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COMPARISON OF DIFFERENT STOCK ASSESSMENT MODELS USING DATA ON THE ICELANDIC SUMMER-SPAWNING HERRING (*CLUPEA HARENGUS*) STOCK

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ABSTRACT

In this study the results obtained by different stock assessment models are compared and their sensitivity to various assumptions is analysed. Extended Survivors Analysis (XSA), Adapt and Statistical Catch-at-Age methods are applied on the Icelandic summer-spawning herring data. The quality of the catch-at-age and acoustic survey data on the Icelandic herring is also analysed using the Shepherd-Nicholson method.

The largest differences in results between the methods were obtained from XSA and Statistical Catch-at-Age. The estimate of stock size by XSA was around 30% lower and fishing mortality higher compared to the point estimates from Statistical Catch-at-Age. The difference between short-term predictions of yield was around 40%. Uncertainty of results from Adapt and Statistical Catch-at-Age was estimated by bootstrapping. Significant differences between the results from these two methods were not found.

Retrospective analysis showed overestimation of spawning stock biomass and underestimation of fishing mortality for all methods. Differences in retrospective patterns between the methods were not observed.

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SYMBOLS AND INDICES

N-stock in numbers
q-catchability
C-catch in numbers
Y-yield
I- abundance index from survey
F-fishing mortality
M-natural mortality
a-age
y-year

1 INTRODUCTION

Numerous stock assessment methods are in use around the world. These can be classified according to their statistical nature, their assumptions, their use of various available data sets etc.

The oldest and the most widely used age-structured assessment method is Virtual Population Analysis (VPA). Cohort Analysis or VPA is based on backward calculations through time and ages given knowledge of all ages in the last year and the last age group in all years (Haddon 2001). Methods that do not take into account measurement errors in catch-at-age observations are sometimes called "VPA-based" (Restrepo *et al*. 2000). The classical VPA analysis is not a statistical analysis. However, it is an important basis for statistical methods (e.g. Adapt) (Lassen & Medley 2001).

In Statistical Catch-at-Age cohorts are projected forward through time and ages (Haddon 2001). Catches used in the population model are not observed catches, but expected catches from the model itself (Lassen & Medley 2001). Separable methods allow for the statistical modelling of the admitted error in the catch-at-age observations, thus increasing the number of data being "fitted" by the model, but reduce the number of estimated parameters by assuming that fishing mortality can be split into age-specific and year-specific components (Restrepo *et al*. 2000).

There are clear geographical preferences in choice of structural models. For most demersal stocks assessed in the northeast Atlantic area, the preferred analytic method is Extended Survivors Analysis (XSA) (described in Shepherd 1999). In the northwest Atlantic, Adapt (Gavaris 1988) is widely used, whilst the Statistical Catch-at-Age models are preferred in the northeast Pacific, Australia and for pelagic stocks in the northeast Atlantic (Patterson *et al*. 2001).

The use of a particular method in a certain geographical region is not always driven by clear reasoning. The continuous development of new stock assessment methods might be related to specific requirements in different regions. In ready-made packages it is often not possible to change assumptions or vary the type of input data. Therefore, a lot of stock assessment packages are tailored to the needs of specific areas. Traditions may also influence the choice. The use of a familiar method already reviewed and accepted will often be preferred over adopting a new method.

Even though all age-structured stock assessment methods share the same theoretical basis, the numerous methods developed in the last decades are quite different with respect to their mathematical formulations, which parameters they estimate, and the techniques by which they are solved. Because of this, each model has its own strengths and weaknesses and different methods contain different sources of error. Application of different methods to a common data set may not give identical results (Megrey 1989), although the difference between the models may be of little importance if reasonably good data is available (Lassen & Medley 2001). In terms of uncertainty, however, different models may still give considerably different results.

Consideration of uncertainty has become an important part of the fisheries management decision process with regard to assessments of the current state of fishery resources as well as for short-and long-term forecasts. Provision of fisheries advice in a form in which uncertainity is explicitly recognised and quantified is becoming a standard requirement from management agencies (Patterson *et al*. 2001). A number of methods for estimating uncertainty in age-structured stock assessments and the estimates of risk have been developed in recent years, e.g. Bayes numerical intergration, bootstraps and various others. Options for estimating uncertainty differ between assessment models. For example determination of uncertainty levels along with model projections present challenges in Cohort Analysis but the Statistical Catch-at-Age models permit it (Haddon 2001).

In the present report three different stock assessment methods: Extended Survivors Analysis (XSA), Adapt and Statistical Catch-at-Age are applied on the Icelandic summer-spawning herring data. XSA was chosen mostly due to its wide usage. Neither Adapt nor XSA take into account errors in catch-at-age and both use backward calculations, but they differ in the estimation procedure. Additionally, Adapt provides the possibility of estimating uncertainty, which is not the case for XSA. Statistical Catch-at-Age was chosen because of its different principals from the other two methods. It performs forward calculations, accounts for errors in catch-at-age, offers the possibility of using separable fishing mortality and provides uncertainty estimates in both historical estimates and in the projection.

The data set used in this study was chosen arbitrarily and the choice of the methods is not related to the biology of the species used, as the underlying theory behind those three methods is similar in that sense and there is no straightforward reason for preferring one method to another. Different methods are often applied on similar species in different parts of the world.

In this report, the sensitivity of the results to some of the assumptions within the methods and differences in the results between the three methods are presented and their possible causes are discussed. The quality of the catch-at-age and acoustic survey data on the Icelandic summer-spawning herring is also analysed.

