# **Addendum:** On Assessment of the Atlantic Menhaden Population

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## Summary

The possibility of a single change in the selectivity function for each of the four fisheries during recent years is introduced into the assessment model. This leads to fits of the data to the model which are considerably preferred in terms of AIC. For scenario II for which only the JAI abundance index is used in the fit, recent fishing mortalities no longer increase substantially, and the recent spawning biomasses become much higher. For scenario III for which the SAD and NAD abundance indices are used, high recent fishing mortalities are no longer evident when such changes in selectivity are admitted. The main selectivity change is in the north reduction fishery, where the peak changes from age 3 to age 2. Of note is that fishing mortality and spawning biomasses estimates become fairly similar over time for the two scenarios, given this selectivity change possibility, except for a recent decrease in spawning biomass and larger fishing mortality for recent years when using the JAI rather than the SAD and NAD indices. Viewed overall, allowing for these selectivity changes leads to considerably improved fits to the data, and to a more positive estimate of the status for the resource over recent years.

## Introduction

In the results presented in the main paper, an important and strong assumption made is that the commercial selectivities remain unchanged throughout the assessment period. This Addendum explores the consequences of relaxing this assumption to some extent, by allowing for a single change in a recent year in each of the reduction and bait fishery selectivity functions for both the north and south regions.

## Methodology

The changes in selectivity examined here are simple, allowing for two periods of fixed selectivity for each fishery. Two sensitivities have been run for each of BCII, BCIII and BCIII* (which is BCIII with $W_{CAA}$=1 and $W_{CAL}$=0.25, i.e. no downweighting of the CAA data as in BCIII).

In sensitivities IIh/IIIh/IIIh*, the two periods of fixed selectivities are taken to be the same for all four fisheries. The year for the switch has been selected by trying each of the years between 2000 and 2012 in turn, and selecting the year providing the best fit in terms of the overall negative log likelihood.

In sensitivities IIi/IIIi/IIIi*, the years when the selectivity switch occurs may be different for the different fleets. As for the sensitivities IIh/IIIh/IIIh*, the year for the switch for each fleet in turn has been selected by starting with the common year selected for that first set of sensitivities, and then trying each of the years between 2000 and 2012 in turn and selecting the year providing the best fit. (Note that though comprehensive, this does not constitute an exhaustive search through all possible options of this type.)

Note that where models are compared using AIC, choosing a year for a switch to a new selectivity function counts as one estimable parameter.

## Results

The results of the two sensitivities to BCII, BCIII and BCIII* are reported in Tables 1, 2a and 2b respectively. The spawning biomass and fishing mortality trajectories are compared in Figures 1 to 3, while the commercial selectivities-at-age are plotted in Figures 4, 5a and 5b.

The fits of BCII, IIh and IIi to the survey indices are compared in Figure 6. Figures 7a and 7b are the corresponding plots for BCIII and its sensitivities, and for BCIII* and its sensitivities respectively.

## Discussion

The following features of the results are of note.

- Allowing for a change in selectivity is very clearly AIC justified, not only when the switch occurs in the same year for all four fisheries, but considerably more so when the year of the change may be different for each. (Tables 1 and 2)
- For scenario II (using the JAI index only), allowing for the change eliminates the very high fishing mortality estimates for the last three years. Although spawning biomass still decreases over recent years, the current level remains well above the low of the mid-1980s. (Figure 1)
- For scenario III (using the NAD and SAD indices only), spawning biomass is lower, and historic fishing mortality in particular somewhat higher. (Figure 2a)
- For scenario III* (with no downweighting of the CAA data from the fisheries), importantly the model fit no longer favours very high fishing mortalities in recent years, and instead of a decreasing trend in spawning biomass, assesses this biomass to be both high and fairly stable. (Figure 3)
- The major changes estimated in selectivities, when these may change in different years for the different fisheries, are for the north reduction fishery (for which the peak changes from age 3 to age 2) and for the south bait fishery (for which the selectivity for age 3 drops substantially). (Figures 4, 5a and 5b).
- The fits to the survey indices do not change greatly, except for scenario III* for which the SAD and particularly the NAD indices are fit rather better for the last few years when the possibility of changes in selectivity is admitted. (Figures 6, 7a and 7b)

Perhaps the most important feature of these results is that evident from the comparison across the three scenarios shown in Figure 3. When a recent commercial selectivity change is allowed, and for different years for the four fisheries, fishing mortality and spawning biomasses estimates are fairly similar over time, except for a recent decrease in spawning biomass and somewhat larger fishing mortality for recent years for scenario II compared to the other two scenarios.

Viewed overall, allowing for these selectivity changes leads to considerably improved fits to the data, and to a more positive estimate of status for the resource over recent years. Of interest would be to discuss whether there is independent evidence in the patterns of fishing that suggests selectivity changes similar to those estimated here. For example, has the north reduction fishery tended to distribute more towards the south over recent years, which could have modified its age selection pattern more towards younger fish?

