biological data used for the analyses are listed in Tables in Appendix A.

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

Results

Results are given for a Base Case (Run 1) and various sensitivities. As indicated in the Introduction, this Base Case makes choices for various options in the assessment in line with those motivated in Butterworth and Rademeyer (2012), specifically:

- Start in 1964
- Estimate the first three numbers-at-age for 1964, and then the parameter ϕ (see equation B11) to provide estimates for the numbers at older ages – note that unlike in Butterworth and Rademeyer (2012), the value of ϕ is not restricted by bounds in this estimation process
- Set M = 0.2 for all ages
- Use the “adjusted” lognormal formulation of equation B.16 to describe the distribution of proportions-at-age (in relation to numbers of fish)
- Admit the possible estimation of domed selectivity for the NEFSC surveys and for the commercial fishery
- Do not fit the stock-recruitment function is within the population model fitting procedure
- Make allowance for additional variance when fitting to time series of abundance indices
- Fit to the aggregated abundance indices as expressed in terms of biomass rather than numbers.

In addition, this Base Case incorporates what are considered to be improvements to the model:

- Allow the assessment data to update the independent estimate of the *Bigelow-Albatross* calibration function parameters that have been determined from experimental paired trawls (see section B.2.7)
- Incorporate data on NEFSC survey length compositions from the 1960s when catches from these surveys were not aged.

Tables 1-4 list results for Base Case and various sensitivities, focusing on the contributions to the assessment period considered, as well values for the survey catchabilities *q*.

Figs 1-4 provide estimates and diagnostic plots for the Base Case fit, while Fig. 5 shows how the *Bigelow-Albatross* survey calibration function has been updated. Figs 6-12 and 14-15 show results for various sensitivities to the Base Case, while Fig, 13 shows results for a retrospective analysis of the Base Case.

Discussion

The Base Case results in Table 1 and Fig. 1 show a spawning biomass that has been decreasing somewhat over the last two years, essentially as a consequence of a decline in recruitment since 2005. As to be expected, the precision of spawning biomass estimates is less in the 1960s and 70s when less age information is available, and also drops for the most recent few years. In contrast the annual recruitment estimates are all fairly precise except for the final year (2011). Survey catchability (*q*) estimates are all below 1, and non-trivial levels of additional variance are estimated for all three abundance indices. The 2011 spawning biomass is estimated at 12.0 thousand tons with an associated CV of 13%.

For this Base Case, both commercial and NEFSC survey selectivities are estimated to be appreciably domed (Fig. 2). Standard fit diagnostics for both abundance indices and proportion-at-age data in Fig. 3 show broadly reasonable fits, though there is some evidence of systematic trends in the proportion-at-age residuals for the Massachusetts Spring survey and for the commercial catch. The last might be ameliorated by allowing for a change in the recent commercial selectivity pattern (for whose values the model often struggles to obtain convergence) to occur in the mid-2000s. The fits to the survey proportions-at-length data over the 1960s (Fig. 4) is fair, but does evidence some data conflict with proportions at the smaller lengths underestimated for the spring surveys and overestimated for the autumn surveys, with the reverse effect at larger lengths.

Updating the *Bigelow-Albatross* calibration function in the model suggests that the results from the paired trawls experiment slightly overestimated the factor at larger lengths, but similarly underestimated it at smaller lengths (Fig.5). Using the existing *Bigelow-Albatross* calibration function without this model-fitting refinement would result in a slightly lower 2011 spawning biomass of 11.7 thousand tons

Moving on to sensitivity tests, alternative starting years for the assessment have a negligible impact on estimates of the current spawning biomass, but there is some sensitivity shown by the estimates of spawning biomass in the 1960s, though these still remain high relative to estimates for the last two decades (Table 1, Runs 2a-d and Fig. 6). For a 1982 start, the catchability coefficient (q) estimate for the NEFSC Spring survey increases above 1 to 1.09.

The parameter ϕ related to the starting numbers-at-age vector for 1964 is estimable, but with quite a high CV of 47%, so that it is not surprising that the starting spawning biomass is not that well determined (Table 1, Runs 3a-e and Figs 1 and 6). The selection of how many ages to estimate starting numbers-at-ages to estimate in this starting vector is clearly suggested to be three (ages 0-2) for the Base Case by the process of considering successive improvements in –lnL as this number is increased (Table 2, Runs 4a-h). Alternative selections for both these factors have minimal impact on estimates of the 2011 spawning biomass.

Increasing the weight given to the survey catch-at-length data from the 1960s suggests a slight decrease in recruitment in the 1960s (Table 3, Runs 5a-b and Fig. 8, so that these data do not contradict earlier inferences of poor recruitment over this period (when spawning biomass was relatively high) which were made in the absence of this information (Butterworth and Rademeyer, 2011 and 2012). If less weight is placed on the input information for the *Bigelow-Albatross* calibration function, the calibration factor moves still lower at higher lengths, and still higher at lower lengths (Table 3, Run 6 and Fig.9). This indicates that the information on calibration provided by the presence of common cohorts in both the pre- and post-vessel-change periods points somewhat differently from the independent experiment in regard to the values of the calibration function, so that estimates of this may change further as more data from these cohorts accumulates over the next few years.

Including estimation of a Ricker stock recruitment function in the assessment leads to a higher estimate of the 2011 spawning biomass of about 14 thousand tons as a result of increased estimates of recruitment over recent years (Table 3, Run 7 and Fig. 10). In contrast using the sqrt(p) option of weighting proportion-at-age data in the log likelihood in place of the “adjusted” lognormal see this estimate drop to some 11 thousand tons (Table 3, Run 8). Fig. 3 also shows the fit residuals for age and length distribution data under this alternative; there is no obvious improvement or deterioration in the pattern of these residuals for the sqrt(p) compared to the “adjusted” lognormal run, and so no clear reason from these plots to prefer one distributional form over the other.

Sensitivities which modify the commercial selectivity-at-age for the pre-1982 period to reflect a relatively greater catch of smaller fish (Palmer, pers. commn, advises that nets in that period tended to have smaller mesh sizes) have scarcely any impact on spawning biomass trends, and are somewhat less preferred in likelihood terms (Table 3, Runs 9a-b, and Fig. 11). Increasing natural mortality M from 0.2 to 0.3 increases spawning biomass estimates as would be expected, and is slightly preferred in likelihood terms (Table 3, Run 10 and Fig. 12).

Fig. 13 shows the results from a retrospective analysis for the Base Case assessment. There is a large difference evident for assessments carried out in 2007 and 2008 (possibly linked to the high NEFSC Spring survey estimates at that time), but thereafter any retrospective effect is fairly small.

Runs 11 and 12 in Table 4 show the consequences of forcing either the survey selectivity or both the survey and commercial selectivities to be flat at older ages above 6. These correspond to estimating 3 or 9 fewer parameter values, with associate deterioration in –lnL by some 7 or 24 points respectively. Assuming domes is thus AIC justified in both cases. Forcing this flatness results in lower spawning biomass (Fig. 14), though most of this effect comes from forcing flatness in the commercial selectivity function, e.g. with the survey selectivities only forced to be flat, the 2011 spawning biomass estimate drops only from 12.0 to 11.6 thousand tons (a 4% effect).

Table 4 and Fig. 15 show results from repeating the flat selectivity sensitivities of Runs 11 and 12, but here under the sqrt(p) weighting approach for proportions data in place of the "adjusted" lognormal distribution assumption. Again the assumption of a dome in the commercial selectivity is AIC justified, but the extension of that to the NEFSC survey data is marginal in that respect. Butterworth and Rademeyer (2012) found that the Massachusetts Spring survey showed a selectivity pattern which was flat for the sqrt(p) case rather than decreasing at ages above 3 as in the case of the "adjusted" lognormal, which they considered of questionable realism given the more near-shore area which this survey covers. However this argument for preferring the "adjusted" lognormal is less clear for these updated computations. These results may be compromised by failure to achieved convergence in some of these runs (see Tables 3 and 4 captions), though as this arises only from sensitivity of the process to estimation of the commercial selectivity parameters for the more recent period, this seems unlikely to have a great influence on abundance estimates and trends. Overall the case for a dome in the commercial relative to the NEFSC survey catches seems reasonably strong, but that for a dome in these survey selectivities themselves less so.

Conclusions

Key features of these results are:

a) Although there is some uncertainty about spawning biomass estimates in the 1960s, nevertheless these are robustly estimated to be towards the higher end of the range of spawning biomasses through the 1964-2011 period considered. Further the recruitments at that time are precisely and robustly estimated to have been towards the low end of the range of recruitment levels throughout this period. This is suggestive of a Ricker-type stock-recruitment relationship, something that is not *a priori* surprising for a cod stock given the species' cannibalistic behaviour.

b) The spawning biomass in 2011 is relatively robustly estimated at 12.0 thousand tons. The range of this estimate across the sensitivities examined is 9.9 to 16.6 thousand tons, with lower values arising from the sqrt(p) weighting for proportions data and from forcing selectivities above age 6 to be flat, and the higher values coming from including the stock-recruitment function in the assessment and increasing the value of *M.*

Note that the authors' general preference is for the inclusion of a stock recruitment relationship in fitting assessment models. This was not included in the Base Case here so that other sensitivities could be examined without the inclusion of the relationship perhaps confounding interpretation of the results.

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References

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Table 1: Estimates of abundance and related quantities for the Gulf of Maine cod for a series of assessment sensitivities. Values in parentheses are Hessian based CV's. Mass units are '000 tons. *y*1 refers to the start year for the assessment. $N_{y1,0}$ is in millions. Refer to Appendix for definition of some of the symbols used. Note that Runs 2a) to 2d) were conducted with the same number of ages in the starting numbers-at-age vector as for the Base Case (*viz*. ages 0-2}; later starting years, it is probable that extending this estimation to further ages is statistically justifiable.

	1) Base Case		2) Alternative start year								3) Alternative fixed values of ϕ									
			2a)		2b)		2c)		2d)		3a) ϕ=0.0		3b) ϕ=0.05		3c) ϕ=0.1		3d) ϕ=0.2		3e) ϕ=0.3	
Start year	1964		1965		1967		1970		1982		1964		1964		1964		1964			
-lnL: overall	-162.8		-158.9		-148.5		-147.9		-95.0		-160.2		-161.7		-162.3		-162.2		-159.4	
-lnL: survey	-37.5		-37.4		-35.5		-32.4		-17.3		-37.5		-37.5		-37.5		-37.3		-36.8	
-lnL: comCAA	-129.6		-129.6		-129.5		-129.5		-120.8		-129.6		-129.6		-129.3		-129.7		-129.5	
-lnL: survCAA	-13.9		-6.4		6.8		17.7		47.6		-13.2		-13.7		-13.9		-13.5		-12.6	
-lnL: survCAL	22.1		18.1		13.3		0.0		0.0		24.0		23.1		22.3		22.1		23.5	
-lnL: RecRes	1.3		1.3		1.3		1.3		1.2		1.3		1.3		1.3		1.3		1.3	
-lnL: calibration	-5.2		-5.0		-5.0		-5.1		-5.6		-5.2		-5.2		-5.3		-5.2		-5.2	
$N_{y1,0}$	7.49	(0.13)	4.15	(0.17)	3.63	(0.17)	4.21	(0.16)	12.94	(0.07)	7.55	(0.13)	7.53	(0.13)	7.42	(0.13)	7.45	(0.13)	7.43	(0.13)
ϕ	0.14	(0.47)	0.45	(0.14)	0.29	(0.15)	0.10	(0.70)	0.52	(0.07)	0.00	-	0.05	-	0.10	-	0.20	-	0.30	-
B^{sp}_{2011}	12.02	(0.13)	12.01	(0.13)	11.97	(0.14)	11.98	(0.16)	12.03	(0.17)	12.03	(0.14)	12.03	(0.13)	12.04	(0.13)	12.03	(0.13)	12.00	(0.13)
B^{sp}_{1982}	32.25	(0.06)	32.24	(0.07)	32.25	(0.06)	32.25	(0.12)	32.31	(0.10)	32.25	(0.06)	32.25	(0.06)	32.40	(0.06)	32.21	(0.06)	32.25	(0.06)
B^{sp}_{y1}	42.40	(0.24)	25.32	(0.20)	42.52	(0.16)	45.17	(0.32)	32.31	(0.10)	56.88	(0.15)	51.58	(0.14)	46.82	(0.14)	36.68	(0.14)	28.46	(0.14)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.91	0.19	0.91	0.19	0.91	0.19	0.91	0.19	1.09	0.24	0.91	0.19	0.91	0.19	0.90	0.19	0.91	0.19	0.91	0.19
NEFSC fall	0.83	0.07	0.84	0.07	0.84	0.07	0.84	0.07	0.73	0.10	0.82	0.07	0.83	0.07	0.83	0.07	0.84	0.07	0.85	0.07
MADMF spring	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.16	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13

Table 2: Estimates of abundance and related quantities for the Gulf of Maine cod for a series of assessment sensitivities relating to the initial numbers-at-age vector. Values in parentheses are Hessian based CV's. Mass units are '000 tons. *y*1 refers to the start year for the assessment. $N_{y1,0}$ is in millions. Refer to Appendix B for definition of some of the symbols used.

	4) Fewer or more $N_{y1,a}$ values estimated															
	4a) age 0		4b) ages 0-1		4c) ages 0-2 (BC)		4d) ages 0-3		4e) ages 0-4		4f) ages 0-5		4g) ages 0-6		4h) ages 0-7	
Start year	1964		1964		1964		1964		1964		1964		1964		1964	
-lnL: overall	-146.7		-147.4		-162.8		-163.1		-163.7		-163.8		-164.9		-164.9	
-lnL: survey	-36.8		-36.7		-37.5		-37.3		-37.4		-37.3		-37.6		-37.6	
-lnL: comCAA	-129.7		-129.8		-129.6		-129.8		-129.6		-130.0		-129.6		-129.5	
-lnL: survCAA	-1.1		-2.2		-13.9		-13.7		-13.9		-13.5		-14.0		-14.0	
-lnL: survCAL	24.6		25.0		22.1		21.7		21.1		20.9		20.2		20.2	
-lnL: RecRes	1.3		1.3		1.3		1.3		1.3		1.3		1.3		1.3	
-lnL: calibration	-5.0		-5.0		-5.2		-5.2		-5.2		-5.2		-5.2		-5.2	
$N_{y1,0}$	7.93	(0.08)	7.17	(0.14)	7.49	(0.13)	7.48	(0.13)	7.57	(0.13)	7.71	(0.13)	7.56	(0.13)	7.57	(0.13)
ϕ	0.38	(0.15)	0.40	(0.16)	0.14	(0.47)	0.19	(0.45)	0.29	(0.44)	0.43	(0.44)	0.68	(0.39)	0.87	(1.19)
B^{sp}_{2011}	12.01	(0.13)	12.02	(0.13)	12.02	(0.13)	12.01	(0.13)	12.01	(0.18)	11.97	(0.14)	12.03	(0.13)	12.03	(0.13)
B^{sp}_{1982}	32.29	(0.07)	32.34	(0.08)	32.25	(0.06)	32.39	(0.06)	32.29	(0.06)	32.58	(0.06)	32.31	(0.06)	32.31	(0.06)
B^{sp}_{y1}	26.88	(0.24)	26.20	(0.24)	42.40	(0.24)	39.90	(0.25)	38.50	(0.24)	36.46	(0.24)	34.55	(0.22)	33.95	(0.23)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.91	0.19	0.92	0.19	0.91	0.19	0.91	0.19	0.91	0.19	0.90	0.19	0.91	0.19	0.91	0.19
NEFSC fall	0.84	0.07	0.84	0.07	0.83	0.07	0.83	0.07	0.83	0.07	0.82	0.07	0.83	0.07	0.83	0.07
MADMF spring	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13	0.20	0.13

Table 3: Estimates of abundance and related quantities for the Gulf of Maine cod for a series of assessment sensitivities. Values in parentheses are Hessian based CV's. Mass units are '000 tons. *y*1 refers to the start year for the assessment. $N_{y1,0}$ is in millions. Refer to Appendix B for definition of some of the symbols used. Runs marked * did not converge fully. The associated sensitivity of the fitting process arises in estimating the selectivity vector for the second commercial period. In all such cases, a rerun was conducted with this vector fixed at the best estimates that had been achieved thus far, and convergence was readily achieved.