The Icelandic summer-spawning herring fishery is targeted at a single stock (Jakobsson & Stefánsson 1999) by Icelandic purse-seiners and trawlers. The stock was heavily overexploited in the early of 1970s but has since recovered. The Icelandic herring fishery is seasonal, with the main fishing taking place from October to January off the southeast, southwest and south coast of Iceland. The stock spawns in July off the southwest, south and southeast coast of Iceland and later undertakes feeding migrations. Fishing at $F_{0.1}$ has traditionally been the target reference point for the stock (Jakobsson & Stefánsson 1999).

2 MATERIAL AND METHODS

Icelandic summer-spawning herring data, which was made available by the Marine Research Institute in Iceland, was used. It includes landings, age-disaggregated catch in numbers, weight-at-age and maturity-at-age for age groups 2-15 in the years 1978-1998 and age-disaggregated acoustic survey indices for age groups 1-15 from 1974 to1998. Survey indices were missing for all age groups in 1982, 1986 and 1994 and several indices were missing for the youngest and older ages in the time series.

Natural mortality 0.1 was assumed in stock assessment models. Weight-at-age in the catch and in the stock were treated as equal.

The data used in the report are presented in Appendix A.

2.1 The quality of the data

The quality of the catch-at-age and survey data was analysed using the approach described by Shepherd and Nicholson (1991).

The catch-at-age is primarily determined by the year-class strength, the overall level of fishing effort in each year, and the combined effect of selection and survival as a function of age.

$$C_{ya} = F_y * R_k * S_a^{'}$$

C-catch
F-fishing mortality
R-cohort size
S′- effect of selection and survival

Indices *y, a, k* note year, age and year-class, respectively (Shepherd & Nicholson 1991).

The analysis of variance model was fitted through the logarithm of the catch-at-age data set taking age, year and year-class as factors. Residuals of the model were then computed.

The same type of model was applied to the acoustic survey data taking the logarithmic survey indices as a function of age, year and year-class.

The analysis was performed in a programming and statistical environment R.

2.2 Stock assessment methods

2.2.1 Extended Survivors Analysis (XSA)

2.2.1.1 General description of the method

Extended Survivors Analysis (XSA) is the standard procedure used in ICES assessment working groups for many stocks (Shepherd 1999). XSA requires data on catch in numbers by age and by year, supplemented by stock abundance indices. Only age-disaggregated abundance indices can be used (Lassen & Medley 2001).

Principal features of the method are:

- The abundance of the survivors in each cohort is treated as a variable to be estimated by a least squares procedure;

- Population abundance for all the other ages and years is estimated by VPA, using estimated survivors as the terminal populations;
- Based on estimated stock sizes and catchability *q,* the exponent *γ* is estimated using linear regression:

$$\ln N_{ay}^{VPA} = \frac{1}{\gamma_a} \ln I_{ay} - \frac{\ln q_a}{\gamma_a}$$

- When *q* and *γ* in the index-stock relation have been determined, then the stock estimates are corrected by:

$$\ln N_{ay}^{corr} = \frac{\ln I_{ay} - \ln q_a}{\gamma_{ay}}$$

- Independent population estimates obtained from calibrated abundance indices for all ages in each cohort are used as the basis for estimating survivors.

$$\ln N^{survivors} = \ln \left[\frac{I_a}{q_a} \right] - F_{a,cum} - M_{a,cum} \,,$$

F and *M* are cumulative over age (*a*) up to the oldest age included in the analysis. For a given cohort, there will be a number of such estimates of survivors, which come from different age groups observed in the abundance index. The XSA combines these weighted estimates into a single estimate of survivors in that cohort. The weights used for the survivor estimates are the inverse prediction of the variance around the regression carried out to estimate *q*, multiplied by $F_{a,cum}$. This estimate is then introduced into a VPA obtaining stock in numbers and fishing mortality. The next iteration loop begins by using these estimates to calculate *q*. The whole process is the repeated until convergence (Lassen & Medley 2001).

The second point mentioned above is where the method departs from integrated statistical methods, since the catch-at-age data are treated here as exact (Shepherd 1999).

2.2.1.2 Lowestoft VPA version 3.1

The Lowestoft VPA version 3.1 programme (Darby & Flatman 1994) was used to perform XSA.

Within the programme the abundance index values are calculated to refer to the stock at the beginning of the year according to the formula:

$$I_{ay} = I_{ay}^{obs} / \left[\exp(-\alpha (F_{ay} + M_a)) \frac{1 - \exp(-\beta - \alpha)(F_{ay} + M_a))}{F_{ay} + M} \right]$$

Where α and β are the start and the end point in time of the observation given as a fraction of the year (Shepherd 1999). The values 0.99 and 1 were used, respectively.

Several runs of XSA were performed in order to select the options to be used in the final XSA assessment following the user guide of the programme (Darby & Flatman 1994). The sensitivity of some of the assumptions was also tested.