**Table 1**: Results for sensitivities based on **BCII**, with different periods of fixed commercial selectivity. 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.

| | | BCII | | IIh | | IIi | |
|---|---|---|---|---|---|---|---|
| | | No change in selectivity | | Change in selectivity: 2003/2004 for all fleets | | Change in selectivity: 2010/2011 North Red. 2003/2004 South Red. 2003/2004 North Bait 2006/2007 South Bait | |
| '-lnL:overall | | -957.5 | | -997.8 | | -1012.5 | |
| ΔAIC | | 0.0 | | -52.7 | | -76.0 | |
| '-lnL:Index | | 1.8 | | 2.4 | | 3.6 | |
| '-lnL:comCAA | | -972.5 | *-(972.5)* | -1010.8 | *-(1010.8)* | -1024.4 | *-(1024.4)* |
| -lnL:indexCAL | | - | | - | | - | |
| '-lnL:catch | | 0.6 | | 0.6 | | 0.4 | |
| '-lnL:RecRes | | 12.5 | | 9.9 | | 8.0 | |
| $h$ | | **0.98** | | **0.98** | | **0.98** | |
| $B^{sp}_{1980}$ | | 1783 | (0.64) | 1380 | (0.59) | 2072 | (0.59) |
| $B^{sp}_{2013}$ | | 214 | (0.17) | 420 | (0.46) | 1025 | (0.46) |
| $B^{sp}_{2013}/B^{sp}_{1980}$ | | 0.12 | (0.60) | 0.30 | (0.59) | 0.49 | (0.59) |
| $B^{sp}_{2013}$/av($B^{sp}_{1990}$-$B^{sp}_{2005}$) | | 0.26 | (0.24) | 0.38 | (0.33) | 0.65 | (0.33) |
| $F_{2013}$ | | 8.59 | (0.61) | 1.66 | (0.54) | 0.92 | (0.54) |
| $q$ ($10^9$): | JAI | 4.1 | (0.07) | 3.5 | (0.16) | 3.0 | (0.16) |
| | SAD | (44.6) | (0.08) | (36.5) | (0.21) | (28.7) | (0.21) |
| | NAD | (77.1) | (0.24) | (57.9) | (0.31) | (39.7) | (0.31) |
| AddVar: | JAI | 0.00 | (0.00*) | 0.00 | (0.00*) | 0.00 | (0.00*) |
| | SAD | - | | - | | - | |
| | NAD | - | | - | | - | |
| $\sigma_{Rout}$ | | 0.52 | (0.06) | 0.46 | (0.11) | 0.41 | (0.11) |

**Table 2**: Results for sensitivities based on **BCIII**, with different periods of fixed commercial selectivity, and equivalent runs with no downweighting of the CAA data ($W_{CAA}$=1 and $W_{CAL}$=0.25). 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.

| | | BCIII | | IIIh | | IIIi | | BCIII* | | IIIh* | | IIIi* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | No change in selectivity | | Change in selectivity: 2005/2006 for all fleets | | Change in selectivity: 2010/2011 North Red. 2003/2004 South Red. 2003/2004 North Bait 2006/2007 South Bait | | No downweighting of CAA No change in selectivity | | No downweighting of CAA Change in selectivity: 2003/2004 for all fleets | | No downweighting of CAA Change in selectivity: 2010/2011 North Red. 2003/2004 South Red. 2003/2004 North Bait 2006/2007 South Bait | |
| '-lnL:overall | | -630.0 | | -657.2 | | -667.1 | | -1289.3 | | -1334.5 | | -1353.3 | |
| ΔAIC | | 0.0 | | -26.4 | | -40.3 | | 0.0 | | -62.3 | | -93.8 | |
| '-lnL:Index | | 7.9 | | 9.8 | | 8.7 | | 23.8 | | 18.0 | | 15.1 | |
| '-lnL:comCAA | | -470.4 | *-(940.7)* | -498.7 | *-(997.4)* | -507.7 | *-(1015.4)* | -970.0 | *-(970.0)* | -1006.3 | *-(1006.3)* | -1022.8 | *-(1022.8)* |
| -lnL:indexCAL | | -175.4 | *-(1403.3)* | -175.2 | *-(1401.6)* | -175.4 | *-(1403.4)* | -355.3 | *-(1421.2)* | -354.3 | *-(1417.3)* | -353.9 | *-(1415.8)* |
| '-lnL:catch | | 0.1 | | 0.1 | | 0.1 | | 0.9 | | 0.4 | | 0.4 | |
| '-lnL:RecRes | | 7.9 | | 6.8 | | 7.2 | | 11.3 | | 7.7 | | 8.0 | |
| $h$ | | **0.98** | | **0.98** | | **0.98** | | **0.98** | | **0.98** | | **0.98** | |
| $B^{sp}_{1980}$ | | 3819 | (0.46) | 2126 | (0.33) | 2251 | (0.72) | 1263 | (0.52) | 2162 | (0.27) | 2243 | (0.56) |
| $B^{sp}_{2013}$ | | 3793 | (0.49) | 2029 | (0.34) | 2244 | (0.34) | 240 | (0.16) | 1896 | (0.45) | 2195 | (0.35) |
| $B^{sp}_{2013}/B^{sp}_{1980}$ | | 0.99 | (0.45) | 0.95 | (0.39) | 1.00 | (0.66) | 0.19 | (0.53) | 0.88 | (0.44) | 0.98 | (0.54) |
| $B^{sp}_{2013}$/av($B^{sp}_{1990}$-$B^{sp}_{2005}$) | | 1.47 | (0.26) | 1.79 | (0.29) | 1.92 | (0.28) | 0.35 | (0.23) | 1.18 | (0.36) | 1.43 | (0.30) |
| $F_{2013}$ | | 0.15 | (0.43) | 0.29 | (0.37) | 0.36 | (0.38) | 6.46 | (0.48) | 0.25 | (0.46) | 0.36 | (0.38) |
| $q$ ($10^9$): | JAI | (2.0) | (0.27) | (2.8) | (0.12) | (2.8) | (0.13) | (4.2) | (0.04) | (2.7) | (0.14) | (2.6) | (0.13) |
| | SAD | 19.5 | (0.36) | 28.0 | (0.25) | 27.8 | (0.25) | 45.4 | (0.15) | 26.2 | (0.23) | 25.9 | (0.22) |
| | NAD | 21.3 | (0.47) | 41.7 | (0.30) | 40.4 | (0.32) | 94.5 | (0.17) | 38.0 | (0.29) | 37.0 | (0.29) |
| AddVar: | JAI | - | | - | | - | | - | | - | | - | |
| | SAD | 0.07 | (2.47) | 0.11 | (1.73) | 0.07 | (2.40) | 0.19 | (1.31) | 0.08 | (2.72) | 0.05 | (3.93) |
| | NAD | 0.00 | (0.00*) | 0.00 | (0.00*) | 0.00 | (0.00*) | 0.18 | (0.21) | 0.02 | (0.17) | 0.00 | (0.00*) |
| $\sigma_{Rout}$ | | 0.41 | (0.12) | 0.38 | (0.10) | 0.39 | (0.09) | 0.49 | (0.06) | 0.40 | (0.10) | 0.41 | (0.12) |

