On Assessment of the Atlantic Menhaden Population

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Summary

The Atlantic menhaden population is assessed using Statistical Catch-at-Age/Length (SCAA/L) methodology. Two dominant issues have important impacts on the assessment results. The first is selectivity doming, which is clearly preferred by the data, and leads to higher estimates of spawning biomass in absolute terms. However, considerably greater differences in results follow depending on which of the incompatible JAI (recruitment) and SAD/NAD (ages 1 to 6+) survey indices are preferred for inclusion in the assessment. Current resource trends are indicated to be negative for the former, and positive for the latter, for which the relative weighting accorded to size composition data in the likelihood also plays a role. Suggestions are made for areas of further investigation to attempt to reduce the wide range of plausible results forthcoming from these assessments.

Introduction

This paper presents initial assessments of the Atlantic menhaden (*Brevoortia tyrannus*) population using Statistical Catch-at-Age/Length (SCAA/L) methodology. This methodology has and continues to be widely applied to other populations, for example to South African hake (Rademeyer *et al*. 2008) and in contributions to assessments of groundfish species in the Gulf of Maine (e.g. Butterworth and Rademeyer 2008, 2011).

The paper first details the data used, and then the methodology applied. The results of applying this methodology, which include some sensitivity tests, are then presented and discussed, followed by some concluding remarks.

Data

The biological information, together with catch and survey related data, which are used for these analyses, are listed in Tables in Appendix A. They were kindly provided by Genny Nesslage (ASFMC).

Methodology

The details of the SCAA/L assessment methodology are provided in Appendix B. These details include specifications for the computation of $F_{n\%}$-based F_{MSY} proxy biological reference points (BRPs); results for these are not shown below, but could be provided on request.

Key elements of the population dynamics assumed for the Base Case applications of this SCAA/L methodology are as follows.

- A Baranov catch equation, with a plus-group at age 6
- A Beverton-Holt egg production-recruitment relationship with log residuals normally distributed with standard deviation σ_R - though the relationship to egg production is of little consequence for the results presented here as a steepness *h* = 0.98 is assumed, i.e. expected recruitment virtually independent of egg production
- Values of demographic parameters and their variability with year and age (see Appendix A) are as advised by Genny Nesslage to have arisen from discussions to date in the committee responsible for the assessment
- Selectivities for catches are age-specific, fishery dependent (for the four "fleets"/fisheries: north and south, with reduction and bait fisheries for each), but assumed to be year-invariant; ageing error is taken into account in developing model-predicted values for observed catches-at-age
- Selectivities for the SAD and NAD survey indices for ages 1 to 6+ are assumed to be length-specific and year-invariant; these selectivities are related to equivalent age-specific selectivities through the assumption of normally distributed length-at-age relationships with assumed CVs of 20%; these age-specific selectivities do vary (slightly) with year because of the differing expected lengths-at-age by year(see Tables A.4).

Similarly important aspects of the estimation process are the following.

- Penalised MLE is applied, implemented using ADMB, with approximate CVs of estimates provided by use of the Hessian
- Most elements of the numbers-at-age vector for the starting year are estimated (see Appendix B section B.1.5 for details)
- Fits to the survey indices assume lognormally distributed errors; additional variance to the CVs advised is assumed, is taken to be year-invariant but differing for each series, and is estimated in the model fitting process
- Fits to the proportions-at-age in the catches and lengths-at age in the SAD and NAD surveys assume normality under square root transformation to mimic a multinomial mean-variance relationship; the Punt-Kennedy (adjusted lognormal) form is used in a sensitivity; thus the weighting of these data (in inverse proportion to their variances about their expected values) is estimated internally in the model fitting process, in contrast to the external iteration process needed when a multinomial formulation is used
- The log-likelihood for the proportions-at-length are downweighted by a multiplicative factor of 0.25 compared to those for the proportions-at age (see Appendix B section B.2.3 for the rationale)
- "Observed" (i.e. reported) catches are assumed to be lognormally distributed about their true values with the log residuals having a standard deviation of 0.1
- The log recruitment residual variability parameter σ_R is set to 0.6. This is based on outputs from initial runs of the model which yielded fits for which these residuals reflected standard deviations σ_{Rout} (see Table 1 and following) of typically 0.6 or slightly less.

Results and Discussion

Choice of Base Cases

Base Case I (BCI) is an assessment with a starting year of 1955 for which all three survey indices (JAI, SAD and NAD) with their associated size composition data/assumptions are used for input. The results are reported in Table 1, Figure 1 (which shows trajectories of spawning biomass, total fishing mortality over all fleets for age 3 and annual recruitment) and Figure 2 (Hessian-based 90% CIs for spawning biomass trajectories).

Fits of BCI to the survey indices are shown in Figure 3. It is immediately apparent that BCI is unable to fit all three survey indices well. Assessment model estimates of recruitment follow the trend indicated by the JAI index reasonably well (given their level of variance), but are unable to reflect to SAD and to a greater extent the NAD survey index trends, especially the increases over the last decade which both of these surveys indicate. This failure is not unexpected – no dynamics model for a closed population will be able to reflect the combination of a decreasing trend in recruitment (the JAI index) and an increasing trend in the abundance of older fish (the NAD index) over an extended period of time. Basically the JAI index and the SAD/NAD indices are inconsistent – they cannot both be reflecting the true underlying population trends.

In these circumstances, there is no statistical justification to continue to consider assessments to which data from all three indices are input. Either the assessment model is fitted to the JAI index ignoring the SAD and NAD indices (Base Case II – BCII), or to the SAD and NAD indices ignoring the JAI index (Base Case III – BCIII). Results for these further Base Cases are also given in Table 1 and Figures 1 to 3.

Both BCII and BCIII assessments commence in 1980, which is the first year for which the NAD index is available, in the interests of comparability. Bridge_I is a variant of BCI (including all three indices) which commences in 1980 rather than 1955; the results (Table 1 and Figures 1 to 3) do not differ greatly from those for BCI over their common period.

Strictly it is Bridge_II rather than BCIII which is the exact equivalent of BCII but with the SAD and NAD indices replacing the JAI index as input, but a further change is made in specifying BCIII. The reason for this follows from consideration of results for various extents of downweighting of the size composition data from catches and surveys in the log likelihood relative to the information on abundance trends from the SAD and NAD indices. Table 2 and Figures 4 and 5 show results achieved by reducing the values of the W_{CAA} and W_{CAL} weighting factors (see Appendix B, equations B20, B23, B26 and B27) in proportion. Such a reduction is not inappropriate – some positive correlation is to be expected in these size composition data as fish of similar size/age tend to occur together, rendering these data non-independent in contradiction to the assumptions underlying the equation used for their likelihood. This correlation implies that this likelihood should be downweighted – the problem is that the extent of downweighting that is appropriate is not immediately evident, and would require more complex modelling of the error structure of the data were its estimation to be attempted.

Figures 4 and 5 show that the assessment results "flip" from one form to another as W_{CAA} changes from 0.8 down to 0.7, from a pattern of decreasing spawning biomass, large and increasing fishing mortality, and decreasing recruitment over the last decade to the complete opposite of this. Decreasing W_{CAA} (and W_{CAL} with it) gives relatively more weight to the NAD survey index in particular, and the assessment shifts to trying to reflect better the increasing trend in this index over the last decade. However, the better this trend is reflected, the higher the associated current spawning biomass in absolute terms, and to an extent that the realism of results for low choices for W_{CAA} might reasonably be questioned. As a compromise for present purposes therefore, BCIII has incorporated a 50% downweighting of the size composition data, i.e. W_{CAA} = 0.5 (and W_{CAL} = 0.125).

Base Cases diagnostics

An interesting aspect when contrasting BCII and BCIII is that additional variance estimates for the survey indices which are fit in each case is either zero or nearly zero (Table 1), so that for each case the magnitude of the residuals of these observations about their predicted trends is compatible with the reported CVs for the input data. In part linked to the downweighting of the size composition data in BCIII, the CVs of quantities estimated in that assessment are roughly double those for comparable BCII quantities (Table 1 and Figure 2). To be able to reflect the recent increasing trends in the SAD and particularly NAD indices, recruitment estimates for the last five years for BCIII have to be appreciably higher than those estimated for BCII (Figures 1 and 3).

A fullish set of diagnostics is provided in Figures 6, 7 and 8 for BCI, BCII and BCIII respectively. There are a number of common features of these results for all of the three Base Cases.

- No obvious egg production-recruitment relationship
- Strongly domed selectivities, both for the catch proportions-at-age for the four fisheries, and for the catch proportions-at-length for the SAD and NAD surveys; however when this selectivity for the NAD surveys is converted into an effective selectivity-at-age, it is flat-topped (for 2013)
- There is relatively little indication of changes with age in the variability of the proportions-at-age residuals (the sigCAA plots in Figs 6b, 7b and 8b which show the estimates of σ^{f}_{CAA} evaluated separately for each age - see Appendix B equation B22 which is adjusted to remove the summation over ages to provide the age-specific results shown)
- There is a marked tendency to predict more fish in the oldest age group of the proportions-at-age for the four fisheries than are observed in the data. This is a consequence of the ageing-error matrix which, given an actual catch of age 4 fish (for example) which is necessary to fit other data, results in a number of these fish being predicted to be classified as age 6 when otoliths are read.

The only marked difference in diagnostics amongst the Base Cases are the systematic trends evident in the residuals for the SAD and NAD indices for BCI and (implicitly) BCII, for which the fits to the JAI index are adequate, and the near reverse situation for BCIII (for which the autocorrelation for the NAD index is not entirely removed).

Sensitivies

The results of a number of sensitivities to BCII and BCIII are reported in Tables 3 and 4 respectively, and shown as well in Figures 9 to 17.

Given the "problem" mentioned above for fits to the catch proportions-at-age data when ageing error is taken into account, so as to provide some bound on the range of uncertainty in results to which this might lead, the assessments have been repeated assuming that there is no ageing error. The comparative results shown in Tables 3 and 4, and in Figures 9 a and b, for sensitivities IIa and IIIa respectively, indicate that this results in better fits to these age data, somewhat reduced doming in the selectivities-at-age, somewhat larger spawning biomasses, and sharply reduced values of fishing mortality for many years, including in particular recent years for IIa. This matter is discussed further in the Concluding Remarks section below.

When σ_{R} is increased from 0.6 to 1.0 to place less restrictions on recruitment estimates to conform to the assumption of a constant expected recruitment over time, spawning biomass increases slightly for sensitivity IIb and somewhat more for IIIb (see Figures 10a and 10b). the estimates for current fishing mortality are higher for IIb but lower for IIIb (tables 3 and 4).

Using the adjusted lognormal (Punt-Kennedy) distributional form for the proportions-at-age/length data in place of the "sqrt(p)" formulation decreases spawning biomass and recruitment for IIc and increases these for IIIc (Figures 11a and b). Selectivities and fits to the size composition data do not appear greatly affected (Figures 12a, 12b and 13), and estimates of current fishing mortality are reduced (Tables 3 and 4).

When the NAD selectivity-at-length is forced to be flat at larger lengths in sensitivity IIId, the estimated spawning biomass is reduced, but the fit to the survey catch-at-length data deteriorates appreciably, with larger proportions being predicted for the largest fish caught than are observed (Figure 14). When in addition the selectivity-at-age for the northern reduction fishery is forced to be flat at larger ages in sensitivity IIIe, the spawning biomass is substantially reduced and the other selectivities-at-age show lesser or no doming (Figure 15b); the fits to the size composition data improve, but those to the SAD and NAD indices deteriorate (Table 4 and Figure 16). For the other Base Case under the corresponding sensitivity IIe for which the selectivity-at-age for the northern bait fishery is again forced to be flat, spawning biomass is lower and the other selectivities-at-age again show lesser or no doming (Figure 15a); the estimate of the current fishing mortality increases, but the fit to the catch proportions-at-age data deteriorates together with the overall log likelihood (Table 3).

An alternative explanation to domed selectivity for low numbers of older fish in catches is an increase in natural mortality-at-age for older fish ("dying of old age"). Sensitivities IIf and IIIf explore this by increasing the value of natural mortality M above age 3 to a little more than double the value given in Table A.1 for age 6+. As to be expected, this results in a decrease in the estimated spawning biomass, but there is little reduction in the extent of doming estimated for both the fisheries and the surveys (Figures 17a and b).

Retrospectives

Figures 18a and 18b provide retrospective results for the BCII and BCIII assessments respectively. There are distinct retrospective patterns for both assessments: for BCII as further years' data become available, estimates of spawning biomass decrease and those of fishing mortality increase; for BCIII exactly the reverse holds. Given the fairly strong downward trend in the JAI index and upward trend in the NAD index over recent years, these patterns are what might have been expected.

Concluding Remarks

In the limited time available for these analyses, it has not been possible to explore further sensitivities such as alternative models for the distribution of lengths-at-age in fitting to survey proportions-at-length data, or for the egg production-recruitment relationship. However these seem unlikely to yield results appreciably different from those shown above. At least at a "single factor" level, the most important sensitivities have probably been covered.

Clearly there are two dominant issues which have important impacts on the assessment results. The first is selectivity doming, which is clearly preferred by the data, and leads to higher estimates of spawning biomass in absolute terms. However, considerably greater differences in results follow depending on which of the incompatible JAI and SAD/NAD survey indices are preferred for inclusion in the assessment.

The biomasses estimated for those corresponding BCII and BCIII scenarios are considerably different in absolute terms, so that any further information that might provide some discrimination on this front seems worth considering. One possibility is that since demersal trawl surveys have been used, they do in principle allow the estimation of biomass in absolute terms. Undertaking this would though be a daunting prospect in this case, not only because the effects of the standard problems of herding, net avoidance, and fish above the net require some level of quantification, but here also because multiple rather than single surveys have been combined to provide the JAI, SAD and NAD indices. Such an exercise would clearly not yield a highly precise result, but it could produce plausible bounds which eliminate at least some at either or both ends of the wide range of assessment outputs reported above.

The other area where further consideration could be fruitful is in modelling the catch (and also survey length) proportions-at-age data. Exactly which elements of these data are most responsible for the remaining conflict between signals from the SAD/NAD indices and the size composition data in the BCIII assessments and its variants need to be identified (the log-likelihood differences in Table 2 indicate that the catch age rather than the survey size composition data that contribute the most to this conflict). This is to facilitate a determination of whether alternative models might be able to better reconcile the data from these two sources. One possibility is allowing some variation in time in the selectivity-at-age functions for the reduction and bait fisheries. Another is the ageing error model. As pointed out above, this seems to result in predicting catches of more older fish than are observed. A possible reason for this is that the model has extrapolated error relationships estimated at lesser ages (for which there are more data from age readers) to higher ages where those relationships are perhaps less appropriate. The data hint that readers may be disinclined to report relatively large ages, perhaps being pre-disposed to suspect that they are unlikely to be present. Further analyses to address these issues might prove beneficial in resolving some of the conflicts evident in the assessment results reported in this paper.

Even so, such initiatives may not fully resolve the differences amongst alternative but nevertheless plausible assessment models and their outputs. Thought thus needs to be given to how to provide scientific advice for management in circumstances of wide-ish uncertainty, where selecting a single "best" model for this purpose becomes questionable. While the adoption of a management procedure based on MSE would probably be the best way forward in such a situation, that exercise would require considerable time to take through to completion. A fall back in the interim could be a "risk analysis", where consideration is given to the consequences for a range of alternative management options that are forecast under each of a number of plausible alternative assessments.

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Table 1: Results for the three Base Cases and bridging runs Bridge_I and Bridge_II. Biomasses and catches are in thousand metric tons. The italised values in parenthesis next to the -lnL:comCAA and -lnL:indexCAL values are the -lnL values without the downweighting. Hessian-based CVs are shown in parentheses (a * on this value means that it cannot be estimated because the estimate of the parameter is on a constraint boundary). Values in **bold** are fixed on input; *y0* is the start year for the assessment (1955 or 1980); W_{CAL} is 0.25 unless otherwise indicated.

		BCI		Bridge_I		BCII		Bridge_II		BCIII	
		Start in 1955, all three indices		Start in 1980, all three indices		Start in 1980, JAI only		Start in 1980, SAD and NAD only		Start in 1980, SAD and NAD only, W_{CAA}=0.5, W_{CAL}=0.125	
'-lnL:overall		-1656.3		-1288.4		-957.5		-1289.3		-630.0	
'-lnL:Index		27.5		23.3		1.8		23.8		7.9	
'-lnL:comCAA		-1357.4	*-(1357.4)*	-969.3	*-(969.3)*	-972.5	*-(972.5)*	-970.0	*-(970.0)*	-470.4	*-(940.7)*
-lnL:indexCAL		-354.4	*-(1417.5)*	-354.9	*-(1419.4)*	-		-355.3	*-(1421.2)*	-175.4	*-(1403.3)*
'-lnL:catch		1.9		1.1		0.6		0.9		0.1	
'-lnL:RecRes		26.1		11.4		12.5		11.3		7.9	
h		**0.98**		**0.98**		**0.98**		**0.98**		**0.98**	
B^{sp}_{y0}		1360	(0.47)	1146	(0.49)	1783	(0.64)	1263	(0.52)	3819	(0.46)
B^{sp}_{2013}		276	(0.23)	232	(0.15)	214	(0.17)	240	(0.16)	3793	(0.49)
$B^{sp}_{2013}/B^{sp}_{y0}$		0.20	(0.51)	0.20	(0.50)	0.12	(0.60)	0.19	(0.53)	0.99	(0.45)
B^{sp}_{2013}/av(B^{sp}_{1965}-B^{sp}_{2005})		0.38	(0.21)	-		-		-		-	
B^{sp}_{2013}/av(B^{sp}_{1990}-B^{sp}_{2005})		0.29	(0.22)	0.36	(0.20)	0.26	(0.24)	0.35	(0.23)	1.47	(0.26)
F_{2013}		3.06	(0.62)	7.14	(0.46)	8.59	(0.61)	6.46	(0.48)	0.15	(0.43)
q (10^9):	JAI	4.6	(0.05)	4.3	(0.04)	4.1	(0.07)	4.2	(0.04)	2.0	(0.27)
	SAD	41.9	(0.16)	46.1	(0.15)	(44.6)	(0.08)	45.4	(0.15)	19.5	(0.36)
	NAD	74.3	(0.19)	98.4	(0.17)	(77.1)	(0.24)	94.5	(0.17)	21.3	(0.47)
AddVar:	JAI	0.00	(0.00*)	0.00	(0.00*)	0.00	(0.00*)	-		-	
	SAD	0.25	(1.01)	0.19	(1.23)	-		0.19	(1.31)	0.07	(2.47)
	NAD	0.22	(0.96)	0.18	(1.12)	-		0.18	(1.14)	0.00	(0.00*)
σ_{Rout}		0.56	(0.04)	0.49	(0.06)	0.52	(0.06)	0.49	(0.06)	0.41	(0.12)

Table 2: Results for a series of runs with different weightings on the commercial CAA and index CAL likelihoods. All runs start in 1980 and are fit to the SAD and NAD indices only. The italised values in parenthesis next to the -lnL:comCAA and -lnL:indexCAL values are the -lnL values without the downweighting. Hessian-based CVs are shown in parentheses (a * on this value means that it cannot be estimated because the estimate of the parameter is on a constraint boundary). Values in **bold** are fixed on input.

		III_1		III_2 (=IIa)		III_3		III_4		III_5 (=BCIII)		III_6		III_7	
		W_{CAA}=1.0 W_{CAL}=1.0		W_{CAA}=1.0 W_{CAL}=0.25		W_{CAA}=0.8 W_{CAL}=0.2		W_{CAA}=0.7 W_{CAL}=0.175		W_{CAA}=0.5 W_{CAL}=0.125		W_{CAA}=0.3 W_{CAL}=0.75		W_{CAA}=0.1 W_{CAL}=0.05	
'-lnL:overall		-2362.0		-1289.3		-1024.5		-889.2		-630.0		-373.0		-246.0	
'-lnL:Index		28.0		23.8		22.6		12.8		7.9		1.8		-2.6	
'-lnL:comCAA		-964.2		-970.0	*-(970.0)*	-774.6	*-(968.3)*	-663.5	*-(947.8)*	-470.4	*-(940.7)*	-278.4	*-(927.9)*	-182.8	*-(1828.3)*
-lnL:indexCAL		-1437.8		-355.3	*-(1421.2)*	-284.0	*-(1419.8)*	-246.7	*-(1409.5)*	-175.4	*-(1403.3)*	-104.6	*-(1394.3)*	-69.3	*-(2770.6)*
'-lnL:catch		1.1		0.9		0.7		0.1		0.1		0.0		0.0	
'-lnL:RecRes		10.9		11.3		10.8		8.1		7.9		8.2		8.6	
h		**0.98**		**0.98**		**0.98**		**0.98**		**0.98**		**0.98**		**0.98**	
B^{sp}_{1980}		1144	(0.49)	1263	(0.52)	1185	(0.55)	3390	(0.39)	3819	(0.46)	4230	(0.58)	4203	(0.67)
B^{sp}_{2013}		247	(0.16)	240	(0.16)	254	(0.19)	3015	(0.60)	3793	(0.49)	4451	(0.52)	4758	(0.55)
$B^{sp}_{2013}/B^{sp}_{1980}$		0.22	(0.51)	0.19	(0.53)	0.21	(0.57)	0.89	(0.50)	0.99	(0.45)	1.05	(0.49)	1.13	(0.55)
B^{sp}_{2013}/av(B^{sp}_{1990}-B^{sp}_{2005})		0.29	(0.27)	0.35	(0.23)	0.39	(0.25)	1.25	(0.30)	1.47	(0.26)	1.68	(0.26)	1.81	(0.27)
F_{2013}		5.53	(0.48)	6.46	(0.48)	5.61	(0.52)	0.17	(0.50)	0.15	(0.43)	0.15	(0.48)	0.15	(0.53)
q (10^9):	JAI	4.1	(0.05)	4.2	(0.04)	4.2	(0.04)	2.2	(0.28)	2.0	(0.27)	1.9	(0.33)	1.9	(0.37)
	SAD	43.9	(0.09)	45.4	(0.15)	45.5	(0.16)	21.3	(0.36)	19.5	(0.36)	18.5	(0.44)	18.4	(0.50)
	NAD	90.8	(0.15)	94.5	(0.17)	97.0	(0.19)	24.6	(0.48)	21.3	(0.47)	19.0	(0.58)	18.1	(0.66)
AddVar:	JAI	1.00		-		-		-		-		-		-	
	SAD	0.16	(1.60)	0.19	(1.31)	0.18	(1.31)	0.09	(2.20)	0.07	(2.47)	0.05	(3.15)	0.02	(5.72)
	NAD	0.27	(0.94)	0.18	(1.14)	0.16	(1.23)	0.00	(0.00*)	0.00	(0.00*)	0.00	(0.00*)	0.00	(0.00*)
σ_{Rout}		0.48	(0.06)	0.49	(0.06)	0.48	(0.06)	0.41	(0.10)	0.41	(0.12)	0.42	(0.13)	0.43	(0.14)

Table 3: Results for a series of sensitivities based on BCII. Hessian-based CVs are shown in parentheses (a * on this value means that it cannot be estimated because the estimate of the parameter is on a constraint boundary). Values in **bold** are fixed on input. For the SAD and NAD indices, the q estimates are shown in parentheses because they follow despite the effective zero weighting given to these data.

		BCII		IIa		IIb		IIc		IIe		IIf	
				No ageing error		σ_R=1		adj log normal		Flat north bait sel. from age 3		Increased *M* from age 3	
'-lnL:overall		-957.5		-989.1		-966.2		489.5		-947.8		-957.6	
'-lnL:Index		1.8		2.8		2.4		-0.2		0.1		1.9	
'-lnL:comCAA		-972.5	*-(972.5)*	-1005.6	*-(1005.6)*	-974.4	*-(974.4)*	477.6	*(477.6)*	-961.5	*-(961.5)*	-972.8	*-(972.8)*
-lnL:indexCAL		-		-		-		-		-		-	
'-lnL:catch		0.6		0.6		0.5		0.7		1.2		0.6	
'-lnL:RecRes		12.5		13.2		5.3		11.5		12.4		12.8	
h		**0.98**		**0.98**		**0.98**		**0.98**		**0.98**		**0.98**	
B^{sp}_{1980}		1783	(0.64)	2028	(0.17)	1890	(0.66)	939	(0.70)	282	(0.37)	1266	(0.64)
B^{sp}_{2013}		214	(0.17)	235	(0.20)	199	(0.17)	255	(0.28)	205	(0.07)	195	(0.15)
$B^{sp}_{2013}/B^{sp}_{1980}$		0.12	(0.60)	0.12	(0.24)	0.11	(0.61)	0.27	(0.73)	0.73	(0.38)	0.15	(0.64)
B^{sp}_{2013}/av(B^{sp}_{1990}-B^{sp}_{2005})		0.26	(0.24)	0.20	(0.22)	0.22	(0.26)	0.51	(0.30)	0.46	(0.09)	0.26	(0.26)
F_{2013}		8.59	(0.61)	3.16	(0.48)	10.76	(0.63)	5.08	(0.73)	12.00	(0.09)	8.72	(0.61)
q (10^9):	JAI	4.1	(0.07)	3.8	(0.05)	4.2	(0.08)	4.4	(0.04)	4.6	(0.02)	4.1	(0.07)
	SAD	(44.6)	(0.08)	(40.1)	(0.06)	(44.5)	(0.09)	(49.9)	(0.04)	(51.1)	(0.02)	44.7	(0.08)
	NAD	(77.1)	(0.24)	(58.2)	(0.11)	(73.4)	(0.27)	(110.1)	(0.14)	(131.4)	(0.02)	87.4	(0.20)
AddVar:	JAI	0.00	(0.00*)	0.00	(0.00*)	0.00	(0.00*)	0.00	(0.00*)	0.00	(0.00*)	0.00	(0.00*)
	SAD	-		-		-		-		-		-	
	NAD	-		-		-		-		-		-	
σ_{Rout}		0.52	(0.06)	0.53	(0.07)	0.56	(0.08)	0.49	(0.06)	0.51	(0.05)	0.52	(0.06)

Table 4: Results for a series of sensitivities based on BCIII. The italised values in parenthesis next to the -lnL:comCAA and -lnL:indexCAL values are the -lnL values without the downweighting. Hessian-based CVs are shown in parentheses (a * on this value means that it cannot be estimated because the estimate of the parameter is on a constraint boundary). Values in **bold** are fixed on input. For the JAI indices, the *q* estimates are shown in parentheses because they follow despite the effective zero weighting given to these data.