- Based on regression statistics, catchability was set independent of year class strength at age 4, thereby allowing a power relationship between the stock in numbers and survey indices for ages younger than 4.
- Catchability was assumed to be constant for age 5 and older based on the catch curve analysis and the assessment history of the stock.
- The option for down-weighting the earlier tuning data was not applied, as obvious changes in the survey over time were not known.
- Based on the analysis of the quality of the survey data from the Shepherd-Nicholson model, ages 1-2 and 11-15 were excluded from tuning. In the diagnostics of XSA ages 9 and 10 showed mean log catchability standard errors higher than 0.5. Therefore, the final XSA run was tuned with ages 3-8. The sensitivity of the results for the age span of the survey indices used was also tested by performing assessments including survey data for ages 1-15 and 3-10.
- Shrinkage to the population mean (terminal population estimates for the recruiting age are shrunk to the time series weighted geometric mean of the population abundance estimates) and shrinkage to a mean of the most recent *F* values were applied. The default standard error value (0.5) was used in applying weight to the *F* shrinkage in the final run. Obvious changes in fishing effort in latest years were not known and the retrospective analysis, that is suggested in the XSA manual for selecting appropriate weight to the shrinkage, did not indicate that another value should be used. The sensitivity of the XSA results to shrinkage was tested by running XSA applying the standard error 0.75 as the weight on the shrinkage.
- For the rest of the options in the Lowestoft VPA version 3.1 programme the default values were used.
- Recruitment (age 2) in 1996-1888 was calculated using the RCT3 programme (Shepherd 1997). Recruitment estimates (age 2) from the XSA run including survey information for age 1 were also presented. For the final XSA run results from the RCT3 were used for recruitment estimates as is traditionally done in ICES assessment working groups.

2.2.2 Adaptive framework

2.2.2.1 General description

Adaptive framework provides a statistical basis, based on least squares theory, for the estimation of population size, based on minimising the discrepancy between observations of variables and the values of those variables predicted as functions of population parameters (Gavaris 1988). As the parameters of the model are estimated simultaneously, it falls into the class of methods referred to as "integrated methods" (Gavaris 1991). The framework is adaptive in the sense that any observed variable, which is a function of the population matrix, can be used (Gavaris 1988).

The Adapt framework assumes that all deviations between the model and the observations are due to measurement error. Catch-at-age data is treated as exact.
The algorithm to find unknown parameters consists of the following steps:

- Initiate the unknown parameters with estimates. Terminal fishing mortality or number of survivors and catchabilty q can be estimated as model parameters.
- Perform a VPA to estimate population and fishing mortality coefficients for all age groups and years.
- Calculate predicted values for abundance indices. Catchability coefficients in the relationship between stock numbers and abundance indices are either calculated or initialised values depending on the parameters which are chosen to be estimated by the model.
- Calculate the sum-of-squares of residuals between observed and predicted abundance indices.
- Estimate model parameters by minimising the objective function:

$$SSQ = \sum_{a,y} \left[\ln I_{ay}^{obs} - \ln I_{ay}^{\mathrm{mod}} \right]^2 ,$$

This is a sum of squares (SSQ) of the difference between observed (I^{obs}) and predicted abundance indices (I^{mod}) by ages (a) and years (y).

In adapt-type assessment age-aggregated stock in numbers or biomass can also be used as abundance indices

In literature different model specifications are referred to as Adapt. For example, Adapt was originally designed as a forward calculation and models taking into account an error in catch-at-age data might also be referred to as Adapt (Lassen & Medley 2001). The description given above is applied as Adapt in this report.

2.2.2.2 Adapt-type assessments applied on the Icelandic herring stock

Two approaches of adapt-type assessments were applied:

1) Using age-aggregated survey indices and estimating terminal F as a model parameter;
2) Using age-disaggregated survey indices and estimating catchability coefficients and survivors as model parameters.

The first approach is currently used in the Marine Research Institute of Iceland (MRI) for assessing the Icelandic herring stock and is referred to as 'MRI-adapt' in thisreport. The programme is written in Splus by Gunnar Stefánsson (MRI). Acoustic survey indices of age groups 5 and older are added up for tuning the VPA. Selection pattern is calculated by dividing catch by stock numbers. The recruitment for the last years (1996-1998 in this report) is estimated by using the RCT3 programme.

The results from this adapt-type assessment are given in this report for comparison with other methods and no further analysis or testing the sensitivity to different assumptions were performed. Somewhat closer analysis was performed for the second adapt-type assessment approach mentioned above.

'Cadapt' and Adapt ver 3 programmes

The adapt-type assessment estimating the number of survivors at the end of the period covered by the VPA-data and catchability coefficients was performed using a programme called 'cadapt'. The 'cadapt' programme was written in AD Model Builder by Sigurður Jónsson (MRI). 'Cadapt' was chosen as it provides the possibility of estimating uncertainty in the results by bootstrapping. It is also convenient for doing retrospective runs. 'Cadapt' is similar to the programme Adapt ver 3 (Rivard & Gavaris 2000) that was also applied for comparing the parameter estimates and results. The advantages of Adapt ver 3 are that it has the possibility of running forward projections in the same programme and it can obtain uncertainty estimates in the projection by bootstrapping.

The main difference in the model structure between 'cadapt' and Adapt ver 3 is that in 'cadapt' population numbers are back-calculated using Pope's approximation but in Adapt ver 3 a Newton-Raphson algorithm is used to solve the catch equation. The final results of Adapt ver 3 are also adjusted to bias, but this option is not available in 'cadapt'. The programmes were run with the following options:

- In 'cadapt' weights calculated as a mean square of age group log residuals were applied to different age groups. The option for intrinsic weighting was used in Adapt ver 3.
- The population abundance for the oldest age group in both 'cadapt' and in Adapt ver 3 was calculated by relating the fishing mortality in the last age group to the fishing mortality in younger ages. The weighted average of ages 12-14 was used. Including ages younger than 12 in the calculation of fishing mortality of the oldest age group resulted in unrealistically high fishing mortality estimates for older ages in the latest years and also in negative estimates in the "bias corrected" results from Adapt ver 3. Excluding older ages, which are probably poorly estimated (e.g. age 14), from the mean did not resolve the problem.
- Catchability was set as equal for ages 5 and older.
- Based on the results from the Shepherd-Nicholson model and retrospective analysis, the run tuned with survey data for ages 3-10 was chosen as final adapt-type assessment. The sensitivity of the results to this assumption was tested by performing adapt-type assessment in 'cadapt' and tuning data for ages 1-14.