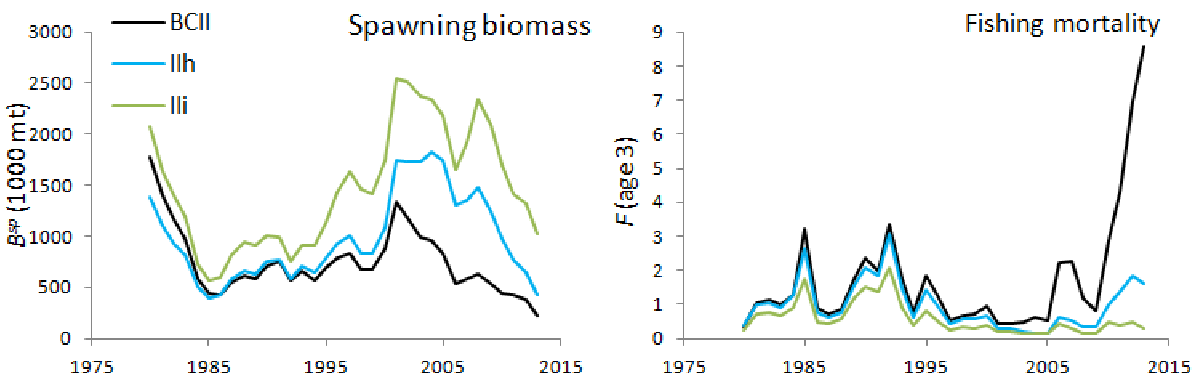


**Figure 1:** Time-trajectory of spawning biomass and fishing mortality for **BCII (black)** and runs **IIh (change in selectivity, same for all fleets - blue)** and **IIi (change in selectivity, different for different fleets)**.

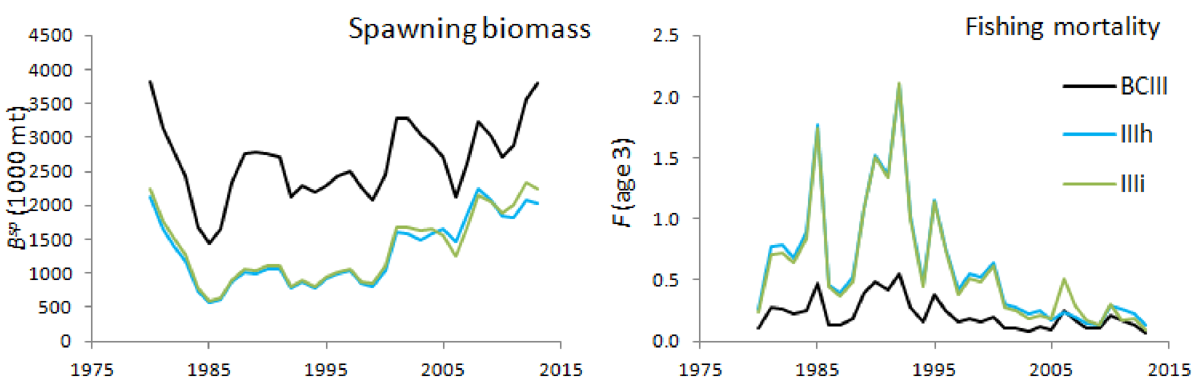


**Figure 2a:** Time-trajectories of spawning biomass and fishing mortality for **BCIII (black)** and runs **IIIh (change in selectivity, same for all fleets - blue)** and **IIIi (change in selectivity, different for different fleets)**.