	1) Base Case		5) Higher weight for CAL				6) Less weight input calibration		7) Ricker internal		8) sqrt(p) option for CAA and CAL weighting		9) Alternative pre-1982 commercial selectivity				10) Higher M	
			5a) W_{CAL}=1		5b) W_{CAL}=5								9a) option 1		9b) option 2		10a) M =0.3	
Start year	1964		1964		1964	*	1964	*	1964		1964	*	1964		1964		1964	*
-lnL: overall	-162.8		15.1		660.2		-160.2		-125.5		-2503.7		-161.2		-158.4		-164.6	
-lnL: survey	-37.5		-37.6		-39.1		-38.0		-35.4		-36.7		-37.8		-37.8		-37.9	
-lnL: comCAA	-129.6		-129.3		-131.0		-129.7		-129.5		-737.6		-128.8		-128.0		-131.3	
-lnL: survCAA	-13.9		2.1		89.6		-16.1		-12.6		-1611.9		-13.0		-10.8		-12.9	
-lnL: survCAL	22.1		183.9		744.8		22.1		22.0		-113.4		22.2		22.3		21.8	
-lnL: RecRes	1.3		1.2		1.3		1.3		35.3		1.4		1.2		1.2		0.7	
-lnL: calibration	-5.2		-5.2		-5.3		1.8		-5.3		-5.5		-5.2		-5.2		-5.0	
$N_{y1,0}$	7.49	(0.13)	6.89	(0.12)	7.45	(0.11)	7.52	(0.13)	7.26	(0.13)	7.23	(0.14)	8.19	(0.13)	8.65	(0.13)	16.30	(0.13)
ϕ	0.14	(0.47)	0.11	(1.21)	0.18	(0.23)	0.14	(0.46)	0.08	(0.99)	0.17	(0.37)	0.12	(0.48)	0.12	(0.45)	0.01	(0.03)
B^{sp}_{2011}	12.02	(0.13)	12.89	(0.48)	11.38	(0.14)	12.04	(0.19)	14.03	(0.17)	10.83	(0.10)	11.94	(0.13)	11.88	(0.11)	16.61	(0.11)
B^{sp}_{1982}	32.25	(0.06)	33.72	(0.25)	29.91	(0.07)	32.24	(0.06)	33.30	(0.07)	28.91	(0.03)	33.29	(0.07)	33.96	(0.04)	39.23	(0.06)
B^{sp}_{y1}	42.40	(0.24)	58.53	(0.86)	34.60	(0.26)	42.15	(0.25)	53.65	(0.29)	33.69	(0.19)	42.54	(0.24)	42.54	(0.18)	74.73	(0.11)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.91	0.19	0.86	0.18	0.89	0.17	0.91	0.19	0.89	0.20	0.95	0.19	0.92	0.18	0.93	0.17	0.63	0.19
NEFSC fall	0.83	0.07	1.03	0.08	1.57	0.07	0.84	0.07	0.82	0.07	0.85	0.07	0.86	0.08	0.87	0.08	0.58	0.07
MADMF spring	0.20	0.13	0.19	0.13	0.20	0.13	0.20	0.13	0.19	0.14	0.32	0.13	0.20	0.13	0.20	0.13	0.13	0.12

Table 4: Estimates of abundance and related quantities for the Gulf of Maine cod for a series of assessment sensitivities. Values in parentheses are Hessian based CV's. Mass units are '000 tons. *y*1 refers to the start year for the assessment. $N_{y1,0}$ is in millions. Refer to Appendix B for definition of some of the symbols used. Runs marked * did not converge fully. The associated sensitivity of the fitting process arises in estimating the selectivity vector for the second commercial period. In all such cases, a rerun was conducted with this vector fixed at the best estimates that had been achieved thus far, and convergence was readily achieved.

	1) Base Case		11) Flat NEFSC survey selectivities		12) Flat NEFSC survey and commercial selectivities		8) sqrt(p) option for CAA and CAL weighting		13) sqrt(p) option and flat NEFSC surv sel		14) sqrt(p) option and flat NEFSC surv and com sel	
Start year	1964		1964	*	1964	*	1964	*	1964	*	1964	*
-lnL: overall	-162.8		-155.6		-138.5		-2503.7		-2501.0		-2491.6	
-lnL: survey	-37.5		-39.3		-36.8		-36.7		-37.8		-37.1	
-lnL: comCAA	-129.6		-129.2		-120.5		-737.6		-737.3		-735.0	
-lnL: survCAA	-13.9		-6.8		1.3		-1611.9		-1609.3		-1601.5	
-lnL: survCAL	22.1		23.3		21.6		-113.4		-112.4		-113.8	
-lnL: RecRes	1.3		1.4		1.4		1.4		1.4		1.5	
-lnL: calibration	-5.2		-5.0		-5.4		-5.5		-5.5		-5.7	
$N_{y1,0}$	7.49	(0.13)	7.39	(0.13)	6.89	(0.13)	7.23	(0.14)	7.56	(0.13)	6.70	(0.14)
ϕ	0.14	(0.47)	0.17	(0.35)	0.17	(0.36)	0.17	(0.37)	0.20	(0.31)	0.17	(0.37)
B^{sp}_{2011}	12.02	(0.13)	11.63	(0.11)	9.94	(0.10)	10.83	(0.10)	10.78	(0.10)	10.03	(0.09)
B^{sp}_{1982}	32.25	(0.06)	29.80	(0.03)	28.09	(0.03)	28.91	(0.03)	28.56	(0.03)	27.03	(0.03)
B^{sp}_{y1}	42.40	(0.24)	31.88	(0.15)	29.72	(0.16)	33.69	(0.19)	28.61	(0.16)	30.19	(0.16)
	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}	q	σ_{Add}
NEFSC spring	0.91	0.19	0.75	0.18	0.90	0.19	0.95	0.19	0.84	0.19	0.92	0.19
NEFSC fall	0.83	0.07	0.73	0.07	0.87	0.07	0.85	0.07	0.79	0.07	0.84	0.07
MADMF spring	0.20	0.13	0.20	0.13	0.20	0.14	0.32	0.13	0.32	0.13	0.32	0.13

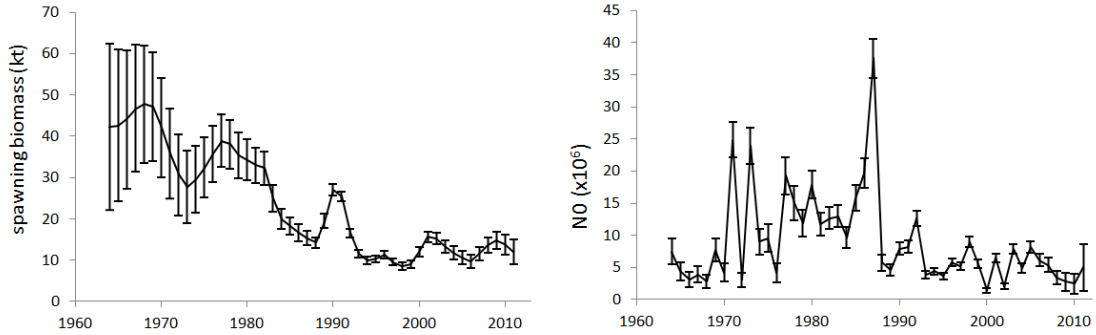

Fig. 1: Spawning biomass and recruitment trajectories for the Base Case with ±2 s.e.

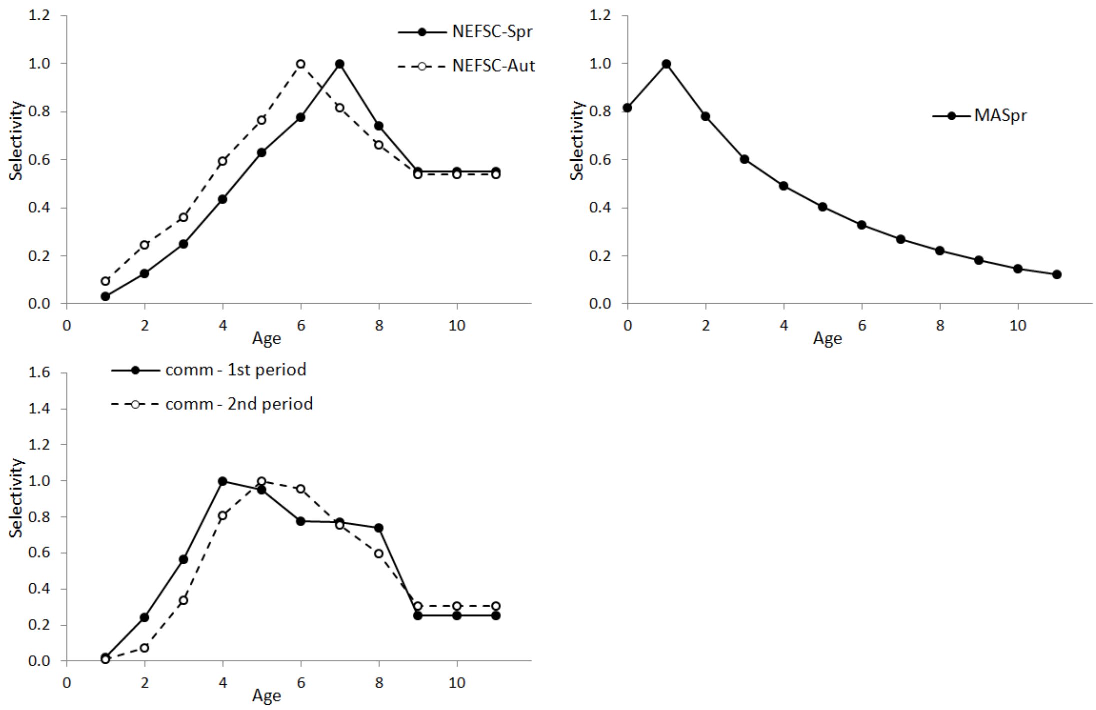

Fig. 2: Survey and commercial selectivities-at-age estimated for the Base Case.

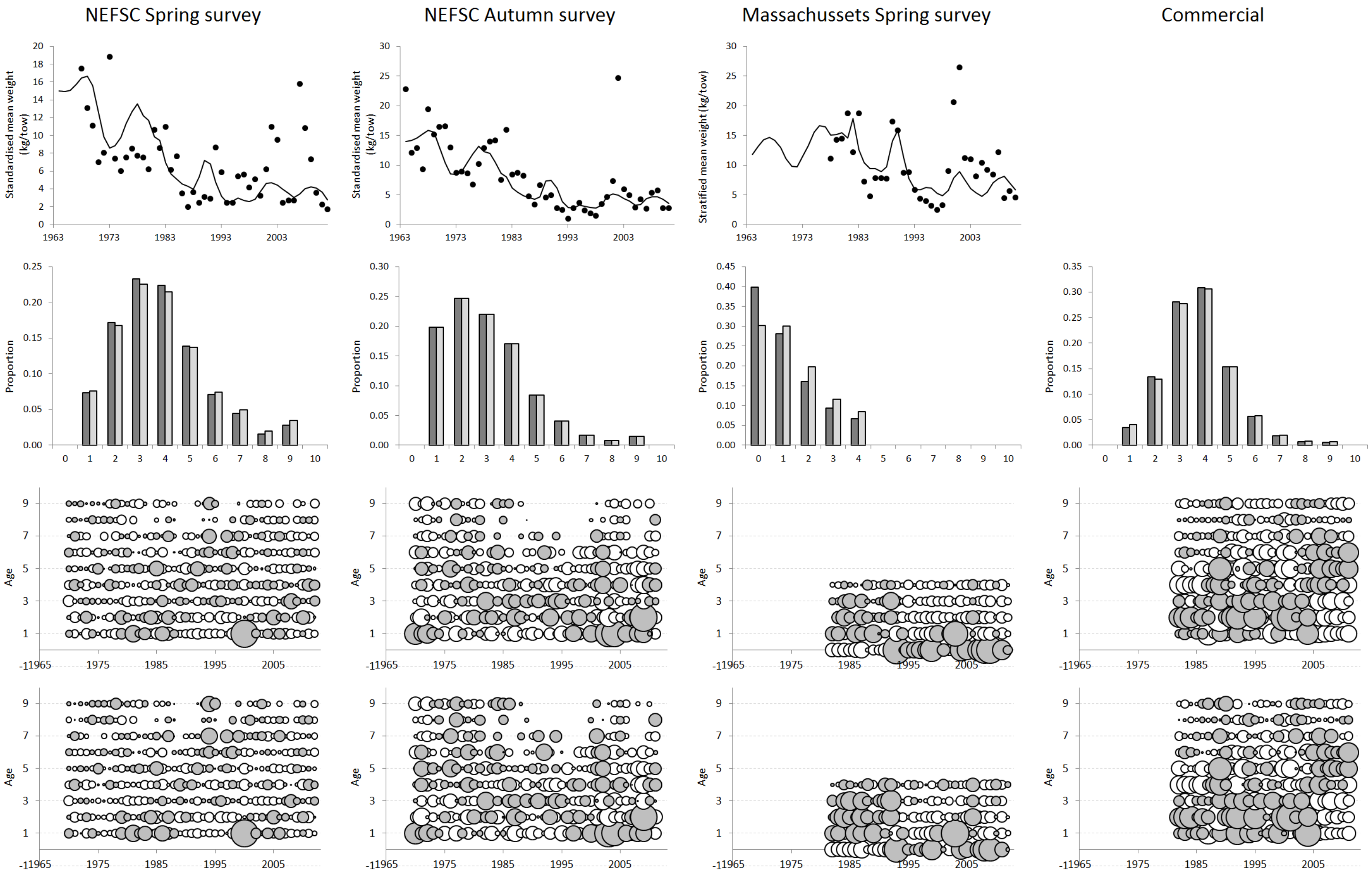

Fig. 3: Fits to the abundance indices (top row) and to the survey and commercial catch-at-age data for the Base Case. The second row plots compare the observed and predicted CAA as averaged over all years for which data are available, while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white. The last row plots show the comparable standardised residuals for Case 8 (sqrt(p))