In adapt-type assessments survey data is corrected to the beginning of the year by using the survey numbers for age *a* obtained at the end of the year as age *a+1* in the beginning of next year. For example survey data for age 1 in 1978 is used as age 2 in 1979. The ages are mentioned in the text and in the figures as 1-14 although for tuning they are used as ages 2-15. This was done for clearness and correspondence to ages in paragraphs considering XSA.

2.2.3 Statistical Catch-at-Age

2.2.3.1 General description

Statistical Catch-at-Age requires catch-at-age data along with some information to tie the model to the stock size (effort, independent population estimates, etc.). An objective function is used to optimise the fit of the model to the available data.

The numbers-at-age at the start of the first year in the population being modelled are model parameters along with recruitment levels in each year of the fishery. With further parameters describing age-specific selectivity, it is possible to project each cohort forward to generate a matrix of numbers-at-age (Haddon 2001).

The fully selected fishing mortality rate in year *y* is one of the foundations of the analysis and values for each year are treated as model parameters in the fitting process.

The fishing mortality rate (*F*) for each age (*a*) in each year (*y*) is

$F_{a,y} = s_a * \hat{F}_y$, where $\hat{F}_y$ is the fitted fishing mortality rate in year *y* and s_a is

the selectivity of age *a*.

Selectivity can be estimated either directly for each age or the parameters of an equation describing the shape of the selectivity curve can be estimated.

Once the predicted numbers-at-age are calculated, the predicted catch-at-age can be generated and compared to the observed data.

Catch-at-age data alone is insufficient to estimate absolute abundance. One possible source that could be added includes fishery independent surveys of stock size. The objective function between the observed and predicted survey indices can then be established.

There are thus two objective functions to minimise, one for the catch-at-age, and the other being the survey indices at age. In order to force the model to fit the observed yield within each year an additional minimisation factor can be set to minimise the difference between observed and predicted yield.

The whole objective function, i.e. sum of squares of differences between observed and predicted values, then becomes:

$$SSE_T = \sum_{ay} \left[\ln(C_{ay}) - \ln(\hat{C}_{ay}) \right]^2 + \sum_{ay} \left[\ln(I_{ay}) - \ln(\hat{I}_{ay}) \right]^2 + \sum_{y} \left[\ln(Y_y) - \ln(\hat{Y}_y) \right]^2$$

2.2.3.2 AMCI ver 2.2

AMCI version 2.2 programme (Skagen 2002) was used to perform Statistical Catch-at-Age type assessment. The advantage of AMCI is the possibility of performing retrospective analysis, forward projections, and of obtaining uncertainty estimations and recruitment estimations in the same framework.

AMCI offers a wide number of options for specifying the model and the runs presented in this report should be taken as trials. Because of time constraints the most appropriate model specification might not have been found, but still the sensitivity of the results to some of the assumptions was analysed.

Notice should be taken that retrospective runs performed by AMCI didn't give identical results for the last assessment year compared to the results from the single minimisation run. The author of the programme noted that it could be because the optimisation starts at different values and stops at certain level of precision (Skagen pers. comm.). But time constraints did not permit a closer look at the problem within the frame of the present project.

The AMCI runs were performed using the following options:

- The number of recruits, the stock number for all the ages in the first assessment year, F level as the yearly component of the separable fishing mortality, selection pattern for the first assessment year and survey catchability values at age were estimated as model parameters.
- Selection values at age for all years, except for the first assessment year, were specified by recursive updating. Gradual change in selection was allowed by using gain factor 0.5 for ages 2 and 3, 0.2 for age 4 and 0.1 for older ages. Setting a gain factor equal to 0 implies a pure separable model, while a gain factor equal to 1 gives a VPA estimation of mortalities. To test the sensitivity for this assumption, the run with constant selection for the whole time period was also performed.
- Selection pattern was assumed to be constant for ages 5 and older.
- The yearly fishing mortality was split into quarters, assuming 0.05 in the third and 0.95 in the fourth quarter of the year.
- The survey catchability was specified as separable:
  $q_{ya} = q_y * q_a$, where q_y and q_a are year and age specific components of the catchability. Catchability was assumed to be constant over the years, implying that the q_y values were kept fixed at a constant value, while the q_a values were estimated as parameters.
- Survey data for ages 3-10 (reference to ages is the same as for Adapt, explained in section 2.2.2.2) was used for tuning in the final run. The effect of including all age groups into the tuning was also tested.
- In the final run weights 0.6, 10 and 0.8 were given to the objective functions of catch-at-age, total yield and survey, respectively. Higher weight was applied on the survey data than on the catch-at-age based on the results from the Shepherd-Nicholson model and because the ages from the survey data with the worst fit to the model were excluded from the assessment. High weight on the yield was applied assuming reasonably good data on landings in the Icelandic fisheries. Results from retrospective analysis were also used to decide upon the weights. Different values were tried for testing the sensitivity of the results to weights. It is possible in the AMCI package to give separate weightings to individual observations, which have to be imported externally. Due to time constraints this option was not used.
- Recruitment in 1996-1998 was estimated by the RCT3 programme.

2.3 Estimation of uncertainty

Uncertainty in the results from adapt-type and statistical catch-at-age assessments was estimated using the bootstrap method.

To characterise the uncertainty in the estimates and generate percentile confidence intervals the residuals from the optimum model fit are combined with the expected catch-at-age data (in Statistical Catch-at-Age) and the survey indices-at-age data (both in Adapt and in Statistical Catch-at-Age) to form bootstrapped samples.