		BCIII		IIIa		IIIb		IIIc		IIId		IIIe		IIIf	
				No ageing error		σ_R=1		adj log normal		Flat NAD selectivity from 29cm FL		Flat NAD sel. from 29cm FL and north bait sel. from age 3		Increased *M* from age 3	
'-lnL:overall		-630.0		-651.3		-635.8		429.9		-623.5		-625.0		-629.7	
'-lnL:Index		7.9		9.7		5.3		0.3		8.2		18.7		8.0	
'-lnL:comCAA		-470.4	*-(940.7)*	-490.9	*-(981.8)*	-470.4	*-(940.8)*	255.4	*(510.9)*	-470.1	*-(940.2)*	-477.5	*-(955.1)*	-470.0	*-(940.1)*
-lnL:indexCAL		-175.4	*-(1403.3)*	-176.7	*-(1413.5)*	-174.7	*-(1397.5)*	164.5	*(1316.0)*	-169.7	*-(1357.3)*	-176.9	*-(1415.4)*	-175.8	*-(1406.6)*
'-lnL:catch		0.1		0.0		0.0		0.0		0.1		0.5		0.1	
'-lnL:RecRes		7.9		6.6		3.9		9.6		7.9		10.3		8.1	
h		**0.98**		**0.98**		**0.98**		**0.98**		**0.98**		**0.98**		**0.98**	
B^{sp}_{1980}		3819	(0.46)	3879	(0.42)	4194	(0.54)	8281	(0.79)	3101	(0.41)	403	(0.45)	2643	(0.48)
B^{sp}_{2013}		3793	(0.49)	5112	(0.50)	4791	(0.60)	7283	(0.74)	2886	(0.51)	287	(0.24)	3396	(0.50)
$B^{sp}_{2013}/B^{sp}_{1980}$		0.99	(0.45)	1.32	(0.37)	1.14	(0.47)	0.88	(0.50)	0.93	(0.45)	0.71	(0.51)	1.28	(0.47)
B^{sp}_{2013}/av(B^{sp}_{1990}-B^{sp}_{2005})		1.47	(0.26)	1.47	(0.24)	1.58	(0.27)	1.59	(0.24)	1.61	(0.28)	0.67	(0.24)	1.66	(0.27)
F_{2013}		0.15	(0.43)	0.09	(0.44)	0.12	(0.53)	0.08	(0.69)	0.18	(0.42)	5.23	(0.59)	0.15	(0.44)
q (10^9):	JAI	(2.0)	(0.27)	(1.7)	(0.33)	(1.8)	(0.37)	(1.4)	(0.57)	(2.4)	(0.23)	(4.4)	(0.03)	(2.0)	(0.28)
	SAD	19.5	(0.36)	15.9	(0.41)	17.9	(0.44)	15.1	(0.66)	23.8	(0.33)	48.3	(0.20)	19.6	(0.37)
	NAD	21.3	(0.47)	16.3	(0.51)	18.0	(0.60)	14.3	(0.81)	15.8	(0.52)	124.2	(0.14)	23.3	(0.48)
AddVar:	JAI	-		-		-		-		-		-		-	
	SAD	0.07	(2.47)	0.03	(5.03)	0.07	(2.59)	0.02	(7.13)	0.07	(2.41)	0.17	(1.30)	0.07	(2.46)
	NAD	0.00	(0.00*)	0.00	(0.00*)	0.00	(0.00*)	0.00	(0.00*)	0.00	(0.00*)	0.10	(1.72)	0.00	(0.00*)
σ_{Rout}		0.41	(0.12)	0.37	(0.11)	0.48	(0.12)	0.45	(0.13)	0.41	(0.11)	0.47	(0.05)	0.41	(0.12)

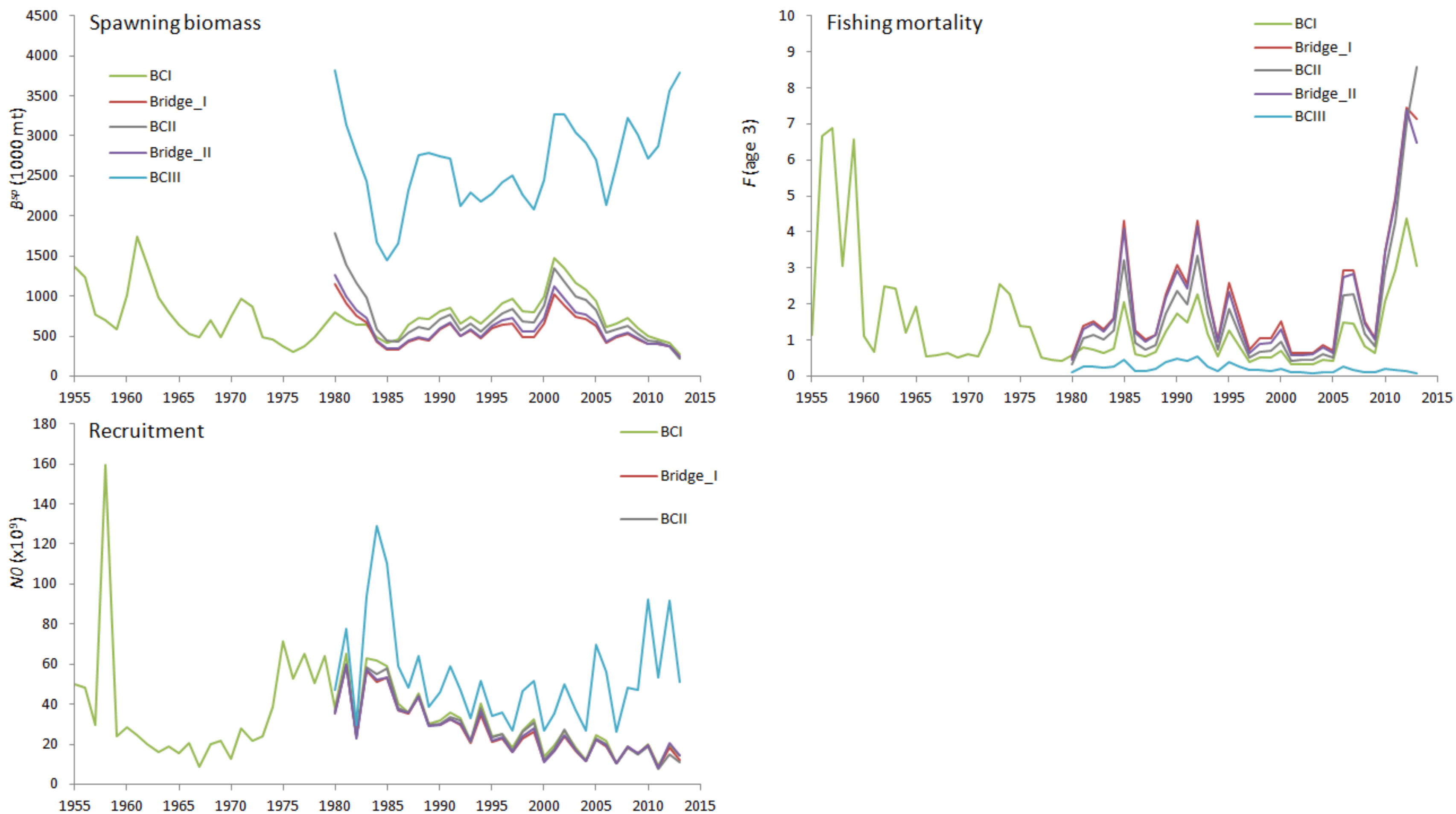

Figure 1: Time-trajectories of spawning biomass, fishing mortality (sum across all four fleets, for age 3[1]) and recruitment for the three Base Cases and bridging runs Bridge_I and Bridge_II.

[1] This convention is used for fishing mortality plots throughout the Figures following, unless otherwise indicated.

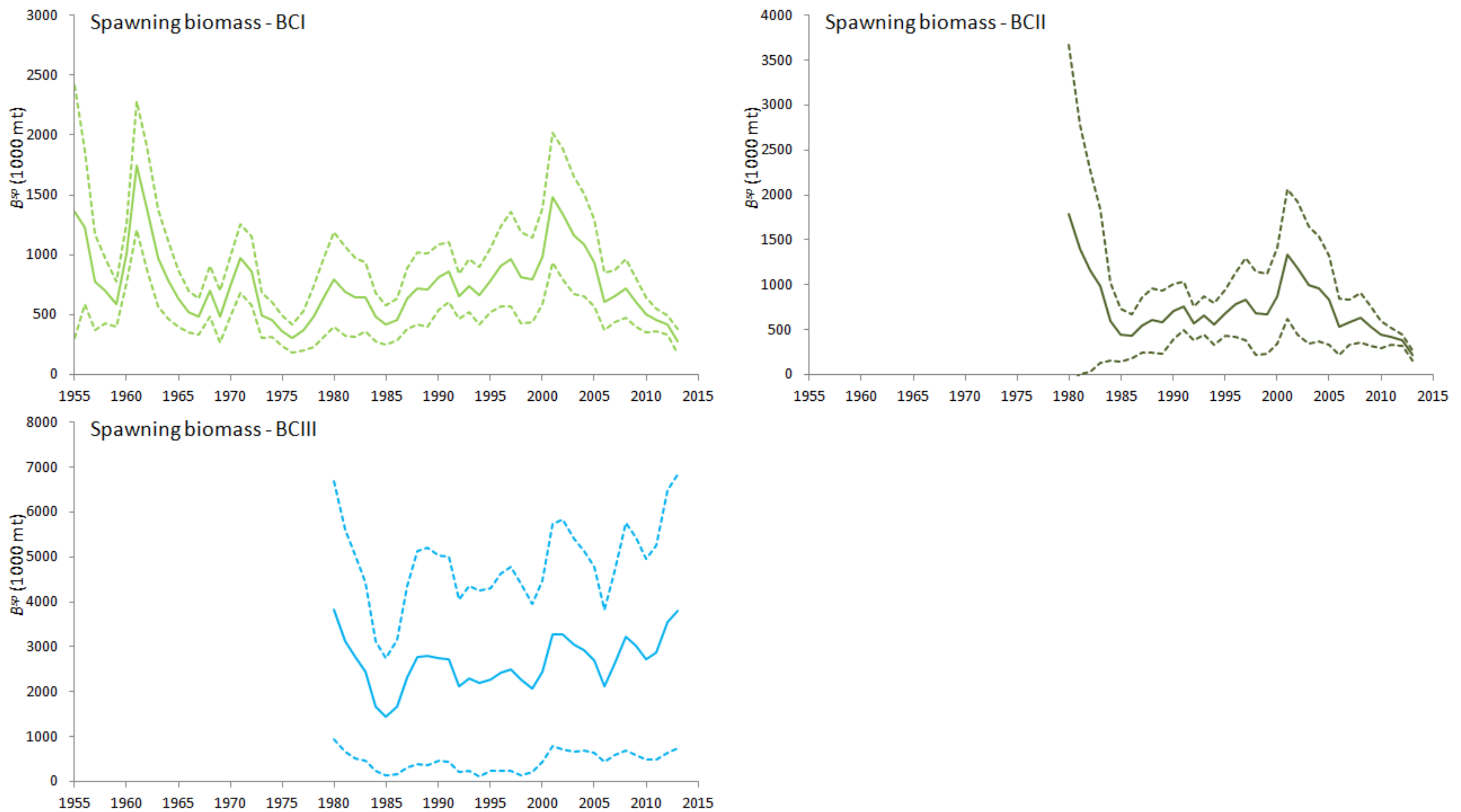

Figure 2: Time-trajectories of spawning biomass with 90% CI (dashed lines) for the three Base Cases.

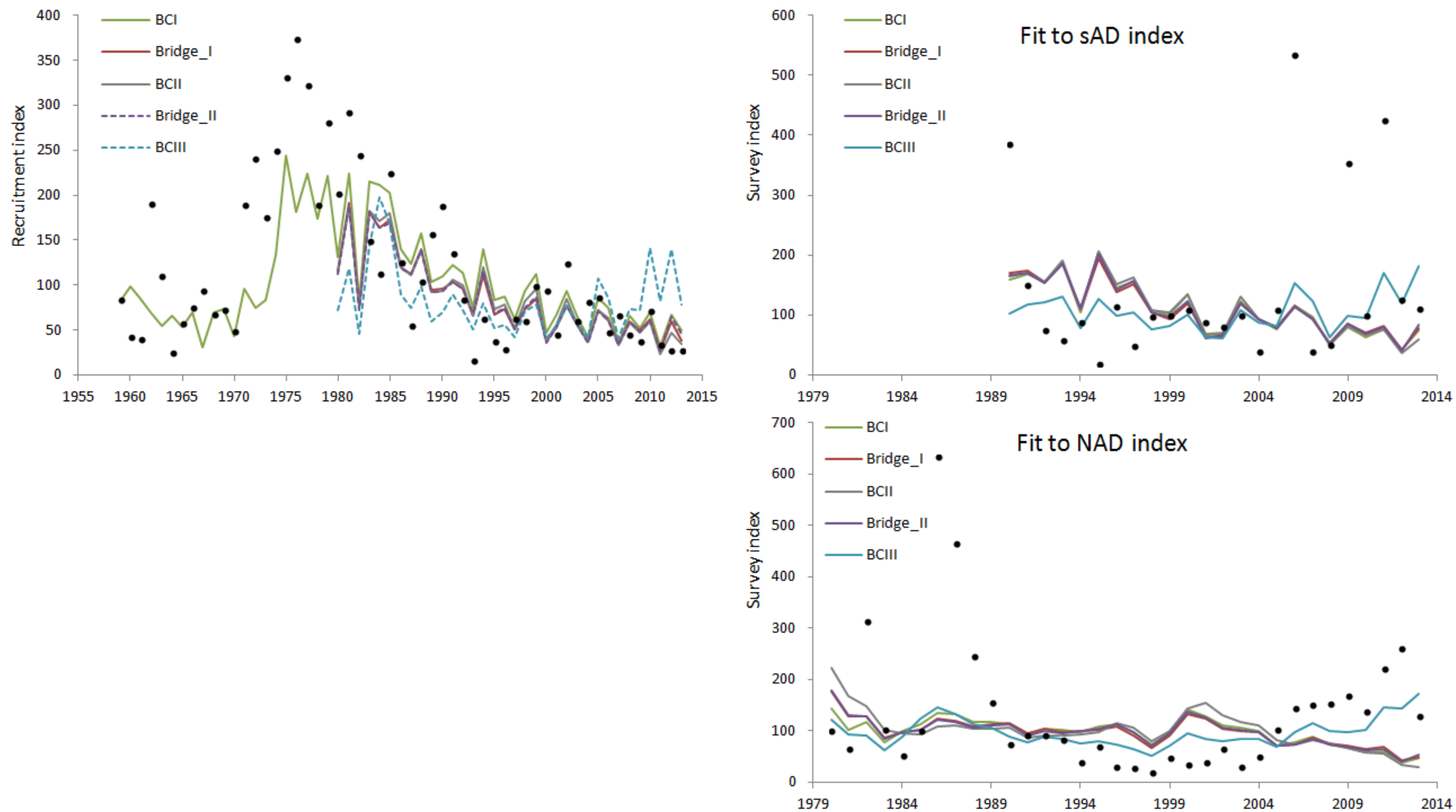

Figure 3: Fit of the three Base Cases and bridging runs Bridge_I and Bridege_II to the survey indices. The fit to JAI is dashed for run Bridge_II and BCIII as these runs do not actually fit to this recruitment index. Similarly, the fit to the SAD and NAD indices are dashed for BCII as this run does not fit to these indices.

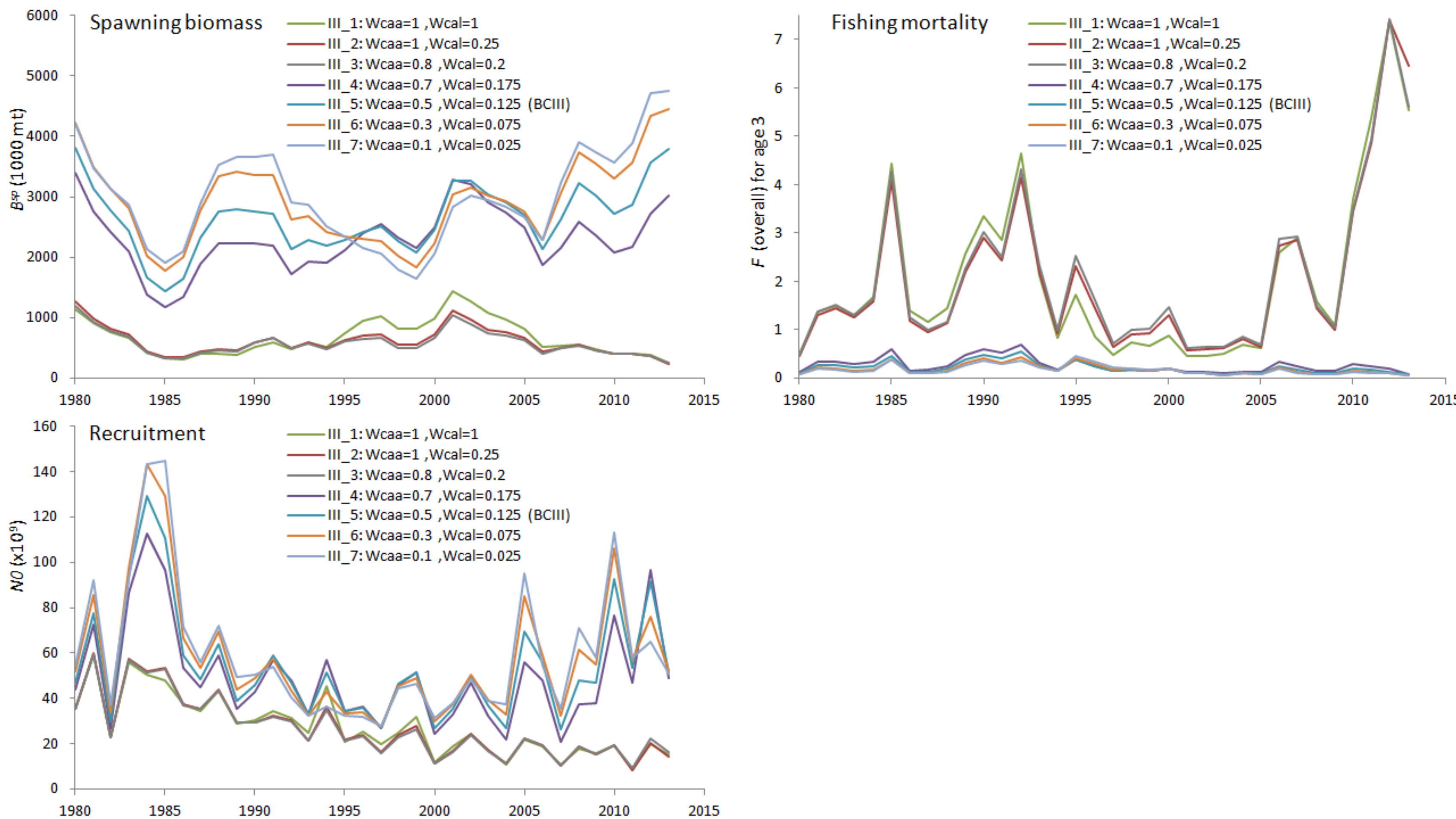

Figure 4: Time-trajectories of spawning biomass, fishing mortality (sum across all four fleets, for age 3) and recruitment for the runs with different weightings for the commercial CAA and survey CAL -lnL.

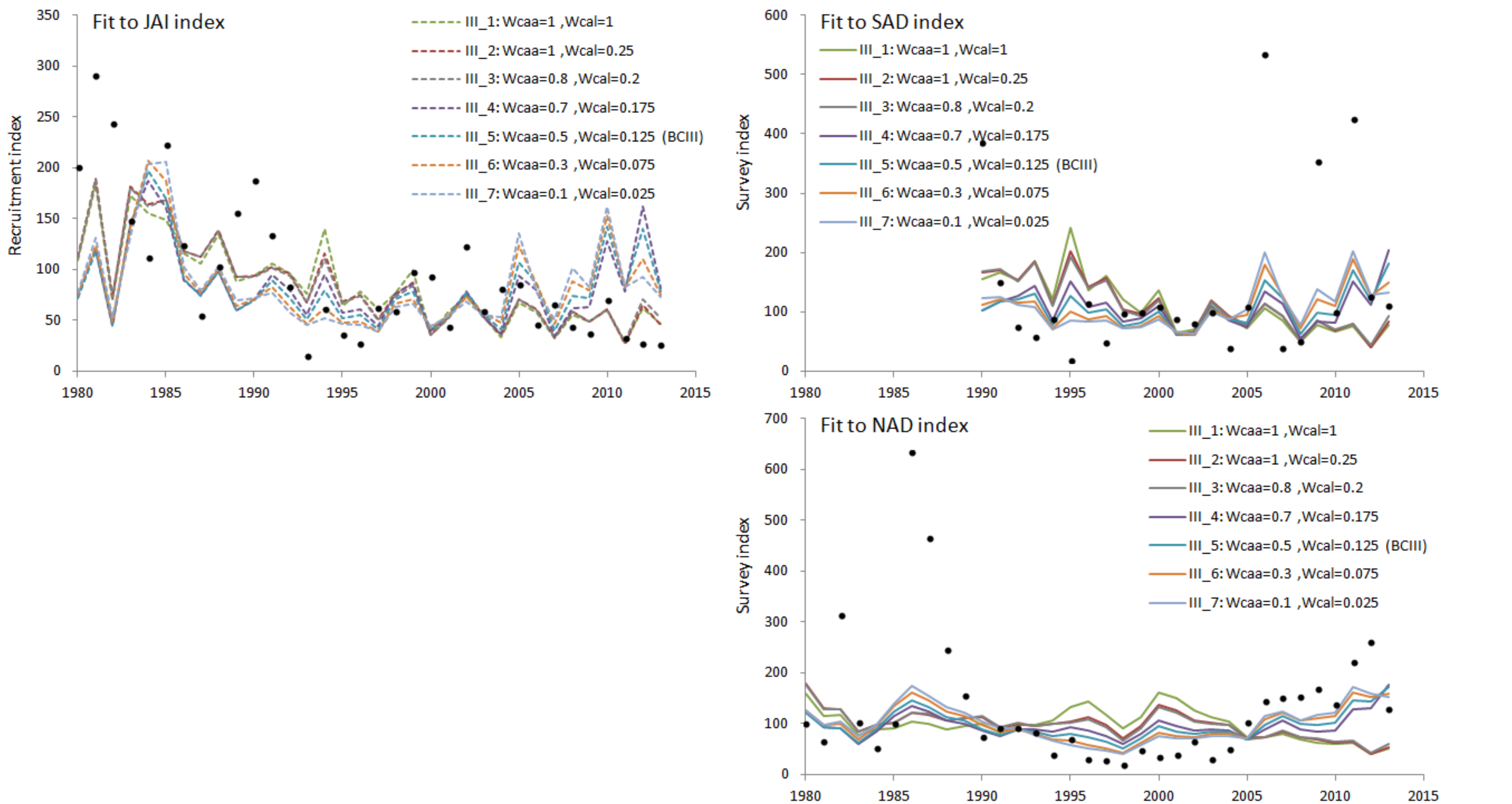

Figure 5: Fit of the runs with difference weighting for the commercial CAA and survey CAL -lnL. The fit to JAI is dashed for run IIa and BCIII as these runs do not actually fit to this recruitment index. Similarly, the fit to the SAD and NAD indices are dashed for BCII as this run does not fit to these indices.

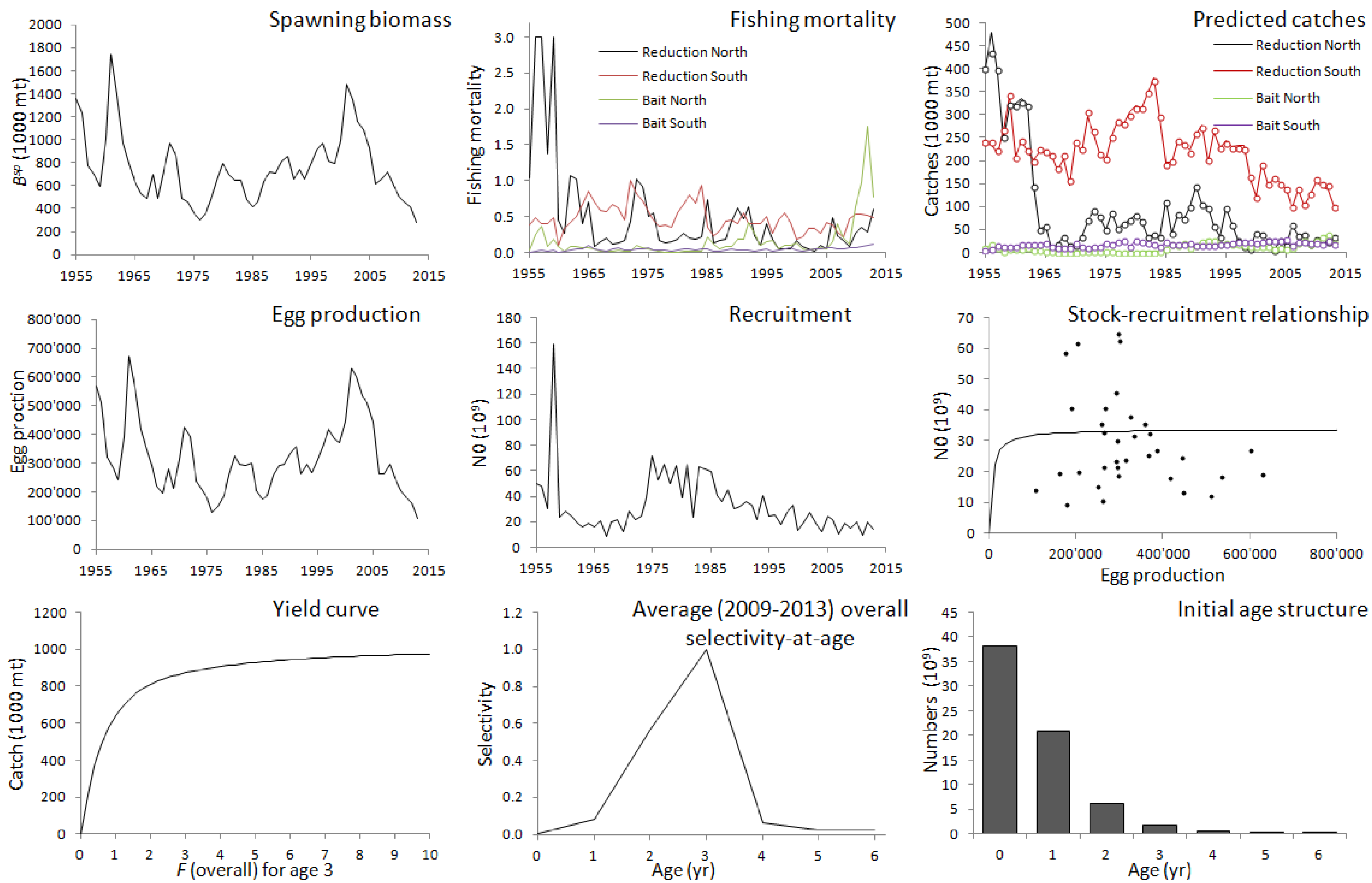

Figure 6a: Results for **BCI** (**start in 1955, fitting to all three indices**). Both here and in all similar plots following, the indication of 6 for age means ages 6+.

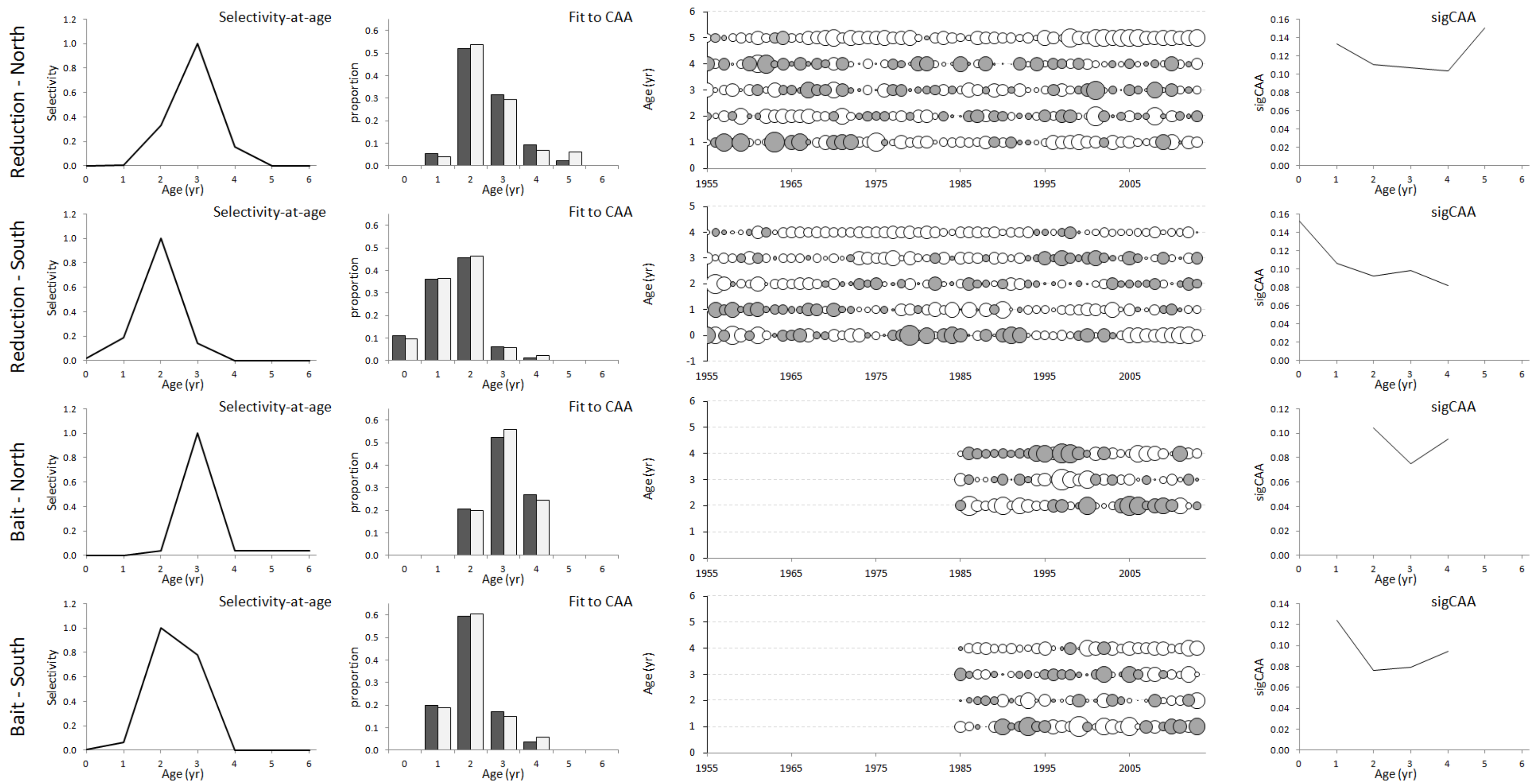

Figure 6b: For each of the four fleet, estimated selectivity-at-age (first column), fit to the commercial catches-at-age averaged over all the years for which data are available (second column), bubble plots of the corresponding standardised residuals (third column - the area of the bubble is proportional to the magnitude of the corresponding standardised residuals; for positive residuals the bubbles are grey, whereas for negative residuals the bubbles are white) and estimated σ_{CAA} for each age (last column – note the model fit was implemented treating these as age-independent) for **BCI (start in 1955, fitting to all three indices)**.