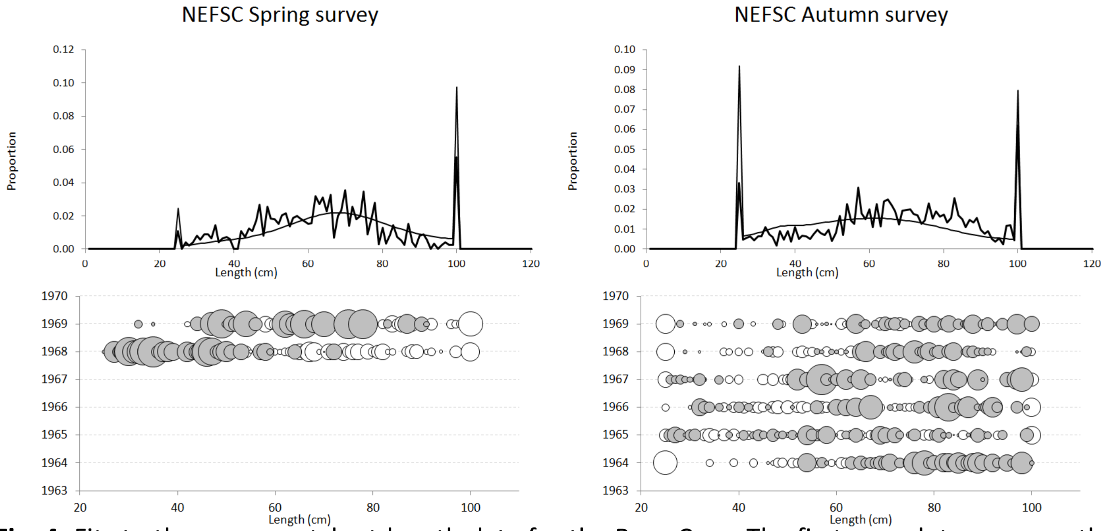

Fig. 4: Fits to the survey catch-at-length data for the Base Case. The first row plots compare the observed and predicted CAL as averaged over all years for which data are available, while the third row plots show the standardised residuals, with the size (area) of the bubbles being proportional to the magnitude of the corresponding standardised residuals. For positive residuals, the bubbles are grey, whereas for negative residuals, the bubbles are white.

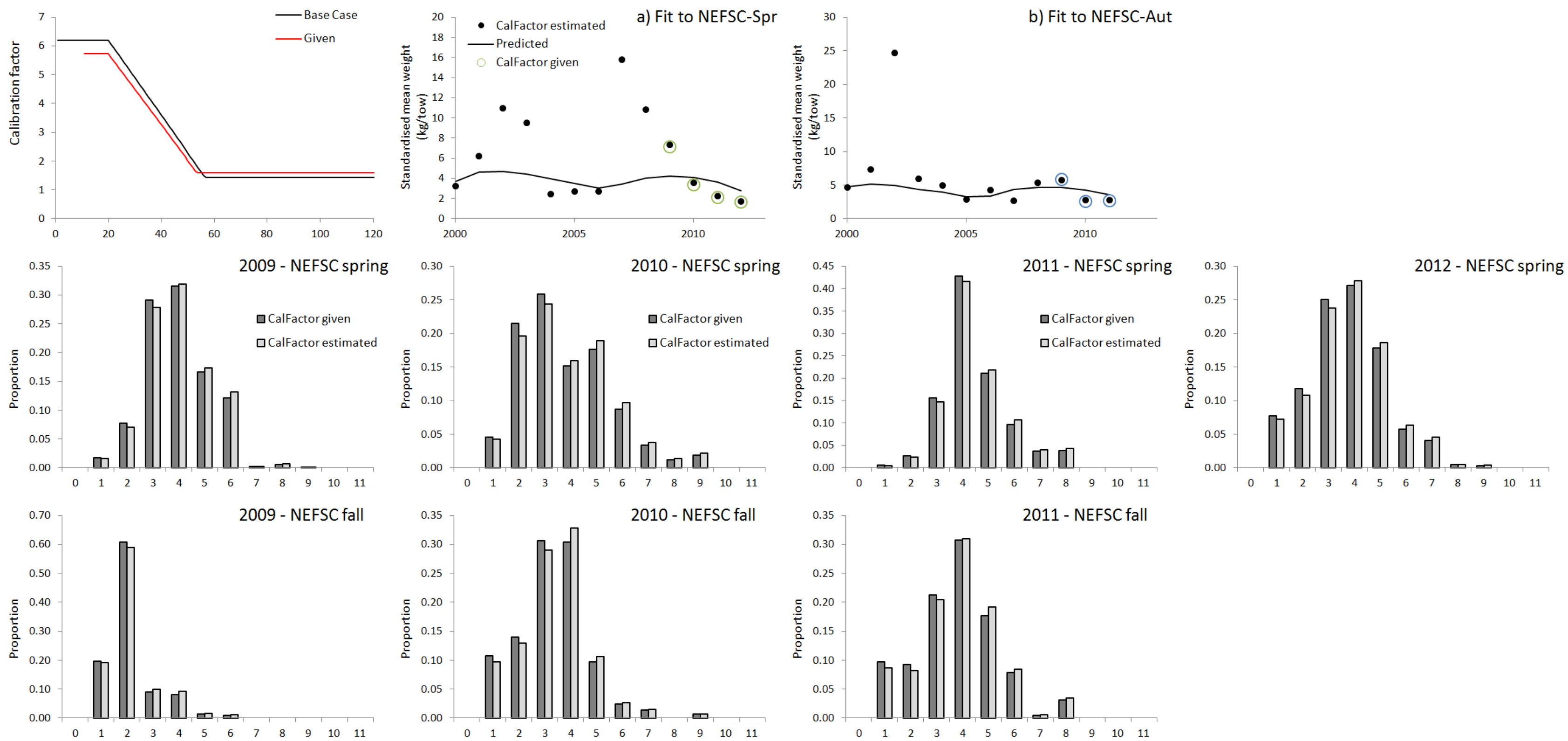

Fig. 5: Comparison of calibration results for the calibration factor estimated within the assessment (Base Case) and calibration factor given.

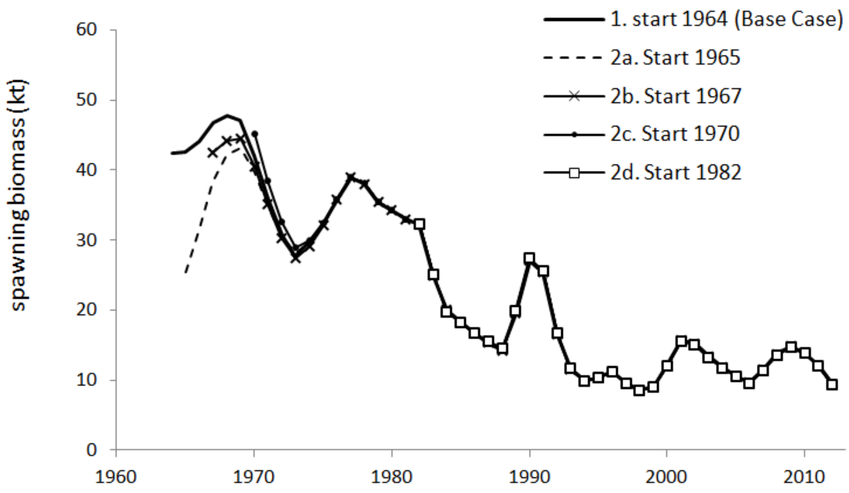

Fig. 6: Spawning biomass trajectories for the Base Case and four sensitivities with different starting year.

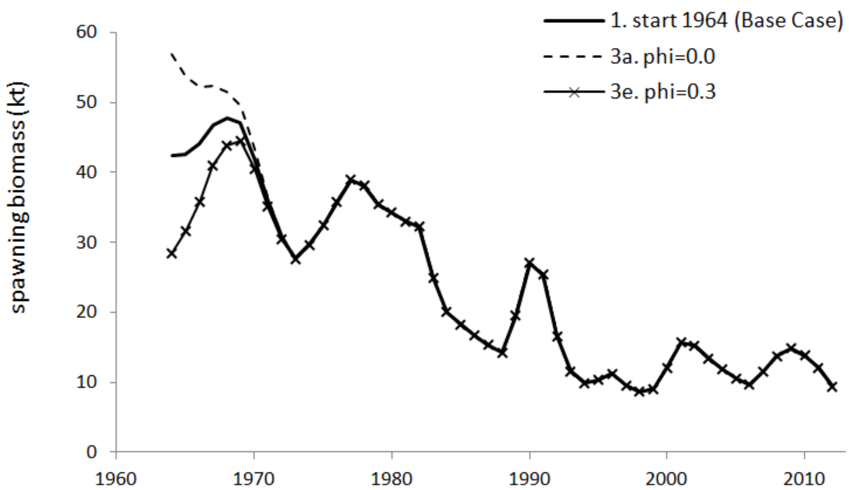

Fig. 7: Spawning biomass trajectories for the Base Case and two sensitivities with different fixed ϕ values. For the Base Case, ϕ is estimated (ϕ=0.14).

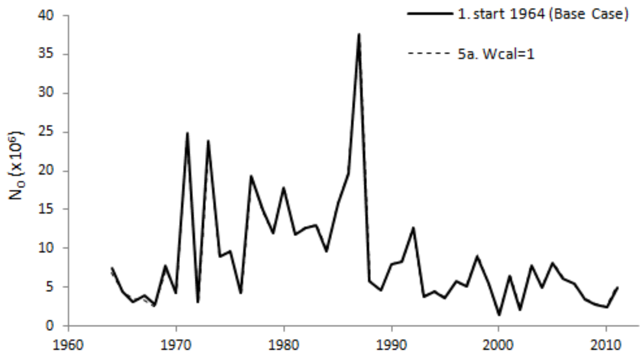

Fig. 8: Recruitment trajectories for the Base Case and Case 5a for which more weight is given to the CAL data.

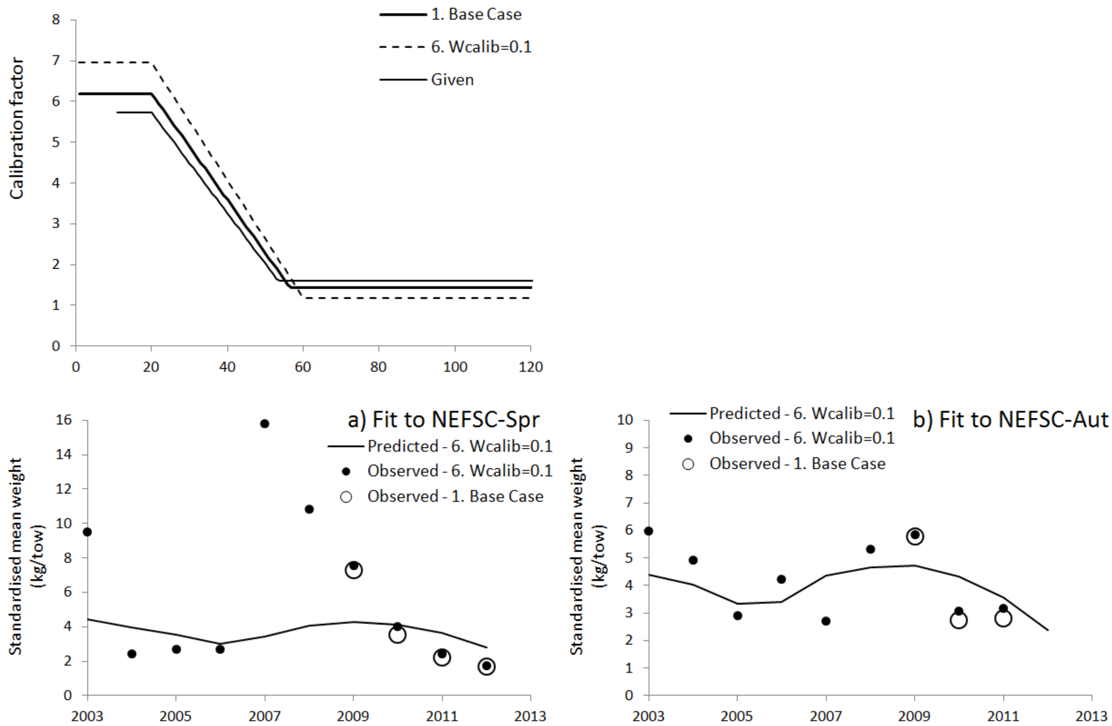

Fig. 9: Calibration factor.

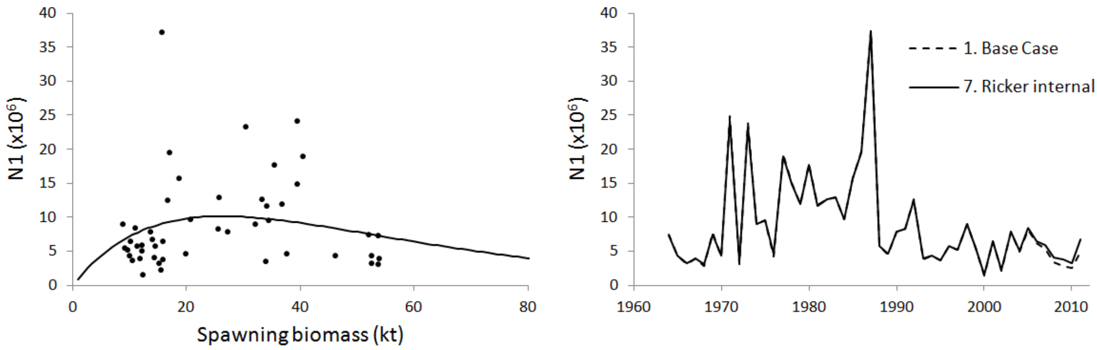

Fig. 10: Fits to the stock-recruitment data for the case with an internal Ricker stock-recruitment curve estimated (Case 7) (left-hand plot) and trajectories of recruitment for the Base Case and Case 7.