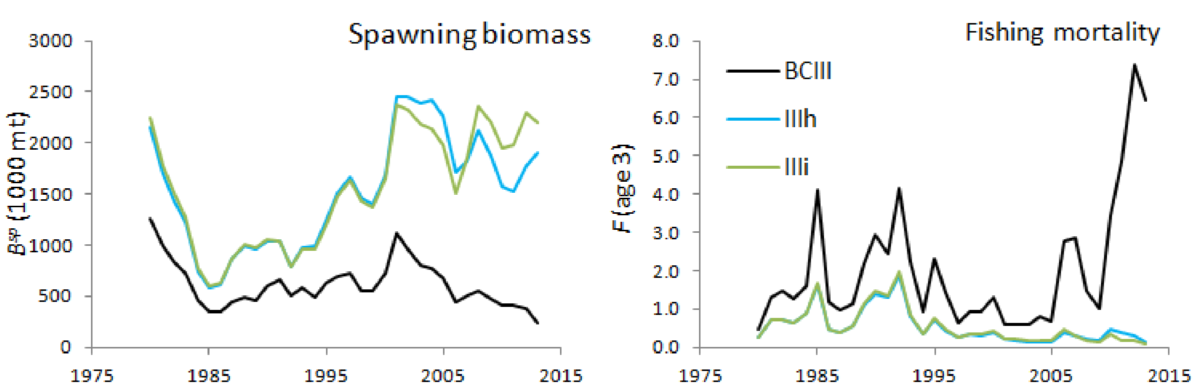


**Figure 2b:** Time-trajectories of spawning biomass and fishing mortality for **BCIII* ($W_{CAA}$=1, black)** and runs **IIIh* ($W_{CAA}$=1, change in selectivity, same for all fleets - blue)** and **IIIi* ($W_{CAA}$=1, change in selectivity, different for different fleets)**.