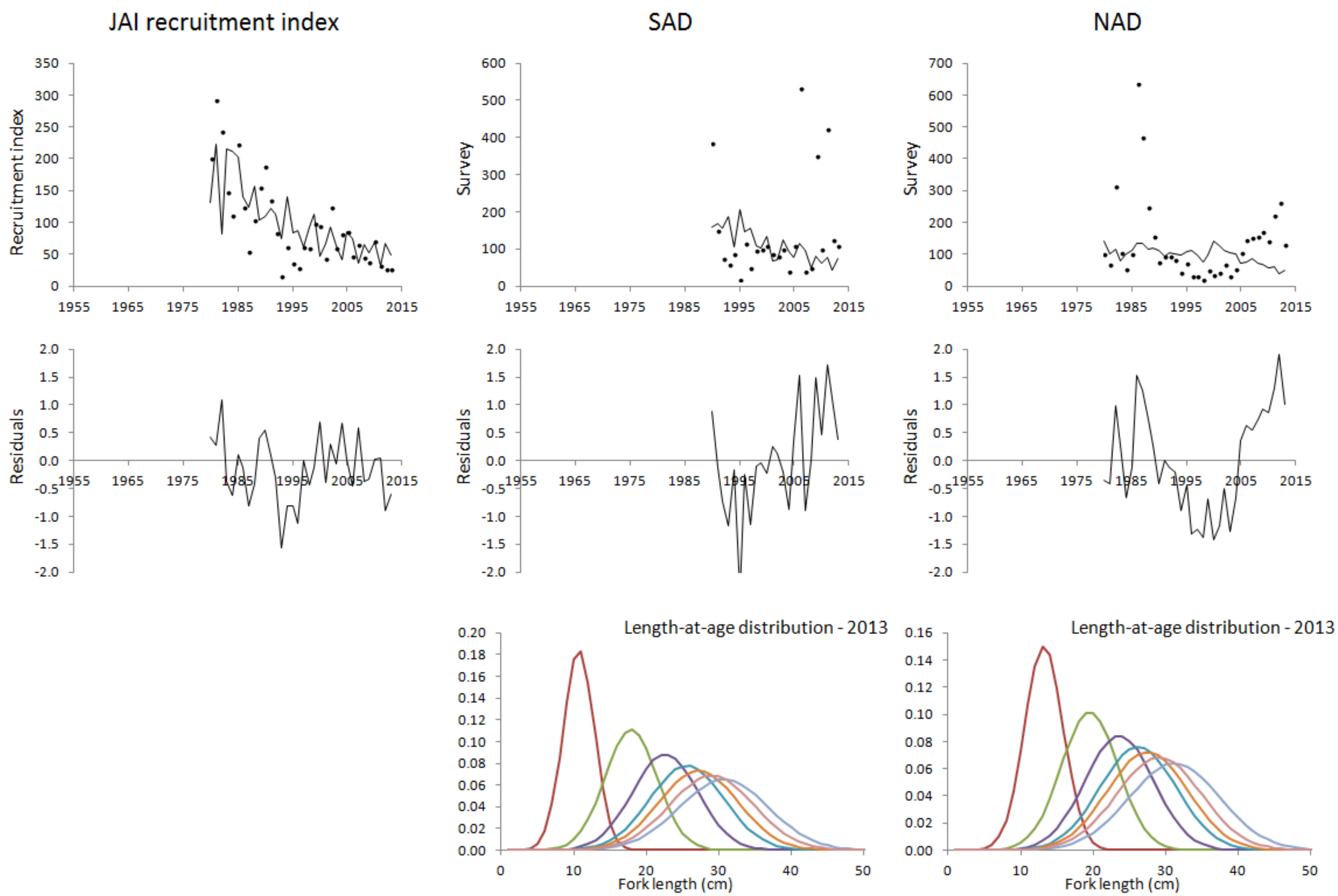

Figure 6c: Fit to the survey indices and corresponding residuals for **BCI (start in 1955, fitting to all three indices)**. The assumed length-at-age distributions for 2013 are also shown.

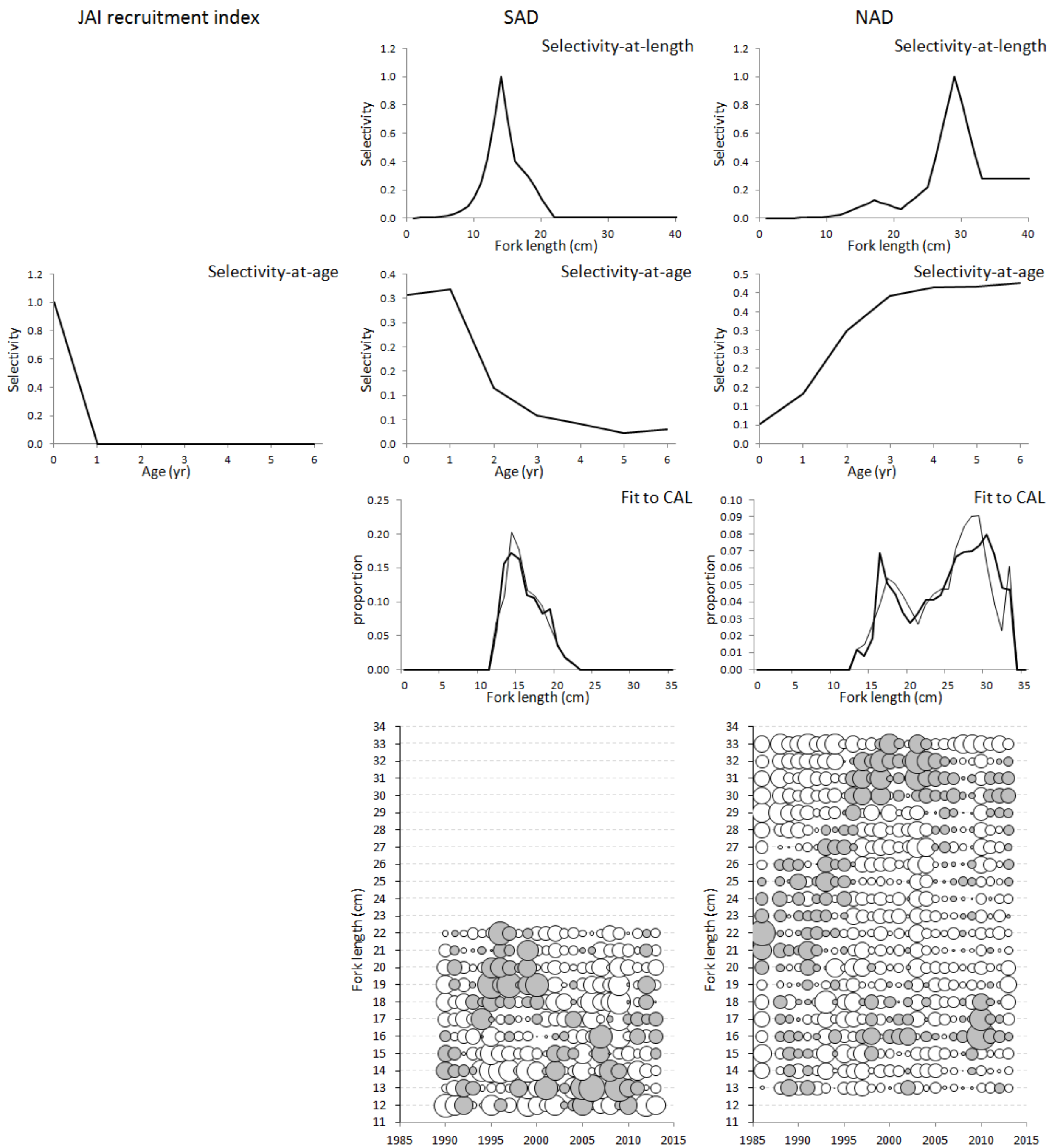

Figure 6d: Estimated selectivity-at-length and resulting 2013 selectivity-at-age for the SAD and NAD survey indices, as well as the fit to the survey catches-at-length averaged over all the years for which data are available (fourth row), and bubble plots of the corresponding standardised residuals (last row - the area of the bubble is proportional to the magnitude of the corresponding standardised residuals; for positive residuals the bubbles are grey, whereas for negative residuals the bubbles are white) for **BCI (start in 1955, fitting to all three indices)**.

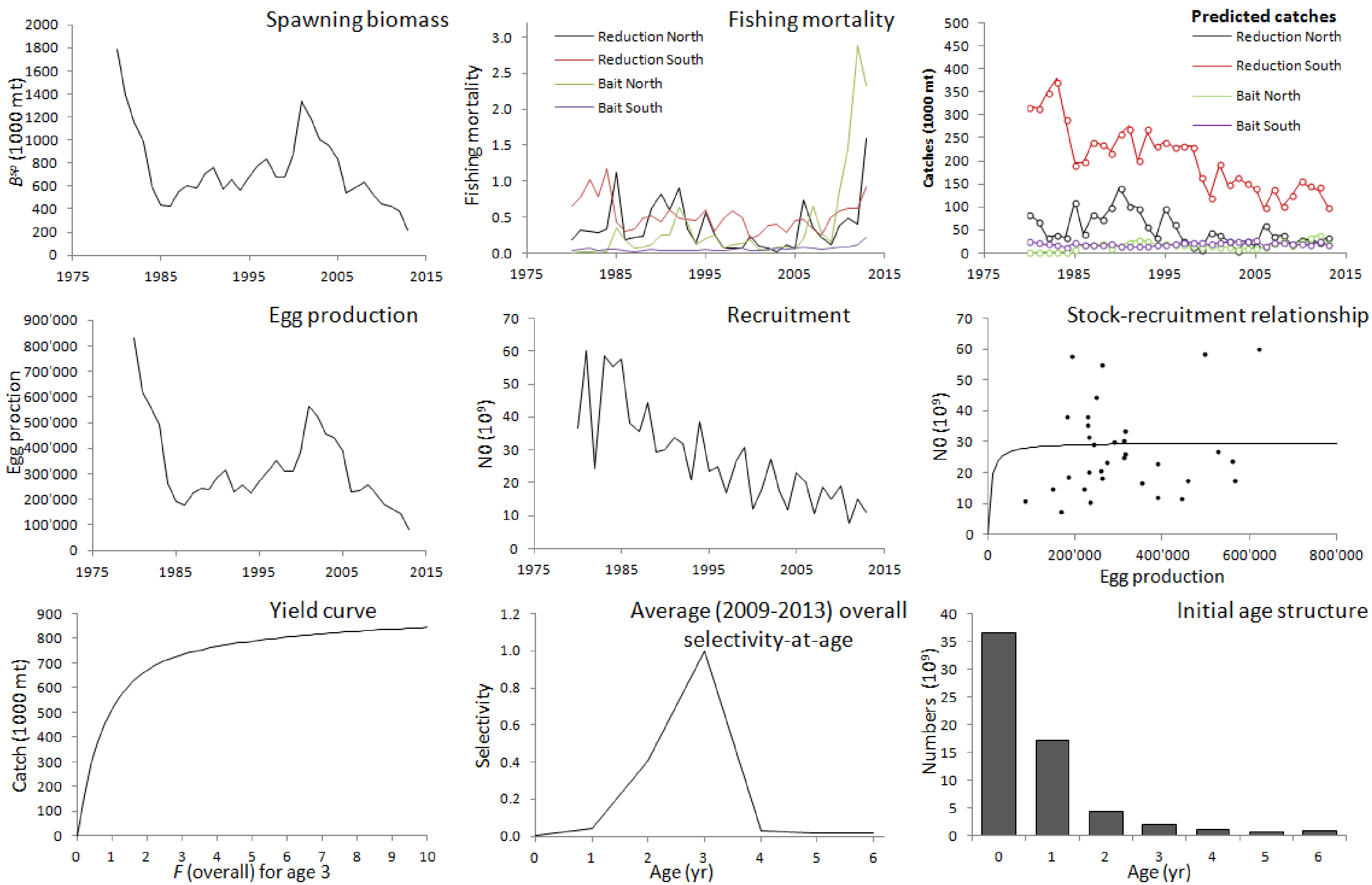

Figure 7a: Results for **BCII** (**start in 1980, fitting to JAI index only).**

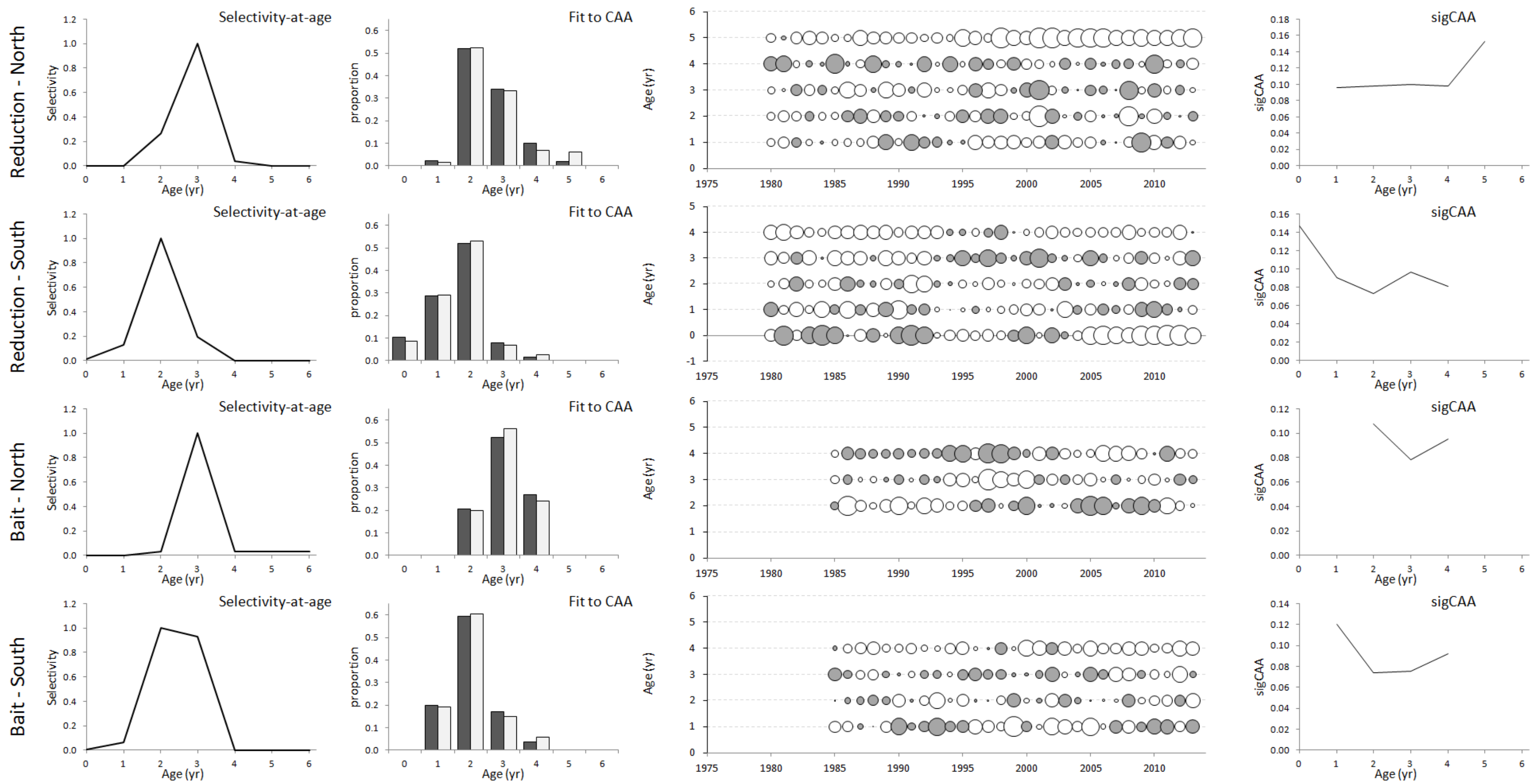

Figure 7b: For each of the four fleet, estimated selectivity-at-age (first column), fit to the commercial catches-at-age averaged over all the years for which data are available (second column), bubble plots of the corresponding standardised residuals (third column - the area of the bubble is proportional to the magnitude of the corresponding standardised residuals; for positive residuals the bubbles are grey, whereas for negative residuals the bubbles are white) and estimated σ_{CAA} for each age (last column– note the model fit was implemented treating these as age-independent) for **BCII (start in 1980, fitting to JAI index only)**.

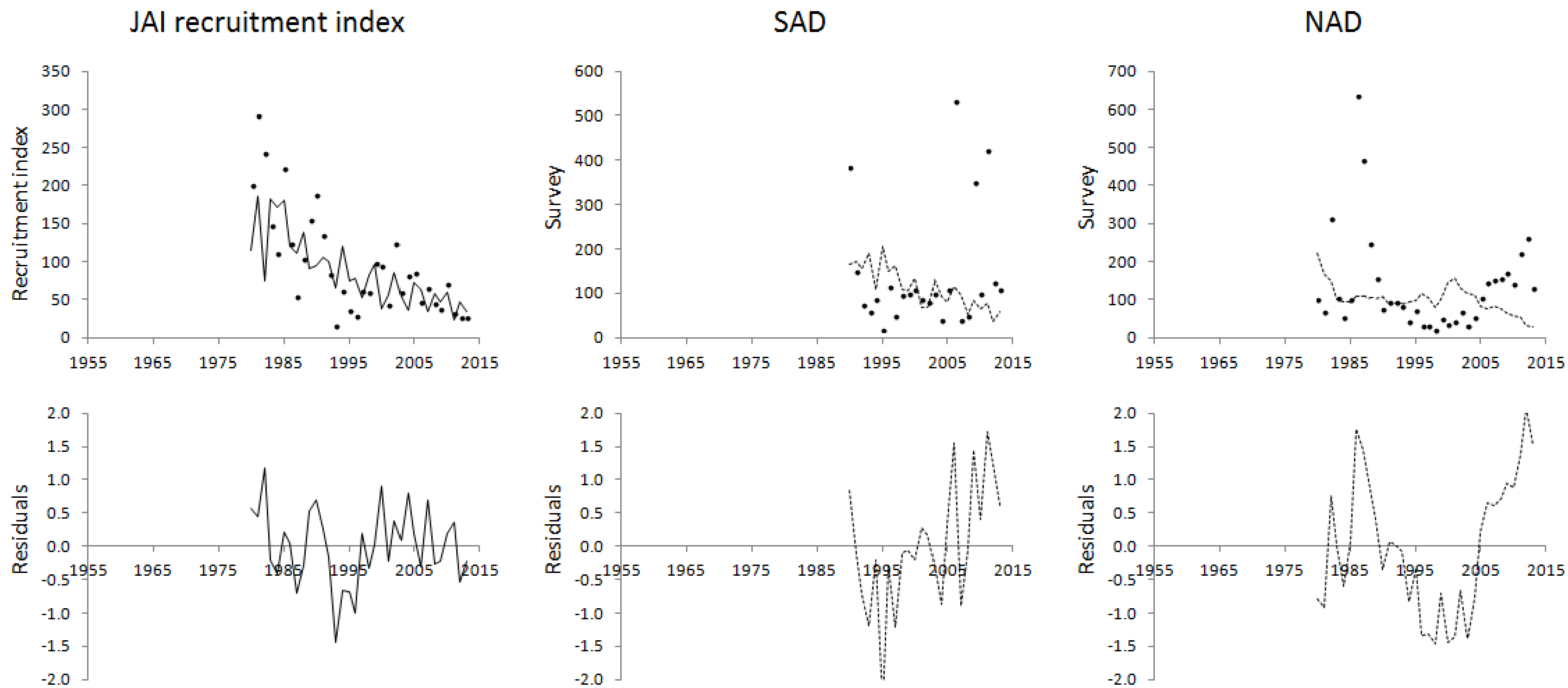

Figure 7c: Fit to the survey indices and corresponding residuals for **BCII (start in 1980, fitting to JAI index only)**. The fit to the SAD and NAD indices are dashed as this run does not fit to these indices.

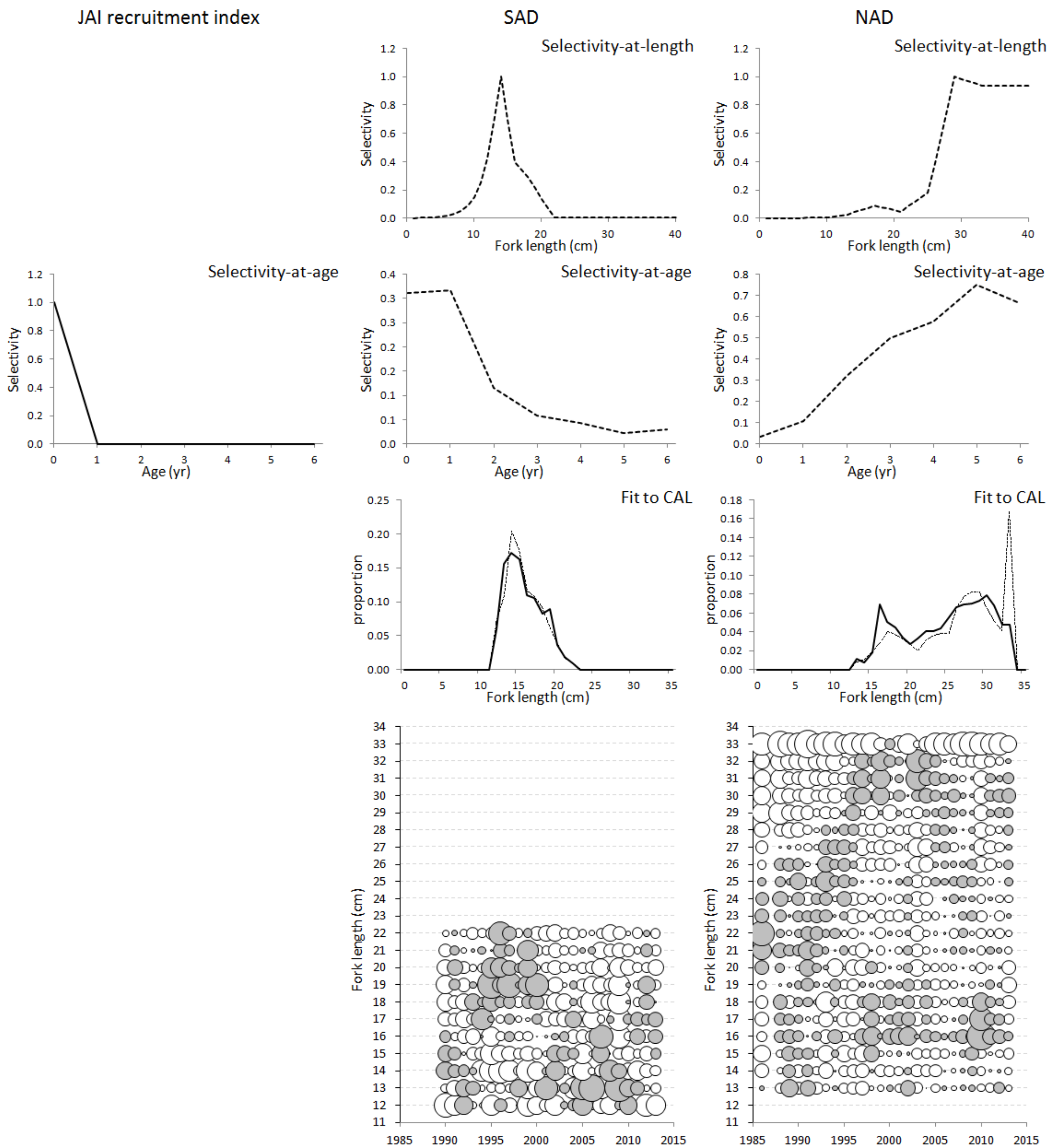

Figure 7d: Estimated selectivity-at-length and resulting 2013 selectivity-at-age for the SAD and NAD survey indices, as well as the fit to the survey catches-at-length averaged over all the years for which data are available (fourth row), and bubble plots of the corresponding standardised residuals (last row - the area of the bubble is proportional to the magnitude of the corresponding standardised residuals; for positive residuals the bubbles are grey, whereas for negative residuals the bubbles are white) for **BCII (start in 1980, fitting to JAI index only)**. The selectivities and fit to the SAD and NAD indices are dashed as this run does not fit to these indices.