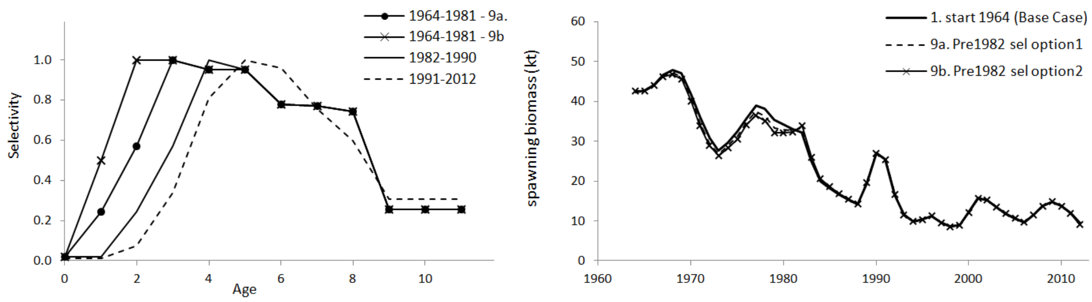

Fig. 11: Commercial selectivities (left-hand plot) for cases 9a-b with alternative pre-1982 commercial selectivities and spawning biomass trajectories.

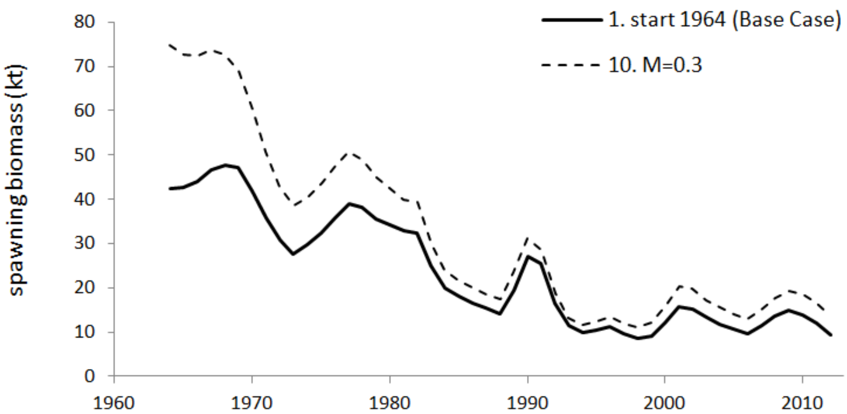

Fig. 12: Spawning biomass trajectories for the Base Case and Case 10 with *M*=0.3.

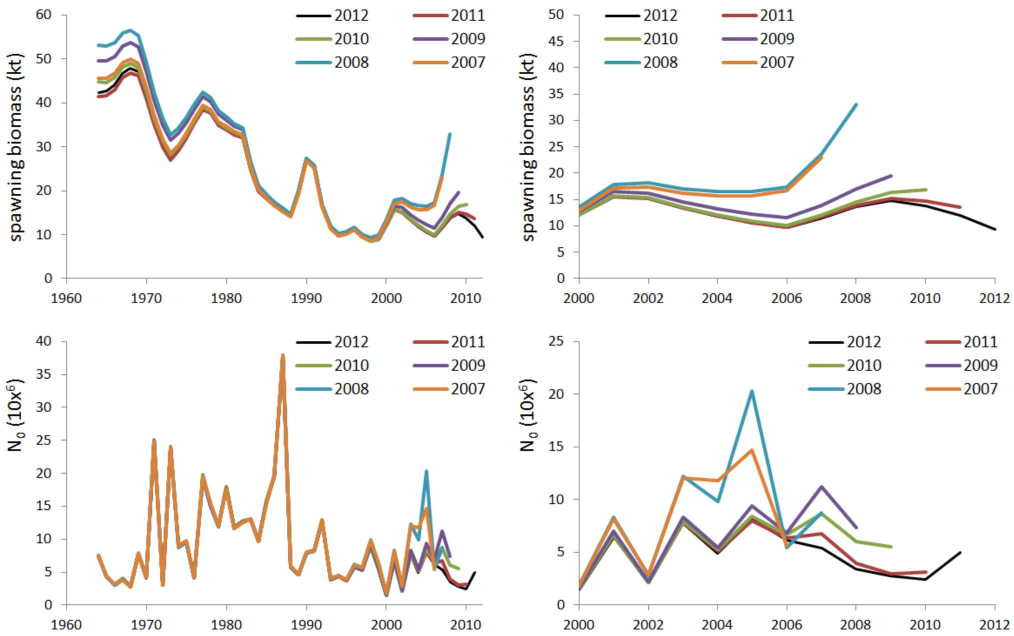

Fig. 13 Retrospective analysis for the **Base Case A** for spawning biomass and recruitment.

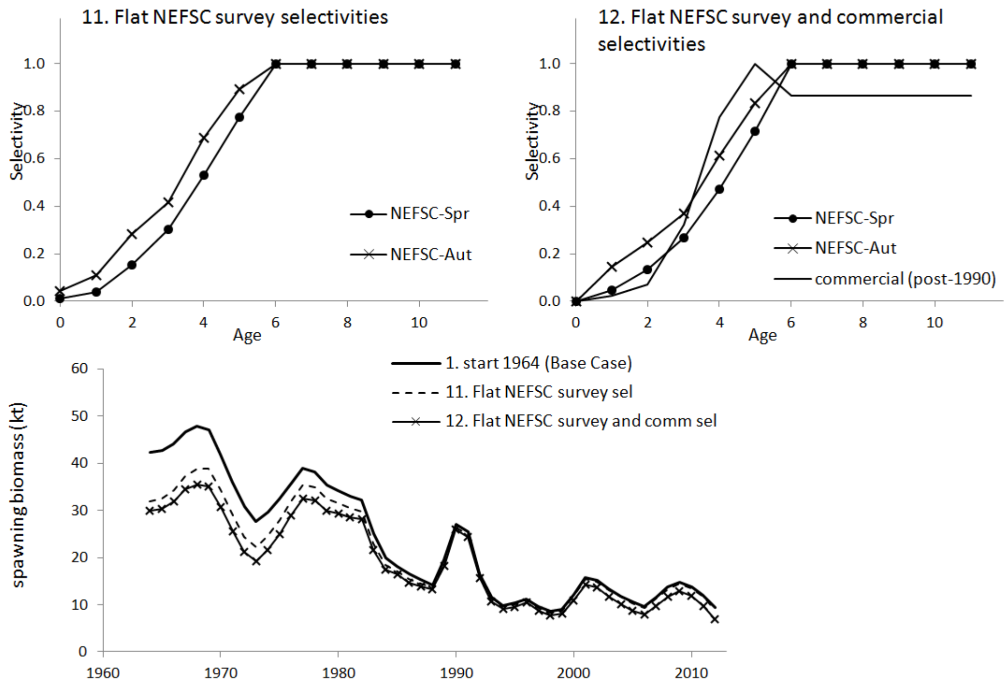

Fig. 14: Selectivities and spawning biomass trajectories for the Base Case and Cases 11 and 12for which the selectivity functions indicated are forced to be flat above age 6..

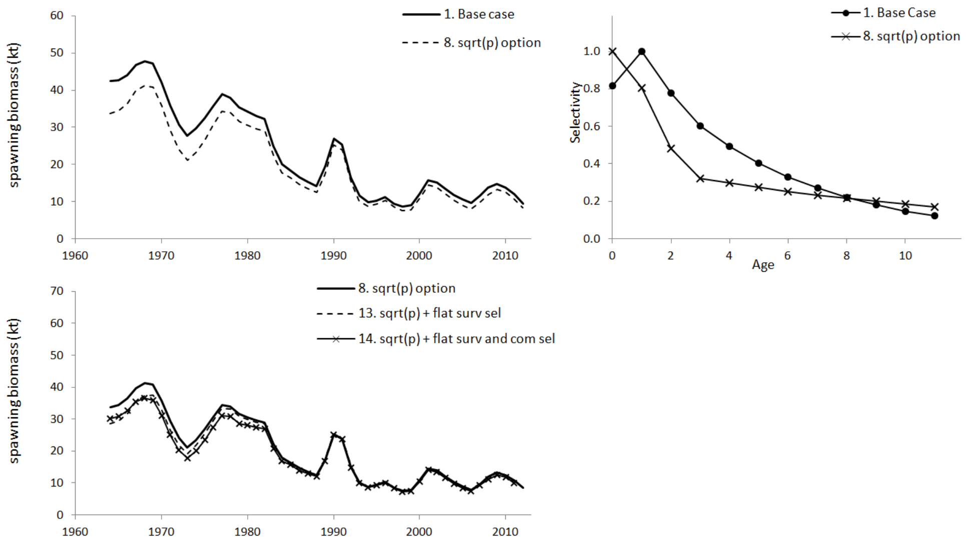

Fig. 15: Selectivities and spawning biomass trajectories for the Base Case and the sqrt(p) cases (Cases 8, 13 and 14).

APPENDIX A – Data

Table A1: Total catch (incl. USA, DWF and recreational landings, and discards) (thousand metric tons) of Atlantic cod from the Gulf of Maine (NAFO Division 5Y), 1964-2012 (Michael Palmer, pers. commn). The revised discard mortality assumptions have been applied. Note that pre-1982 catches have been increased by 25% in the Base Case to allow for levels of discards suggested by recent analyses by the NEFSC. The 2012 catch is assumed to be 6.830 thousand metric tons, as in 2011; some assumption is needed to be able to take account of the Spring 2012 NEFSC survey given that this occurs though equation B.9 which requires this input.

Year	Total catch	Year	Total catch	Year	Total catch
1964	3.242	1980	12.515	1996	7.757
1965	3.759	1981	16.512	1997	5.814
1966	4.225	1982	17.096	1998	4.578
1967	5.824	1983	16.487	1999	3.078
1968	6.137	1984	12.868	2000	5.823
1969	8.155	1985	14.391	2001	8.055
1970	7.961	1986	12.572	2002	6.509
1971	7.475	1987	12.005	2003	6.497
1972	6.927	1988	10.333	2004	5.766
1973	6.138	1989	13.371	2005	5.441
1974	7.550	1990	19.314	2006	4.268
1975	8.788	1991	20.978	2007	5.527
1976	9.894	1992	12.347	2008	7.375
1977	11.993	1993	9.960	2009	8.355
1978	11.890	1994	9.060	2010	7.670
1979	10.972	1995	7.566	2011	6.830

Table A2: Mean weight-at-age (kg) at the beginning of the year for the Gulf of Maine cod stock. Values derived from aggregated commercial landings and discard mean weight-at-age data (mid-year) using procedures described by Rivard (1980) (Michael Palmer, pers. commn) and applying the revised mortality assumptions. Pre-1982, the 1982-1991 average mean weight-at-age is assumed; for 2012, the 2002-2011 average mean weight-at-age is used.

	0	1	2	3	4	5	6	7	8	9	10	11+
1982	0.0024	0.241	0.594	1.165	2.127	4.635	7.622	9.289	9.037	13.235	15.592	18.240
1983	0.0077	0.050	0.501	1.114	1.894	3.136	5.539	6.549	9.962	10.565	12.076	18.713
1984	0.0001	0.075	0.372	1.019	2.021	2.952	4.593	7.118	7.845	11.843	12.834	16.087
1985	0.0146	0.014	0.403	0.910	2.013	3.532	4.608	6.863	9.700	11.147	13.591	14.610
1986	0.0009	0.104	0.316	1.077	1.917	3.670	5.504	6.908	9.315	12.169	13.018	18.102
1987	0.0007	0.028	0.406	0.777	2.273	3.574	5.889	8.079	9.487	11.842	14.008	16.407
1988	0.0003	0.022	0.293	0.980	1.709	4.010	4.927	6.705	10.069	10.761	15.633	12.054
1989	0.0223	0.027	0.292	0.887	2.179	3.172	5.578	6.945	8.799	13.032	14.593	24.532
1990	0.0063	0.095	0.431	0.937	1.742	3.627	5.750	8.043	10.440	13.894	16.575	22.637
1991	0.0069	0.071	0.450	1.083	1.689	2.846	5.654	8.972	11.518	13.416	9.721	24.937
1992	0.0116	0.028	0.476	1.215	2.026	2.564	4.629	8.832	10.453	12.827	17.092	23.406
1993	0.0116	0.046	0.191	1.254	1.702	3.449	4.083	7.388	12.219	12.332	15.361	23.790
1994	0.0095	0.038	0.236	1.003	2.244	2.571	5.294	6.601	11.095	11.435	17.872	22.643
1995	0.0122	0.051	0.275	0.946	2.021	3.934	4.722	8.526	10.045	15.741	14.877	22.643
1996	0.0223	0.060	0.356	1.462	1.784	2.971	6.185	8.967	12.844	14.654	19.623	22.643
1997	0.0049	0.049	0.391	1.466	2.407	2.571	3.973	8.245	11.940	14.994	17.039	17.655
1998	0.0015	0.059	0.256	1.445	2.245	3.423	3.558	5.739	10.442	14.585	15.340	17.655
1999	0.0224	0.044	0.343	1.196	2.237	3.139	4.752	5.301	8.351	12.198	17.158	17.655
2000	0.0092	0.120	0.461	1.063	2.257	3.422	4.773	5.508	7.882	11.040	13.348	18.741
2001	0.0229	0.097	0.456	1.305	2.420	3.851	5.091	6.513	6.912	9.042	14.823	16.934
2002	0.0115	0.089	0.465	1.050	2.249	3.247	5.296	6.514	7.924	10.032	9.746	18.741
2003	0.0217	0.089	0.346	1.053	1.742	2.977	4.118	6.837	8.011	9.693	11.538	15.128
2004	0.0105	0.066	0.351	0.971	2.110	2.620	4.199	5.908	8.627	10.747	12.280	15.612
2005	0.0082	0.060	0.248	0.821	1.654	3.338	3.841	5.758	7.593	10.204	13.212	15.649
2006	0.0428	0.089	0.295	0.808	1.890	2.467	4.076	4.912	6.744	8.837	11.620	16.704
2007	0.0086	0.124	0.450	0.925	1.771	3.005	3.723	5.020	6.329	8.703	10.979	15.470
2008	0.0464	0.085	0.420	1.117	1.888	2.892	3.630	5.147	6.803	8.308	12.351	16.157
2009	0.0137	0.171	0.480	1.248	2.283	2.908	3.658	4.735	6.735	9.047	9.942	15.516
2010	0.0061	0.100	0.589	1.168	2.328	3.198	3.685	4.778	7.153	8.815	10.755	14.649
2011	0.0836	0.087	0.492	1.353	1.972	3.262	4.114	4.788	5.751	10.189	11.448	18.157
2012	0.0253	0.096	0.414	1.052	1.989	2.991	4.034	5.440	7.167	9.457	11.387	16.178

Table A3: Mean weight-at-age (kg) of landings for the Gulf of Maine cod stock applying the revised mortality assumptions (Michael Palmer, pers. commn). Pre-1982, the 1982-1991 average mean weight-at-age is assumed.