The bootstrap samples for catch-at-age are generated as:

$C^{b}_{ay} = \hat{C}_{ay}\left(\frac{C_{ay}}{\hat{C}_{ay}}\right)^{boot}$, where $\hat{C}$ is the expected catch-at-age and the residual is a randomly selected residual from those available (Haddon 2001).

The bootstrap data for the survey indices is generated in a similar fashion, i.e.:

$$I^{b}_{ay} = \hat{I}_{ay}\left(\frac{I_{ay}}{\hat{I}_{ay}}\right)^{boot}$$

In the 'cadapt' programme the year-blocks of residuals are picked at random. The years in the assessment are sampled with replacement and in a given position of the vector of years, all the residuals originating from the bootstrapped year are used in producing a matrix of bootstrapped residuals.

AMCI ver 2.2 bootstrap was run with the option of drawing random data from the residuals around the model. Residuals are drawn from the yearly residuals at actual age (Skagen 2002).

Uncertainty is estimated for assessment results obtained by including survey data for all the age groups available in the data. In the assessments that are presented as final runs in the report, the data for youngest and oldest ages is excluded and recruitment in the latest years is estimated by using the RCT3 programme. For estimating uncertainty in assessment, younger ages should be included in order to have a better estimate for recruiting ages. Uncertainty cannot be estimated for assessment results that include additional estimations from the RCT3.

One thousand bootstrap replicates were run in 'cadapt' and seven hundred in AMCI ver 2.2.

3 RESULTS

3.1 Quality of catch-at-age and survey data

3.1.1 Catch-at-age data

The analysis of variance model was fitted through the observed catch-at-age data using age, year and year class as factors. All the factors had a significant effect on the model (Table 1). Relative residuals of the model are presented in Figure 1. Sum of squared residuals for each age (Figure 2a) and for each year (Figure 2b) divided by the number of data points were also calculated. The worst fit of the model is in the youngest and oldest age groups, which show the highest residuals. The observed value that fits the model worse than any other data point is the value for age group 13 in 1980 (Figure 1). Trends in residuals for some years (e.g. 1986-1988, 1991 and 1992) can be observed as blocks of positive or negative values in the residual matrix (Figure 1). This is an indication of relatively poor quality data or of some change in the fishing pattern. In general, the residuals show an improved fit of the data to the model in recent years (Figures 1-2).

Table 1: Analysis of Variance for the Shepherd-Nicholson model for catch-at-age (log) data in 1978-1998 (*** shows p<0.001).

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
age	13	960.03	73.85	88.9506	<2.2E-16 ***
year	20	126.08	6.3	7.5929	<2.2E-16 ***
cohort	32	119.25	3.73	4.4885	7.804E-12 ***
Residuals	228	189.29	0.83		

3.1.2 Survey data

Age, year and cohort were used as factors in the analysis of variance model fitted to the acoustic survey data. In addition to age and cohort, the factor year was unexpectedly found to have a significant effect on the model (Table 2). Relative residuals of the model are presented in Figure 3 and sum of squared residuals divided by the number of observations by ages and by years are shown in Figure 4. The worst fit was observed for age 2 and high residuals were obtained also for older ages starting at age 11 (Figure 4a). Residuals from the model fitted to survey data were in general more random compared to catch-at-age and blocks of positive or negative residuals were not obvious. A slight decreasing trend in residuals over the time period was observed (Figure 4b).

Table 2: Analysis of Variance for the Shepherd-Nicholson model for acoustic survey (log) data in 1974-1998 (*** shows p<0.001).

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
age	14	346.94	24.78	63.3705	<2.2E-16 ***
year	20	112.05	5.6	14.3261	<2.2E-16 ***
cohort	28	64.9	2.32	5.9272	4.721e-14 ***
Residuals	170	66.48	0.39		

3.2 Results from different stock assessment models

3.2.1 XSA

The stock in numbers and fishing mortality estimates from the final XSA assessment (tuned with ages 3-8, giving weight to the shrinkage as standard error 0.5 and using RCT3 for recruitment estimates in 1996-1998) are given in Appendix B.

Retrospective analysis of SSB, Fbar and recruitment from the final run are presented in Figure 5. There is an observed tendency of overestimating SSB and underestimating fishing mortality in the latest years.

Catchability residuals are presented in Figure 6. For ages 3-8, which are used in the final XSA run, the catchability residuals are relatively homogenous in size and trends in residuals were not observed.

Effect of the age span included for tuning

Three different runs of XSA were performed in order to test the sensitivity of the results to the ages used for tuning. The runs were performed with:

1) Ages 1-15
2) Ages 3-10
3) Ages 3-8

The results are presented in Figure 7.

In general, the number of age groups included from the survey data had relatively little effect on the results. Excluding age groups from the tuning increased estimated fishing mortality slightly and decreased stock in numbers correspondingly for the latest years. The difference between the runs with the highest and lowest number of age groups was maximum 7% in spawning stock biomass, 5% in recruitment and 9% in fishing mortality in the latest year. In survivor estimates the difference was up to 5% for younger ages until age 11 (except age 8 that had a difference of 15%) when it increased to over 20%.

The runs tuned with different number of age groups showed a similar retrospective pattern. Retrospective analysis of SSB for assessments tuned with ages 1-15 and 3-10 are given in Figure 8.

Estimate of the latest years recruitment

The RCT3 programme uses the long-term mean of the population numbers and the survey data for estimating recruitment in a particular year. When the survey indices have high standard errors, then the recruitment estimate from the RCT3 is basically the VPA mean. In the XSA run including survey data for age 1, the recruitment (age 2) estimate incorporates additionally information on catch in numbers. To analyse the difference in recruitment estimates from the traditionally used RCT3 and from the XSA run including survey data for younger ages than the catch numbers, two assessment results were compared.