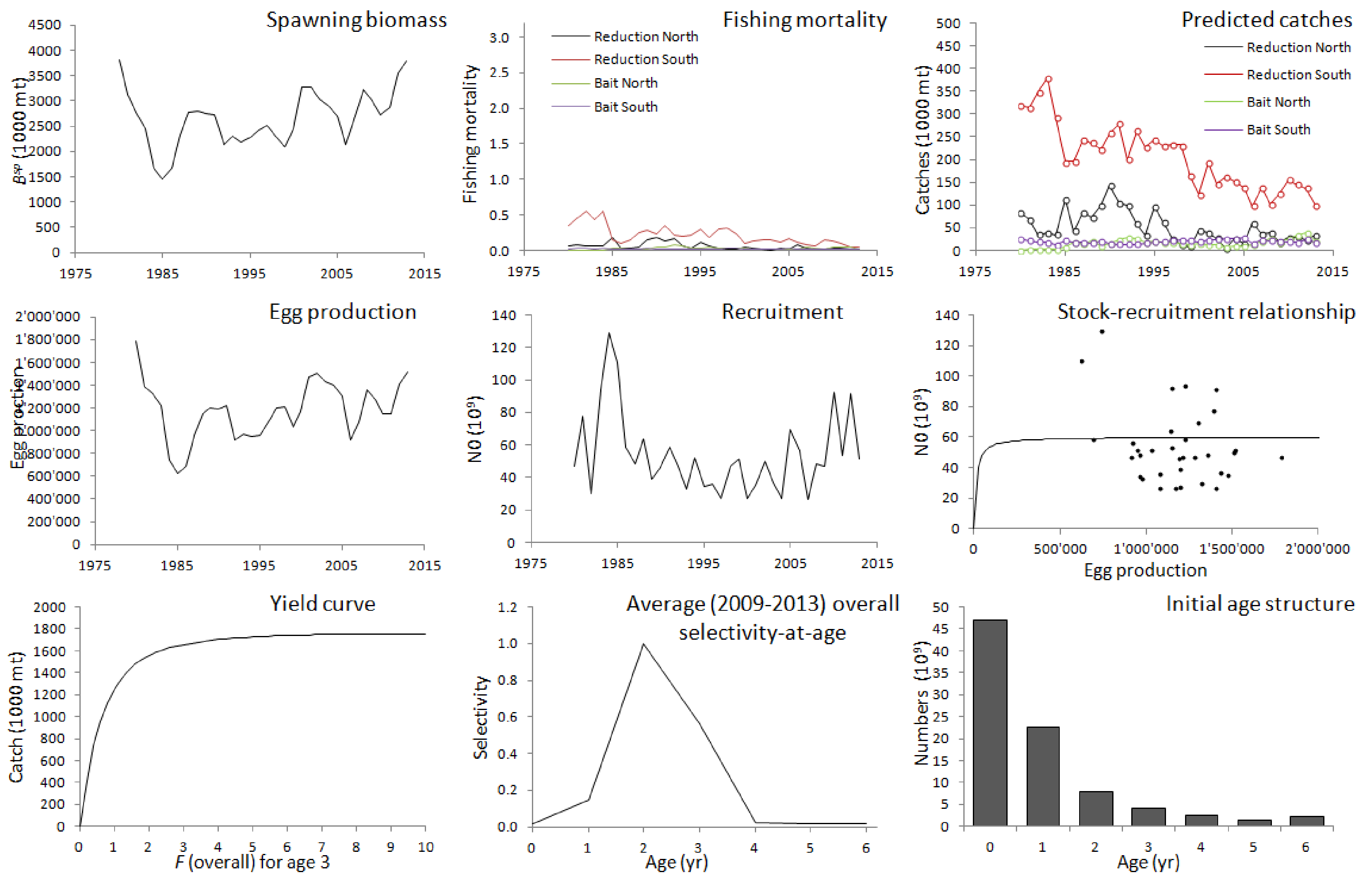

Figure 8a: Results for **BCIII (start in 1980, fitting to SAD and NAD only, W_{CAA}=0.5, W_{CAL}=0.125).**

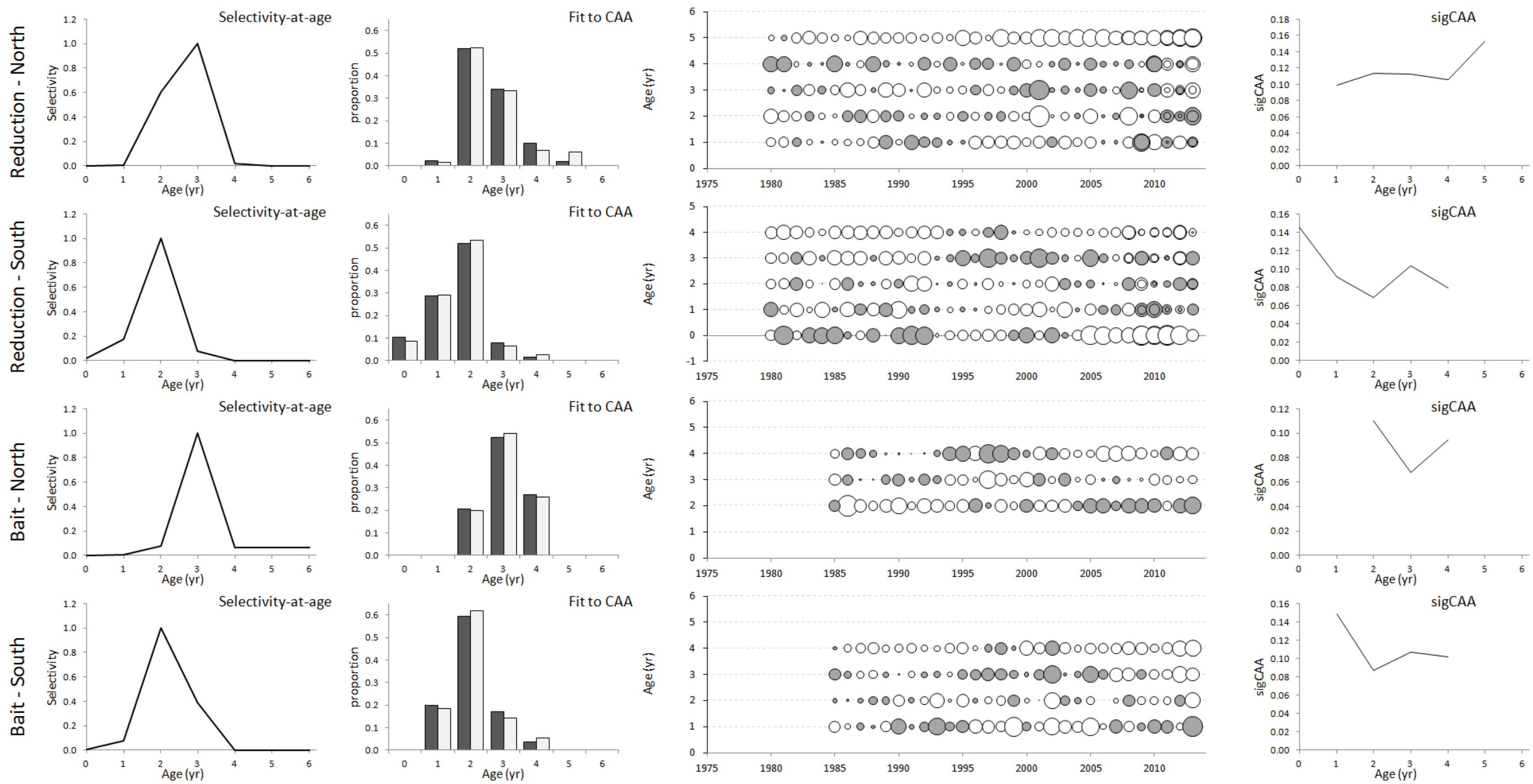

Figure 8b: For each of the four fleet, estimated selectivity-at-age (first column), fit to the commercial catches-at-age averaged over all the years for which data are available (second column), bubble plots of the corresponding standardised residuals (third column - the area of the bubble is proportional to the magnitude of the corresponding standardised residuals; for positive residuals the bubbles are grey, whereas for negative residuals the bubbles are white) and estimated σ_{CAA} for each age (last column– note the model fit was implemented treating these as age-independent) for **BCIII** (**start in 1980, fitting to SAD and NAD only, W_{CAA}=0.5, W_{CAL}=0.125).**

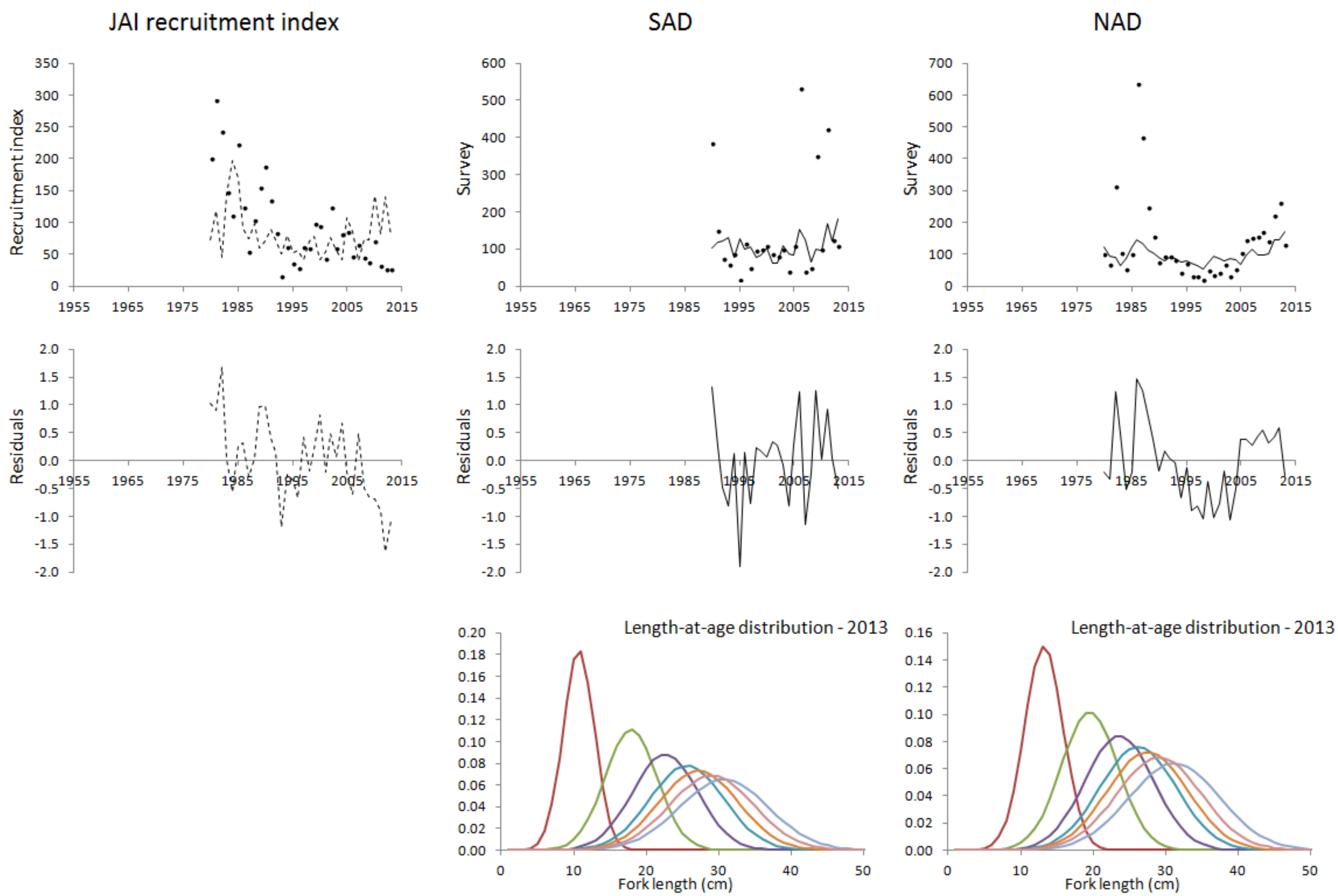

Figure 8c: Fit to the survey indices and corresponding residuals for **BCIII (start in 1980, fitting to SAD and NAD only, W_{CAA}=0.5, W_{CAL}=0.125).** The assumed length-at-age distributions for 2013 are also shown. For the JAI index, the lines are dashed as this run is not fit to this series.

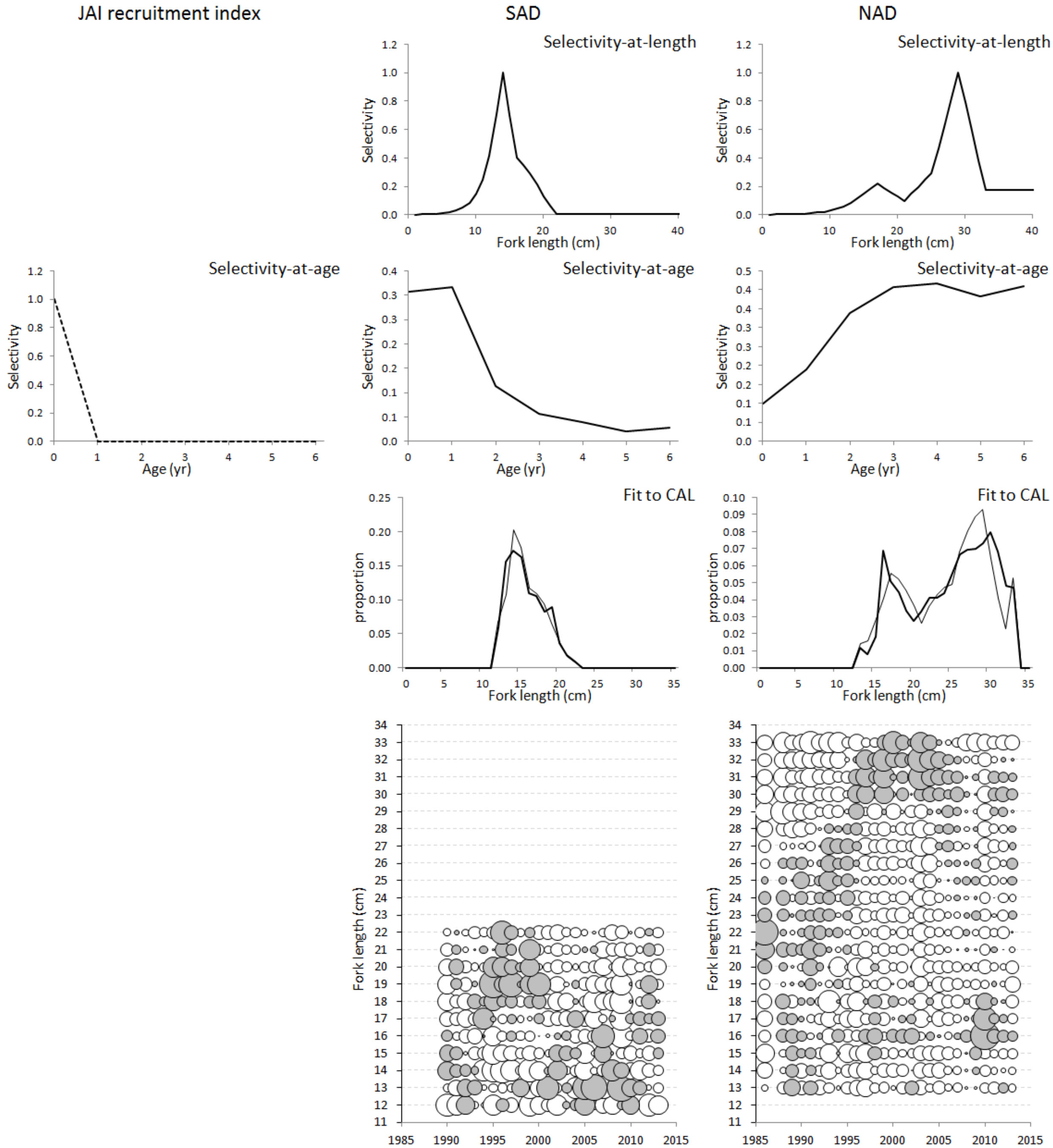

Figure 8d: Estimated selectivity-at-length and resulting 2013 selectivity-at-age for the SAD and NAD survey indices, as well as the fit to the survey catches-at-length averaged over all the years for which data are available (fourth row), and bubble plots of the corresponding standardised residuals (last row - the area of the bubble is proportional to the magnitude of the corresponding standardised residuals; for positive residuals the bubbles are grey, whereas for negative residuals the bubbles are white) for **BCIII** (**start in 1980, fitting to SAD and NAD only, W_{CAA}=0.5, W_{CAL}=0.125).** The JAI selectivity is dashed as this run does not fit to this recruitment index.

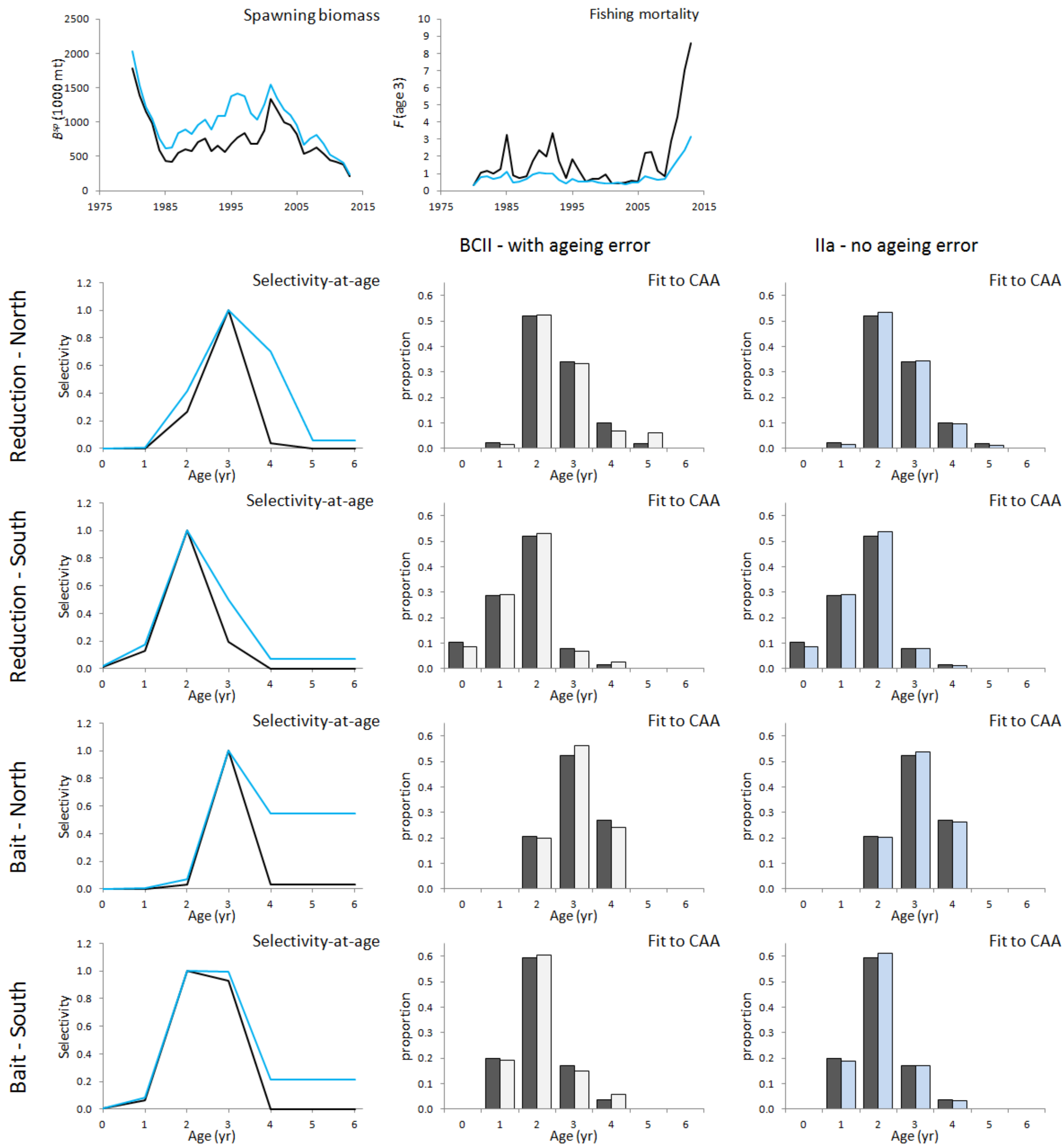

Figure 9a: Time-trajectory of spawning biomass and fishing mortality, commercial selectivities-at-age and fits to the commercial CAA data (averaged over all the years for which data are available) for **BCII (black)** and run **IIa (no ageing error - blue)**.

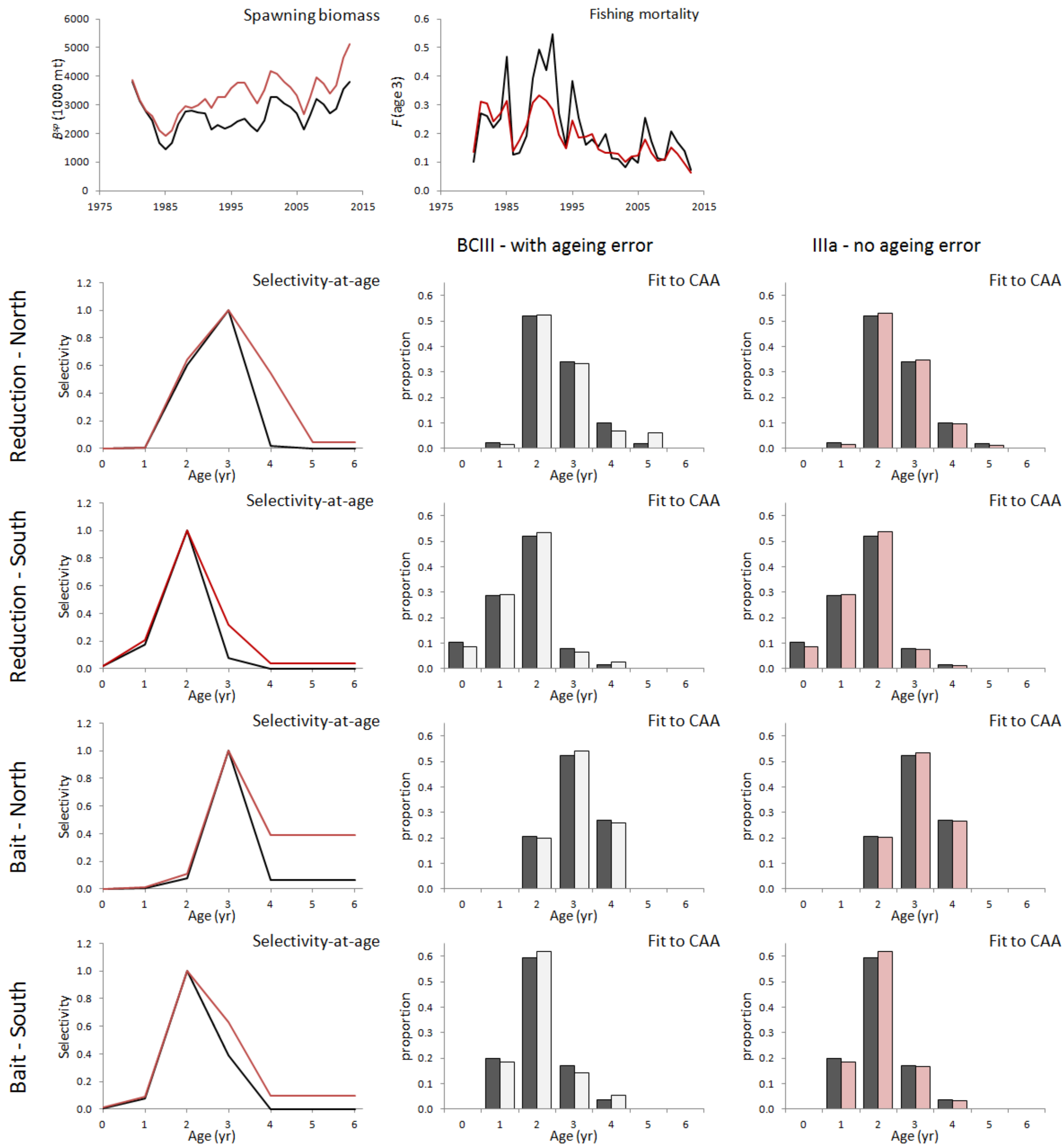

Figure 9b: Time-trajectories of spawning biomass and fishing mortality, commercial selectivities-at-age and fits to the commercial CAA data (averaged over all the years for which data are available) for **BCIII (black)** and run **IIIa (no ageing error - red)**.

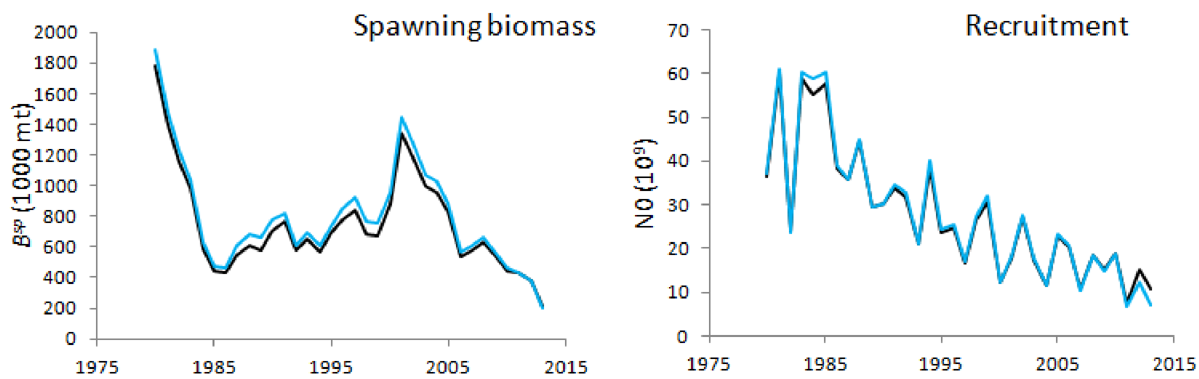

Figure 10a: Time-trajectory of spawning biomass and recruitment for **BCII (black line)** and run **IIb (**σ_R**=1.0- blue line)**.

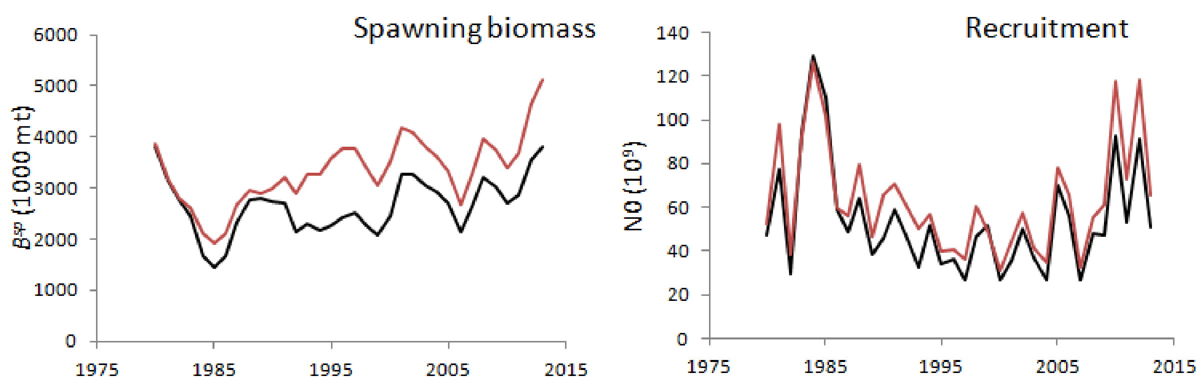

Figure 10b: Time-trajectory of spawning biomass and recruitment for **BCIII (black line)** and run **IIIb (**σ_R**=1.0- red line)**.

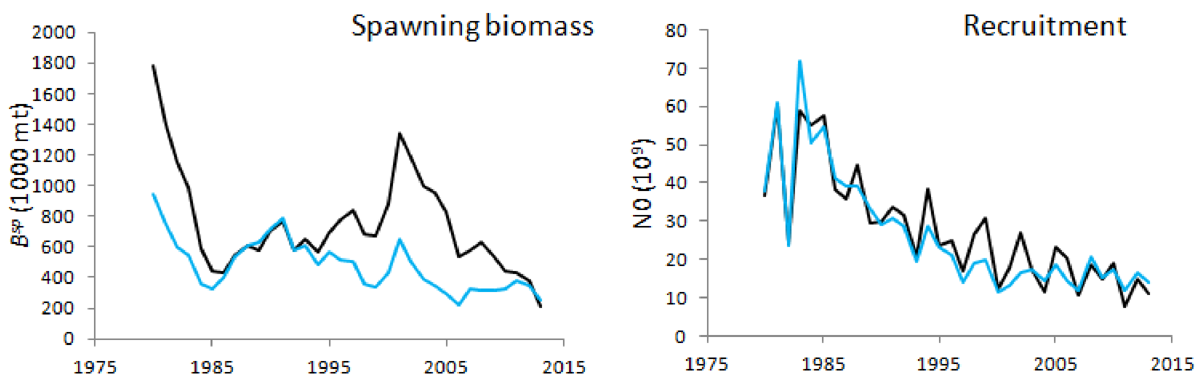

Figure 11a: Time-trajectories of spawning biomass and recruitment for **BCII (black line)** and run **IIc (adj. log normal - blue line)**.

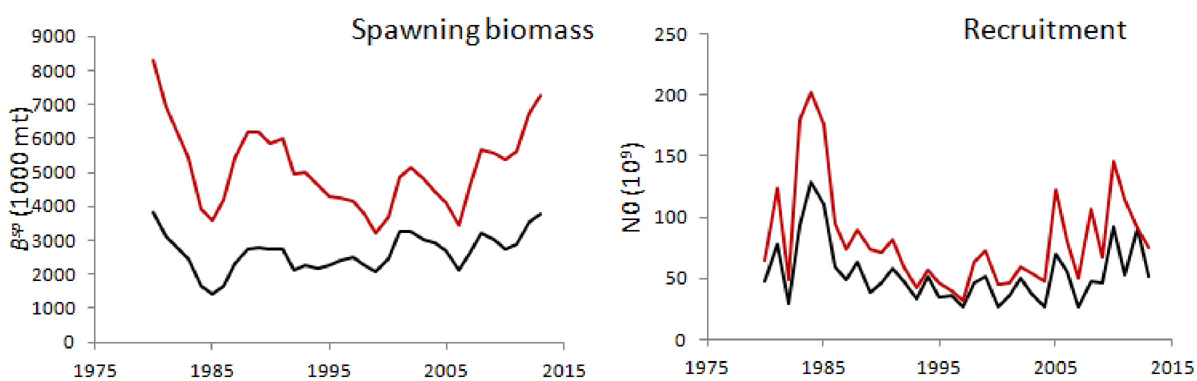

Figure 11b: Time-trajectories of spawning biomass and recruitment for **BCIII (black line)** and run **IIIc (adj. log normal - red line)**.