	0	1	2	3	4	5	6	7	8	9	10	11+
1982	0.013	0.356	0.858	1.514	2.606	5.067	7.065	9.620	9.772	12.642	19.230	18.240
1983	0.024	0.224	0.768	1.542	2.418	3.808	6.055	6.071	10.317	11.424	11.535	18.713
1984	0.001	0.234	0.653	1.478	2.678	3.609	5.540	8.368	10.138	13.595	14.419	16.087
1985	0.039	0.206	0.733	1.404	2.819	4.658	5.884	8.502	11.244	12.256	13.587	14.610
1986	0.005	0.277	0.501	1.699	2.774	4.778	6.504	8.109	10.207	13.170	13.827	18.102
1987	0.004	0.154	0.642	1.323	3.090	4.668	7.259	10.036	11.099	13.739	14.899	16.407
1988	0.003	0.122	0.577	1.667	2.360	5.206	5.200	6.193	10.103	10.434	17.787	12.054
1989	0.046	0.237	0.752	1.518	2.959	4.282	5.980	9.276	12.519	16.810	20.410	24.532
1990	0.021	0.193	0.811	1.349	2.141	4.474	7.721	10.820	11.750	15.440	16.344	22.637
1991	0.014	0.236	1.113	1.601	2.281	3.894	7.144	10.429	12.261	15.276	6.122	24.937
1992	0.023	0.055	1.033	1.530	2.747	2.976	5.588	10.921	10.483	13.418	19.072	23.406
1993	0.021	0.081	0.690	1.748	2.150	4.420	5.670	9.817	13.673	12.332	17.586	23.790
1994	0.022	0.058	0.730	1.712	3.085	3.251	6.335	7.684	12.542	9.563	22.008	22.643
1995	0.027	0.103	1.288	1.591	2.649	5.090	6.865	11.466	13.128	19.756	23.143	22.643
1996	0.033	0.100	1.293	2.096	2.260	3.462	7.558	11.728	14.455	16.269	19.490	22.643
1997	0.017	0.064	1.351	2.128	3.022	3.074	4.699	9.000	12.156	15.625	17.749	17.655
1998	0.008	0.202	1.071	1.931	2.633	3.972	4.255	7.122	12.118	17.500	15.060	17.655
1999	0.052	0.222	0.635	1.723	2.777	3.892	5.670	6.704	9.811	12.279	16.823	17.655
2000	0.030	0.282	1.081	2.150	3.316	4.325	5.898	5.352	9.331	12.401	14.506	19.056
2001	0.045	0.316	0.890	2.176	3.144	4.666	6.140	7.273	9.072	8.788	17.660	15.417
2002	0.032	0.185	0.795	1.797	2.906	3.792	6.132	6.969	8.809	11.036	10.796	19.056
2003	0.038	0.202	0.809	1.843	2.378	3.654	5.112	7.649	9.191	10.871	11.890	15.176
2004	0.025	0.111	0.483	1.606	2.965	3.547	5.350	7.220	9.764	12.557	13.931	15.657
2005	0.027	0.126	0.558	1.625	2.401	4.233	4.502	6.350	8.002	10.698	13.899	15.627
2006	0.071	0.289	0.648	1.493	2.932	3.357	4.463	5.562	7.430	9.779	12.646	16.704
2007	0.025	0.220	0.744	1.731	2.922	3.735	4.771	6.167	7.302	10.554	12.338	15.470
2008	0.085	0.247	0.862	2.179	2.818	3.530	3.988	5.819	7.528	9.464	14.461	16.174
2009	0.032	0.337	0.911	2.153	3.126	3.575	4.368	5.959	8.000	10.894	10.454	15.523
2010	0.023	0.264	1.200	1.995	3.203	3.914	4.447	5.708	8.730	9.967	10.628	14.650
2011	0.0856	0.3289	0.9331	2.0561	2.874	3.8696	4.839	5.7166	5.9528	11.876	13.15	18.157

Table A4: Mean weight-at-age (kg) in the NEFSC spring and fall surveys, used to compute Albatross converted survey biomass indices.

	0	1	2	3	4	5	6	7	8	9	10	11+
NEFSC spring survey												
2009	0.000	0.031	0.523	1.441	2.067	2.601	2.876	8.067	9.930	0.000	12.919	-
2010	0.000	0.076	0.356	1.203	2.805	3.849	4.602	7.314	10.712	10.247	22.407	17.019
2011	0.000	0.064	0.453	1.177	1.717	2.706	3.509	5.906	8.521	-	-	-
2012	0.000	0.082	0.517	1.299	2.060	2.462	3.235	5.047	11.576	6.323	-	-
NEFSC fall survey												
2009	0.035	0.555	1.174	3.366	4.503	10.575	6.618	-	-	-	-	-
2010	0.019	0.335	1.170	1.774	3.904	4.784	4.548	3.461	-	-	-	25.000
2011	0.022	0.286	0.942	1.775	2.323	4.581	4.931	10.775	7.135	-	-	-

Table A5: Total (commercial and recreational landings and discards) catches-at-age for the Gulf of Maine cod stock, applying the revised mortality assumptions (Michael Palmer, pers. commn).

	0	1	2	3	4	5	6	7	8	9+
1982	1346	448849	2926542	2287192	1430682	748755	65880	94051	72553	90055
1983	13645	597496	2462037	2913215	1201593	704010	452680	50022	62542	56198
1984	18275	370324	2129556	1675931	1643588	437453	219625	105649	9495	53395
1985	67101	505660	1944327	2405137	1151815	738096	161362	107192	48359	33213
1986	17767	760701	1747046	2747811	991982	279282	202725	48016	38188	47527
1987	100702	281794	2018317	1568334	1574499	345353	89415	81032	14459	37549
1988	3446	415081	1542790	2086633	1156925	447729	67430	25560	26247	9267
1989	43	166436	1247203	2385088	1651856	521108	87147	70289	9369	19564
1990	0	65527	812544	5547767	2717623	541353	189069	29703	36417	43315
1991	3251	121627	499588	942731	5561272	1037852	150670	55540	25983	15805
1992	23803	370302	830147	867564	502084	2189957	226167	80181	6044	5530
1993	26570	105929	512307	2149041	944709	103328	497117	41561	11264	0
1994	11734	123996	201923	1525603	1294203	266291	66224	74158	28714	7870
1995	11572	78932	319462	1321833	1260435	221653	29931	6521	18184	2808
1996	22067	37536	111569	627693	2003886	405881	36651	4039	491	1623
1997	1472	69144	137484	519557	467768	869161	72472	5523	2272	1029
1998	917	5941	171062	492301	628941	152820	205873	28696	5168	2257
1999	63	73948	90853	347840	336596	172344	53699	59469	12388	1067
2000	0	24758	485043	556537	813684	176640	85157	12485	10521	0
2001	0	584	393951	1163770	684449	385530	106600	57232	8262	11577
2002	0	16831	41591	374949	912638	323797	163476	66392	28087	20263
2003	22873	44899	125587	167812	582079	706098	186022	75694	29224	26844
2004	187	149420	105917	609344	259720	407447	251632	68378	33017	27442
2005	1487	23545	180064	159581	945815	89223	246596	109148	28457	31674
2006	231	19249	59082	426566	290132	461742	30341	79655	39016	27343
2007	430	12171	108471	299416	976424	137404	230163	7947	19244	21999
2008	415	12156	130508	598424	707392	780450	86355	110576	4041	16558
2009	99	10651	101492	622453	1093273	477852	304754	20896	30506	9646
2010	213	8159	83580	394486	888549	668256	164291	71683	11213	7611
2011	653	8683	60526	322164	589583	573856	339910	34926	38408	9433

Table A6: Standardized stratified mean numbers per tow at age and standardized mean weight (kg) per tow of Atlantic cod in NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine, 1968-2012 (Michael Palmer, pers. commn).

	0	1	2	3	4	5	6	7	8	9	10	11+	Stratified mean wt/tow	CV
1968													17.480	(0.153)
1969													13.100	(0.329)
1970	0.000	0.159	0.124	0.053	0.098	0.290	0.475	0.589	0.073	0.045	0.076	0.210	11.089	(0.237)
1971	0.000	0.069	0.109	0.099	0.280	0.086	0.096	0.280	0.207	0.142	0.050	0.013	7.004	(0.211)
1972	0.053	0.300	0.153	0.499	0.208	0.205	0.052	0.083	0.119	0.300	0.027	0.059	8.031	(0.233)
1973	0.000	0.053	4.273	0.917	0.614	0.384	0.144	0.106	0.186	0.276	0.186	0.386	18.807	(0.415)
1974	0.164	0.311	0.081	1.534	0.177	0.231	0.082	0.000	0.064	0.038	0.089	0.131	7.419	(0.199)
1975	0.012	0.094	0.707	0.095	1.139	0.246	0.073	0.000	0.006	0.025	0.028	0.088	6.039	(0.249)
1976	0.000	0.052	0.253	1.114	0.150	0.870	0.131	0.056	0.038	0.000	0.036	0.081	7.556	(0.166)
1977	0.000	0.068	0.264	0.460	2.015	0.139	0.775	0.000	0.114	0.000	0.000	0.038	8.541	(0.208)
1978	0.000	0.070	0.083	0.297	0.383	0.764	0.084	0.226	0.013	0.108	0.000	0.022	7.697	(0.207)
1979	0.044	0.426	1.407	0.186	0.470	0.301	0.549	0.094	0.104	0.013	0.031	0.020	7.555	(0.176)
1980	0.070	0.037	0.500	0.436	0.123	0.294	0.226	0.337	0.000	0.105	0.026	0.000	6.232	(0.182)
1981	0.000	1.091	0.619	0.850	1.335	0.318	0.304	0.080	0.144	0.091	0.000	0.000	10.650	(0.205)
1982	0.014	0.357	1.040	0.498	0.737	0.848	0.083	0.135	0.000	0.040	0.010	0.000	8.616	(0.223)
1983	0.013	0.610	0.968	1.042	0.453	0.336	0.250	0.060	0.000	0.071	0.033	0.077	10.962	(0.225)
1984	0.000	0.151	1.309	0.987	0.853	0.229	0.047	0.090	0.000	0.000	0.000	0.000	6.143	(0.324)
1985	0.000	0.029	0.238	0.676	0.612	0.707	0.094	0.109	0.026	0.026	0.000	0.000	7.645	(0.223)
1986	0.000	0.537	0.259	0.767	0.218	0.075	0.046	0.038	0.000	0.000	0.000	0.018	3.476	(0.197)
1987	0.000	0.030	0.471	0.191	0.222	0.075	0.000	0.068	0.011	0.000	0.000	0.015	1.976	(0.314)
1988	0.029	0.719	0.926	0.791	0.283	0.205	0.099	0.036	0.020	0.020	0.000	0.000	3.603	(0.281)
1989	0.000	0.025	0.609	0.712	0.630	0.069	0.068	0.000	0.000	0.000	0.000	0.000	2.424	(0.207)
1990	0.000	0.009	0.233	1.325	0.669	0.076	0.032	0.018	0.000	0.000	0.000	0.000	3.077	(0.280)
1991	0.000	0.028	0.077	0.233	1.750	0.247	0.041	0.018	0.000	0.000	0.000	0.000	2.891	(0.240)
1992	0.000	0.050	0.247	0.223	0.248	1.368	0.213	0.073	0.000	0.012	0.000	0.000	8.627	(0.374)
1993	0.000	0.201	0.507	0.804	0.364	0.084	0.446	0.055	0.023	0.000	0.023	0.000	5.875	(0.347)
1994	0.000	0.015	0.316	0.407	0.201	0.083	0.053	0.142	0.009	0.027	0.018	0.000	2.428	(0.216)
1995	0.000	0.037	0.187	1.165	0.321	0.147	0.034	0.000	0.011	0.000	0.028	0.000	2.432	(0.257)
1996	0.000	0.057	0.022	0.586	1.355	0.385	0.060	0.000	0.000	0.000	0.000	0.000	5.427	(0.275)
1997	0.000	0.159	0.139	0.390	0.271	0.874	0.244	0.115	0.000	0.000	0.000	0.000	5.616	(0.192)
1998	0.000	0.018	0.228	0.359	0.513	0.143	0.408	0.021	0.020	0.000	0.000	0.000	4.180	(0.324)
1999	0.000	0.166	0.342	0.726	0.351	0.305	0.134	0.266	0.000	0.000	0.000	0.011	5.090	(0.320)
2000	0.026	1.173	0.737	0.438	0.485	0.099	0.092	0.011	0.022	0.000	0.000	0.000	3.211	(0.155)
2001	0.000	0.029	0.355	0.683	0.510	0.342	0.065	0.097	0.055	0.000	0.011	0.000	6.215	(0.327)
2002	0.000	0.340	0.045	0.548	1.584	0.606	0.342	0.185	0.057	0.017	0.000	0.000	10.934	(0.215)
2003	0.000	0.075	0.825	0.059	0.718	1.072	0.387	0.340	0.081	0.082	0.030	0.011	9.495	(0.368)
2004	0.000	0.136	0.045	0.230	0.116	0.208	0.213	0.011	0.011	0.010	0.000	0.000	2.412	(0.293)
2005	0.000	0.029	0.739	0.081	0.623	0.011	0.138	0.128	0.015	0.000	0.000	0.000	2.701	(0.248)
2006	0.028	0.184	0.237	0.434	0.049	0.197	0.023	0.126	0.069	0.000	0.015	0.000	2.702	(0.249)
2007	0.000	0.100	3.422	3.077	4.446	0.437	0.796	0.075	0.041	0.000	0.000	0.000	15.811	(0.540)
2008	0.000	0.079	1.165	3.930	1.582	1.099	0.053	0.082	0.000	0.000	0.000	0.000	10.823	(0.609)
2009	0.000	0.063	0.279	1.050	1.135	0.600	0.438	0.008	0.022	0.000	0.004	0.000	7.161	(0.491)
2010	0.000	0.059	0.279	0.335	0.197	0.229	0.113	0.043	0.016	0.010	0.005	0.010	3.336	(0.264)
2011	0.000	0.005	0.024	0.140	0.383	0.189	0.086	0.033	0.035	0.000	0.000	0.000	2.133	(0.201)
2012	0.000	0.069	0.105	0.224	0.243	0.159	0.051	0.036	0.004	0.003	0.000	0.000	1.645	(0.209)

Table A7: Standardized stratified mean numbers per tow at age and standardized mean weight (kg) per tow of Atlantic cod in NEFSC offshore autumn research vessel bottom trawl surveys in the Gulf of Maine, 1964-2011 (Michael Palmer, pers. commn).