An XSA run was performed including survey information starting from 1-year-olds. XSA estimates of 2-year-olds for years 1996-1998 from that run were used as recruitment estimates for 1996-1998 in the XSA run tuned with ages 3-8. The results were compared against the assessment tuned with the same age range (3-8) but the recruitment for 1996-1998 was estimated using the RCT3 (presented as the final XSA run). Recruitment estimates for the latest years from the XSA were about 25% higher than estimated by the RCT3. It gave 10% difference in SSB in the latest year and up to 33% difference in survivor estimates for younger ages (Figure 9).

Effect of the shrinkage on the results

Sensitivity of the XSA results to the shrinkage was tested by two runs of XSA applying standard errors 0.5 and 0.75 as the weights on the shrinkage. Both runs were tuned with survey data for ages 3-8.

Giving lower weight to the shrinkage increased the SSB up to 10% and decreased fishing mortality estimates by a maximum of 15% in the latest years (Figure 10). The survivor estimates were higher and fishing mortality lower in the last year for all fully recruited ages when giving lower weight to the shrinkage.

Retrospective analysis of SSB, Fbar and recruitment, applying standard error 0.75 as weight on the shrinkage, are given in Figure 11. Compared to the retrospective pattern from the assessment giving the weight to the shrinkage as standard error 0.5, no obvious difference was observed (Figures 5 and 11).

3.2.2 Adapt

Adapt-type assessment was performed using two approaches.

The resulting stock in numbers and fishing mortalities from the adapt-type method (MRI-adapt) using age-aggregated survey indices and estimating terminal F as model parameters are given in Appendix C.

The adapt-type assessment estimating the number of survivors and catchability coefficients as model parameters was performed using the programmes 'cadapt' and Adapt ver 3. 'Cadapt' is used for the final adapt-type assessment of the second approach. Comparison of the parameters estimated by 'cadapt' and Adapt ver 3 is presented in Appendix D. Difference between the parameters estimated by the two programmes was less than 3%.

Spawning stock biomass and reference fishing mortality from MRI-adapt, 'cadapt' and Adapt ver 3 are presented in Figure 12 for comparison of three adapt-type assessments. The difference between results from 'cadapt' and Adapt ver 3 (bias corrected) is less than 5% as expected due to the similar estimation procedure, although Adapt ver 3 results are corrected for bias which is not the case in 'cadapt'. SSB from MRI-adapt was up to 17% lower in the last year compared to the 'cadapt' estimate.

Stock in numbers and fishing mortalities from the final 'cadapt' run are presented in the Appendix E. Residuals of the model are shown in Figure 13. Trends in residuals can be seen for 1983 and 1988. Negative residuals were obtained for all ages but age 5 in 1984. The size of the residuals was relatively homogenous; the highest values were obtained for older ages in 1978.

Retrospective analysis of SSB, Fbar and recruitment are presented in Figure 14. The retrospective patterns are similar to those of XSA overestimating SSB and underestimating fishing mortality in the latest years.

Effect of age span included for tuning

In order to test the sensitivity of adapt-type assessment to ages used for tuning, adapt-type assessment by 'cadapt' was also performed including survey data for ages 1-14. The number of ages included had a negligible effect on the SSB or fishing mortality estimates. Including the survey information for younger and older ages resulted in 2% higher SSB and 4% lower fishing mortality estimates in the latest year compared to the final assessment tuned with ages 3-10. Survivor estimates differed over 20% for 8-year-olds and for ages older than 12 (Figure 15).

Retrospective analysis of SSB, Fbar and recruitment for Adapt assessments tuned with ages 1-14 and also with ages 1-10 are shown in Figures 16 and 17. The retrospective patterns were more consistent when the older ages were excluded from the tuning.

Uncertainty

Uncertainty estimates are presented for the assessment including survey data for ages 1-14 and without using the RCT3 programme for estimating recruitment in the latest years.

Percentile confidence intervals for spawning stock biomass, fishing mortality and recruitment estimates from 'cadapt' are presented in Figure 18. The 90% confidence interval for spawning stock biomass in 1998 was between 472 and 754 thousand tons. Ninety percent of bootstrapped reference fishing mortality estimates in 1998 were between 0.1 and 0.2. The 90% probability interval for the recruitment estimate in 1998 was between 1400 and 4400 million.

3.2.3 Statistical Catch-at-Age

The stock in numbers and fishing mortality estimates from the final AMCI run are given in Appendix F (including survey data for ages 3-10, using 0.6, 0.8 and 10 as weights on the objective functions of catch-at-age, survey and yield, respectively and allowing selection pattern to change gradually over time).

Residuals of the catch-at-age and survey data are presented in Figures 19 and 20. Residuals of the catch-at-age showed trends by years (e.g. 1986, 1987) and cohorts (e.g. 2-year-olds in 1981, 1985) forming blocks of positive or negative values in the residual matrix. Residuals were generally higher for younger and older ages compared to the probably better sampled middle age groups. Residuals of survey indices looked more random compared to the catch-at-age, but still some cohorts (e.g. 3-year-old in 1984 and in1986) showed entirely positive or negative residuals.

Retrospective analysis of SSB, fishing mortality and recruitment is presented in Figure 21. Overestimation of the spawning stock biomass and underestimation of fishing mortality in the latest years can be observed similar to the results from the methods presented above.