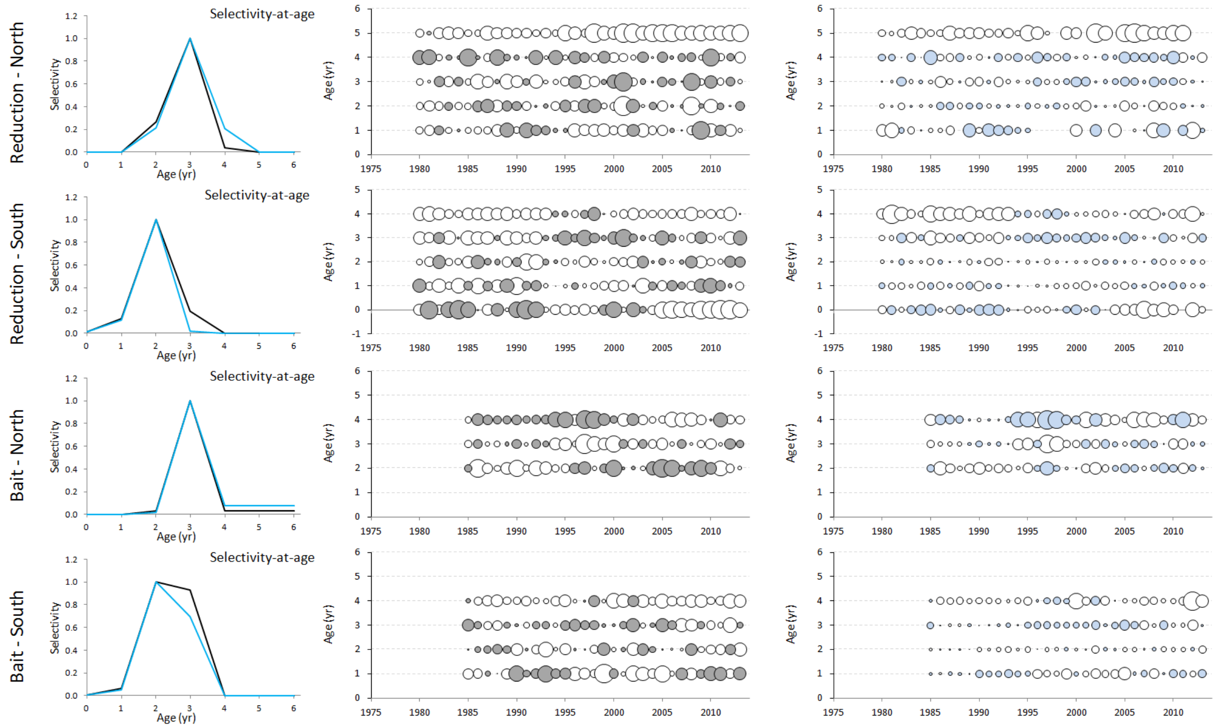

Figure 12a: Commercial selectivities-at-age and fit to the commercial CAA data for **BCII (black)** and run **IIc (adj. log normal - blue)**.

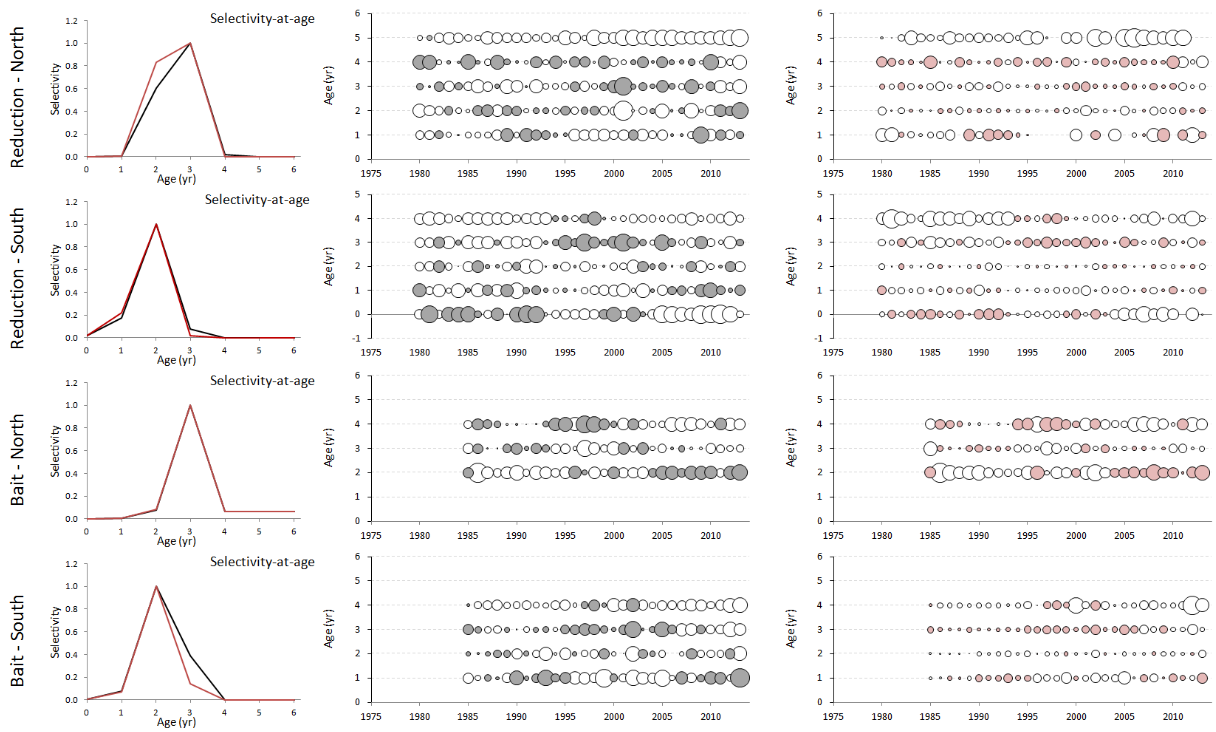

Figure 12b: Commercial selectivities-at-age and fit to the commercial CAA data for **BCIII (black)** and run **IIIc (adj. log normal - red)**.

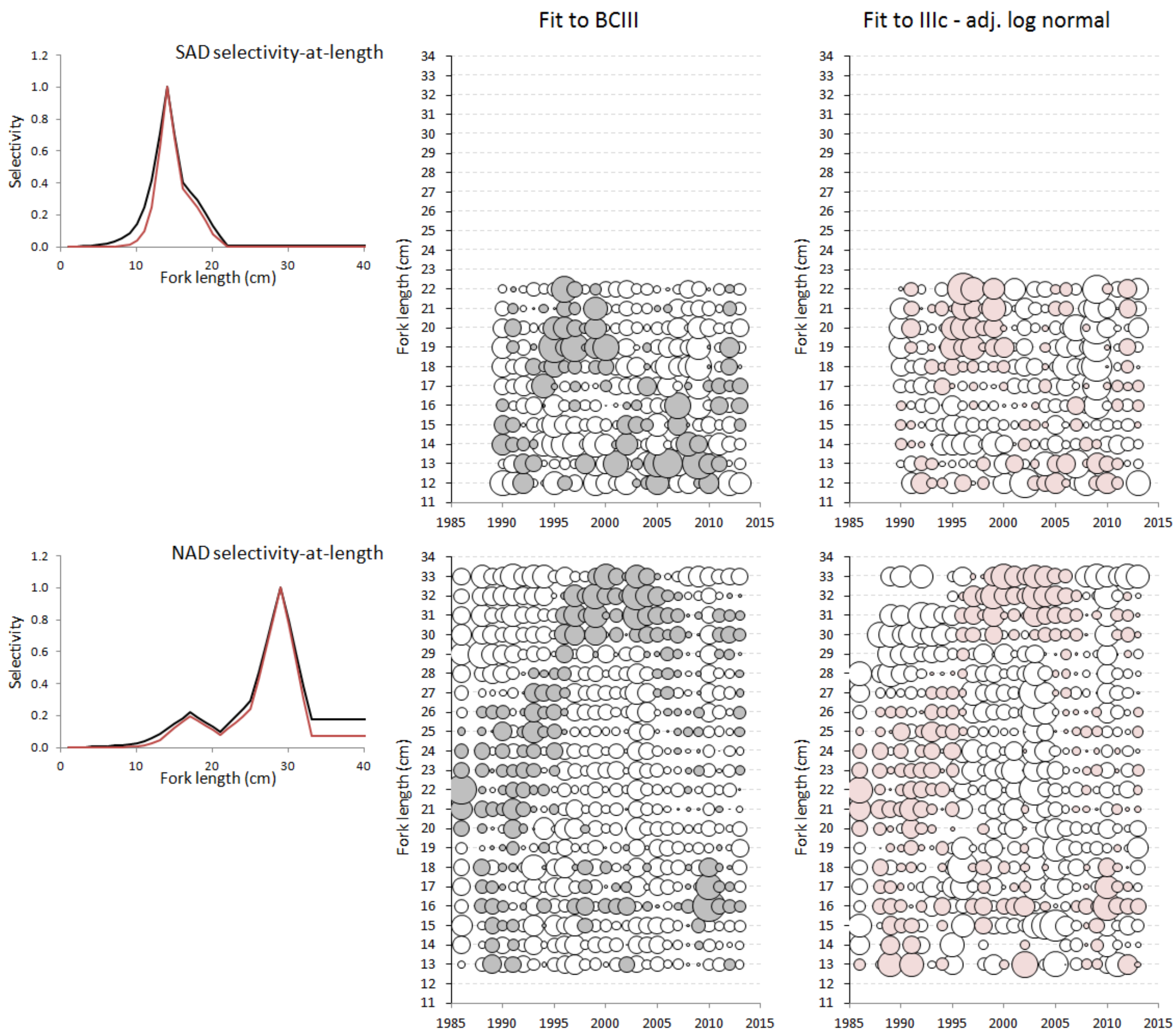

Figure 13: Survey selectivities-at-length and fit to the survey CAL data for **BCIII (black)** and run **IIIc (adj. log normal - red)**. Absent values in the NAD bubble plot for run IIIc reflect cells for which there is no observed catch (see footnote associated with equation B26 in Appendix B).

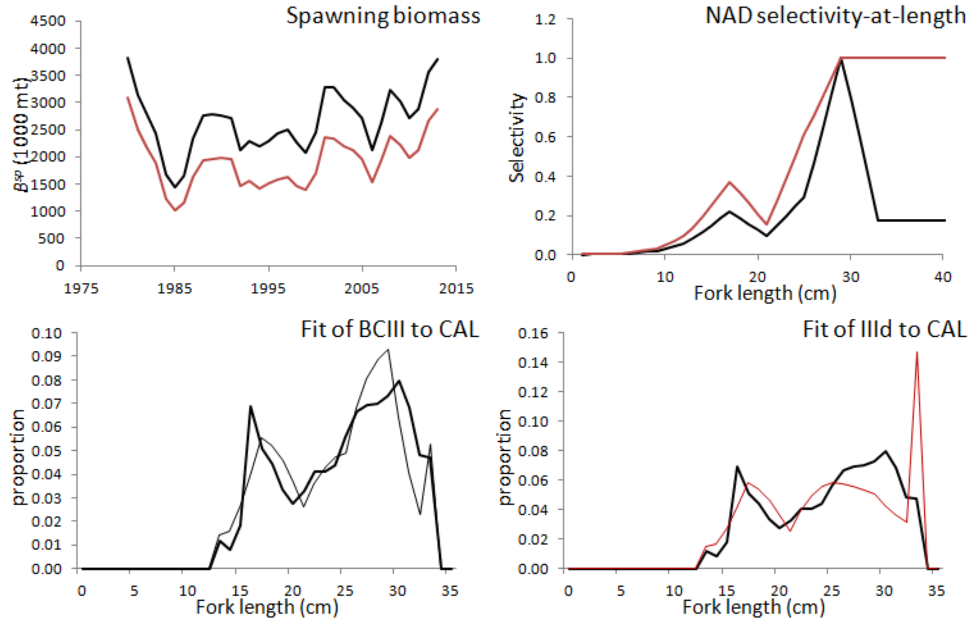

Figure 14: Time-trajectory of spawning biomass and selectivity-at-length for **BCIII (black lines)** and run **IIId (flat NAD selectivity-at-length from length 29cm - red lines)**. The fit to the NAD CAL are also shown.

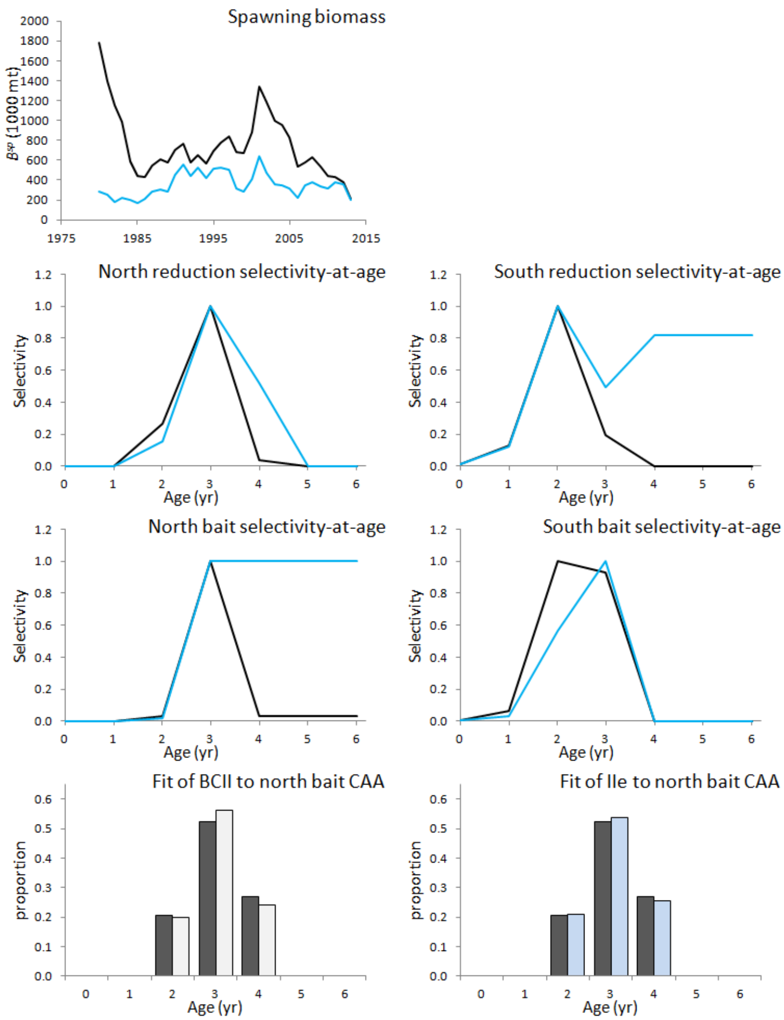

Figure 15a: Time-trajectory of spawning biomass and selectivity-at-length for **BCII (black lines)** and run **IIe (flat north bait selectivity-at-age from age 3- blue lines)**. The fit to the north bait CAA is also shown.

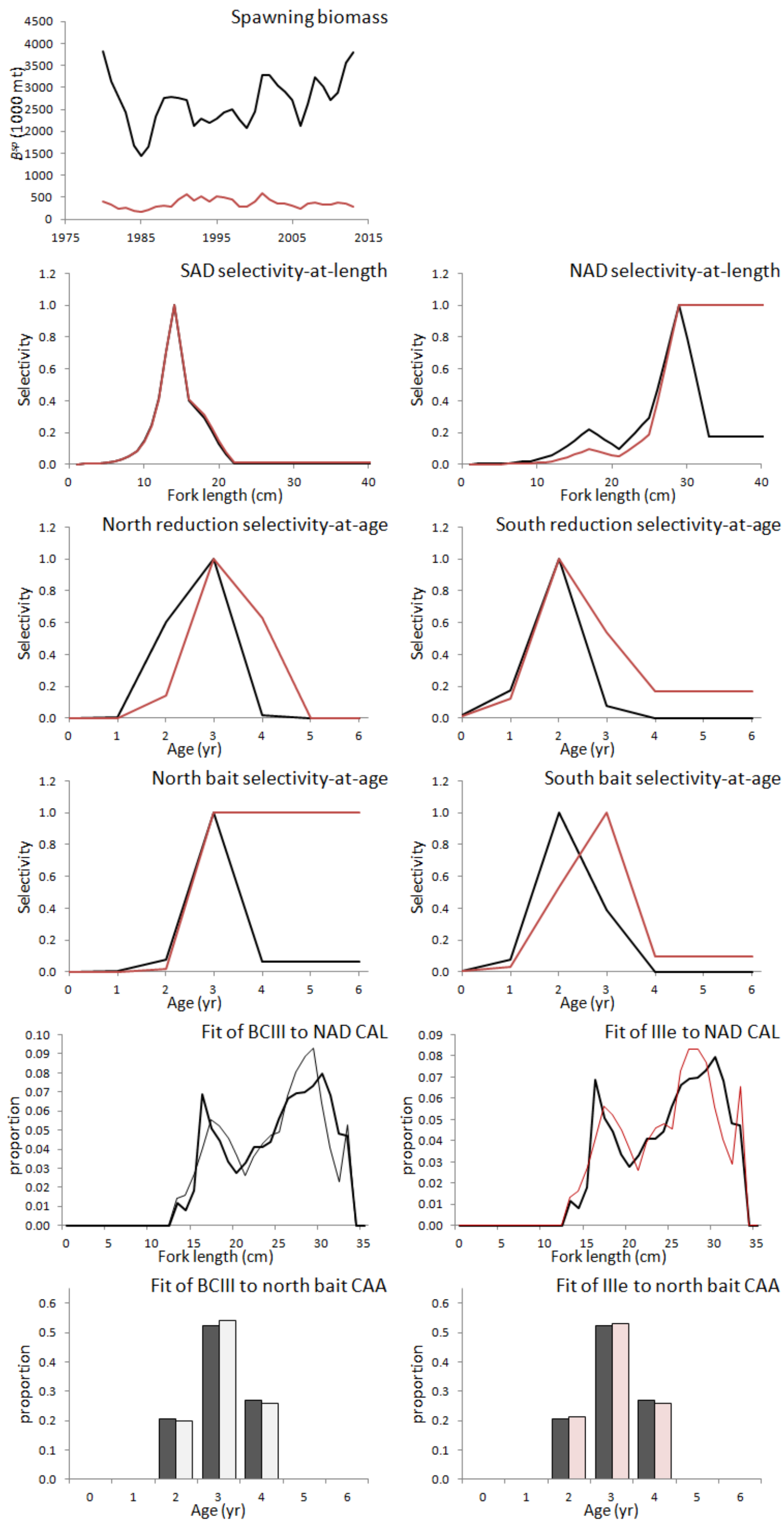

Figure 15b: Time-trajectory of spawning biomass and selectivity-at-length for **BCIII (black lines)** and run **IIIe (flat NAD selectivity-at-length from length 29cm and flat north bait selectivity-at-age from age 3- red lines)**. The fit to NAD CAL and north bait CAA are also shown.

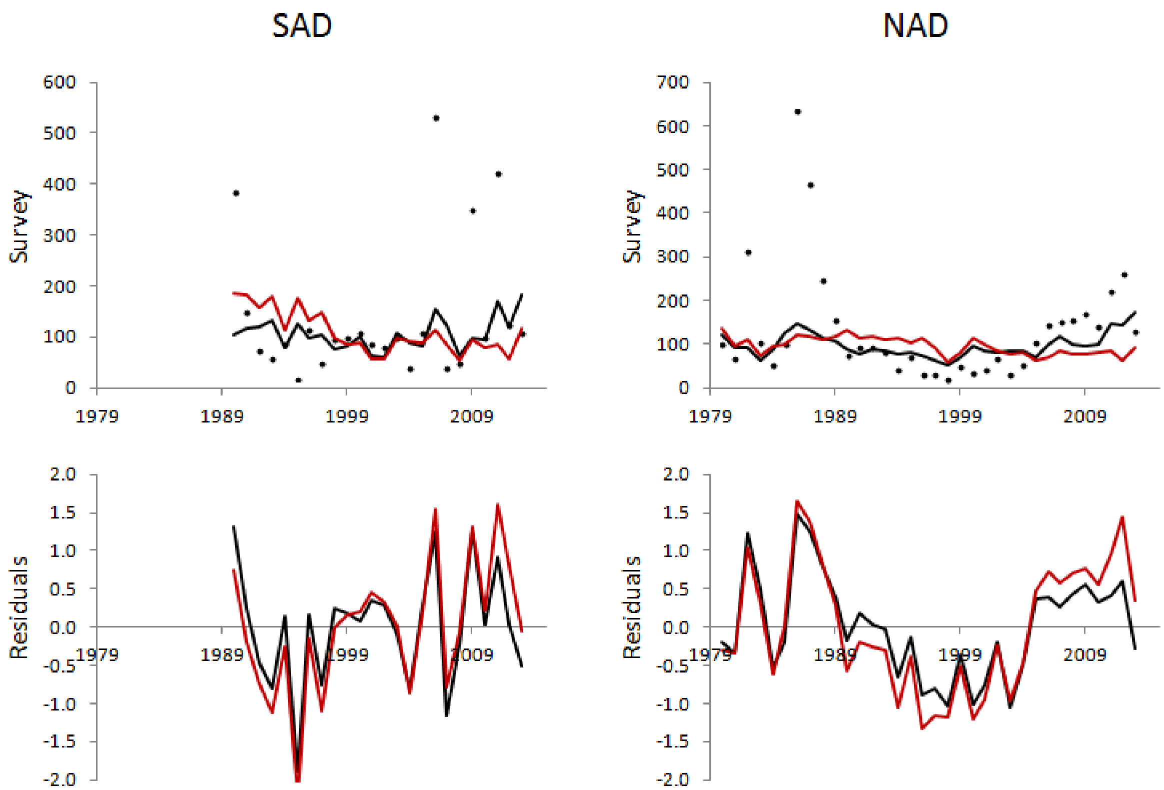

Figure 16: Fit to the SAD and NAD survey indices and corresponding residuals for **BCIII (black lines)** and run **IIIe (flat NAD selectivity-at-length from length 29cm and flat north bait selectivity-at-age from age 3- red lines)**.

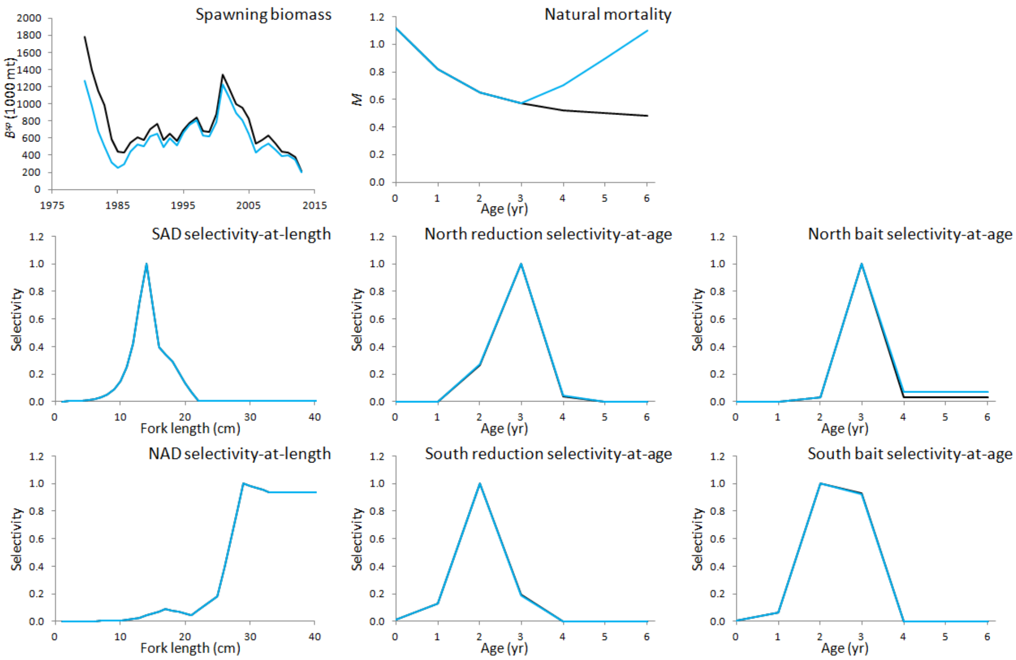

Figure 17a: Time-trajectory of spawning biomass, natural mortality, index selectivities-at-length and commercial selectivities-at-age for **BCII (black lines)** and run **IIf (increased *M* from age 3- blue lines)**.

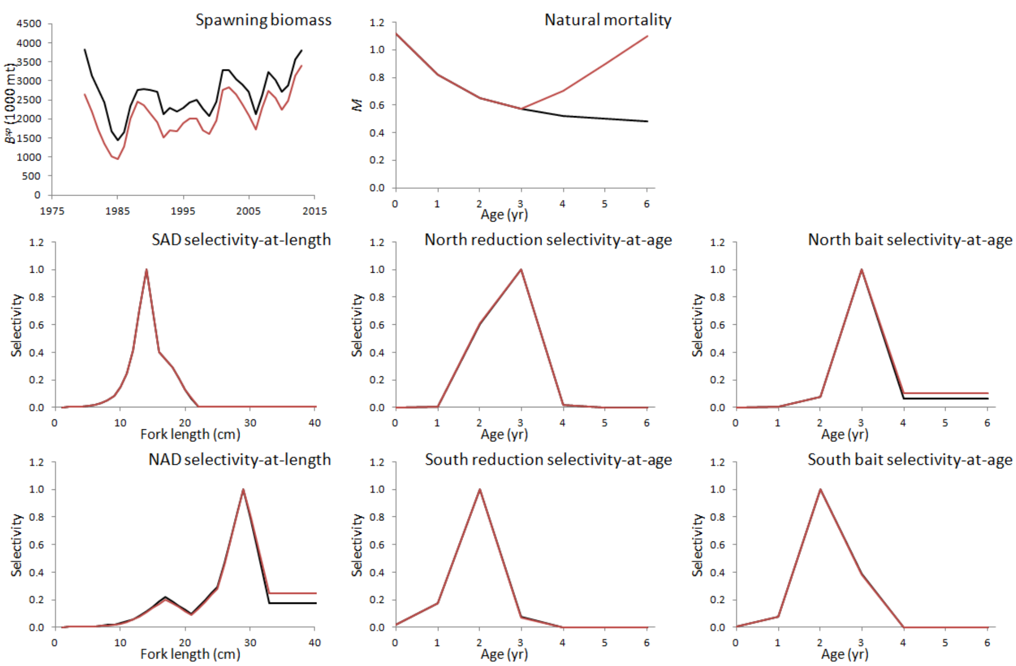

Figure 17b: Time-trajectory of spawning biomass, natural mortality, index selectivities-at-length and commercial selectivities-at-age for **BCIII (black lines)** and run **IIIf (increased *M* from age 3- red lines)**.

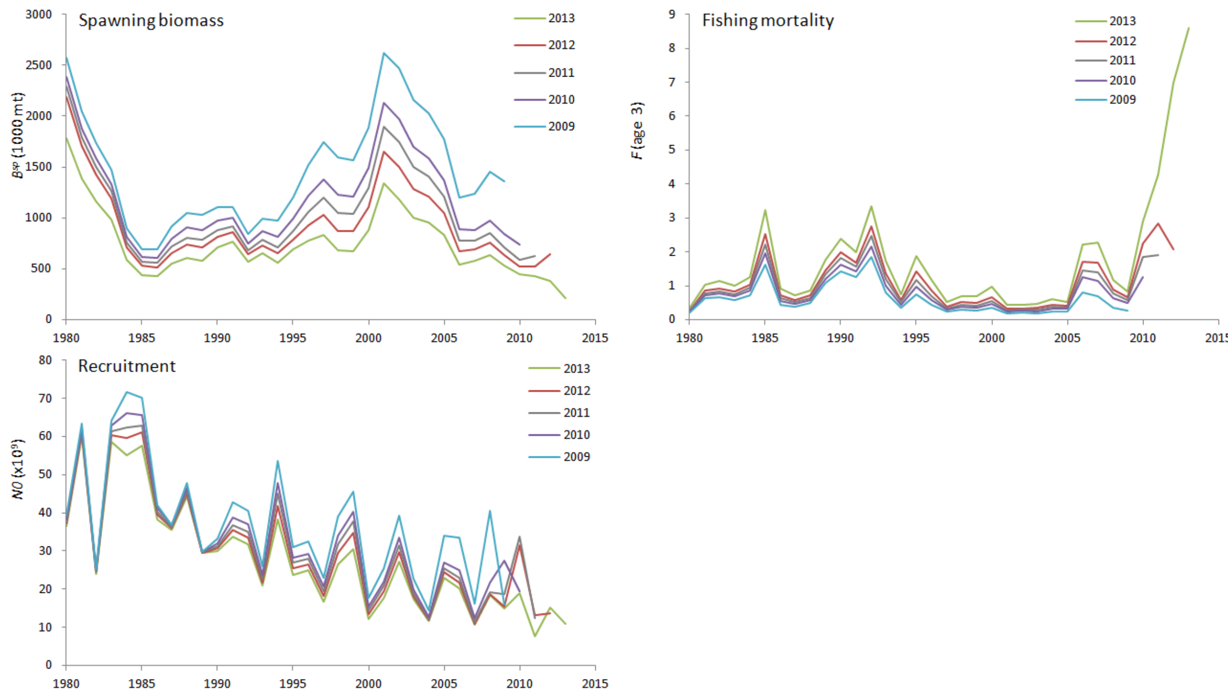

Figure 18a: Retrospective analysis for BCII.