	0	1	2	3	4	5	6	7	8	9	10	11+	Stratified mean wt/tow	CV
1964	-	-	-	-	-	-	-	-	-	-	-	-	22.799	(0.496)
1965	-	-	-	-	-	-	-	-	-	-	-	-	12.089	(0.273)
1966	-	-	-	-	-	-	-	-	-	-	-	-	12.838	(0.227)
1967	-	-	-	-	-	-	-	-	-	-	-	-	9.313	(0.219)
1968	-	-	-	-	-	-	-	-	-	-	-	-	19.437	(0.198)
1969	-	-	-	-	-	-	-	-	-	-	-	-	15.154	(0.217)
1970	0.743	0.938	0.254	0.520	0.336	0.487	0.424	0.836	0.130	0.090	0.037	0.110	16.442	(0.248)
1971	1.334	0.207	0.224	0.190	0.607	0.444	0.509	0.222	0.280	0.193	0.031	0.121	16.529	(0.307)
1972	0.031	5.663	1.118	1.595	0.181	0.072	0.122	0.031	0.121	0.351	0.000	0.016	12.988	(0.199)
1973	0.638	0.327	2.146	0.179	0.540	0.191	0.055	0.018	0.039	0.182	0.122	0.016	8.764	(0.267)
1974	0.265	1.131	0.267	1.922	0.125	0.276	0.000	0.052	0.036	0.066	0.000	0.189	8.959	(0.201)
1975	0.006	0.223	3.028	0.139	2.354	0.250	0.105	0.020	0.000	0.000	0.000	0.018	8.619	(0.153)
1976	0.000	0.209	0.216	0.578	0.104	0.835	0.044	0.099	0.000	0.000	0.063	0.000	6.740	(0.214)
1977	0.000	0.046	0.446	0.456	1.151	0.133	0.604	0.024	0.083	0.021	0.061	0.048	10.199	(0.126)
1978	0.241	1.411	0.359	1.141	0.661	1.450	0.101	0.269	0.012	0.082	0.000	0.047	12.899	(0.151)
1979	0.000	0.364	0.617	0.131	0.696	0.319	0.754	0.056	0.135	0.000	0.053	0.018	13.927	(0.128)
1980	0.027	1.319	2.558	1.664	0.518	0.236	0.402	0.192	0.022	0.012	0.000	0.085	14.202	(0.153)
1981	0.010	0.581	0.399	0.469	0.509	0.092	0.081	0.081	0.099	0.000	0.028	0.000	7.533	(0.233)
1982	0.000	0.835	3.264	2.476	0.971	0.222	0.000	0.000	0.000	0.000	0.000	0.000	15.919	(0.670)
1983	0.000	0.305	0.905	0.757	0.267	0.250	0.219	0.000	0.000	0.000	0.018	0.065	8.416	(0.188)
1984	0.000	0.513	0.418	0.586	0.384	0.196	0.194	0.062	0.000	0.016	0.000	0.080	8.735	(0.334)
1985	0.218	0.445	0.917	0.627	0.201	0.246	0.064	0.000	0.034	0.070	0.000	0.000	8.264	(0.354)
1986	0.000	0.394	0.404	0.626	0.368	0.073	0.041	0.000	0.000	0.045	0.000	0.000	4.715	(0.228)
1987	0.128	0.570	1.388	0.586	0.198	0.125	0.000	0.000	0.000	0.000	0.000	0.000	3.394	(0.234)
1988	0.000	1.889	2.366	1.069	0.367	0.146	0.000	0.044	0.000	0.011	0.011	0.000	6.616	(0.232)
1989	0.000	0.145	2.468	1.458	0.283	0.138	0.053	0.000	0.009	0.000	0.000	0.000	4.535	(0.181)
1990	0.000	0.057	0.218	1.788	0.611	0.255	0.048	0.010	0.000	0.000	0.000	0.000	4.912	(0.204)
1991	0.009	0.144	0.151	0.230	0.621	0.075	0.000	0.023	0.000	0.000	0.000	0.000	2.782	(0.246)
1992	0.059	0.289	0.448	0.144	0.041	0.327	0.126	0.000	0.000	0.000	0.000	0.000	2.448	(0.243)
1993	0.031	0.210	0.575	0.361	0.017	0.000	0.038	0.000	0.000	0.000	0.000	0.000	1.003	(0.263)
1994	0.032	0.184	0.909	0.816	0.093	0.051	0.000	0.045	0.000	0.000	0.000	0.000	2.737	(0.292)
1995	0.008	0.068	0.308	1.226	0.304	0.082	0.011	0.000	0.000	0.000	0.000	0.000	3.665	(0.325)
1996	0.029	0.122	0.379	0.231	0.516	0.050	0.000	0.000	0.000	0.000	0.000	0.000	2.352	(0.249)
1997	0.000	0.297	0.091	0.165	0.168	0.151	0.000	0.000	0.000	0.000	0.000	0.000	1.872	(0.307)
1998	0.050	0.085	0.342	0.110	0.185	0.041	0.031	0.000	0.000	0.000	0.000	0.000	1.501	(0.287)
1999	0.025	0.432	0.375	0.590	0.244	0.122	0.019	0.000	0.000	0.000	0.000	0.000	3.505	(0.193)
2000	0.008	0.540	0.981	0.399	0.492	0.140	0.010	0.000	0.034	0.000	0.000	0.000	4.652	(0.332)
2001	0.018	0.000	0.171	0.720	0.478	0.356	0.124	0.092	0.000	0.023	0.000	0.000	7.324	(0.279)
2002	0.000	0.269	0.104	0.333	2.683	1.070	0.750	0.077	0.043	0.000	0.000	0.000	24.659	(0.686)
2003	0.542	0.461	0.186	0.216	0.518	0.451	0.071	0.062	0.000	0.011	0.000	0.011	5.988	(0.251)
2004	1.369	0.661	0.172	0.577	0.254	0.250	0.149	0.057	0.023	0.010	0.011	0.000	4.906	(0.214)
2005	0.034	0.153	0.378	0.078	0.456	0.023	0.090	0.082	0.023	0.021	0.000	0.000	2.897	(0.228)
2006	0.064	1.241	0.599	1.007	0.252	0.293	0.037	0.053	0.036	0.000	0.000	0.014	4.229	(0.188)
2007	0.011	0.136	0.863	0.395	0.496	0.023	0.067	0.000	0.000	0.000	0.000	0.000	2.714	(0.277)
2008	0.165	0.650	1.227	1.060	0.189	0.139	0.000	0.000	0.000	0.010	0.021	0.000	5.307	(0.285)
2009	0.020	0.660	2.096	0.314	0.277	0.045	0.035	0.000	0.000	0.000	0.000	0.000	5.845	(0.429)
2010	0.008	0.094	0.132	0.290	0.288	0.092	0.023	0.013	0.000	0.000	0.000	0.006	2.572	(0.304)
2011	0.036	0.060	0.091	0.210	0.304	0.175	0.078	0.005	0.031	0.000	0.000	0.000	2.647	(0.336)

Table A8: Stratified mean catch per tow in numbers and weight (kg) of Atlantic cod in State of Massachusetts inshore spring bottom trawl surveys in territorial waters adjacent to the Gulf of Maine (Mass. Regions 4-5), 1978-2012 (Michael Palmer, pers. commn).

	0	1	2	3	4	5	6	7	8	9	10	11+	Stratified mean wt/tow	CV
1978													11.058	(0.138)
1979													14.276	(0.219)
1980													14.509	(0.128)
1981													18.689	(0.265)
1982	1.668	13.218	6.649	2.921	1.024	0.216	0.049	0.046	0.050	0.000	0.000	0.000	12.161	(0.175)
1983	0.718	30.253	17.570	4.710	0.347	1.121	0.075	0.023	0.033	0.000	0.000	0.000	18.746	(0.153)
1984	0.257	1.898	5.090	2.101	0.751	0.147	0.086	0.000	0.000	0.000	0.000	0.000	7.240	(0.259)
1985	1.569	1.670	2.695	2.024	0.498	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.765	(0.194)
1986	1.075	18.031	3.376	0.903	0.582	0.100	0.023	0.000	0.000	0.000	0.000	0.000	7.841	(0.354)
1987	0.725	8.622	5.376	2.045	0.168	0.147	0.053	0.000	0.000	0.070	0.000	0.000	7.865	(0.271)
1988	1.895	10.409	6.750	1.927	1.211	0.016	0.033	0.000	0.000	0.000	0.000	0.000	7.703	(0.237)
1989	0.298	21.463	22.947	6.868	0.513	0.108	0.048	0.000	0.000	0.000	0.000	0.000	17.346	(0.342)
1990	4.930	4.972	5.938	14.182	2.149	0.155	0.083	0.000	0.000	0.000	0.000	0.000	15.879	(0.341)
1991	0.355	5.331	2.295	1.801	3.669	0.249	0.000	0.000	0.000	0.000	0.000	0.000	8.730	(0.122)
1992	1.506	4.379	5.699	3.444	0.484	1.301	0.066	0.044	0.000	0.000	0.000	0.000	8.766	(0.321)
1993	80.090	2.842	6.100	2.509	0.879	0.166	0.074	0.000	0.000	0.000	0.000	0.000	5.861	(0.270)
1994	4.627	5.406	3.883	1.703	0.608	0.131	0.000	0.000	0.000	0.000	0.000	0.000	4.334	(0.241)
1995	11.998	5.985	2.420	2.408	0.525	0.028	0.000	0.000	0.000	0.000	0.000	0.000	3.993	(0.225)
1996	8.843	0.777	0.497	0.955	1.590	0.299	0.000	0.000	0.000	0.000	0.000	0.000	3.152	(0.305)
1997	12.431	2.910	1.035	0.920	0.190	0.383	0.018	0.000	0.000	0.000	0.000	0.000	2.500	(0.250)
1998	23.481	1.487	0.924	0.779	0.637	0.034	0.211	0.017	0.000	0.000	0.000	0.000	3.250	(0.468)
1999	143.000	11.832	2.407	2.275	0.735	0.630	0.036	0.127	0.017	0.000	0.000	0.000	8.997	(0.261)
2000	2.151	35.360	6.995	2.371	2.316	0.784	0.663	0.059	0.073	0.000	0.000	0.000	20.604	(0.459)
2001	25.987	0.084	4.998	4.710	3.448	1.961	0.323	0.227	0.106	0.000	0.000	0.000	26.445	(0.536)
2002	0.924	19.340	0.220	1.379	1.145	0.561	0.318	0.111	0.253	0.025	0.049	0.012	11.158	(0.390)
2003	0.000	17.109	5.496	0.439	1.938	0.937	0.221	0.074	0.014	0.025	0.000	0.014	10.984	(0.219)
2004	116.135	8.927	1.882	2.627	0.361	1.083	0.455	0.076	0.029	0.000	0.014	0.000	8.147	(0.278)
2005	179.479	5.524	4.141	0.795	1.955	0.263	0.663	0.243	0.094	0.105	0.000	0.000	10.402	(0.197)
2006	0.000	9.992	7.139	3.930	0.525	1.532	0.109	0.057	0.000	0.017	0.028	0.000	9.177	(0.181)
2007	49.323	3.776	3.078	2.303	2.163	0.343	0.519	0.025	0.046	0.000	0.000	0.000	8.430	(0.251)
2008	456.954	7.275	10.336	3.242	2.287	1.695	0.155	0.155	0.000	0.000	0.000	0.000	12.229	(0.215)
2009	466.098	8.907	2.350	1.654	1.045	0.348	0.112	0.000	0.000	0.000	0.000	0.000	4.489	(0.187)
2010	1.165	2.415	1.393	1.423	0.819	0.678	0.129	0.000	0.000	0.000	0.052	0.000	5.645	(0.456)
2011	55.378	0.326	1.001	0.621	0.933	0.558	0.139	0.086	0.021	0.000	0.000	0.000	4.519	(0.424)
2012	6.239	3.368	0.671	0.446	0.304	0.415	0.021	0.000	0.000	0.000	0.000	0.000	2.276	(0.401)

Table A9: Percentage of mature females for each age for the Gulf of Maine cod stock (Michael Palmer, pers. commn).

0	1	2	3	4	5	6	7	8	9	10	11+
0.025	0.092	0.287	0.613	0.862	0.961	0.990	0.997	0.999	1.000	1.000	1.000