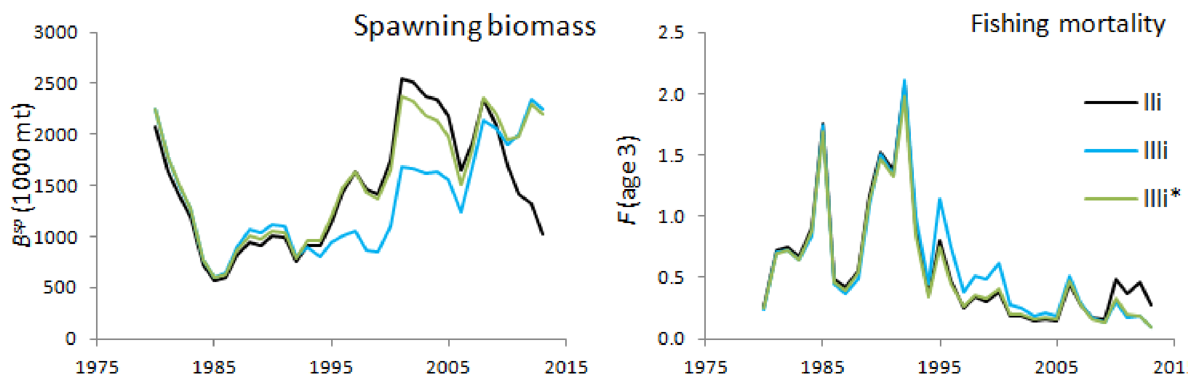


**Figure 3:** Time-trajectories of spawning biomass and fishing mortality for **IIi, IIIi** and **IIIi*.**

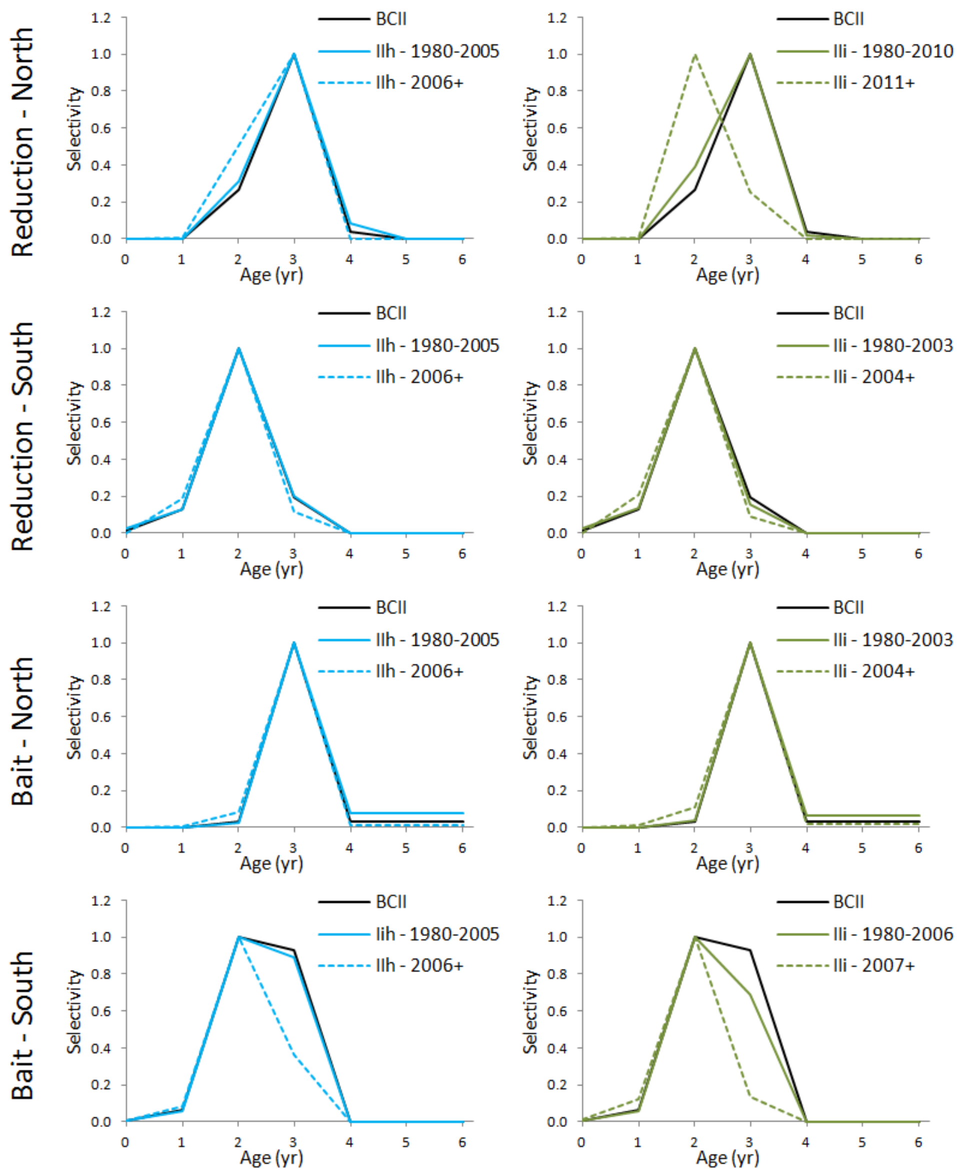


**Figure 4:** Commercial selectivities-at-age mortality for **BCII (black)** and runs **IIh (change in selectivity, same for all fleets - blue)** and **IIi (change in selectivity, different for different fleets)**.

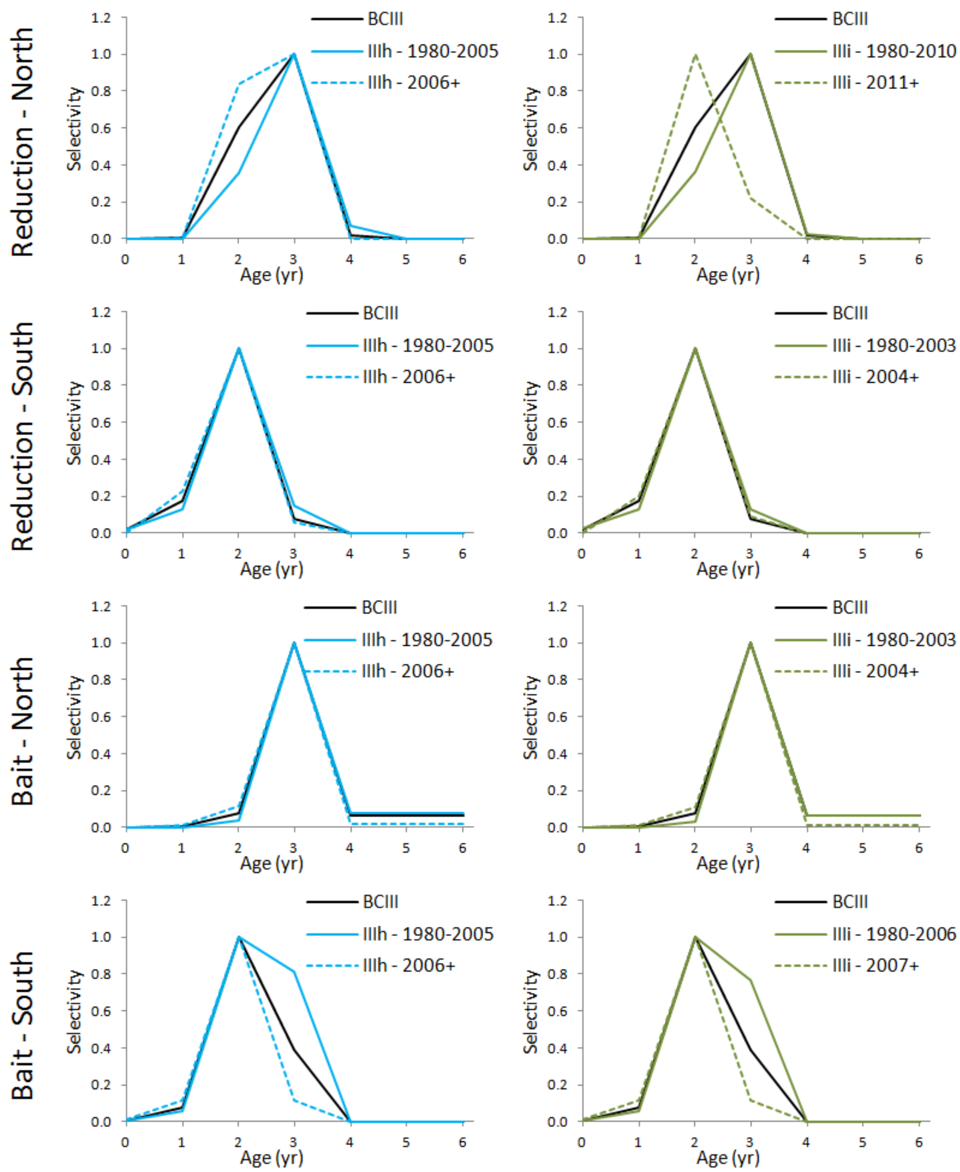


**Figure 5a:** Commercial selectivities-at-age mortality for **BCIII (black)** and runs **IIIh (change in selectivity, same for all fleets - blue)** and **IIIi (change in selectivity, different for different fleets)**.