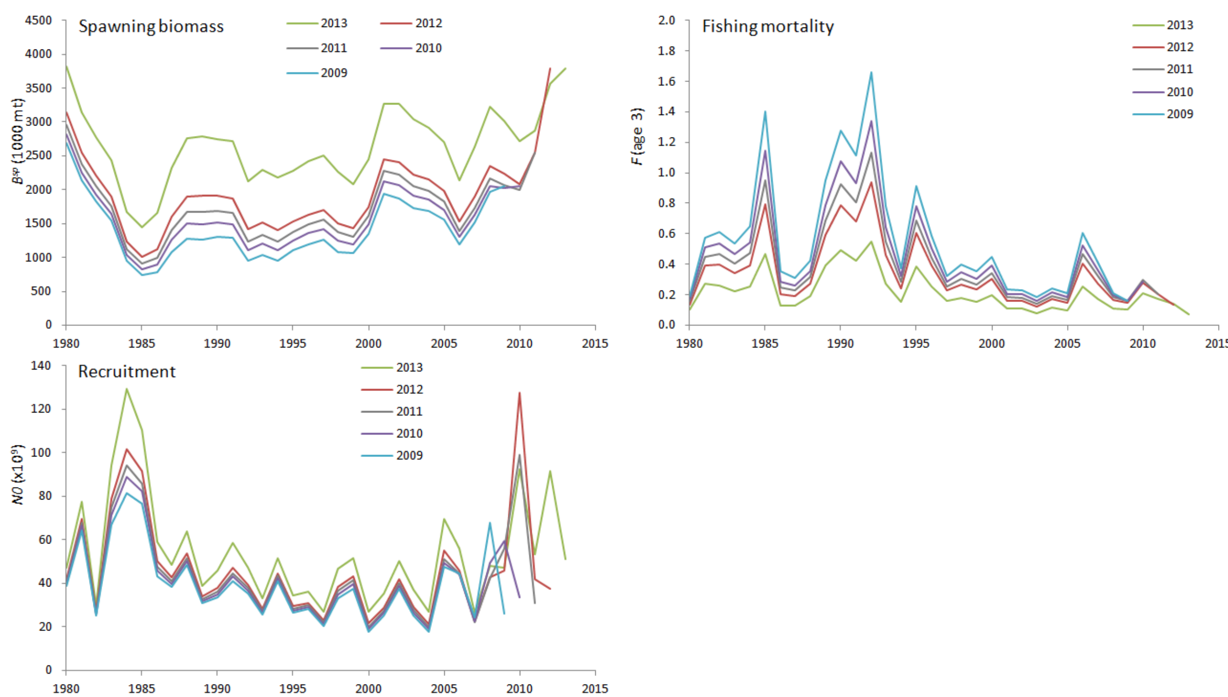

Figure 18b: Retrospective analysis for BCIII.

Appendix A - Data

Table A.1: Natural mortality-at-age ($M_{y,a}$ yr^{-1}), taken here to be year-invariant

0	1	2	3	4	5	6+
1.12	0.82	0.65	0.57	0.52	0.50	0.48

Table A.2: Maturity-at-age ($f_{y,a}$)

	0	1	2	3	4	5	6+
1955	0.00	0.07	0.70	0.93	0.97	0.99	1.00
1956	0.00	0.06	0.66	0.95	0.98	0.99	0.99
1957	0.00	0.05	0.49	0.95	0.99	0.99	0.99
1958	0.00	0.08	0.49	0.90	0.99	0.99	1.00
1959	0.00	0.03	0.49	0.89	0.98	1.00	1.00
1960	0.00	0.14	0.35	0.88	0.98	1.00	1.00
1961	0.00	0.08	0.65	0.83	0.98	0.99	1.00
1962	0.00	0.11	0.61	0.93	0.97	0.99	1.00
1963	0.00	0.13	0.63	0.93	0.99	0.99	1.00
1964	0.00	0.15	0.66	0.91	0.98	1.00	1.00
1965	0.00	0.14	0.69	0.92	0.97	0.99	1.00
1966	0.00	0.10	0.75	0.94	0.98	0.99	1.00
1967	0.00	0.17	0.66	0.97	0.98	0.99	0.99
1968	0.00	0.13	0.83	0.96	0.99	0.99	0.99
1969	0.00	0.16	0.67	0.98	1.00	1.00	1.00
1970	0.00	0.24	0.73	0.96	1.00	1.00	1.00
1971	0.00	0.20	0.90	0.96	0.99	1.00	1.00
1972	0.00	0.10	0.91	0.99	1.00	1.00	1.00
1973	0.00	0.05	0.57	0.99	1.00	1.00	1.00
1974	0.00	0.06	0.66	0.92	1.00	1.00	1.00
1975	0.00	0.04	0.52	0.94	0.99	1.00	1.00
1976	0.00	0.03	0.30	0.90	0.98	1.00	1.00
1977	0.00	0.02	0.23	0.78	0.98	0.99	1.00
1978	0.00	0.02	0.19	0.69	0.96	0.99	0.99
1979	0.00	0.03	0.22	0.66	0.92	0.99	1.00
1980	0.00	0.02	0.20	0.72	0.93	0.98	1.00
1981	0.00	0.02	0.15	0.62	0.95	0.98	0.99
1982	0.00	0.03	0.23	0.52	0.89	0.99	1.00
1983	0.00	0.03	0.26	0.68	0.85	0.97	1.00
1984	0.00	0.03	0.29	0.73	0.91	0.96	0.99
1985	0.00	0.02	0.22	0.79	0.94	0.97	0.99
1986	0.00	0.02	0.22	0.68	0.96	0.99	0.99
1987	0.00	0.03	0.19	0.67	0.92	0.99	1.00
1988	0.00	0.02	0.24	0.65	0.91	0.98	1.00
1989	0.00	0.04	0.25	0.69	0.92	0.98	1.00
1990	0.00	0.07	0.41	0.73	0.92	0.98	0.99
1991	0.00	0.05	0.56	0.86	0.94	0.98	1.00
1992	0.00	0.11	0.45	0.89	0.97	0.98	0.99
1993	0.00	0.04	0.59	0.87	0.97	0.99	0.99
1994	0.00	0.10	0.42	0.92	0.97	0.99	1.00
1995	0.00	0.04	0.66	0.89	0.98	0.99	0.99
1996	0.00	0.03	0.63	0.95	0.99	1.00	1.00
1997	0.00	0.03	0.57	0.96	0.99	1.00	1.00
1998	0.00	0.04	0.39	0.95	0.99	1.00	1.00
1999	0.00	0.14	0.50	0.89	0.99	1.00	1.00
2000	0.00	0.08	0.69	0.91	0.98	1.00	1.00
2001	0.00	0.06	0.80	0.95	0.98	1.00	1.00
2002	0.00	0.14	0.75	0.98	0.99	1.00	1.00
2003	0.00	0.08	0.70	0.96	1.00	1.00	1.00
2004	0.00	0.08	0.60	0.91	0.99	1.00	1.00
2005	0.00	0.03	0.57	0.92	0.96	0.99	1.00
2006	0.00	0.06	0.46	0.91	0.98	0.97	0.99
2007	0.00	0.09	0.60	0.90	0.98	0.99	0.98
2008	0.00	0.11	0.64	0.89	0.98	0.99	1.00
2009	0.00	0.11	0.65	0.90	0.95	0.99	1.00
2010	0.00	0.12	0.53	0.90	0.96	0.97	1.00
2011	0.00	0.13	0.65	0.87	0.95	0.98	0.98
2012	0.00	0.12	0.63	0.89	0.96	0.97	0.98
2013	0.00	0.12	0.60	0.88	0.95	0.99	0.98

Table A.3: Fecundity-at-age ($g_{y,a}$)

Year	0	1	2	3	4	5	6+
1955	15567	26267	76356	134072	171499	225574	314702
1956	13431	24883	72366	143502	198473	238833	279006
1957	17813	23368	57467	144117	219979	262471	296958
1958	12581	27254	57476	117858	230192	293759	320304
1959	20803	20527	57823	113474	218295	316474	357302
1960	14827	32777	47911	109417	189742	370470	392930
1961	17456	26775	71349	96300	187906	279836	583275
1962	19250	30235	67500	134037	171141	297215	375348
1963	20150	32403	68920	131049	223455	274818	438442
1964	19543	33692	72330	120396	210941	338151	405941
1965	17700	33326	75794	127224	175648	296815	473099
1966	19187	29143	82221	136478	189256	226831	379233
1967	20535	35572	71658	169108	209101	250238	269709
1968	22194	32194	96373	156906	300776	284953	304553
1969	21693	35028	73488	203311	310553	476360	356683
1970	16872	40785	80098	153362	355629	562879	687690
1971	18546	37767	116588	165349	295467	540609	944933
1972	10120	28938	120135	264616	312075	530105	739806
1973	14006	23352	64090	251253	501646	544506	892560
1974	14086	24271	71970	126973	402194	826354	886857
1975	11982	21245	59625	138682	228571	542898	1219898
1976	11440	18604	44895	118252	203248	378919	657341
1977	11555	17400	39935	86830	199236	253960	585202
1978	13208	17768	37208	75112	155318	296465	289161
1979	12347	19244	39023	72427	126644	259346	401304
1980	11574	17524	37913	78409	129836	195075	407546
1981	12951	18298	33502	68360	145595	216542	278839
1982	11150	19817	39834	60076	114123	252076	339017
1983	13069	18579	42124	74366	101690	178182	410168
1984	11965	19306	44310	79989	122730	163410	262470
1985	11895	18410	39323	89194	137999	183470	250572
1986	12195	17838	39010	73718	156641	219434	253334
1987	11140	19072	37306	72816	128431	246471	325540
1988	12005	18035	40898	71494	122319	209725	354998
1989	14451	21041	41123	75715	126859	188243	323439
1990	14039	26177	52198	80213	124490	210324	269352
1991	18883	23564	63325	103370	137864	185986	328444
1992	13539	29834	55250	114350	172802	213846	257181
1993	16786	21955	65819	106374	169801	254310	305240
1994	10353	29190	52835	126214	176012	221209	340065
1995	8849	21827	72214	114326	215661	259222	264026
1996	10149	19204	69223	144185	225319	335133	349075
1997	11492	18541	64206	156512	244434	409063	481664
1998	19958	21465	51057	151852	278590	365730	690935
1999	12353	32798	58256	113812	280572	418758	497451
2000	9393	27487	75179	121790	214629	434711	558555
2001	17576	24369	89659	144090	209972	354575	594044
2002	14983	33274	82031	196498	240004	313961	527521
2003	16233	26878	76273	157805	330756	358097	422592
2004	9555	27465	66446	120859	224531	467296	490110
2005	11655	19130	63834	126059	156028	271539	587754
2006	14563	24912	55360	119383	198305	179784	300837
2007	15875	28460	66301	116016	190006	273240	194493
2008	20487	30382	69774	113395	194201	268277	342797
2009	16557	30670	71500	117175	152188	277993	346570
2010	18411	31077	61013	116070	158122	178830	356863
2011	18415	31910	70991	106252	152698	188034	195368
2012	18415	31215	69046	112949	166207	178345	207843
2013	18415	31215	66874	111211	146641	238433	194730

Table A.4a: Corrected Fork Length (in mm) at age at May 15.

Year	0.5	1	2	3	4	5	6+
1955	101.0	171.6	236.5	270.1	285.7	302.0	321.0
1956	86.5	164.0	233.9	275.3	294.4	305.9	315.0
1957	111.7	161.4	218.0	276.2	301.5	311.8	319.2
1958	85.6	168.8	217.9	264.4	305.0	319.3	324.1
1959	120.5	151.5	217.3	260.7	304.2	324.6	331.3
1960	91.0	181.7	205.7	258.3	293.0	338.3	337.9
1961	103.1	171.1	231.3	250.4	293.2	317.4	367.6
1962	111.3	177.9	228.6	271.6	287.2	322.7	335.9
1963	114.9	182.0	228.5	269.9	304.2	317.5	347.7
1964	112.9	184.6	231.7	262.8	299.5	330.6	342.5
1965	108.5	184.8	235.1	266.7	286.0	320.7	352.0
1966	107.5	175.4	242.2	271.8	291.3	301.7	335.9
1967	120.5	190.9	233.6	288.1	298.3	308.6	312.3
1968	125.3	180.8	253.5	284.4	324.7	317.6	320.7
1969	115.5	186.5	234.5	300.3	328.6	353.9	331.6
1970	88.5	200.7	240.2	282.4	335.4	367.1	377.3
1971	113.7	198.5	267.1	287.2	325.1	361.7	400.7
1972	51.6	173.4	268.7	319.0	328.3	363.1	381.4
1973	89.6	166.6	224.8	313.5	359.5	364.4	397.0
1974	96.9	163.8	233.6	268.9	342.0	391.1	396.1
1975	84.5	152.0	220.4	272.6	306.9	360.2	415.7
1976	82.6	143.7	200.6	263.6	295.4	339.5	371.8
1977	83.0	138.9	192.6	243.4	296.4	308.6	367.6
1978	93.9	140.6	188.2	233.1	281.2	321.4	316.3
1979	90.7	144.4	191.8	231.4	266.5	314.4	340.5
1980	81.2	137.6	188.3	237.1	269.2	294.2	343.8
1981	90.5	142.9	179.9	226.5	277.4	302.4	317.1
1982	76.5	147.6	192.4	218.0	259.7	313.0	331.4
1983	92.8	145.3	196.2	232.2	252.3	288.5	344.7
1984	84.8	145.1	200.7	237.5	264.0	283.2	313.6
1985	85.9	142.7	191.3	245.2	272.7	289.6	311.1
1986	85.2	140.2	190.9	232.1	281.1	302.5	310.2
1987	77.7	145.4	188.1	230.9	268.2	310.0	328.0
1988	78.7	142.6	194.0	230.3	264.2	300.0	333.2
1989	88.4	154.5	195.2	233.3	267.6	291.8	328.1
1990	91.2	169.3	211.6	237.8	265.0	300.4	314.8
1991	114.0	161.1	223.4	254.5	272.3	290.6	329.3
1992	91.3	175.6	214.9	259.7	286.8	300.3	311.2
1993	101.5	156.1	226.2	256.2	283.9	311.0	323.0
1994	60.0	176.2	213.1	267.9	288.0	300.1	329.3
1995	48.4	161.2	233.3	263.2	302.2	312.4	310.9
1996	66.2	153.5	232.8	276.9	307.2	330.4	331.2
1997	72.8	147.4	228.4	283.3	310.1	345.9	353.6
1998	115.7	157.4	211.7	281.9	319.1	335.5	379.9
1999	68.5	182.7	219.8	262.6	320.0	344.3	354.9
2000	39.7	177.5	235.2	266.0	302.9	347.2	362.2
2001	97.3	171.5	249.8	276.5	300.0	334.7	366.6
2002	91.8	185.4	242.6	297.8	308.8	325.2	360.0
2003	100.2	171.1	234.2	280.9	329.7	334.1	343.8
2004	56.8	171.4	227.2	261.3	301.5	350.8	354.0
2005	63.8	151.1	224.2	266.9	276.4	312.7	364.8
2006	83.7	168.7	216.7	263.4	295.0	284.7	318.7
2007	90.2	175.9	226.3	262.4	292.5	314.9	289.4
2008	121.6	179.7	229.2	257.8	294.3	314.1	329.0
2009	93.9	175.9	230.3	260.0	275.1	316.4	330.1
2010	105.8	180.7	219.8	258.9	277.8	284.6	331.9
2011	107.1	181.1	229.5	255.1	275.2	288.1	289.8
2012	107.1	179.2	227.6	256.9	283.6	284.4	294.0
2013	107.1	179.2	225.6	256.3	272.3	306.6	289.6

Table A.4b: Corrected Fork Length (in mm) at age at September 1.

Year	0.5	1	2	3	4	5	6+
1955	120.3	192.2	249.4	278.0	292.4	306.3	321.4
1956	110.4	180.5	247.9	284.0	300.1	310.3	317.9
1957	129.2	179.4	232.2	285.7	307.4	315.8	322.1
1958	106.1	183.7	231.6	276.6	311.5	323.3	327.0
1959	139.6	168.3	229.9	271.0	314.6	329.0	334.0
1960	117.0	197.2	219.6	269.0	300.8	347.3	340.9
1961	127.9	189.8	243.9	261.8	302.2	323.3	375.3
1962	134.4	194.7	242.0	281.7	296.6	330.4	340.4
1963	137.5	198.3	239.9	279.5	312.4	325.3	354.2
1964	135.4	200.9	243.1	270.5	306.4	337.3	348.9
1965	128.8	202.8	247.0	274.7	291.2	325.6	357.4
1966	134.2	193.1	256.6	280.4	296.9	305.2	339.5
1967	138.7	211.0	249.1	299.6	304.6	312.5	314.7
1968	143.9	197.0	268.5	297.8	333.9	322.2	323.5
1969	142.4	202.8	249.0	311.6	340.3	361.3	334.9
1970	125.6	221.7	254.4	295.3	343.8	377.3	383.1
1971	131.9	222.2	283.5	299.7	336.5	368.0	409.6
1972	91.6	189.1	283.8	331.8	339.3	373.3	386.1
1973	113.2	189.9	238.3	323.1	369.4	374.0	406.1
1974	113.6	181.9	247.1	280.5	348.2	398.8	404.5
1975	102.8	166.7	234.2	280.5	316.9	364.1	421.8
1976	99.7	158.8	213.6	274.0	300.0	348.1	374.3
1977	100.4	153.9	205.1	254.8	304.4	311.3	375.0
1978	109.3	156.1	201.3	243.4	291.2	327.5	317.9
1979	104.8	157.8	205.5	242.9	275.1	323.3	345.1
1980	100.5	150.3	199.9	249.3	279.3	301.3	351.6
1981	108.0	158.4	191.3	236.6	288.2	311.2	322.9
1982	98.0	162.5	204.9	228.3	268.4	322.6	339.2
1983	108.6	162.6	208.9	242.1	261.6	296.1	353.2
1984	102.7	159.1	214.6	248.3	272.1	291.6	320.2
1985	102.3	157.6	203.6	256.4	281.8	296.1	318.7
1986	104.0	154.7	203.3	243.0	290.1	310.3	315.3
1987	98.0	160.6	200.9	241.2	277.8	317.2	334.6
1988	102.9	159.0	206.3	241.6	272.7	308.5	339.0
1989	115.3	172.8	208.5	243.2	277.5	298.9	335.7
1990	113.4	187.3	225.3	248.6	273.0	309.2	320.7
1991	133.1	178.2	235.5	264.8	281.1	297.0	337.1
1992	111.0	191.3	228.0	267.7	294.5	307.4	316.4
1993	125.3	173.4	239.1	266.3	289.3	316.9	328.8
1994	93.1	194.4	228.3	278.5	295.7	303.7	333.7
1995	82.6	184.6	247.2	276.5	310.9	318.3	313.3
1996	91.7	177.9	249.3	287.4	318.9	337.6	335.7
1997	100.0	167.7	245.8	295.0	318.2	356.2	359.5
1998	136.8	177.5	227.7	294.3	327.3	341.7	389.0
1999	104.8	199.3	234.7	275.3	328.9	350.2	359.6
2000	86.6	201.6	248.2	276.9	312.9	353.5	366.3
2001	128.4	196.8	265.8	286.7	308.1	342.7	371.1
2002	117.7	202.6	256.2	308.4	316.8	331.2	366.2
2003	123.1	189.4	243.8	288.2	336.7	340.4	348.2
2004	87.7	188.3	240.2	266.7	305.5	355.5	358.9
2005	101.0	172.6	236.8	276.1	279.3	314.8	367.9
2006	115.8	189.1	231.7	272.7	301.5	286.4	319.8
2007	121.6	194.5	237.4	272.9	299.4	319.5	290.3
2008	138.6	197.4	239.9	263.9	301.6	319.2	332.2
2009	124.4	189.6	240.3	266.2	278.4	321.5	333.9
2010	131.5	197.8	230.8	264.6	281.4	286.4	335.4
2011	131.5	196.9	239.1	264.0	278.4	290.2	290.8
2012	131.5	194.8	237.4	262.3	290.8	286.2	295.2
2013	131.5	194.8	235.8	262.3	275.4	312.4	290.6

Table A.5a: Weight-at-age at spawning ($w_{y,a}^{\text{strt}}$ in gm) (which is taken to correspond to the start of the fishing year).

Year	0.5	1	2	3	4	5	6+
1955	27.9	62.5	206.5	335.5	406.1	496.0	622.3
1956	21.3	58.1	196.3	354.1	452.5	516.3	574.4
1957	35.1	53.1	156.6	355.3	487.2	551.0	598.9
1958	18.8	65.7	156.6	302.1	503.1	594.6	629.6
1959	44.8	43.9	157.5	292.8	484.6	624.6	675.8
1960	25.6	83.4	129.4	284.0	437.8	691.6	717.8
1961	34.0	64.2	193.7	254.5	434.7	575.5	911.7
1962	39.7	75.3	183.7	335.4	405.5	599.2	697.4
1963	42.7	82.2	187.4	329.4	492.7	568.5	768.5
1964	40.7	86.3	196.2	307.5	472.8	652.2	732.6
1965	34.7	85.1	205.0	321.6	413.5	598.7	805.0
1966	39.5	71.8	221.0	340.3	437.0	497.9	701.9
1967	43.9	92.2	194.5	401.8	469.9	533.2	561.3
1968	49.3	81.5	254.7	379.5	604.0	582.6	609.0
1969	47.7	90.5	199.2	460.4	616.9	808.4	675.0
1970	32.1	108.2	215.8	372.9	673.8	892.9	1002.1
1971	37.5	99.0	299.4	395.1	596.9	871.9	1193.6
1972	11.8	71.2	306.9	554.1	618.9	861.9	1044.1
1973	23.1	53.1	174.6	534.7	834.0	875.6	1157.6
1974	23.3	56.1	195.3	321.1	728.4	1110.0	1153.6
1975	17.0	46.2	162.5	344.7	500.6	874.1	1364.6
1976	15.5	37.6	120.5	303.0	460.3	701.6	976.8
1977	15.8	33.8	105.6	232.2	453.7	538.7	913.5
1978	20.7	35.0	97.2	203.3	376.6	598.2	588.3
1979	18.1	39.7	102.8	196.5	320.5	546.5	727.4
1980	15.8	34.2	99.4	211.6	327.0	446.8	734.4
1981	19.9	36.7	85.7	185.9	358.1	481.8	574.1
1982	14.6	41.6	105.3	163.7	294.2	535.9	653.3
1983	20.2	37.6	112.2	201.4	266.8	417.9	737.4
1984	17.0	39.9	118.8	215.5	312.4	391.5	551.0
1985	16.8	37.0	103.7	237.9	343.3	427.1	533.7
1986	17.6	35.2	102.8	199.8	379.1	486.4	537.8
1987	14.6	39.2	97.5	197.5	324.1	527.7	636.3
1988	17.1	35.8	108.5	194.1	311.5	470.9	673.0
1989	24.5	45.6	109.2	204.8	320.9	435.3	633.6
1990	23.2	62.3	141.7	216.1	316.0	471.8	560.8
1991	38.5	53.8	172.5	270.6	343.1	431.4	640.0
1992	21.7	74.0	150.4	294.7	408.4	477.5	543.4
1993	31.8	48.5	179.2	277.3	403.1	539.2	609.9
1994	12.4	72.0	143.6	319.6	414.1	489.1	654.6
1995	8.5	48.1	195.9	294.6	480.4	546.3	553.2
1996	11.9	39.6	188.2	355.4	495.6	648.4	665.8
1997	15.6	37.4	174.9	378.8	524.7	736.1	813.8
1998	42.0	46.9	138.5	370.1	573.8	685.9	1004.8
1999	18.1	83.4	158.7	293.5	576.5	746.9	829.8
2000	9.9	66.5	203.5	310.4	478.7	764.4	888.9
2001	34.3	56.4	239.0	355.2	471.3	672.5	921.5
2002	26.1	84.9	220.6	449.2	518.0	621.4	859.4
2003	30.0	64.5	206.3	381.2	642.9	676.8	751.2
2004	10.3	66.4	180.9	308.5	494.3	799.0	822.4
2005	16.1	39.3	173.9	319.3	377.9	563.9	915.8
2006	24.8	58.1	150.7	305.4	452.2	420.7	604.1
2007	28.9	69.6	180.5	298.2	438.3	566.3	445.8
2008	43.8	75.8	189.6	292.6	445.3	559.3	658.0
2009	31.1	76.7	194.1	300.7	370.7	573.0	662.7
2010	37.0	78.0	166.3	298.3	381.8	419.0	675.3
2011	37.0	80.6	192.8	277.0	371.7	434.9	447.3
2012	37.0	78.4	187.7	291.6	396.6	418.2	467.8
2013	37.0	78.4	182.0	287.9	360.1	515.7	446.2

Table A.5b: Weight-at-age at the middle of the fishing year ($w_{y,a}^{\text{mid}}$ in gm).

Year	0	1	2	3	4	5	6+
1955	36.7	126.2	279.1	397.5	459.9	533.3	622.6
1956	25.3	105.8	269.1	431.5	502.2	563.4	606.7
1957	43.2	94.0	232.5	410.6	545.5	586.4	634.6
1958	24.0	110.2	227.0	368.9	530.1	622.7	651.3
1959	62.8	77.5	230.6	367.0	494.1	622.4	672.2
1960	35.3	132.3	189.8	363.2	488.8	599.3	690.3
1961	51.6	118.9	254.9	328.0	489.7	585.0	683.1
1962	57.5	128.0	265.9	396.4	471.3	600.8	656.5
1963	62.0	140.9	248.2	407.2	542.2	606.4	693.4
1964	63.7	142.7	266.4	360.2	520.9	682.4	726.0
1965	52.8	143.7	270.0	377.5	450.9	604.4	810.9
1966	65.6	121.0	280.1	392.7	462.8	518.8	662.5
1967	63.8	158.4	251.0	426.5	496.4	523.7	567.4
1968	73.0	124.8	307.7	411.7	565.3	577.8	565.3
1969	75.6	138.4	243.6	452.7	587.6	687.3	638.9
1970	55.7	177.6	258.8	404.1	575.4	766.0	789.5
1971	48.4	167.4	344.6	411.4	603.0	671.5	937.8
1972	24.8	125.4	339.9	511.8	588.8	834.8	743.4
1973	40.5	118.0	263.8	486.2	658.5	783.1	1093.6
1974	28.6	104.0	266.0	414.5	591.5	777.6	986.9
1975	27.1	84.2	213.8	377.5	556.6	661.3	870.0
1976	18.0	67.4	186.2	328.0	445.9	679.7	705.5
1977	21.2	64.2	145.2	294.9	430.8	484.3	781.1
1978	28.9	68.1	157.4	240.2	393.5	516.1	504.9
1979	25.3	67.8	161.4	262.4	341.6	475.4	583.3
1980	22.1	55.7	141.2	269.1	361.0	441.2	539.7
1981	20.8	69.0	117.5	230.4	373.8	444.8	534.0
1982	24.9	71.9	159.3	202.1	325.7	466.2	511.8
1983	30.6	69.9	171.6	260.0	306.0	420.0	543.2
1984	23.8	67.7	157.8	279.9	354.8	425.0	508.6
1985	21.9	67.5	138.9	262.0	378.1	436.1	554.5
1986	25.5	65.9	150.3	228.9	367.8	458.8	502.1
1987	25.9	73.7	149.9	243.7	330.5	466.1	521.5
1988	27.3	69.0	160.6	243.7	333.8	437.1	552.5
1989	41.2	93.2	150.8	252.2	332.5	413.4	543.4
1990	37.5	114.7	207.7	246.0	334.3	409.3	479.9
1991	52.5	94.0	228.2	315.9	341.6	401.8	472.1
1992	30.1	128.3	192.9	327.1	401.2	429.6	454.3
1993	51.0	95.3	247.2	298.8	400.7	462.7	506.4
1994	25.2	122.8	218.5	358.6	397.3	451.5	504.8
1995	23.5	118.6	243.0	351.9	449.3	481.7	484.8
1996	18.2	98.5	286.6	366.4	473.6	517.7	550.5
1997	29.7	88.3	243.1	435.1	477.0	574.9	567.0
1998	61.1	94.7	227.0	388.4	541.6	568.5	654.4
1999	40.3	134.7	219.5	363.3	507.8	610.8	640.7
2000	28.2	136.2	261.3	357.0	471.4	596.4	653.6
2001	55.4	128.0	291.6	400.2	484.6	548.7	658.6
2002	37.8	145.9	289.3	426.1	535.1	592.5	600.9
2003	48.1	116.9	262.8	414.7	523.7	656.8	678.6
2004	24.8	114.4	242.1	345.9	494.5	588.5	761.4
2005	35.3	88.3	224.0	350.8	397.0	540.9	629.6
2006	43.6	114.2	199.2	334.7	430.7	426.2	566.7
2007	53.7	129.6	233.0	303.1	432.7	484.5	442.5
2008	59.7	134.8	252.5	328.1	384.1	512.8	519.3
2009	53.4	117.6	245.6	347.3	392.2	441.6	575.2
2010	57.7	134.6	215.1	331.7	409.4	432.1	480.5
2011	56.9	132.7	241.5	324.0	389.7	447.2	455.8
2012	56.9	128.1	239.1	320.4	433.7	426.1	469.2
2013	56.9	128.1	231.7	328.5	371.1	537.1	448.1

Table A.6: Ageing error matrix ($\chi_{a,a'}$).