Table A10: Length frequency distributions for NEFSC offshore spring and autumn research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC spring survey				NEFSC call survey		
Year	2009	2010	2011	2012	2009	2010	2011
-25cm	0.5634	0.4138	0.0286	0.4159	0.3967	0.0605	0.2489
26cm	0.0496	0.0189	0.0000	0.0113	0.1330	0.0283	0.0850
27cm	0.0425	0.0756	0.0000	0.0057	0.1731	0.0142	0.0283
28cm	0.0638	0.1501	0.0000	0.0170	0.1251	0.0000	0.0142
29cm	0.0553	0.0945	0.0000	0.0057	0.1330	0.0283	0.0000
30cm	0.0283	0.1134	0.0000	0.0113	0.2330	0.0567	0.0142
31cm	0.0544	0.1397	0.0486	0.0057	0.2834	0.0283	0.0136
32cm	0.0142	0.0945	0.0113	0.0337	0.4412	0.1134	0.0377
33cm	0.0213	0.0935	0.0113	0.0113	0.5951	0.0425	0.0142
34cm	0.0958	0.1572	0.0000	0.0404	0.9068	0.0567	0.0506
35cm	0.0743	0.1407	0.0227	0.0170	0.7147	0.0142	0.0283
36cm	0.0887	0.1029	0.0000	0.0582	0.6659	0.0394	0.0142
37cm	0.0695	0.0853	0.0340	0.0283	0.5014	0.0278	0.0000
38cm	0.1204	0.0945	0.0113	0.0207	0.6155	0.0425	0.0000
39cm	0.1748	0.0567	0.0000	0.0659	0.3400	0.0142	0.0543
40cm	0.1559	0.0283	0.0431	0.0548	0.2516	0.0242	0.0283
41cm	0.1629	0.0283	0.0227	0.0453	0.2888	0.0425	0.0364
42cm	0.1771	0.0276	0.0599	0.0639	0.3103	0.0850	0.0380
43cm	0.1565	0.0378	0.0793	0.0564	0.2834	0.0425	0.0401
44cm	0.2125	0.0378	0.0907	0.0860	0.3400	0.0283	0.0222
45cm	0.2287	0.0378	0.0340	0.0746	0.3280	0.0384	0.0640
46cm	0.2196	0.0283	0.0214	0.0380	0.2776	0.0283	0.0567
47cm	0.1913	0.0189	0.0340	0.0434	0.1901	0.0242	0.0000
48cm	0.2371	0.0095	0.0340	0.0283	0.2692	0.0425	0.0364
49cm	0.2017	0.0283	0.0214	0.0394	0.2125	0.0343	0.0623
50cm	0.2240	0.0647	0.0793	0.0510	0.1700	0.0283	0.0647
51cm	0.1845	0.0095	0.0441	0.0264	0.0951	0.0394	0.0364
52cm	0.3077	0.0953	0.0768	0.0944	0.1199	0.0778	0.0383
53cm	0.2122	0.0000	0.0680	0.0394	0.0992	0.0142	0.0425
54cm	0.2517	0.1236	0.0826	0.0567	0.0809	0.0425	0.0506
55cm	0.3245	0.0322	0.0340	0.0453	0.0708	0.0384	0.0330
56cm	0.1946	0.0646	0.0700	0.0491	0.0000	0.0425	0.0599
57cm	0.2046	0.0276	0.0441	0.0377	0.0492	0.0567	0.0000
58cm	0.2358	0.0370	0.0582	0.0644	0.0384	0.0242	0.0000
59cm	0.2347	0.0455	0.0000	0.0519	0.0686	0.0257	0.0161
60cm	0.2537	0.0444	0.0227	0.0349	0.0425	0.0142	0.0383
61cm	0.2547	0.0000	0.0803	0.0511	0.0447	0.0242	0.0588
62cm	0.1164	0.0081	0.0214	0.0227	0.0307	0.0401	0.0383
63cm	0.2003	0.0180	0.0113	0.0154	0.0142	0.0236	0.0222
64cm	0.1725	0.0227	0.0214	0.0406	0.0874	0.0142	0.1130
65cm	0.0341	0.0000	0.0302	0.0227	0.0142	0.0336	0.0222
66cm	0.0611	0.0189	0.0467	0.0170	0.0667	0.0401	0.0303
67cm	0.0850	0.0544	0.0101	0.0321	0.0201	0.0242	0.0303
68cm	0.0414	0.0276	0.0227	0.0154	0.0196	0.0848	0.0401
69cm	0.0370	0.0000	0.0372	0.0154	0.0142	0.0000	0.0481
70cm	0.0923	0.0632	0.0259	0.0170	0.0283	0.0201	0.0581
71cm	0.0387	0.0161	0.0101	0.0097	0.0142	0.0353	0.0283
72cm	0.0287	0.0719	0.0322	0.0057	0.0696	0.0236	0.0259
73cm	0.0259	0.0322	0.0349	0.0000	0.0350	0.0310	0.0420
74cm	0.0128	0.0423	0.0113	0.0097	0.0108	0.0142	0.0081
75cm	0.0199	0.0000	0.0101	0.0000	0.0101	0.0360	0.0081
76cm	0.0704	0.0081	0.0000	0.0000	0.0283	0.0840	0.0222
77cm	0.0058	0.0161	0.0000	0.0196	0.0142	0.0000	0.0222
78cm	0.0115	0.0181	0.0101	0.0057	0.0000	0.0201	0.0000
79cm	0.0058	0.0563	0.0227	0.0057	0.0283	0.0283	0.0108
80cm	0.0270	0.0181	0.0101	0.0040	0.0000	0.0101	0.0000
81cm	0.0270	0.0343	0.0000	0.0054	0.0000	0.0000	0.0540
82cm	0.0000	0.0000	0.0101	0.0000	0.0101	0.0000	0.0222
83cm	0.0283	0.0000	0.0000	0.0000	0.0000	0.0000	0.0161
84cm	0.0115	0.0489	0.0000	0.0000	0.0000	0.0454	0.0000
85cm	0.0115	0.0081	0.0259	0.0000	0.0000	0.0236	0.0081
86cm	0.0071	0.0262	0.0101	0.0000	0.0000	0.0101	0.0000
87cm	0.0186	0.0081	0.0000	0.0000	0.0000	0.0000	0.0000
88cm	0.0058	0.0000	0.0000	0.0057	0.0142	0.0101	0.0142
89cm	0.0058	0.0161	0.0000	0.0000	0.0000	0.0000	0.0000
90cm	0.0071	0.0081	0.0113	0.0000	0.0101	0.0000	0.0000
91cm	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
92cm	0.0058	0.0000	0.0000	0.0057	0.0000	0.0000	0.0142
93cm	0.0000	0.0000	0.0000	0.0000	0.0101	0.0000	0.0081
94cm	0.0058	0.0081	0.0340	0.0000	0.0000	0.0000	0.0000
95cm	0.0058	0.0000	0.0000	0.0000	0.0000	0.0000	0.0081
96cm	0.0128	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
97cm	0.0000	0.0000	0.0000	0.0000	0.0142	0.0000	0.0000
98cm	0.0000	0.0081	0.0000	0.0057	0.0000	0.0000	0.0081
99cm	0.0000	0.0175	0.0000	0.0000	0.0000	0.0000	0.0000
100cm+	0.0115	0.0403	0.0214	0.0000	0.0000	0.0101	0.0081

Table A11a: Age-length keys for NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC Spring, 2009						Age						NEFSC Spring, 2010						Age					
Length	0	1	2	3	4	5	6	7	8	9	10	11+	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	0	39	24	0	0	0	0	0	0	0	0	0	0	28	11	0	0	0	0	0	0	0	0	0
26	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
27	0	0	4	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
28	0	0	3	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
29	0	0	7	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
30	0	0	2	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
31	0	0	6	0	0	0	0	0	0	0	0	0	0	0	6	1	0	0	0	0	0	0	0	0
32	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
33	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
34	0	0	1	5	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0
35	0	0	4	3	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0
36	0	0	4	1	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
37	0	0	2	4	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0
38	0	0	2	4	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
39	0	0	1	2	1	0	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0	0	0
40	0	0	2	6	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0
41	0	0	2	2	1	1	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0
42	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0
43	0	0	2	5	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0
44	0	0	1	5	0	0	0	0	0	0	0	0	0	0	2	3	1	0	0	0	0	0	0	0
45	0	0	1	6	4	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
46	0	0	0	3	2	2	1	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0
47	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0
48	0	0	0	2	4	1	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0
49	0	0	0	3	4	1	2	0	0	0	0	0	0	0	0	2	0	1	1	0	0	0	0	0
50	0	0	0	2	5	1	0	0	0	0	0	0	0	0	0	2	3	2	0	0	0	0	0	0
51	0	0	1	2	2	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
52	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	4	2	1	0	0	0	0	0	0
53	0	0	0	3	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	7	1	2	0	0	0	0	0	0
55	0	0	0	5	1	2	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0
56	0	0	0	1	2	0	1	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0
57	0	0	0	2	3	2	1	0	0	0	0	0	0	0	0	1	2	0	1	0	0	0	0	0
58	0	0	0	0	5	3	1	0	0	0	0	0	0	0	0	3	0	1	1	0	0	0	0	0
59	0	0	0	1	3	1	5	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0
60	0	0	0	1	3	1	2	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0
61	0	0	0	4	2	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
62	0	0	0	1	1	3	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
63	0	0	0	0	3	3	4	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
64	0	0	0	1	5	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
65	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
67	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0
68	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
69	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	3	1	2	0	0	0	0	0	0	0	0	0	1	2	1	1	0	0	0	0
71	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
72	0	0	0	0	2	2	1	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0
73	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
74	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
75	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	2	3	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
77	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
78	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
79	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
80	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
81	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0
85	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
86	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
87	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
88	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
90	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
95	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
>100	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	1	2

Table A11b: Age-length keys for NEFSC offshore spring research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC Spring, 2011							Age					NEFSC Spring, 2012							Age				
Length	0	1	2	3	4	5	6	7	8	9	10	11+	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	0	2	0	0	0	0	0	0	0	0	0	0	1	38	3	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
31	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
32	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
33	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
35	0	0	1	1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0
37	0	0	0	2	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
38	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0
40	0	0	1	2	0	0	0	0	0	0	0	0	0	0	5	6	0	0	0	0	0	0	0	0
41	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	5	0	0	0	0	0	0	0	0
42	0	0	1	1	1	0	0	0	0	0	0	0	0	0	3	7	1	0	0	0	0	0	0	0
43	0	0	0	2	2	0	0	0	0	0	0	0	0	0	2	7	2	1	0	0	0	0	0	0
44	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	9	1	0	0	0	0	0	0	0
45	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	5	2	2	0	0	0	0	0	0
46	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3	2	1	0	0	0	0	0	0
47	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	4	1	0	0	0	0	0	0
48	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	2	0	0	0	0	0	0	0
49	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	5	4	0	0	0	0	0	0	0
50	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	4	1	3	0	0	0	0	0	0
51	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	3	1	0	0	0	0	0	0
52	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	3	7	4	1	0	0	0	0	0
53	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	5	1	0	0	0	0	0	0
54	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	3	2	3	0	0	0	0	0	0
55	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	6	1	0	0	0	0	0	0
56	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	5	4	5	2	0	0	0	0	0
57	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	2	3	1	1	0	0	0	0	0
58	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	6	3	1	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	1	2	0	0	0	0
60	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	2	2	1	0	0	0	0	0
61	0	0	0	0	3	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
62	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	6	1	0	0	0	0	0	0
63	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	3	1	1	0	0	0	0
64	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	2	1	0	0	0	0	0
65	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0
66	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0
67	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0
68	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
69	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0
70	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0
71	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
72	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
73	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
78	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
79	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
80	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
82	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>100	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A12: Age-length keys for NEFSC offshore autumn research vessel bottom trawl surveys in the Gulf of Maine conducted by the *Bigelow* (Michael Palmer, pers. commn).

	NEFSC Autumn, 2009							Age					NEFSC Autumn, 2010							Age					NEFSC Autumn, 2011							Age				
Length	0	1	2	3	4	5	6	7	8	9	10	11+	0	1	2	3	4	5	6	7	8	9	10	11+	0	1	2	3	4	5	6	7	8	9	10	11+
≤25	9	11	2	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	15	4	0	0	0	0	0	0	0	0	0	0
26	0	4	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
27	0	4	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
28	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
29	0	4	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	3	1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
31	0	1	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
32	0	4	1	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
33	0	2	4	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
34	0	1	2	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0
35	0	2	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
36	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
37	0	0	2	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	2	5	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	1	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
40	0	1	3	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
41	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
42	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
43	0	0	4	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
44	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
45	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0	0	0
46	0	0	7	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0
47	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0
49	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0
50	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	3	0	1	0	0	0	0	0	0
51	0	0	3	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
52	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	1	1	3	0	0	0	0	0	0	0
53	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0
54	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	2	0	1	0	0	0	0	0
55	0	0	2	1	2	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0
57	0	0	1	1	2	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
58	0	0	1	0	2	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
59	0	0	0	4	2	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
60	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0
61	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	1	2	2	0	0	0	0	0	0	0
62	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0
63	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
64	0	0	1	1	3	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	4	6	1	0	0	0	0	0	0
65	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
66	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0
67	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0
68	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
69	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0
70	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0
71	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
72	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
73	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
74	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
75	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
76	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
77	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
82	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
93	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0

Appendix B - The Statistical Catch-at-Age Model

The text following sets out the equations and other general specifications of the SCAA 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 then 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).

For the convenience of readers, details which are changed or newly added relative to the specifications used for the analyses reported in Butterworth and Rademeyer (2012) are shown highlighted.

B.1. Population dynamics

B.1.1 Numbers-at-age

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

$$N_{y+1,0} = R_{y+1} \quad \text{(B1)}$$

$$N_{y+1,a+1} = N_{y,a} e^{-Z_{y,a}} \qquad \text{for } 0 \le a \le m-2 \quad \text{(B2)}$$

$$N_{y+1,m} = N_{y,m-1} e^{-Z_{y,m-1}} + N_{y,m} e^{-Z_{y,m}} \quad \text{(B3)}$$

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).

$Z_{y,a} = F_y S_{y,a} + M_a$ 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 old) at the start of year *y* is assumed to be related to the spawning stock size (i.e. the biomass of mature fish) by either a modified Ricker or a standard or adjusted Beverton-Holt stock-recruitment relationship, allowing for annual fluctuation about the deterministic relationship.

For the modified Ricker:

$$R_y = \alpha B_y^{\text{sp}} \exp\left[-\beta \left(B_y^{\text{sp}}\right)^{\gamma}\right] e^{(\varsigma_y - (\sigma_R)^2/2)} \quad \text{(B4)}$$

for the (standard) Beverton-Holt:

$$R_y = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{(\varsigma_y - (\sigma_R)^2/2)} \tag{B5}$$

and for the adjusted Beverton-Holt:

$$R_y = \begin{cases} \dfrac{\alpha B_y^{sp}}{\beta + B_y^{sp}} & \text{if } B_y^{sp} \le B^* \\ \dfrac{\alpha B^*}{\beta + B^*} \exp\left(-\left(\dfrac{B_y^{sp} - B^*}{\sigma_N}\right)^2\right) & \text{if } B_y^{sp} > B^* \end{cases} \tag{B6}$$

where

α, β, γ, B^* and σ_N are spawning biomass-recruitment relationship parameters,

ς_y reflects fluctuation about the expected recruitment for year *y*, which is assumed to be normally distributed with standard deviation σ_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:

$$B_y^{sp} = \sum_{a=0}^{m} f_a w_{y,a}^{strt} N_{y,a} e^{-M_a/4} \tag{B7}$$

because spawning for the cod stock under consideration is taken to occur three months after the start of the year and some mortality has therefore occurred,

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.

Section *B.2.6* details the procedure adopted when recruitment is not assumed to be related to spawning biomass , at least internal to the assessment.

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

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

$$C_y = \sum_{a=0}^{m} w_{y,a}^{mid} C_{y,a} = \sum_{a=0}^{m} w_{y,a}^{mid} N_{y,a} \; S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right) \Big/ Z_{y,a} \tag{B8}$$

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*,

The model estimate of survey biomass is computed as:

$$B_y^{surv} = \sum_{a=0}^{m} w_{y,a}^{surv} S_a^{surv} N_{y,a} e^{-Z_{y,a} T^{surv}/12} \tag{B9}$$

where

S_a^{surv} is the survey selectivity for age *a*, which is taken to be year-independent.

T^{surv} is the season in which the survey is taking place (T^{surv}=1 for spring surveys and T^{surv}=3 for fall surveys), and

$w_{y,a}^{surv} = w_{y,a}^{strt}$ for spring surveys and $w_{y,a}^{surv} = w_{y,a}^{mid}$ for fall surveys.