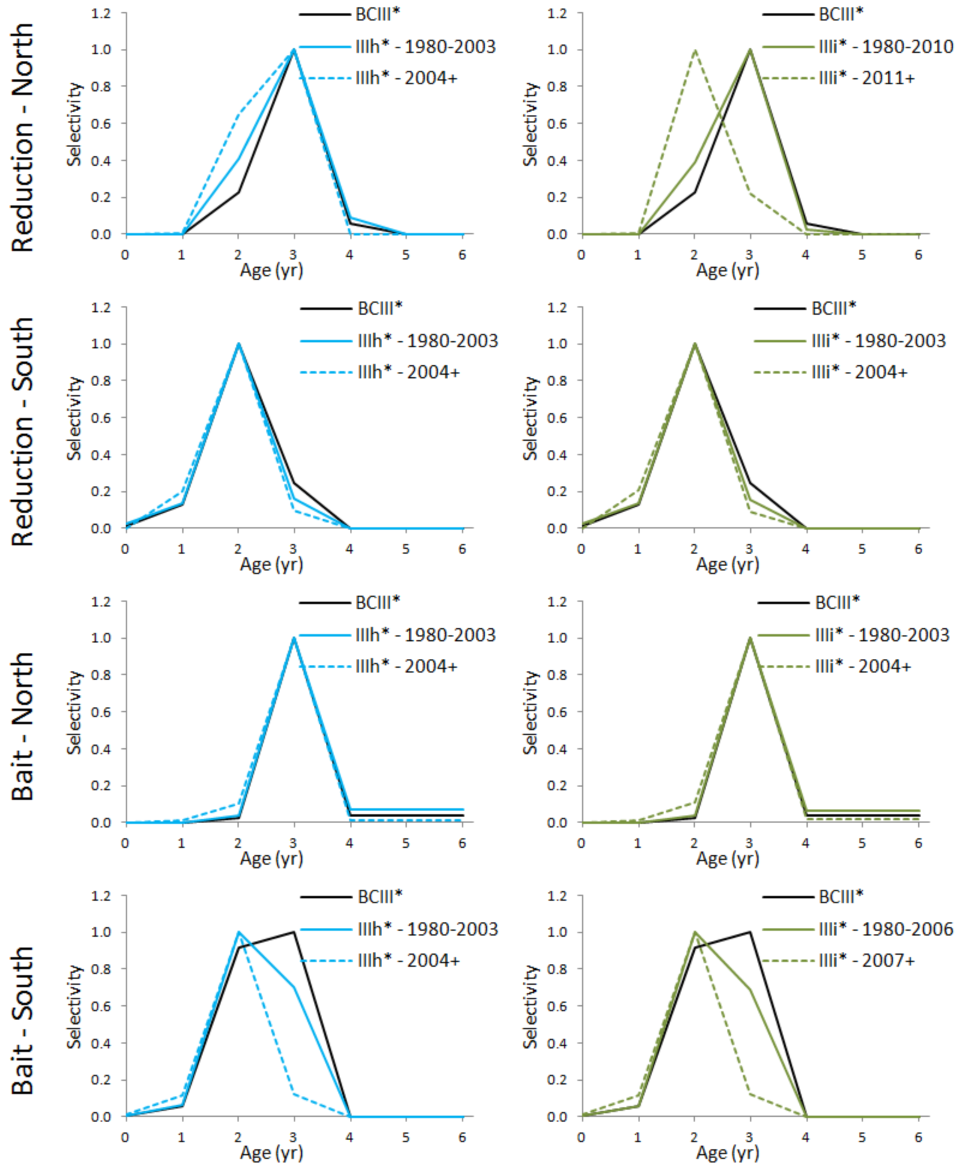


**Figure 5b:** Commercial selectivities-at-age mortality for **BCIII* ($W_{CAA}$=1, black)** and runs **IIIh* ($W_{CAA}$=1, change in selectivity, same for all fleets - blue)** and **IIIi* ($W_{CAA}$=1, change in selectivity, different for different fleets)**.