	0	1	2	3	4	5	6+
0	0.98	0.02	0.00	0.00	0.00	0.00	0.00
1	0.02	0.97	0.02	0.00	0.00	0.00	0.00
2	0.00	0.03	0.93	0.03	0.00	0.00	0.00
3	0.00	0.00	0.09	0.82	0.09	0.00	0.00
4	0.00	0.00	0.00	0.19	0.62	0.19	0.00
5	0.00	0.00	0.01	0.06	0.24	0.39	0.31
6+	0.00	0.01	0.02	0.06	0.12	0.18	0.60

Table A.7: Unscaled composite recruitment index (JAI, $\tilde{N}_y^{JAI}$) and unscaled composite trawl age 1+ indices (SAD ($\tilde{N}_y^{SAD}$) and NAD ($\tilde{N}_y^{NAD}$)) with CVs in parenthesis.

year	JAI	CV	SAD	CV	NAD	CV
1959	83.15	(0.96)	-		-	
1960	41.60	(0.98)	-		-	
1961	39.62	(1.02)	-		-	
1962	190.18	(0.92)	-		-	
1963	110.32	(0.98)	-		-	
1964	24.61	(1.01)	-		-	
1965	57.09	(0.94)	-		-	
1966	74.81	(1.00)	-		-	
1967	94.10	(1.01)	-		-	
1968	66.75	(0.82)	-		-	
1969	71.98	(0.80)	-		-	
1970	48.86	(0.89)	-		-	
1971	189.17	(0.77)	-		-	
1972	240.47	(0.73)	-		-	
1973	175.58	(0.93)	-		-	
1974	248.84	(0.86)	-		-	
1975	331.01	(0.85)	-		-	
1976	374.14	(0.86)	-		-	
1977	321.63	(0.86)	-		-	
1978	188.71	(0.88)	-		-	
1979	280.10	(0.86)	-		-	
1980	201.52	(0.67)	-		100.66	(0.74)
1981	292.05	(0.75)	-		66.72	(0.79)
1982	243.75	(0.70)	-		314.27	(0.76)
1983	148.71	(0.74)	-		102.60	(0.69)
1984	112.11	(0.76)	-		51.68	(0.85)
1985	223.58	(0.58)	-		101.52	(0.77)
1986	124.56	(0.63)	-		633.38	(0.64)
1987	55.02	(0.58)	-		465.48	(0.68)
1988	103.35	(0.52)	-		246.30	(0.38)
1989	156.31	(0.46)	-		155.42	(0.38)
1990	188.37	(0.45)	385.73	(0.49)	74.92	(0.35)
1991	134.69	(0.45)	149.67	(0.44)	93.06	(0.35)
1992	83.40	(0.45)	75.24	(0.51)	91.71	(0.33)
1993	15.41	(0.49)	58.44	(0.53)	82.60	(0.40)
1994	61.65	(0.45)	88.44	(0.57)	39.61	(0.39)
1995	36.95	(0.44)	19.00	(0.44)	70.21	(0.36)
1996	28.27	(0.44)	113.94	(0.38)	29.93	(0.40)
1997	62.67	(0.42)	48.62	(0.45)	28.50	(0.35)
1998	59.39	(0.44)	97.73	(0.50)	18.43	(0.36)
1999	98.43	(0.47)	98.33	(0.53)	49.12	(0.33)
2000	94.20	(0.43)	108.24	(0.79)	34.21	(0.33)
2001	44.48	(0.42)	88.35	(0.52)	39.46	(0.39)
2002	124.02	(0.43)	80.33	(0.51)	66.48	(0.35)
2003	59.90	(0.42)	99.52	(0.40)	29.51	(0.31)
2004	81.71	(0.42)	38.77	(0.46)	50.89	(0.31)
2005	86.62	(0.40)	108.35	(0.39)	102.05	(0.30)
2006	46.72	(0.40)	534.94	(0.39)	143.75	(0.28)
2007	66.05	(0.41)	38.92	(0.39)	151.73	(0.27)
2008	44.70	(0.41)	50.50	(0.41)	153.21	(0.34)
2009	37.50	(0.41)	352.56	(0.41)	169.58	(0.30)
2010	71.29	(0.42)	98.67	(0.44)	139.14	(0.28)
2011	33.31	(0.40)	424.04	(0.34)	221.31	(0.31)
2012	27.42	(0.41)	125.11	(0.33)	261.15	(0.30)
2013	26.88	(0.43)	109.95	(0.35)	130.40	(0.29)

Table A.8a: Length composition shown as proportions ($p_{y,l}^{obs,SAD}$)for SAD index with length intervals given in mm.

	(0,110]	(110,120]	(120,130]	(130,140]	(140,150]	(150,160]	(160,170]	(170,180]	(180,190]	(190,200]	(200,210]	(210,220]	(220,230]	(230,240]	(240,250]	(250,260]	(260,270]	(270,280]	(280,290]	(290,300]	(300,310]	(310,320]	(320,330]	(330,340]	N of fish sampled
1990	0.0000	0.0000	0.0835	0.3635	0.2907	0.1642	0.0551	0.0241	0.0085	0.0044	0.0023	0.0023	0.0003	0.0003	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3904
1991	0.0000	0.0105	0.0526	0.3078	0.2575	0.0931	0.0563	0.0413	0.0788	0.0736	0.0210	0.0060	0.0008	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1332
1992	0.0000	0.1560	0.2083	0.2529	0.1705	0.0678	0.0378	0.0397	0.0339	0.0165	0.0136	0.0010	0.0000	0.0000	0.0000	0.0000	0.0010	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1032
1993	0.0000	0.0746	0.2157	0.2661	0.1250	0.0484	0.0524	0.1431	0.0504	0.0141	0.0101	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	496
1994	0.0000	0.0497	0.0839	0.0466	0.1056	0.1211	0.3137	0.1366	0.0807	0.0280	0.0311	0.0031	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	322
1995	0.0000	0.0091	0.1000	0.0545	0.0455	0.0273	0.1091	0.1909	0.3364	0.1182	0.0091	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	110
1996	0.0000	0.1548	0.1081	0.0467	0.0860	0.0811	0.0663	0.0934	0.1032	0.1057	0.0393	0.0074	0.0025	0.0172	0.0197	0.0221	0.0270	0.0074	0.0074	0.0025	0.0025	0.0000	0.0000	0.0000	407
1997	0.0000	0.0588	0.1303	0.0840	0.1050	0.1345	0.1008	0.0882	0.2059	0.0504	0.0168	0.0084	0.0000	0.0042	0.0042	0.0000	0.0042	0.0000	0.0000	0.0000	0.0042	0.0000	0.0000	0.0000	238
1998	0.0000	0.0821	0.2646	0.1867	0.1446	0.0862	0.0821	0.0472	0.0544	0.0390	0.0113	0.0000	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010	0.0000	0.0000	975
1999	0.0000	0.0000	0.0084	0.0279	0.0891	0.0919	0.1142	0.1616	0.2117	0.1476	0.1281	0.0111	0.0028	0.0028	0.0000	0.0000	0.0000	0.0028	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	359
2000	0.0000	0.0063	0.0252	0.0734	0.1321	0.1195	0.1551	0.1782	0.2683	0.0356	0.0063	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	477
2001	0.0000	0.0265	0.3117	0.2163	0.1573	0.1131	0.0452	0.0433	0.0482	0.0256	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1017
2002	0.0000	0.0011	0.0622	0.3607	0.2941	0.1332	0.0666	0.0333	0.0277	0.0166	0.0044	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	901
2003	0.0008	0.0796	0.1418	0.1766	0.2886	0.1501	0.0489	0.0307	0.0572	0.0182	0.0058	0.0000	0.0000	0.0008	0.0000	0.0000	0.0000	0.0000	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	1206
2004	0.0016	0.0950	0.0125	0.1480	0.2212	0.0670	0.2181	0.1106	0.0841	0.0312	0.0093	0.0000	0.0016	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	642
2005	0.0017	0.2659	0.4163	0.0969	0.0533	0.0559	0.0322	0.0378	0.0148	0.0075	0.0131	0.0044	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	4129
2006	0.0000	0.0509	0.4336	0.1871	0.1700	0.0768	0.0300	0.0056	0.0111	0.0122	0.0189	0.0010	0.0028	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	6736
2007	0.0000	0.0142	0.0057	0.1331	0.3201	0.3683	0.0963	0.0340	0.0227	0.0028	0.0000	0.0000	0.0000	0.0000	0.0028	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	353
2008	0.0000	0.0033	0.1135	0.4073	0.1653	0.0467	0.1352	0.0351	0.0417	0.0451	0.0067	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	599
2009	0.0003	0.0781	0.4674	0.2996	0.1276	0.0105	0.0070	0.0039	0.0036	0.0008	0.0011	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	19418
2010	0.0000	0.1441	0.2017	0.0879	0.0965	0.0922	0.1542	0.1138	0.0850	0.0101	0.0058	0.0014	0.0000	0.0000	0.0000	0.0029	0.0000	0.0000	0.0029	0.0014	0.0000	0.0000	0.0000	0.0000	694
2011	0.0028	0.0499	0.1493	0.0616	0.1413	0.2141	0.1908	0.0849	0.0604	0.0285	0.0149	0.0015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3228
2012	0.0000	0.0000	0.0801	0.1088	0.0987	0.0691	0.1585	0.1906	0.1939	0.0295	0.0531	0.0135	0.0042	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1186
2013	0.0016	0.0020	0.0669	0.1469	0.2184	0.1976	0.1947	0.1041	0.0510	0.0082	0.0073	0.0008	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	2450

Table A.8b: Length composition shown as proportions ($p_{y,l}^{obs,NAD}$)for NAD index with length intervals given in mm. The length compositions in years in which less than 100 fish were sampled have been ignored (not fitted to) in the models and are shown in grey and italised below.

	(0,110]	(110,120]	(120,130]	(130,140]	(140,150]	(150,160]	(160,170]	(170,180]	(180,190]	(190,200]	(200,210]	(210,220]	(220,230]	(230,240]	(240,250]	(250,260]	(260,270]	(270,280]	(280,290]	(290,300]	(300,310]	(310,320]	(320,330]	(330,340]	N of fish sampled
1980	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.1429*	*0.0000*	*0.1429*	*0.1429*	*0.2857*	*0.1429*	*0.1429*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*7*
1981	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.2500*	*0.0000*	*0.0000*	*0.5000*	*0.0000*	*0.0000*	*0.2500*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*4*
1982	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0392*	*0.0588*	*0.0980*	*0.2941*	*0.2549*	*0.2353*	*0.0196*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*51*
1983	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.1000*	*0.0000*	*0.0000*	*0.1000*	*0.5000*	*0.1000*	*0.2000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*10*
1984	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*1.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*1*
1985	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.2000*	*0.4000*	*0.1000*	*0.0000*	*0.1000*	*0.1000*	*0.1000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*10*
1986	0.0000	0.0273	0.0182	0.0091	0.0091	0.0545	0.0455	0.0364	0.0364	0.0909	0.1273	0.2909	0.0818	0.0727	0.0455	0.0273	0.0182	0.0091	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	110
1987	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0313*	*0.0156*	*0.0156*	*0.0469*	*0.1406*	*0.3125*	*0.1563*	*0.0625*	*0.0469*	*0.0156*	*0.0469*	*0.0781*	*0.0156*	*0.0000*	*0.0156*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*64*
1988	0.0000	0.0000	0.0093	0.0187	0.0280	0.1028	0.1121	0.1215	0.0374	0.0467	0.0654	0.0374	0.0654	0.0935	0.0561	0.0935	0.0654	0.0374	0.0000	0.0093	0.0000	0.0000	0.0000	0.0000	107
1989	0.0291	0.0388	0.0194	0.0583	0.0971	0.1165	0.1165	0.0291	0.0583	0.0388	0.0583	0.0291	0.0388	0.0291	0.0388	0.0971	0.0583	0.0097	0.0097	0.0097	0.0097	0.0000	0.0000	0.0097	103
1990	0.0000	0.0000	0.0000	0.0000	0.0390	0.0584	0.0584	0.0649	0.0519	0.0260	0.0519	0.0519	0.0779	0.0974	0.1364	0.1169	0.0714	0.0260	0.0260	0.0260	0.0130	0.0000	0.0000	0.0065	154
1991	0.0096	0.0096	0.0385	0.0385	0.0577	0.0385	0.0481	0.0769	0.0865	0.1154	0.1250	0.0769	0.0673	0.0096	0.0192	0.0481	0.0481	0.0481	0.0288	0.0096	0.0000	0.0000	0.0000	0.0000	104
1992	0.0000	0.0000	0.0000	0.0040	0.0121	0.0526	0.0364	0.0405	0.0526	0.0607	0.0688	0.0972	0.1053	0.0850	0.0810	0.0769	0.0729	0.0729	0.0526	0.0202	0.0040	0.0000	0.0000	0.0040	247
1993	0.0000	0.0000	0.0074	0.0000	0.0000	0.0110	0.0147	0.0000	0.0368	0.0368	0.0294	0.0441	0.0735	0.0846	0.1691	0.1507	0.1654	0.1140	0.0404	0.0147	0.0074	0.0000	0.0000	0.0000	272
1994	0.0000	0.0069	0.0000	0.0069	0.0208	0.0694	0.0278	0.0486	0.0625	0.0000	0.0208	0.0625	0.0417	0.0417	0.0833	0.1181	0.1806	0.1111	0.0556	0.0208	0.0208	0.0000	0.0000	0.0000	144
1995	0.0000	0.0017	0.0000	0.0017	0.0000	0.0170	0.0119	0.0187	0.0272	0.0340	0.0424	0.0306	0.0611	0.1087	0.0866	0.1154	0.1460	0.1104	0.0798	0.0458	0.0153	0.0204	0.0136	0.0119	589
1996	0.0000	0.0000	0.0000	0.0000	0.0041	0.0185	0.0062	0.0021	0.0082	0.0000	0.0062	0.0082	0.0021	0.0062	0.0472	0.0739	0.1047	0.1417	0.2074	0.1889	0.1253	0.0370	0.0082	0.0041	487
1997	0.0000	0.0000	0.0000	0.0000	0.0000	0.1081	0.0378	0.0649	0.0324	0.0000	0.0000	0.0162	0.0054	0.0054	0.0216	0.0108	0.0108	0.0324	0.0757	0.1946	0.1892	0.1351	0.0432	0.0162	185
1998	0.0000	0.0000	0.0054	0.0109	0.0761	0.1250	0.1033	0.1141	0.0326	0.0489	0.0163	0.0217	0.0217	0.0217	0.0272	0.0163	0.0326	0.0380	0.0272	0.0489	0.0761	0.0707	0.0380	0.0272	184
1999	0.0000	0.0014	0.0000	0.0000	0.0072	0.0243	0.0200	0.0129	0.0172	0.0100	0.0100	0.0129	0.0129	0.0215	0.0372	0.0329	0.0286	0.0329	0.0887	0.1788	0.1774	0.1559	0.0687	0.0486	699
2000	0.0000	0.0060	0.0000	0.0000	0.0060	0.0655	0.0417	0.0714	0.0417	0.0238	0.0179	0.0357	0.0179	0.0417	0.0476	0.0357	0.0417	0.0833	0.0298	0.0536	0.0476	0.0774	0.1131	0.1012	168
2001	0.0000	0.0000	0.0000	0.0000	0.0059	0.0587	0.0411	0.0196	0.0157	0.0078	0.0039	0.0098	0.0039	0.0117	0.0372	0.0528	0.0607	0.0607	0.1194	0.1468	0.1057	0.0920	0.0763	0.0705	511
2002	0.0000	0.0174	0.0136	0.0074	0.0062	0.0819	0.0509	0.0434	0.0397	0.0273	0.0236	0.0236	0.0360	0.0459	0.0484	0.0471	0.0521	0.0546	0.0620	0.0769	0.0707	0.0682	0.0447	0.0583	806
2003	0.0000	0.0000	0.0000	0.0000	0.0023	0.0264	0.0057	0.0069	0.0115	0.0000	0.0023	0.0011	0.0069	0.0046	0.0069	0.0057	0.0034	0.0138	0.0356	0.1079	0.2698	0.2503	0.1435	0.0953	871
2004	0.0000	0.0010	0.0029	0.0000	0.0019	0.0489	0.0412	0.0594	0.0402	0.0115	0.0096	0.0163	0.0144	0.0086	0.0163	0.0125	0.0182	0.0517	0.1092	0.1466	0.1322	0.1274	0.0862	0.0441	1044
2005	0.0000	0.0011	0.0000	0.0000	0.0011	0.0410	0.0103	0.0057	0.0046	0.0068	0.0091	0.0137	0.0114	0.0228	0.0399	0.0559	0.0992	0.1254	0.1163	0.1300	0.1311	0.0992	0.0468	0.0285	877
2006	0.0000	0.0013	0.0078	0.0091	0.0078	0.0365	0.0313	0.0326	0.0195	0.0195	0.0260	0.0352	0.0404	0.0430	0.0495	0.0755	0.1133	0.1081	0.1211	0.0742	0.0768	0.0391	0.0182	0.0143	768
2007	0.0000	0.0010	0.0019	0.0048	0.0114	0.0439	0.0353	0.0181	0.0210	0.0191	0.0296	0.0172	0.0400	0.0667	0.0677	0.0906	0.0629	0.1096	0.1182	0.1258	0.0705	0.0286	0.0076	0.0086	1049
2008	0.0000	0.0024	0.0024	0.0059	0.0130	0.0485	0.0355	0.0379	0.0213	0.0189	0.0237	0.0426	0.0497	0.0473	0.0781	0.0888	0.0899	0.1053	0.1183	0.0923	0.0521	0.0213	0.0036	0.0012	845
2009	0.0000	0.0014	0.0085	0.0197	0.0508	0.0592	0.0339	0.0141	0.0254	0.0226	0.0254	0.0296	0.0649	0.0508	0.0677	0.0973	0.0889	0.1001	0.0931	0.0719	0.0564	0.0155	0.0028	0.0000	709
2010	0.0000	0.0000	0.0012	0.0012	0.0035	0.3429	0.2392	0.1295	0.0281	0.0094	0.0117	0.0158	0.0205	0.0317	0.0334	0.0199	0.0275	0.0311	0.0281	0.0117	0.0076	0.0018	0.0012	0.0029	1706
2011	0.0000	0.0000	0.0007	0.0074	0.0133	0.0893	0.0804	0.0686	0.0583	0.0280	0.0399	0.0303	0.0509	0.0590	0.0399	0.0413	0.0435	0.0627	0.1041	0.1004	0.0664	0.0111	0.0022	0.0022	1355
2012	0.0000	0.0038	0.0151	0.0075	0.0056	0.0621	0.0583	0.0452	0.0329	0.0273	0.0263	0.0141	0.0235	0.0339	0.0480	0.0724	0.0668	0.0856	0.1364	0.1421	0.0668	0.0245	0.0009	0.0009	1063
2013	0.0009	0.0000	0.0037	0.0065	0.0084	0.0596	0.0298	0.0177	0.0084	0.0121	0.0251	0.0428	0.0680	0.0456	0.0791	0.1182	0.1034	0.1099	0.0912	0.0959	0.0503	0.0205	0.0028	0.0000	1074

Table A.9: Commercial landings by fleet ($C_y^{obs,f}$ in 1000 mt). North and south MRFSS landings have been added to north and south bait landings respectively.

Year	North reduction	South reduction	North bait	South bait
1955	402.74	241.74	10.14	4.50
1956	478.89	236.36	17.51	5.74
1957	389.80	215.78	10.60	14.11
1958	248.34	264.05	3.46	11.23
1959	318.44	343.73	7.98	12.61
1960	323.86	208.37	7.61	11.83
1961	334.76	243.85	8.44	16.63
1962	321.36	219.31	10.60	15.98
1963	147.55	200.89	6.11	18.28
1964	50.61	219.80	4.27	15.97
1965	57.96	216.64	3.30	20.32
1966	7.89	212.80	1.76	11.96
1967	17.21	177.18	1.44	10.17
1968	33.07	202.80	0.75	8.71
1969	15.41	146.92	1.11	9.50
1970	15.80	243.59	1.41	20.23
1971	33.44	216.87	1.87	11.60
1972	69.09	296.78	2.14	8.21
1973	90.69	256.23	2.61	12.16
1974	77.90	214.31	2.11	12.43
1975	48.40	201.81	1.89	19.80
1976	86.84	253.70	1.98	17.65
1977	53.31	287.85	1.39	21.70
1978	63.53	280.55	1.07	24.80
1979	70.19	305.55	1.17	11.85
1980	83.02	318.51	1.07	25.05
1981	68.06	313.25	1.15	21.37
1982	35.08	347.38	1.41	18.60
1983	39.37	379.26	1.46	17.73
1984	34.97	291.33	1.69	12.82
1985	111.25	195.42	8.23	22.01
1986	42.57	195.42	18.24	17.11
1987	82.99	243.91	16.71	18.00
1988	73.64	235.65	21.30	16.58
1989	98.82	223.18	11.32	20.47
1990	144.10	257.05	15.88	14.49
1991	104.55	276.87	24.00	13.30
1992	99.14	198.50	27.69	13.25
1993	58.37	262.23	26.02	13.92
1994	33.39	226.60	18.10	16.58
1995	96.30	243.62	21.45	18.39
1996	61.55	231.38	17.45	18.77
1997	25.17	233.98	19.11	21.90
1998	12.33	233.58	16.37	23.01
1999	8.42	162.77	12.91	21.73
2000	43.19	124.08	14.62	18.84
2001	39.62	193.94	12.69	22.75
2002	27.17	146.89	12.78	23.98
2003	4.15	161.96	8.25	25.00
2004	25.91	152.55	10.14	24.86
2005	15.37	137.48	9.33	28.84
2006	60.15	97.21	11.73	15.63
2007	36.63	137.84	20.13	22.40
2008	39.30	101.84	26.60	21.90
2009	18.66	125.09	18.89	20.15
2010	28.67	154.43	25.62	18.54
2011	29.57	144.45	34.18	17.29
2012	23.91	136.71	40.33	23.61
2013	32.70	98.32	21.07	17.33

Table A.10a: North and south reduction catch-at-age ($C_{y,a}^{obs,f}$ in millions).

North reduction catch-at-age (in millions)							
Year	0	1	2	3	4	5	6+
1955	0.0	16.3	510.6	235.0	274.0	34.9	12.5
1956	0.0	190.6	797.9	280.7	35.4	104.2	28.9
1957	0.0	412.3	930.3	77.5	49.9	25.7	30.2
1958	0.0	22.7	840.1	38.9	8.9	7.0	7.9
1959	0.0	883.9	485.2	264.1	15.0	6.1	11.3
1960	0.0	12.3	1229.2	51.1	67.0	12.9	5.2
1961	0.0	3.5	169.3	849.0	12.8	19.2	3.3
1962	0.0	11.8	196.4	175.1	366.0	26.3	26.0
1963	0.0	157.9	234.0	50.5	36.0	43.0	12.2
1964	0.0	3.7	39.8	38.5	14.3	7.2	8.0
1965	0.0	22.9	53.1	53.4	10.2	1.8	2.0
1966	0.0	4.5	10.5	4.8	2.3	0.2	0.3
1967	0.0	1.8	9.5	18.2	2.3	0.3	0.0
1968	0.0	0.4	31.7	25.7	7.7	0.6	0.1
1969	0.0	0.0	6.6	15.7	3.9	0.1	0.0
1970	0.0	12.3	64.8	4.1	0.5	0.0	0.0
1971	0.0	12.1	27.6	41.5	13.2	1.6	0.0
1972	0.0	29.4	49.6	78.4	14.8	1.4	0.0
1973	0.0	5.7	225.6	36.4	6.7	0.3	0.0
1974	0.0	10.8	319.9	44.5	2.4	1.3	0.0
1975	0.0	0.0	177.0	38.8	5.7	0.2	0.1
1976	0.0	51.3	458.1	39.6	7.3	0.3	0.0
1977	0.0	4.9	126.3	72.6	17.6	1.4	0.1
1978	0.0	0.0	59.2	112.4	23.8	2.9	0.0
1979	0.0	1.7	146.2	83.8	19.3	1.5	0.1
1980	0.0	0.5	54.5	106.1	55.7	11.8	1.0
1981	0.0	0.3	78.8	78.9	46.3	15.4	1.3
1982	0.0	8.4	78.2	94.1	12.5	4.9	0.8
1983	0.0	5.8	405.2	58.9	18.1	2.4	0.2
1984	0.0	6.6	95.0	140.3	27.0	8.0	0.1
1985	0.0	6.1	236.4	27.6	34.6	5.2	1.0
1986	0.0	1.5	119.0	16.1	7.5	4.7	0.9
1987	0.0	1.5	215.1	91.3	19.1	2.0	0.7
1988	0.0	0.0	50.6	109.3	58.4	5.9	0.6
1989	0.0	37.0	283.8	78.9	44.2	11.2	0.2
1990	0.0	5.7	423.8	72.3	26.2	9.5	0.4
1991	0.0	32.9	166.1	148.8	27.7	8.9	1.8
1992	0.0	23.4	280.0	43.5	48.2	10.5	1.8
1993	0.0	9.0	136.1	45.5	7.3	3.4	0.3
1994	0.0	1.8	44.6	35.4	19.4	5.0	0.0
1995	0.0	7.0	200.0	115.9	27.7	1.9	0.0
1996	0.0	0.0	97.0	53.6	15.5	1.3	0.0
1997	0.0	0.0	22.5	13.3	7.2	2.5	0.0
1998	0.0	0.0	10.7	4.6	1.0	0.0	0.0
1999	0.0	0.0	9.4	10.3	4.1	0.4	0.0
2000	0.0	0.6	57.4	41.6	2.0	1.1	0.0
2001	0.0	0.0	11.3	60.4	4.1	0.0	0.0
2002	0.0	2.7	23.1	32.7	8.0	0.2	0.0
2003	0.0	0.0	4.2	3.3	1.2	0.1	0.0
2004	0.0	0.2	39.6	20.6	3.9	0.0	0.0
2005	0.0	0.0	10.0	27.5	7.9	0.1	0.0
2006	0.0	4.3	87.6	81.3	19.0	0.2	0.0
2007	0.0	3.6	123.0	28.1	6.7	0.4	0.0
2008	0.0	0.2	26.7	82.7	13.2	1.0	0.0
2009	0.0	8.7	21.2	32.8	7.2	0.9	0.0
2010	0.0	0.0	48.7	37.2	20.7	0.4	0.0
2011	0.0	7.1	90.1	23.6	2.8	0.4	0.0
2012	0.0	0.2	80.4	19.8	3.0	0.0	0.0
2013	0.0	3.3	83.9	27.1	1.7	0.0	0.0