Effect of the weighting of the objective functions

The sensitivity of the AMCI results to weighting of the objective functions was tested. Three different runs of AMCI were performed with different weighting of objective functions (catch in numbers, survey data and yield):

1) Applying weight 1 for all three objective functions.
2) Applying weight 0.6 to the catch-at-age, 0.8 to the survey and 1 to the yield matrix.
3) Applying weight 0.6 to the catch-at-age, 0.8 to the survey and 10 to the yield matrix.

Weighting all objective functions equally gave up to 4% lower SSB and higher fishing mortality in the latest years compared to the second run. Giving higher weight (10) to the yield resulted in up to 13% higher SSB and lower fishing mortality in latest years compared to the second run. The effect on the historical fishing mortality estimates was greater for some years. The effect of different weighting on SSB, fishing mortality, recruitment and stock numbers in 1999 are shown in Figure 22. The difference between modelled and observed yield from those three runs is presented in Figure 23. Applying lower weight to the yield gave greatest difference between modelled and observed yield in 1988 (20-30 thousand tons) and in the beginning of the 1990s.

Retrospective analysis of SSB showed the best behaviour while applying the weight 10 to the yield matrix (Figures 21, 24).

For further analysis of the catch-at-age residuals that showed trends and blocks of positive or negative values in the final run, an additional run was performed by giving the weight 10 to both catch-at-age and yield matrix and 0.8 to the survey. Residuals of catch-at-age did not show obvious difference from the residuals of the final run giving the weights 0.6 and 10 to the catch-at-age and yield, respectively (Figures 19 and 25).

Effect of age span used for tuning

An AMCI run with survey data for ages 1-14 was performed for testing the sensitivity of the results to the number of ages included from the survey indices. Weights 0.6, 0.8 and 10 were applied to the objective functions of catch-at-age, survey and yield, respectively. The difference in stock in numbers in the final year was less than 3%. Retrospective analysis of SSB behaved slightly better for the latest years while excluding younger and older ages (Figures 21 and 26).

Effect of allowing changes in selection over time

An AMCI run keeping the selection pattern constant over time was compared to the run where gradual change in the selection pattern was allowed. The weights 0.6, 0.8

and 10 were applied on objective functions of catch-at-age, survey and yield. Survey data for ages 3-10 was used in both of these runs.

The results of AMCI were found to be quite sensitive to the assumption concerning the selection. Keeping the selection pattern constant over time resulted in about 17% higher SSB and 25% lower fishing mortality compared to the assessment allowing gradual change in selection. Projected stock numbers for 1999 differed up to 42% (Figure 27). A retrospective pattern of SSB showed considerably less consistency while keeping selection constant over time (Figure 28).

<u>Uncertainty</u>

Uncertainty estimates are presented for assessment including survey data for ages 1-14 and without using the RCT3 programme for estimating recruitment in the latest years.

Percentile confidence intervals for spawning stock biomass, fishing mortality and recruitment estimates from AMCI are presented in Figure 29. The 90% confidence interval for spawning stock biomass was between 380 and 600 tons and for reference fishing mortality between 0.2 and 0.4 in 1998. Ninety percent of the bootstrapped estimates of recruitment were between 280 and 10000 million in 1998.

3.3 Comparison of the results from different stock assessment methods

3.3.1 Comparison of the assessment results

Comparison of the estimated stock in numbers in 1999 from the four assessments is presented in Figure 30. The largest difference between the methods was observed for age 3 that was estimated higher in numbers for 'cadapt' compared to the other methods, although in all methods 3-year-olds in 1999 is the result from the RCT3 programme estimate of the recruitment. Fishing mortalities (Figure 31) in 1998 were estimated higher from XSA for all the ages compared to the other methods. The lowest fishing mortality estimates were obtained from 'cadapt' and the difference with other methods was largest for ages 10-13.

The comparison of the estimated spawning stock biomass, reference fishing mortality and recruitment from the final runs of XSA, two adapt-type assessments and Statistical-Catch-at-Age are presented in Figures 32-34. The recruitment estimate (obtained by the RCT3 programme) in 1998 for the 'cadapt' was the highest and differed the most from the rest of the methods. The highest spawning stock biomass in latest years was obtained from AMCI and lowest from XSA. XSA also gave the highest fishing mortality but the lowest was obtained from 'cadapt'. The most similar spawning stock biomass and fishing mortalities in the latest years were obtained from AMCI and 'cadapt'. The difference between the results of these two methods was less than 10%, except for fishing mortality in the last year, which was 20% higher from AMCI. The results from the MRI-adapt were in the same range as AMCI and 'cadapt' but the results from XSA differed the most from the other methods. The difference between the spawning stock biomass from XSA and AMCI was up to 30% in the latest years.

Stock in numbers in 1979-1999 for ages 3-12 estimated by the four methods used are presented in Figure 35. The highest variation in estimated stock in numbers was observed for the 1989 year-class. The estimate was higher from AMCI and lower from XSA compared to the other methods.

3.3.2 Short-term projections

Short-term predictions using estimated stock in numbers for 1999 and fishing mortalities obtained from XSA, 'cadapt' and AMCI were performed. Reference fishing mortalities in predictions were assumed to be equal to the fishing effort in 1998 for all of the methods. The fishing pattern used in prediction was estimated by scaling the average fishing mortalities in 1996-1998 according to the reference F in 1998. Average weight-at-age and maturity-at-age in 1996-1998 was used in the predictions. Recruitment of 600 million was assumed in the predictions based on the geometric mean over the last 10 years.

The predicted yield in 2000 differed about 40% between estimates from XSA and AMCI. The largest difference in predicted spawning stock biomass in 2001 was obtained between projections from 'cadapt' and XSA. The prediction from 'cadapt' was about 30% higher (Table 3). The yield in 2000 and SSB in 2001 for different fishing mortalities and for different methods are presented in Figure 36.