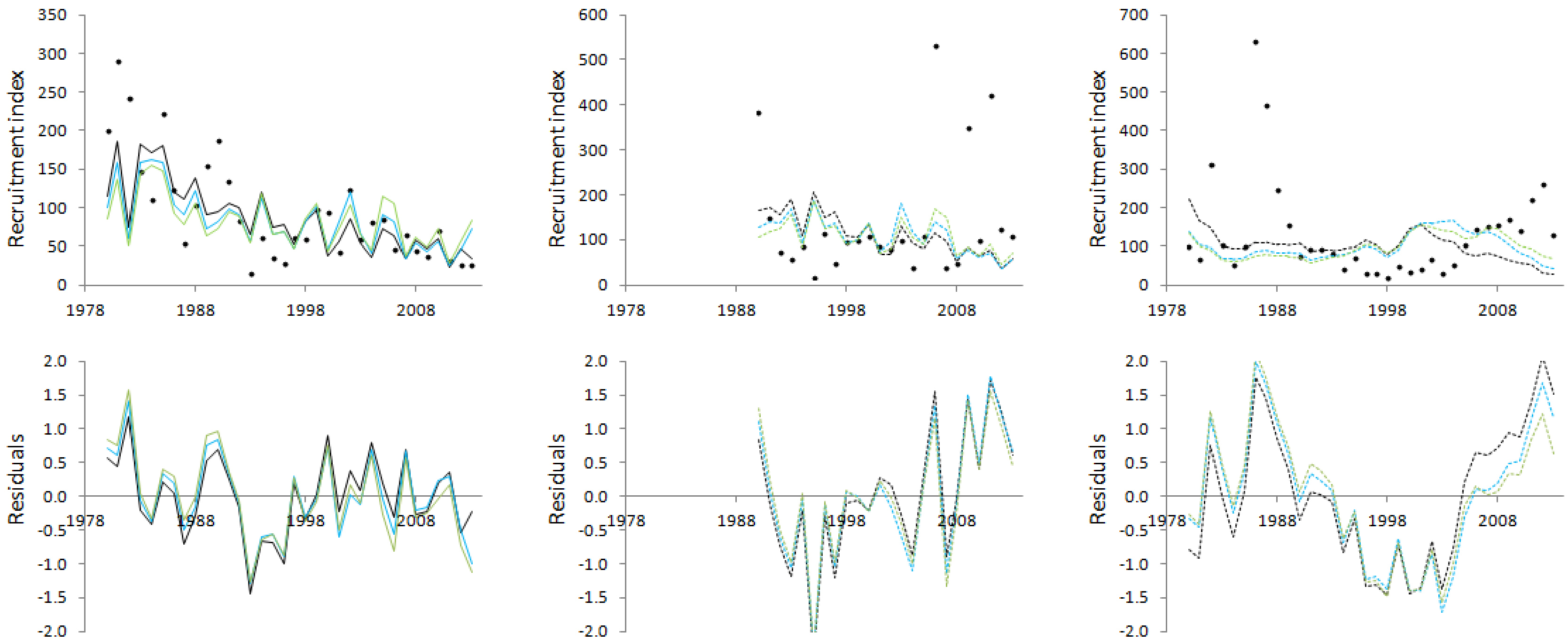


**Figure 6**: Fit to the survey indices and corresponding residuals for **BCII**, **IIh** and **IIi.** The fit to the SAD and NAD indices are dashed as this run does not fit to these indices.