B.1.4. Initial conditions

For the first year (y_0) considered in the model, the numbers-at-age are estimated directly for ages 0 to a^{est}, with a parameter ϕ mimicking recent average fishing mortality for ages above a^{est}, i.e.

$$N_{y_0,a} = N_{\text{start},a} \qquad \text{for } 0 \le a \le a^{est} \tag{B10}$$

and

$$N_{\text{start},a} = N_{\text{start},a-1} e^{-M_{a-1}} (1-\phi S_{a-1}) \qquad \text{for } a^{est} < a \le m-1 \tag{B11}$$

$$N_{\text{start},m} = N_{\text{start},m-1} e^{-M_{m-1}} (1-\phi S_{m-1}) \big/ (1-e^{-M_m}(1-\phi S_m)) \tag{B12}$$

B.2. The (penalised) likelihood function

The model can be fit to (a subset of) CPUE and survey abundance indices, and commercial and survey catch-at-age and catch-at-length 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 (-$\ell\text{n}L$) are as follows. Details related to fitting to CPUE series are not included below, as such series are not considered in the analyses of this paper.

B2.1. Survey abundance data

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

$$I_y^{surv} = \hat{I}_y^{surv} \exp\left(\varepsilon_y^{surv}\right) \quad \text{or} \quad \varepsilon_y^{surv} = \ell\text{n}\left(I_y^{surv}\right) - \ell\text{n}\left(\hat{I}_y^{surv}\right) \tag{B13}$$

where

I_y^{surv} is the survey biomass index for survey *surv* in year *y*,

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

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

ε_y^{surv} from $N\left(0, \left(\sigma_y^{surv}\right)^2\right)$.

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

$$-\ell\mathrm{n}\,L^{\mathrm{survey}}=\sum_{surv}\sum_{y}\left\{\ell\mathrm{n}\left(\sqrt{\left(\sigma_y^{surv}\right)^2+\left(\sigma_{Add}^{surv}\right)^2}\right)+\left(\varepsilon_y^{surv}\right)^2/\left[2\left(\left(\sigma_y^{surv}\right)^2+\left(\sigma_{Add}^{surv}\right)^2\right)\right]\right\} \qquad \text{(B14)}$$

where

σ_y^{surv} is the standard deviation of the residuals for the logarithm of index *i* in year *y* (which is input), and

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

The catchability coefficient q^{surv} for survey biomass index *surv* is estimated by its maximum likelihood value:

$$\ell n\,\hat{q}^{surv}=1/n_{surv}\sum_{y}\left(\ln I_y^{surv}-\ln\hat{B}_y^{surv}\right) \qquad \text{(B15)}$$

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:

$$-\ell\mathrm{n}\,L^{\mathrm{CAA}}=\sum_{y}\sum_{a}\left[\ell n\left(\sigma_a^{com}/\sqrt{p_{y,a}}\right)+p_{y,a}\left(\ell n\,p_{y,a}-\ell n\,\hat{p}_{y,a}\right)^2/2\left(\sigma_a^{com}\right)^2\right] \qquad \text{(B16)}$$

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*,

where

$$\hat{C}_{y,a}=N_{y,a}\;S_{y,a}F_y\left(1-e^{-Z_{y,a}}\right)/Z_{y,a} \qquad \text{(B17)}$$

and

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

$$\hat{\sigma}_a^{com}=\sqrt{\sum_{y}p_{y,a}\left(\ell n\,p_{y,a}-\ell n\,\hat{p}_{y,a}\right)^2/\sum_{y}1} \qquad \text{(B18)}$$

Commercial catches-at-age are incorporated in the likelihood function using equation (B16), for which the summation over age *a* is taken from age a_{minus} (considered as a minus group) to a_{plus} (a plus group).

In application of this approach ages are often aggregated to avoid values of $p_{y,a}$ or $\hat{p}_{y,a}$ that are too small in the interests of estimation robustness. In this paper individual ages have been maintained between the selected minus and plus-groups to provide potential discrimination of different shapes for the selectivity functions at older ages in particular. This however does mean that there are certain cells for which $p_{y,a}$ values are zero. That does not cause any problems because the limit of $p_{y,a}(\ln p_{y,a})^2$ as $p_{y,a} \to 0$ is 0, so these terms can be omitted from the summation in equation B16. One could argue that they should nevertheless be included in the summations in equation B18, but exclusion seems more appropriate as the structural zero contributions then included would seem likely to bias the estimates of $\hat{\sigma}_a^{com}$ downwards.

In addition to this "adjusted" lognormal error distribution, some computations use an alternative "sqrt(p)" formulation, for which equation B19 is modified to:

$$-\ell\text{n}\, L^{\text{CAA}} = \sum_y \sum_a \left[\ell n\left(\sigma_a^{com}\right) + \left(\sqrt{p_{y,a}} - \sqrt{\hat{p}_{y,a}}\right)^2 / 2\left(\sigma_a^{\text{com}}\right)^2 \right] \tag{B19}$$

and equation B21 is adjusted similarly:

$$\hat{\sigma}_a^{com} = \sqrt{\sum_y \left(\sqrt{p_{y,a}} - \sqrt{\hat{p}_{y,a}}\right)^2 / \sum_y 1} \tag{B20}$$

This formulation mimics a multinomial form for the error distribution by forcing a near-equivalent variance-mean relationship for the error distributions.

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 (B19)) where:

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

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

$$\hat{p}_{y,a}^{surv} = S_a^{\text{surv}} N_{y,a} e^{-Z_{y,a} T^{surv}/12} \Big/ \sum_{a'=0}^{m} S_{a'}^{\text{surv}} N_{y,a'} e^{-Z_{y,a'} T^{surv}/12} \quad . \tag{B21}$$

B.2.5. Survey catches-at-length

In some runs, catches-at-length are also incorporated in the likelihood function. These data are incorporated in the similar manner as the catches-at-age. When the model is fit to catches-at-length, the predicted catches-at-age are converted to catches-at-length:

$$\hat{p}_{y,l}^{surv} = \sum_a \hat{p}_{y,a}^{surv} A_{a,l} \tag{B22}$$

where $A_{a,l}$ is the proportion of fish of age *a* that fall in the length group *l* (i.e., $\sum_l A_{a,l} = 1$ for all ages).

The matrix $A_{a,l}$ is calculated under the assumption that length-at-age is normally distributed about a mean given by the von Bertalanffy equation, i.e.:

$$L_a \sim N\left[L_\infty\left(1 - e^{-\kappa(a-t_o)}\right); \theta_a^2\right] \tag{B23}$$

where

θ_a is the standard deviation of mid-year length-at-age a, which is modelled to be proportional to the expected length-at-age *a*, i.e.:

$$\theta_a = \beta\left[L_\infty\left(1-e^{-\kappa(a+0.5-t_o)}\right)\right]^\gamma \qquad \text{(B24)}$$

with β an estimable parameter and $\gamma = 0.5$ (a value which was found to lead to reasonable fits to the data).

$L_\infty = 150.93\,cm$,

$\kappa = 0.11\,yr^{-1}$,

$t_o = 0.13\,yr$,

The following term is then added to the negative log-likelihood:

$$-\ell\text{n}\,L^{\text{CAL}} = w_{len}\sum_{surv}\sum_{y}\sum_{l}\left[\ell n\left(\sigma_{\text{len}}^{surv}/\sqrt{p_{y,l}^{surv}}\right) + p_{y,l}^{surv}\left(\ell n\, p_{y,l}^{surv} - \ell n\,\hat{p}_{y,l}^{surv}\right)^2/2\left(\sigma_{\text{len}}^{surv}\right)^2\right] \qquad \text{(B25)}$$

The w_{len} weighting factor may be set to a value less than 1 to downweight the contribution of the catch-at-length data (which tend to be positively correlated between adjacent length groups because the length distributions for adjacent ages overlap) to the overall negative log-likelihood compared to that of the CPUE data. The value used for w_{len} is 0.1, being roughly equivalent to the ratio of the number to length groups to the number of age groups considered. Instances of observed proportions of zero are dealt with in the same manner as for catches-at-age, as is the alternative "sqrt(p)" error distribution formulation.

B.2.6. Stock-recruitment function residuals

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

$$-\ell nL^{\text{pen}} = \sum_{y=y_1+1}^{y_2}\left[\varepsilon_y^2/2\sigma_{\text{R}}^2\right] \qquad \text{(B26)}$$

where

ε_y from $N\left(0,(\sigma_R)^2\right)$,

σ_{R} is the standard deviation of the log-residuals, which is input.

In the analyses reported in this paper, unless otherwise stated, this "stock-recruitment" term is included for the last two years only, simply to stabilise these estimates which are not well determined by the other data. The ε_y are calculated as the deviations from the mean log recruitment for the ten preceding years, i.e. recruitment estimates for 2010 and 2011 are shrunk towards the geometric mean recruitment over the preceding decade.

B.2.7 Incorporation of Bigelow vs Albatross survey calibration

The survey data provided are adjusted for the years 2009 to 2012 which were obtained from *Bigelow* surveys have been adjusted to "*Albatross* equivalents" through use of calibration factors estimated independently from paired tow experiments (Miller *et al*., 2010). However the survey data before and after the switch of vessels also provide information on the calibration factors because they sample the same cohorts. Incorporation of this information in assessments in this paper has been effected by treating the estimates, with their variance-covariance matrix, as a form of "joint-prior" which is effectively updated in the penalised likelihood estimation when fitting the model. The process is as follows.

First *Bigelow* length frequency distributions are converted to *Albatross* equivalent length frequency distributions:

$$C_{y,l}^{surv,A} = C_{y,l}^{surv,B} / F_l \qquad \text{(B27)}$$

where

$C_{y,l}^{surv,B}$ is the measured catch-at-length for the *Bigelow* in year *y* for survey *surv,*

$C_{y,l}^{surv,A}$ is the inferred catch-at-length for the *Albatross* equivalent in year *y* for survey *surv,*

F_l is the length-based calibration factor (*Bigelow/Albatross*),

The Albatross equivalent length distributions are then converted to age distributions:

$$C_{y,a}^{surv,A} = \sum_l C_{y,l}^{surv,A} ALK_{y,a,l}^{surv} \qquad \text{(B28)}$$

where

$ALK_{y,a,l}^{surv}$ is the age-length key (proportion of fish of length *l* that have age *a*) in year *y* for survey *surv.*

Biomass indices are then obtained from the *Albatross* equivalent age distributions as follows:

$$I_y^{surv,A} = \sum_a C_{y,a}^{surv,A} w_{y,a}^{surv} \qquad \text{(B29)}$$

where

$w_{y,a}^{surv}$ is the weight-at-age in year *y* for survey *surv*.

The calibration factor has four parameters, three of which are estimable and the other input: X_1=20cm, X_2, F_1 and F_2

$$F_l = \begin{cases} F_1 & \text{if } l \le X_1 \\ \dfrac{(F_2 - F_1)}{(X_2 - X_1)} l + \dfrac{(F_1 X_2 - F_2 X_1)}{(X_2 - X_1)} & \text{if } X1 < l < X_2 \\ F_2 & \text{if } l \ge X_2 \end{cases} \qquad \text{(B30)}$$

The following contribution is therefore added to the negative log-likelihood in the assessment:

$$-\ln L^{calib} = \frac{1}{2}\ln|\mathbf{\Sigma}| + \frac{1}{2}(\mathbf{x}-\boldsymbol{\mu})^{\mathrm{T}}\mathbf{\Sigma}^{-1}(\mathbf{x}-\boldsymbol{\mu})$$

where the parameters X_2, F_1 and F_2 are components of the vector $\boldsymbol{x}$,

Σ is the variance covariance matrix as estimated by Miller *et al.* (2010), and

μ is a vector which contains the Miller *et al.* (2010) estimates of the parameters.

These estimates and the variance-covariance matrix are given in table B1 below:

Table B1: Estimates and variance-covariance matrix for the calibration parameters (Miller, pers. commn).

μ	$ln(F_2)$	$ln(F_1\text{-}F_2)$	$ln(X_2\text{-}X_1)$
	0.4713	1.4163	3.5086
Σ	$ln(F_2)$	$ln(F_1\text{-}F_2)$	$ln(X_2\text{-}X_1)$
$ln(F_2)$	0.006674	-0.002515	-0.002559
$ln(F_1\text{-}F_2)$	-0.002515	0.051592	-0.007601
$ln(X_2\text{-}X_1)$	-0.002559	-0.007601	0.006757

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:

The commercial fishing selectivity, S_a, as well as the fishing selectivities for the Massachusetts inshore spring survey, are estimated separately for ages a_{minus} to a_{plus}. The estimated proportional decrease from ages a_{plus}-1 to a_{plus} is assumed to continue multiplicatively to age 9+ for the commercial selectivity and to age 11+ (the model plus group) for the Massachusetts spring survey (if not otherwise specified) (see Table below for a_{minus} to a_{plus}). For the NEFSC offshore surveys, the fishing selectivities are estimated separately for ages a_{minus} to age 7 for the spring survey, and to age 6 for the fall survey, and thereafter an exponential decline to age 9+ is estimated separately for each survey.

The commercial selectivity is taken to differ over the 1893-1991 and 1992+ periods. The decision to incorporate a change after 1991 was made to remove non-random residual patterns in the fit to the commercial catch-at-age data if time-independence in selectivity was assumed.

B.4.2. Other parameters

Model plus group			
m	11		
Commercial CAA			
a_{minus}	1		
a_{plus}	9		
Survey CAA	NEFSC spr	NEFSC fall	MASS spr
a_{minus}	1	1	0
a_{plus}	9	9	4
Natural mortality:			
M	0.2 and age independent		
Proportion mature-at-age:			
f_a	input, see Table A8		
Weight-at-age:			
$w_{y,a}^{strt}$	input, see Table A2		
$w_{y,a}^{mid}$	input, see Table A3		
Initial conditions for a 1964 starting year:			
$N_{y0,a}$	estimated directly for ages 0 to 2		
ϕ	estimated, eqns B9-B10 for ages 3+		

B.5.Reference points

It is possible to estimate reference points internally within the assessment by fitting the stock-recruitment relationship directly within the assessment itself.

For most results reported here, however, the stock-recruitment relationships are fitted to the estimates of recruitment and spawning biomass provided by the various assessments to provide a basis to estimate reference points. The rationale for estimation external to the assessment itself is to avoid assumptions about the form of the relationship influencing the assessment results. These fits are achieved by minimising the following negative log-likelihood:

$$-\ln L = \sum_{y=y1}^{2009}\left[\frac{\left(\ln(N_{y,0}) - \ln\left(\hat{N}_{y,0}\right)\right)^2}{2\left((\sigma_R)^2 + \left(CV_y\right)^2\right)} + \ln\left(\sqrt{(\sigma_R)^2 + \left(CV_y\right)^2}\right)\right] \tag{B31}$$

where

$N_{y,0}$ is the "observed" (assessment estimated) recruitment in year *y*,

$\hat{N}_{y,0}$ is the stock-recruitment model predicted recruitment in year *y*,

σ_R is the standard deviation of the log-residuals, and

CV_y is the Hessian-based CV for the "observed" recruitment in year *y*.

Note that the differential precision of the assessment estimates of recruitment is taken into account, and that the summation ends at 2009 because little by way of direct observation is as yet available to inform estimates of recruitment for 2010 and 2011.