South reduction catch-at-age (in millions)							
Year	0	1	2	3	4	5	6+
1955	761.0	657.8	547.0	32.3	33.3	3.2	0.5
1956	36.4	1882.7	104.8	38.9	9.4	46.5	8.5
1957	299.6	1187.7	431.4	19.2	20.9	14.8	12.1
1958	106.1	835.4	795.2	33.1	8.4	9.0	6.5
1959	11.4	3154.8	366.1	124.2	18.4	5.8	7.4
1960	72.2	268.7	979.4	25.3	35.2	10.9	5.8
1961	0.3	829.0	334.3	360.6	6.4	10.2	0.6
1962	51.6	502.3	638.1	42.2	57.4	4.4	2.3
1963	96.9	566.3	475.2	72.0	8.9	9.4	2.1
1964	302.6	700.2	565.2	45.0	3.7	0.6	0.3
1965	249.1	716.4	364.5	24.3	1.9	0.0	0.1
1966	349.5	546.3	393.6	26.9	1.6	0.2	0.0
1967	7.0	631.4	256.2	54.5	2.8	0.2	0.0
1968	154.6	375.9	503.8	40.0	3.0	0.4	0.0
1969	158.1	372.3	277.7	32.2	1.5	0.0	0.0
1970	21.4	857.5	407.9	28.4	3.4	0.1	0.0
1971	72.9	251.2	496.7	46.8	4.7	0.9	0.0
1972	50.2	951.9	438.8	94.6	4.3	0.5	0.0
1973	56.0	582.8	927.3	2.2	0.3	0.0	0.0
1974	315.6	625.9	666.0	4.1	0.0	0.0	0.0
1975	298.6	720.0	909.6	11.4	1.0	0.0	0.0
1976	274.2	1560.6	883.0	8.3	0.7	0.0	0.0
1977	484.6	998.0	1957.2	10.9	0.2	0.0	0.0
1978	457.4	664.1	1611.8	145.7	7.3	0.6	0.0
1979	1492.5	621.5	1457.1	44.1	2.5	0.0	0.0
1980	88.3	1477.6	1403.8	116.7	13.6	2.5	0.5
1981	1187.6	698.4	1732.7	143.3	1.1	0.0	0.0
1982	114.1	911.0	1661.3	285.6	3.8	0.9	0.1
1983	964.4	511.4	1887.8	55.5	29.3	2.6	0.5
1984	1294.2	1017.6	797.1	131.2	23.4	7.2	0.4
1985	637.2	1069.7	988.2	16.5	1.0	1.0	0.7
1986	98.4	222.7	1404.1	33.0	2.9	1.4	0.2
1987	42.9	503.2	1372.5	60.6	6.1	0.1	0.0
1988	338.8	282.7	1107.0	192.1	11.3	1.3	0.0
1989	149.7	1117.6	874.7	29.5	3.2	0.4	0.0
1990	308.1	127.1	1129.3	36.7	16.0	2.9	0.1
1991	881.8	1001.0	780.0	105.2	10.3	1.8	0.4
1992	399.6	703.8	515.4	22.6	3.1	0.4	0.1
1993	67.9	370.0	847.0	103.4	3.6	0.5	0.0
1994	88.6	272.7	844.3	129.7	47.8	2.5	0.2
1995	56.8	526.7	471.8	193.2	39.8	2.4	0.0
1996	33.7	209.1	582.2	85.4	13.5	0.7	0.0
1997	25.2	246.9	402.1	224.2	44.4	6.5	1.2
1998	72.8	185.0	529.9	121.7	72.0	9.0	0.8
1999	193.9	301.1	441.4	71.5	20.9	2.9	0.4
2000	77.8	113.6	283.2	70.3	9.1	0.9	0.0
2001	23.0	43.5	358.1	157.2	10.8	0.7	0.0
2002	178.2	209.1	236.7	103.1	9.1	0.3	0.0
2003	60.7	127.5	443.1	50.4	6.6	0.8	0.3
2004	18.0	213.7	612.5	55.1	13.5	0.9	0.0
2005	12.1	78.9	372.9	126.6	10.8	1.7	0.0
2006	9.2	294.6	212.5	40.4	4.6	0.3	0.0
2007	1.1	235.6	486.3	41.4	6.3	0.3	0.0
2008	7.9	52.1	368.2	23.9	1.5	0.0	0.0
2009	4.4	343.7	207.8	98.0	12.7	0.9	0.0
2010	15.5	409.5	452.4	30.9	7.6	0.2	0.0
2011	0.0	411.3	402.9	41.6	6.0	1.3	0.0
2012	4.7	127.1	546.5	13.8	0.9	0.0	0.0
2013	22.1	236.7	200.9	49.2	8.4	0.3	0.0

Table A.10b: North and south bait catch-at-age ($C_{y,a}^{obs,f}$ in millions) (includes MRFSS).

North bait catch-at-age (in millions)							
Year	0	1	2	3	4	5	6+
1985	0.0	0.0	19.1	5.5	3.4	0.7	0.2
1986	0.0	0.0	3.3	29.0	13.1	1.2	0.1
1987	0.0	0.0	3.1	26.5	12.0	1.1	0.1
1988	0.0	0.0	3.7	33.7	15.3	1.4	0.2
1989	0.0	0.0	2.4	17.6	7.9	0.7	0.1
1990	0.0	0.0	4.6	24.2	10.6	1.0	0.1
1991	0.0	0.0	7.6	35.9	15.6	1.5	0.2
1992	0.0	0.0	10.6	40.2	17.0	1.8	0.2
1993	0.0	0.0	10.5	37.5	15.8	1.6	0.2
1994	0.0	0.0	4.7	20.7	14.3	2.1	0.1
1995	0.0	0.0	4.9	26.6	24.3	0.1	0.0
1996	0.0	0.0	18.0	19.9	5.7	0.3	0.0
1997	0.0	0.0	6.4	15.2	16.8	4.8	0.7
1998	0.1	0.0	3.6	13.9	13.1	2.5	0.4
1999	0.2	0.0	4.4	14.2	9.2	1.2	0.3
2000	0.0	0.1	14.6	11.2	8.0	1.0	0.3
2001	0.0	0.0	3.1	20.2	3.8	0.4	0.1
2002	0.0	0.0	1.5	15.1	8.4	1.4	0.0
2003	0.0	0.0	2.4	12.6	3.8	0.2	0.0
2004	0.0	0.0	6.3	12.5	4.7	0.6	0.1
2005	0.0	0.0	5.4	12.1	4.7	0.6	0.1
2006	0.0	0.1	8.4	17.2	4.2	0.2	0.0
2007	0.0	0.0	24.5	30.9	6.8	0.5	0.1
2008	0.0	0.0	19.1	46.6	10.1	1.1	0.0
2009	0.0	0.0	10.1	34.2	10.4	0.9	0.0
2010	0.0	0.0	30.3	32.1	17.9	2.0	0.2
2011	0.0	0.0	15.5	53.0	35.5	4.9	0.0
2012	0.0	0.0	53.2	63.9	16.9	1.1	0.3
2013	0.0	0.0	18.3	39.5	10.9	1.8	0.0

South bait catch-at-age (in millions)							
Year	0	1	2	3	4	5	6+
1985	0.3	16.5	62.7	13.5	2.6	0.3	0.0
1986	0.2	10.2	58.2	12.2	1.7	0.2	0.0
1987	0.2	9.5	53.4	11.0	2.2	0.2	0.0
1988	0.2	10.2	45.2	11.2	2.1	0.2	0.0
1989	0.2	12.5	55.2	13.8	2.5	0.2	0.0
1990	0.4	24.2	39.2	8.4	1.6	0.2	0.0
1991	0.2	16.3	40.6	8.2	1.5	0.2	0.0
1992	0.3	21.1	35.4	8.0	1.5	0.1	0.0
1993	0.6	24.3	25.3	8.7	1.7	0.2	0.0
1994	0.2	14.5	45.4	10.7	1.9	0.2	0.0
1995	0.0	37.1	35.4	20.8	1.6	0.0	0.0
1996	0.0	2.9	43.2	10.5	1.9	0.0	0.0
1997	0.0	5.9	37.2	21.7	5.3	0.9	0.4
1998	2.9	5.3	41.5	18.1	8.2	0.9	0.2
1999	0.0	4.8	65.8	15.5	4.5	0.6	0.0
2000	0.6	17.1	46.9	8.6	0.1	0.0	0.0
2001	0.2	4.5	49.7	16.9	1.0	0.2	0.0
2002	0.0	2.5	15.1	29.2	10.3	1.2	0.1
2003	0.5	8.8	65.6	11.3	1.1	0.0	0.0
2004	0.0	7.5	78.5	17.2	3.2	0.3	0.0
2005	0.0	1.7	49.8	39.6	2.3	0.3	0.0
2006	0.0	18.9	32.7	13.0	1.5	0.0	0.0
2007	0.0	34.5	87.5	3.7	1.3	0.0	0.0
2008	0.0	4.1	79.5	7.4	1.2	0.3	0.0
2009	0.3	23.4	36.1	25.7	2.6	0.0	0.0
2010	0.0	32.4	52.5	6.2	2.0	0.0	0.0
2011	0.0	39.2	48.3	7.7	1.5	0.0	0.0
2012	0.0	10.3	102.7	2.1	0.0	0.0	0.0
2013	0.9	60.3	28.3	9.0	0.3	0.0	0.0

Appendix B

Algebraic details of the Statistical Catch-at-Age/Length Model

The text following sets out the equations and other general specifications of the Statistical Catch-at-Age/Length (SCAA/L) assessment model applied to Atlantic menhaden, 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 various Base Case (BC) runs considered in the main text..

B.1. Population dynamics

B.1.1 Numbers-at-age

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

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

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

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

where

$N_{y,a}$ is the number of fish of age *a* at the start of fishing year *y*, where this "start" is taken to be 1 March,

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, where here *m* = 6),

$Z_{y,a} = \sum_f F_y^f S_{y,a}^f + M_{y,a}$ is the total mortality in year *y* on fish of age *a*, where

f denotes one of four fisheries (reduction north, reduction south, bait north and bait south)

$M_{y,a}$ denotes the natural mortality rate for fish of age *a* in year *y* (taken here to be year-independent – see Table A1),

F_y^f is the fishing mortality of a fully selected age class in year *y* for fishery *f*, and

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

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 egg production by the mature fish by a Beverton-Holt stock-recruitment relationship, allowing for annual fluctuation about the deterministic relationship.

$$R_y = \frac{\alpha E_y^{sp}}{\beta + E_y^{sp}} e^{(\varsigma_y - (\sigma_R)^2/2)} \tag{B4}$$

where

α and β are egg production-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,

E_y^{sp} is the egg production at the start of year *y*, computed as:

$$E_y^{sp} = \sum_{a=0}^{m} f_{y,a} g_{y,a} N_{y,a} e^{-Z_{y,a}\mu_{spawn}} \tag{B5}$$

where

spawning for the menhaden stock under consideration is taken to occur at the beginning of the fishing year, i.e. $\mu_{spawn} = 0$,

$f_{y,a}$ is the proportion of fish of age *a* which are (reproductively) mature in year *y* (see Table A2), and

$g_{y,a}$ is the fecundity (egg production) of fish of age *a* that are mature in year *y* (see Table A3).

Note that spawning biomass B_y^{sp} at the start of year *y* is computed as:

$$B_y^{sp} = \sum_{a=0}^{m} f_{y,a} w_{y,a}^{strt} N_{y,a} e^{-Z_{y,a}\mu_{spawn}} \tag{B6}$$

where

$w_{y,a}^{strt}$ is the weight of a fish of age *a* at the start of fishing year *y* (see Table A5a).

Further, for the Beverton-Holt relationship, the parameters α and β parameters are related to steepness *h* and the deterministic pristine egg production E_0 by the equations:

$$\alpha = \frac{4hR_0}{5h-1} \quad \text{and} \quad \beta = \frac{E_0(1-h)}{(5h-1)}$$

For the Base Cases, the standard Beverton-Holt form with *h* fixed at 0.98 has been used.

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

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

$$C_y^f = \sum_{a=0}^{m} w_{y,a}^{mid} C_{y,a}^f = \sum_{a=0}^{m} w_{y,a}^{mid} N_{y,a} S_{y,a}^f F_y^f \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a} \tag{B7}$$

where

$w_{y,a}^{mid}$ denotes the (middle of the fishing year) mass of fish of age *a* landed in year *y* (see Table A5b),

$C^f_{y,a}$ is the catch-at-age, i.e. the number of fish of age *a*, caught in year *y* in fishery *f*).

B.1.4. Survey indices and survey selectivity

The model estimate of JAI recruitment survey index is computed as:

$$\tilde{N}^{\mathrm{JAI}}_y = N_{y,o} e^{-Z_{y,0} T^{JAI}/12} \tag{B8}$$

T^{JAI} is the number of months after the start of the fishing year when the survey takes place (T^{JAI}=3).

The SAD and NAD surveys of 1-6+ fish are each assumed to reflect the effect of year-invariant length-specific selectivity. The year-invariant selectivity-at-length S^{i}_l for index *i* (where *i* = SAD or NAD) is converted to year-dependent selectivity-at-age $S^{\mathrm{i}}_{y,a}$:

$$S^i_{y,a} = \sum_l S^i_{y,l} A^i_{y,a,l} \tag{B9}$$

where

$A^i_{y,a,l}$ is the proportion of fish of age *a* in year *y* that fall in the length group *l* for index *i* (i.e. $\sum_l A^i_{y,a,l} = 1$ for all ages *a*)

The matrix *A* is calculated under the assumption that length-at-age is normally distributed about a mean ($L^i_{y,a}$) given in Tables A.4a (SAD) and A.4b (SAD), i.e.:

$$L_a \sim N\left[L^i_{y,a} ; \left(\theta^i_{y,a}\right)^2\right] \tag{B10}$$

where

N is the normal distribution, and

$\theta^i_{y,a}$ is the standard deviation of length-at-age *a* in year *y* for survey *i*, which is modelled to be proportional to the expected length at age *a*, i.e.:

$$\theta^i_{y,a} = \gamma L^i_{y,a} \tag{B11}$$

with γ = 0.2 for the Base Cases.

The predicted indices are then computed as:

$$\tilde{N}^{\mathrm{i}}_y = \sum_{a=1}^{m} S^{\mathrm{i}}_{y,a} N_{y,a} e^{-Z_{y,a} T^i/12} \tag{B12}$$

where

$T^i = 2$ for SAD and $T^i = 6$ for NAD.

B.1.5. Initial conditions

As the first year for which data are available for Atlantic menhaden 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 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.

$$N_{y_0,a} = N_{\text{start},a} \qquad \text{for } 0 \le a \le a^{est} \tag{B13}$$

and

$$N_{\text{start},a} = N_{\text{start},a-1} e^{-M_{a-1}} (1-\phi S_{a-1}) \qquad \text{for } a^{est} < a \le m-1 \tag{B14}$$

$$N_{\text{start},m} = N_{\text{start},m-1} e^{-M_{m-1}} (1-\phi S_{m-1}) \big/ (1-e^{-M_m}(1-\phi S_m)) \tag{B15}$$

where

$$S_a = \sum_f S^f_{y0,a} C^{obs,f}_{y0} \Big/ \sum_f C^{obs,f}_{y0} \tag{B16}$$

For the Base Cases a^{est}=2. Thus the abundances of the first three ages plus the value of the parameter ϕ are estimated; there is insufficient information content in the data to allow all elements of the starting numbers-at-age vector to be estimated with reasonable precision.

B.2. The (penalised) likelihood function

The model can be fit to (a subset of) fleet-specific catches, survey abundance indices, and commercial and survey catch-at-age and catch-at-length data to estimate model parameters (these 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.

B.2.1. Survey abundance data

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

$$I^{obs,i}_y = I^i_y \exp(\varepsilon^i_y) \quad \text{or} \quad \varepsilon^i_y = \ell\text{n}(I^{obs,i}_y) - \ell\text{n}(I^i_y) \tag{B17}$$

where

$I^{obs,i}_y$ is the survey index for survey *i* (where *i* is JAI, NAD or SAD) in year *y*,

$I^i_y = \hat{q}^i \tilde{N}^i_y$ is the corresponding model estimate, where

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

$\tilde{N}^i_y$ is defined by equation B8 for JAI and B12 for SAD and NAD, and

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

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

$$-\ell\mathrm{n}\,L^{\mathrm{survey}}=\sum_i\sum_y\left\{\ell\mathrm{n}\left(\sqrt{\left(\sigma_y^i\right)^2+\left(\sigma_{Add}^i\right)^2}\right)+\left(\varepsilon_y^i\right)^2/\left[2\left(\left(\sigma_y^i\right)^2+\left(\sigma_{Add}^i\right)^2\right)\right]\right\} \quad \text{(B18)}$$

where

$\sigma_y^i=\sqrt{\ln(CV_y^2+1)}$ is the standard deviation of the residuals for the logarithm of survey *i* in year *y* (which is input), and

σ_{Add}^i is the square root of the additional variance for survey series *i*, which is estimated in the model fitting procedure.

The catchability coefficient q^i for survey index *i* is estimated by its maximum likelihood value:

$$\ell n\,\hat{q}^i=1/n_i\sum_y\left(\ln I_y^i-\ln\tilde{N}_y^i\right) \quad \text{(B19)}$$

B.2.2. Commercial catches-at-age

The contribution of the catch-at-age data for fleet *f* to the negative of the log-likelihood function under the assumption of an "adjusted" lognormal error distribution (Punt and Kennedy, 1997) is given by:

$$-\ell\mathrm{n}\,L^{\mathrm{CAA}}=W_{CAA}\sum_f\sum_y\sum_a\left[\ell n\left(\sigma_{CAA}^f/\sqrt{p_{y,a}^{obs,f}}\right)+p_{y,a}^{obs,f}\left(\ell n\,p_{y,a}^{obs,f}-\ell n\,p_{y,a}^{*f}\right)^2/2\left(\sigma_{CAA}^f\right)^2\right] \quad \text{(B20)}$$

where

$p_{y,a}^{obs,f}=C_{y,a}^{obs,f}/\sum_{a'}C_{y,a'}^{obs,f}$ is the observed proportion of fish caught in year *y* by fleet *f* that are of age *a* (see Tables A10a and b),

$p_{y,a}^{*f}=\sum_{a'}\chi_{a,a'}p_{y,a'}^f$ is the model-predicted proportion of fish caught in year *y* by fleet *f* that are of age *a*, taking account of ageing error, with

$\chi_{a,a'}$ the ageing error on a fish of age a (see Table A.6), and

$p_{y,a}^f=C_{y,a}^f/\sum_{a'}C_{y,a'}^f$ is the model-predicted proportion of fish caught in year *y* by fleet *f* that are of age *a*, where

$$C_{y,a}^f=N_{y,a}\;S_{y,a}^f\,F_y^f\left(1-e^{-Z_{y,a}}\right)/Z_{y,a} \quad \text{(B21)}$$

and

σ_{CAA}^f is the standard deviation associated with the catch-at-age data for fleet *f*, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{CAA}^f=\sqrt{\sum_y\sum_a p_{y,a}^{obs,f}\left(\ell n\,p_{y,a}^{obs,f}-\ell n\,p_{y,a}^{*f}\right)^2\Big/\sum_y\sum_a 1} \quad \text{(B22)}$$

Commercial catches-at-age are incorporated in the likelihood function using equation (B20), for which the summation over age *a* is taken from age a_{minus} (considered as a minus group) to a_{plus} (a plus group).

An alternative to this "adjusted" lognormal error distribution, is the "sqrt(p)" formulation, for which equation B20 is modified to:

$$-\ell\mathrm{n}\,L^{\mathrm{CAA}} = W_{CAA}\sum_f\sum_y\sum_a\left[\ell n\left(\sigma^f_{CAA}\right)+\left(\sqrt{p^{obs,f}_{y,a}}-\sqrt{p^{*f}_{y,a}}\right)^2/2\left(\sigma^f_{CAA}\right)^2\right] \quad \text{(B23)}$$

and equation B1.21 is adjusted similarly:

$$\hat{\sigma}^f_{CAA}=\sqrt{\sum_y\sum_a\left(\sqrt{p^{obs,f}_{y,a}}-\sqrt{p^{*f}_{y,a}}\right)^2\Big/\sum_y\sum_a 1} \quad \text{(B24)}$$

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

The W_{CAA} factor can be selected on input to downweight the contributions of these data to the negative log likelihood, to account for their possible non-independence.

For the Base Cases, the sqrt(p) formulation has been used with W_{CAA} = 1 (i.e. no downweighting).

B.2.3. Survey catches-at-length

For runs including the NAD and SAD indices, 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-length are computed using the data provided [as described in section B1.1.4)]:

$$p^i_{y,l}=\sum_{a=1}^{m}A^i_{y,a,l}S^i_{y,l}N_{y,a}e^{-Z_{y,a}T^i/12} \quad \text{(B25)}$$

The following term is then added to the negative log-likelihood[2]:

$$-\ell\mathrm{n}\,L^{\mathrm{CAL}} = W_{CAL}\sum_i\sum_y\sum_l\left[\ell n\left(\sigma^i_{\mathrm{len}}/\sqrt{p^{obs,i}_{y,l}}\right)+p^{obs,i}_{y,l}\left(\ell n\,p^{obs,i}_{y,l}-\ell n\,p^i_{y,l}\right)^2/2\left(\sigma^i_{\mathrm{len}}\right)^2\right] \quad \text{(B26)}$$

for the adjusted log normal distribution assumption, and for the sqrt(p) formulation:

$$-\ell\mathrm{n}\,L^{\mathrm{CAL}} = W_{CAL}\sum_i\sum_y\sum_l\left[\ell n\left(\sigma^i_{\mathrm{len}}\right)+\left(\sqrt{p^{obs,i}_{y,l}}-\sqrt{p^i_{y,l}}\right)^2/2\left(\sigma^i_{\mathrm{len}}\right)^2\right] \quad \text{(B27)}$$

$$\hat{\sigma}^i_{len}=\sqrt{\sum_y\sum_l\left(\sqrt{p^{obs,i}_{y,l}}-\sqrt{p^i_{y,l}}\right)^2\Big/\sum_y\sum_l 1} \quad \text{(B28)}$$

Survey catches-at-length are incorporated in the likelihood function using equation (B26) or (B27), for which the summation over length *l* is taken from length l_{minus} (considered as a minus group) to l_{plus} (a plus group).

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[2] In cases where the value of $p^{obs,i}_{y,l}$ is zero, that term is omitted from these summation and the corresponding ones to estimate σ^i_{len}. Note that in any case the limit as $p\to 0$ of $p(\ln p)^2$ is zero.

The W_{CAL} 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 particularly because the length distributions for adjacent ages overlap) to the overall negative log-likelihood.

Note: The CAL data for the years 1980 to 1985 and 1987 for SAD were omitted from the fit as these are based on less than 100 fish.

For the Base Cases, the sqrt(p) formulation has been used with W_{CAL} = 0.25.

The reason for this W_{CAL} value choice is that for the NAD and SAD survey series, the number of length groups considered with non-zero data is roughly four times the number of age-groups represented to an appreciable extent (NAD: 21 length groups *vs* about 5 ages; SAD: 11 length groups *vs* about 3 ages). While length distributions can be broken down to very narrow length ranges, clearly this provides no actual additional information to the likelihood, as these length distributions reflect at best the relative magnitudes of the different age groups of which they are comprised. In cases where the value of W_{CAA} is changed from 1, the value of W_{CAL} is usually changed at the same time to maintain this 1:0.25 ratio of relative weightings.

B.2.4. 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:

$$-\ell n L^{\text{pen}} = \sum_{y=y_1}^{y_2}\left[\varepsilon_y^2 / 2\sigma_{\text{R}}^2\right] + 10000\sum_{y=y_1}^{y_2}\varepsilon_y \tag{B29}$$

where

y1 and y2 are the first and last years over which these residuals are included (the full period of the assessment is used here)

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

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

The second term on the right hand side of equation B29 is simply a device to assist estimation stability by ensuring that the residuals sum to zero, as would follow were this the only term in the likelihood.

For the Base Cases, σ_{R} has been set to 0.6.

The reason for this choice was that for a large number of assessment runs conducted initially, the output standard deviation of the recruitment residuals was typically 0.6 or slightly less.

B.2.5. Catches

$$-\ell n L^{\text{Catch}} = \sum_f \sum_y \left[\frac{\ell n C_y^{obs,f} - \ell n C_y^f}{2\sigma_{\text{C}}^2}\right] \tag{B30}$$

where

$C_y^{obs,f}$ is the observed catch in year *y* for fleet *f*,

C_y^f is the predicted catch in year *y* for fleet *f* (equation B7), and

σ_{C} is the CV input: 0.1 throughout.

B.3. Estimation of precision

Where quoted, CV's or 90% probability interval estimates are based on the Hessian.

B.4. Model parameters

B.4.1. Commercial fishing selectivity-at-age

The commercial fishing selectivities are estimated separately for ages a_{minus} to age a_{plus} and are taken to be flat thereafter. For the north reduction fleet a_{minus}=1 and age a_{plus}=5, for the south reduction fleet a_{minus}=0 and age a_{plus}=4, for the north bait fleet a_{minus}=2 and age a_{plus}=4, and for the south bait fleet a_{minus}=1 and age a_{plus}=4.

The selectivities are assumed to be year-independent for the Base Cases. The option of allowing changes between "blocks" of years is available.

B.4.2. Survey fishing selectivity-at-length

The fishing selectivities-at-length for SAD and NAD are estimated separately for six pre-determined of lengths (see Table B.1). Between these lengths, selectivity is assumed to change linearly and above the maximum pre-determined length, selectivity is taken to be flat.

Table B.1: Parameters for the Base Cases

Stock-recruit standard deviations	σ_R	0.6			
Model plus group	m	6			
Commercial CAA		North reduction	South reduction	North bait	South bait
	a_{minus}	1	0	2	1
	a_{plus}	5	4	4	4
Survey					
Pre-determined lengths (cm) at which selectivity is estimated directly		SAD	NAD		
	l_{minus}	12	13		
		14	17		
		16	21		
		18	25		
		20	29		
	l_{plus}	22	33		

B.5.Biological Reference Points (BRPs)

The equilibrium catch for a fully selected fishing proportion *F* is calculated as:

$$C(F)=\sum_a w_a^{mid}\frac{S_a F}{Z_a}N_a(F)\left(1-e^{-Z_a(F)}\right) \tag{B31}$$

where

$$w_a^{mid}=\sum_{y1=2009}^{2013} w_{y,a}^{mid}\Big/5,$$

$$S_a=\frac{\sum_{y1=2009}^{2013}\sum_f F_{y,a}^f}{\max\left(\sum_{y1=2009}^{2013}\sum_f F_{y,a}^f\right)} \text{ and}$$

$$M_a=\sum_{y1=2009}^{2013} M_{y,a}\Big/5$$

and where numbers-at-age *a* are given by:

$$N_a(F) = \begin{cases} R_0(F) & \text{for } a = 0 \\ N_{a-1}(F)e^{-Z_{a-1}(F)} & \text{for } 0 < a < m \\ \dfrac{N_{m-1}(F)e^{-Z_{m-1}(F)}}{\left(1 - e^{-Z_m(F)}\right)} & \text{for } a = m \end{cases} \tag{B32}$$

where

$$R_0(F) = \frac{\alpha E^{sp}(F)}{\beta + E^{sp}(F)} \tag{B33}$$

with

$$E^{sp}(F) = \sum_a g_a f_a N_a(F) e^{-Z_a(F)\mu_{spawn}} \tag{B34}$$

$g_a = \sum_{y1=2009}^{2013} g_{y,a} \Big/ 5$ and

$f_a = \sum_{y1=2009}^{2013} f_{y,a} \Big/ 5$

$F_{n\%}$ is found by searching over F to find the value where $\dfrac{E^{sp}(F_n)}{E^{sp}(F=0)}$ is equal 0.n. The associated spawning biomass and yield are given by

$$B^{sp}(F_n) = \sum_a f_a w_a^{strt} N_a(F_n) e^{-Z_a(F_n)\mu_{spawn}} \tag{B35}$$

$$C(F_n) = \sum_a w_a^{mid} \frac{S_a F_n}{Z_a(F_n)} N_a(F_n)\left(1 - e^{-Z_a(F_n)}\right) \tag{B36}$$