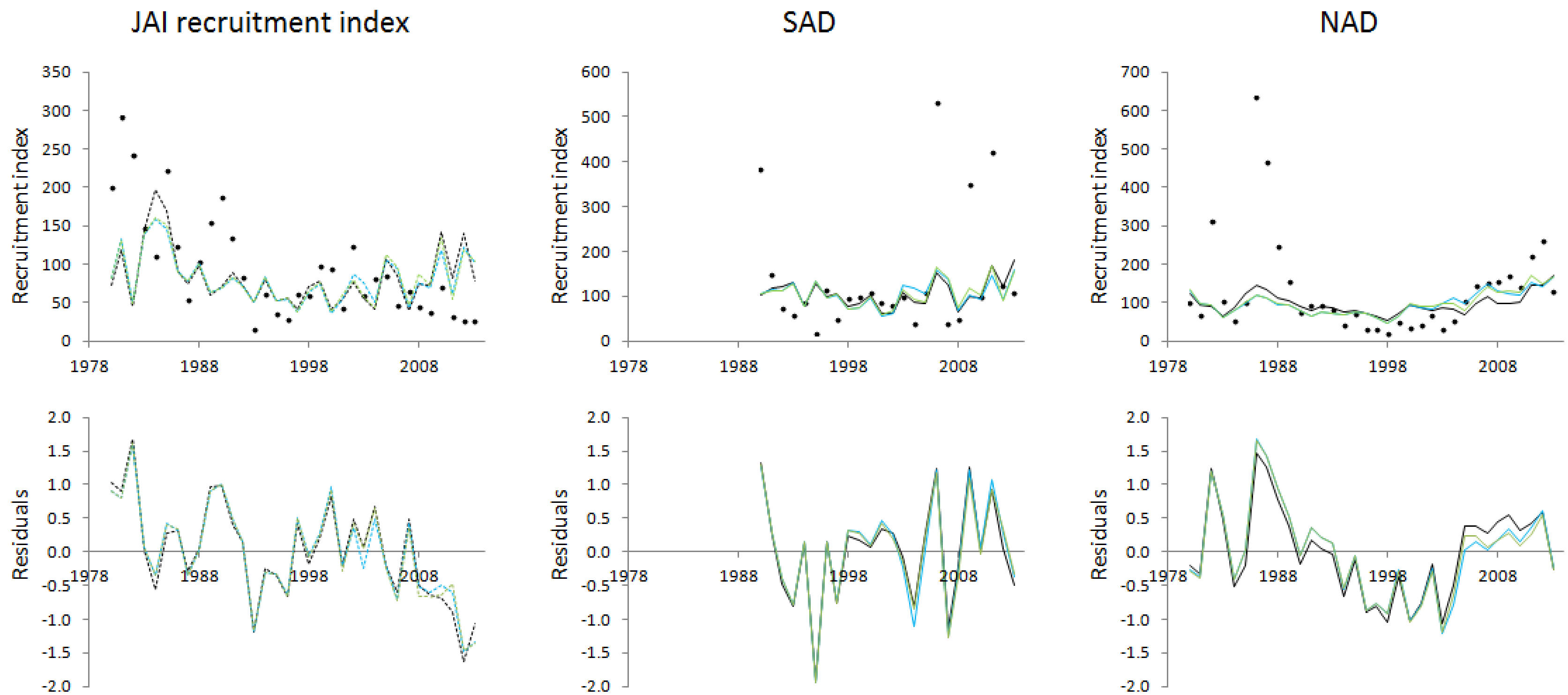


**Figure 7a**: Fit to the survey indices and corresponding residuals for **BCIII**, **IIIh** and **IIIi.** The assumed length-at-age distributions for 2013 are also shown. For the JAI index, the lines are dashed as this run is not fit to this series.

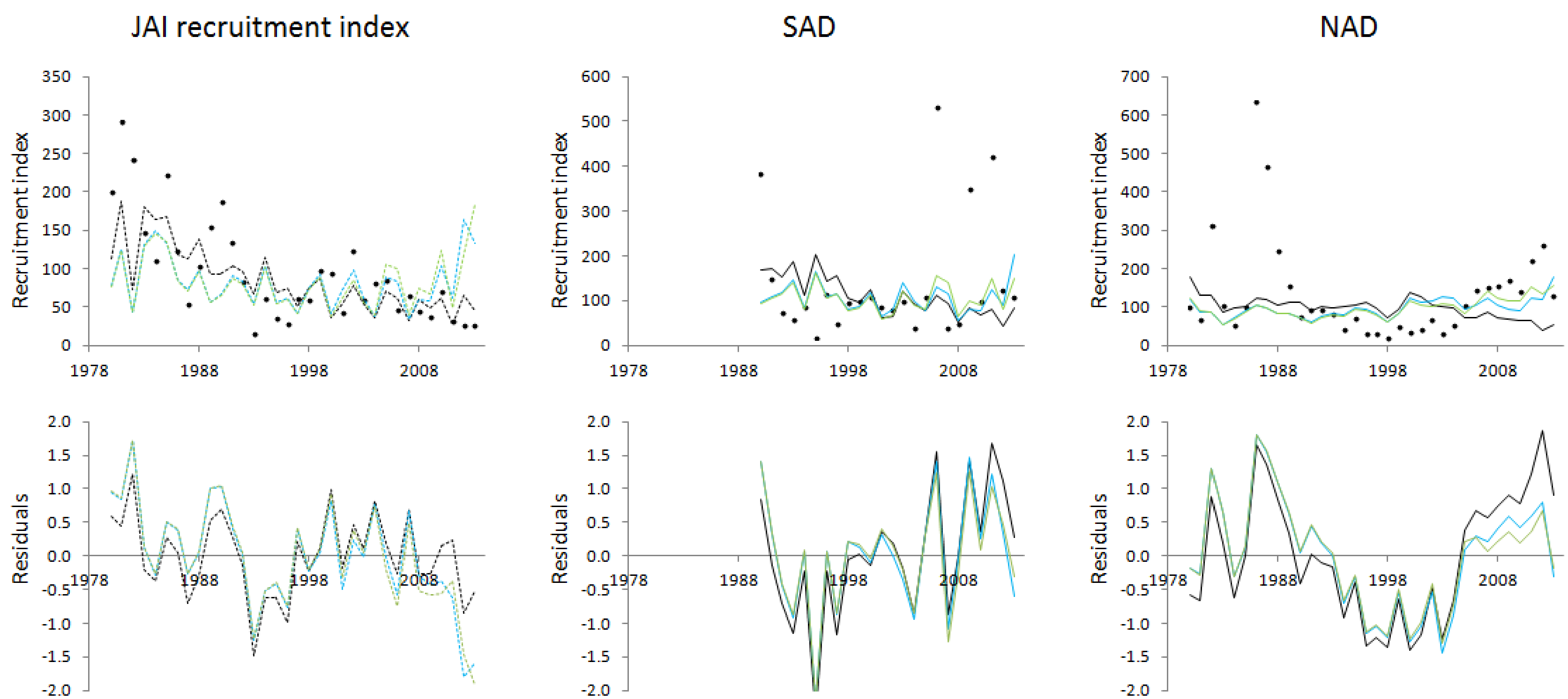


**Figure 7b**: Fit to the survey indices and corresponding residuals for **BCIII***, **IIIh*** and **IIIi*.** The assumed length-at-age distributions for 2013 are also shown. For the JAI index, the lines are dashed as this run is not fit to this series.