Table 3: Predicted yield (tons) in 2000 and spawning stock biomass (tons) in 2001 using stock in numbers in 1999 and fishing effort in 1998 obtained from XSA, 'cadapt' and AMCI.

method	Yield-2000	SSB-2001
XSA	64578	404454
Adapt	93647	554349
AMCI	109978	467817

Projection in AMCI was run with the reference fishing mortality and selection equal to the estimate for 1998. Uncertainty in projection of spawning stock biomass and modelled catch from AMCI is shown in Figure 37. The 90% confidence interval for the predicted catch in 2000 and 2001 was in the range of 75 to 250 thousand tons. The estimated 90% confidence interval for predicted spawning stock biomass in 2000 and 2001 was between 300 and 900 thousand tons.

4 DISCUSSION

Quality of the catch-at-age and acoustic survey data

The residuals from the Shepherd-Nicholson model for catch-at-age data and also catch-at-age residuals from AMCI showed trends and blocks of positive or negative values. This residual pattern could be related to several things, e.g. non-random sampling, errors in age reading or the behaviour of the fishery, which might be chasing certain cohorts. Observed higher residuals for younger and older age groups compared to the middle age groups are expected as middle age groups are usually the best sampled. A decreasing trend in the residuals in the latest years might be an indication of better sampling and/or more consistent age reading in recent years. A very large value of the mean squared residual of catch-at-age data is probably related to very high residuals for age 2 and also for some of the older ages. In order to analyse the data better for the middle age groups the youngest and oldest ages should probably have been excluded from the model.

In the acoustic survey data age group 2 showed the highest residuals. According to the information from the MRI staff this is most likely due to the inconsistent distribution of this particular age group from year to year and incomplete survey coverage. A significant year-effect in the Shepherd-Nicholson model for the survey data was observed possibly due to the annual variability in the availability of herring to acoustic survey. Smaller residuals in the latest years might be related to the changes in distribution of herring that have taken place according to information obtained from MRI and possibly also due to increased experience and improved technology in performing acoustic surveys.

Comparison of the results from different stock assessment methods

Recruitment estimates for age 2 in 1998 and 3 year-olds in 1999 are estimated higher from 'cadapt' assessment compared to the other methods. Recruitment from the RCT3 programme for the particular year-class in the case of 'cadapt' is estimated by giving higher weight to the survey compared to e.g. AMCI where the RCT3 estimate for this year-class is mostly based on the VPA mean. An acoustic estimate for the 1996 year-class as 1-year-olds in 1997 is the highest in the data series, therefore giving higher weight to the survey data in the RCT3 results in a higher recruitment estimate for this year-class in 'cadapt'.

A comparison of the historical results from the four assessments showed the largest difference between the results from XSA and other methods. Higher fishing mortality and lower stock in numbers estimates were obtained from XSA. This might be at least partly related to the shrinkage applied in XSA. Giving lower weight to the shrinkage increased SSB and decreased fishing mortality estimates in the latest years and the results from XSA became more similar to the results from other methods. This can be an indication that the assumption of unchanged fishing mortality in the latest 5 years and applying the weight 0.5 on the shrinkage might have been incorrect. The use of weak shrinkage (SE 0.5) has been recommended by the Working Group on Methods of Fish Stock Assessment (ICES 1999). Shrinkage in XSA is used to reduce the effect of erratic behaviour of the terminal values. There is a risk that shrinking of parameter estimates towards historic values (i.e. including information from the past) may introduce bias in the parameters (ICES 1999). Shrinkage can be used to improve retrospective pattern in the assessment (ICES 1999) but in this study, changing the weight applied on the shrinkage affected the assessment results but not the behaviour of the retrospective pattern.

Historical estimates of stock in numbers showed the largest variation for the 1989 year-class (10-year-olds in 1999). Estimates from AMCI were higher in numbers throughout the development of the cohort compared to the other methods. This might be related to the relatively big catch in numbers for this particular cohort until the last year available in the data.

Probability distributions of spawning stock biomass in 1998 from 'cadapt' and AMCI showed around 50% coverage indicating that the stock size in the final assessment year estimated by these two methods are not significantly different. The 90% confidence interval for recruitment from AMCI in the latest years was wider compared to 'cadapt' and covered the 90% probability interval of the recruitment estimates from the latter method. High uncertainty in recruitment resulted in high uncertainty in predicted spawning stock biomass and catch. Higher uncertainty in AMCI compared to 'cadapt' might be related to the equal weighting of different age groups in AMCI while in 'cadapt' poorly determined age groups are down-weighted. It should be noticed that uncertainty is estimated for assessments including survey data for all ages available and not using the RCT3 programme for recruitment estimates. Therefore, the point estimates from these assessments differ from the point estimates of the assessments that are presented as final runs in this report.

Retrospective patterns from XSA, 'cadapt' and AMCI showed relatively similar behaviour. All methods indicated overestimation of spawning stock biomass and underestimation of fishing mortality in previous years. Retrospective biases can arise for many reasons, ranging from bias in the data to different types of model misspecifications, e.g. parameters that are assumed to be constant in the analysis, actually change (National Research Council 1998). Retrospective patterns can be the result of trends in catchability in the tuning indices, misspecification of partial recruitment for the oldest ages in the stock etc. (ICES 1991). Retrospective patterns can also be stock specific regardless of the method used (ICES. 1991) as seems to be the case for the Icelandic herring. A given combination of factors can affect the data in a particular way that causes all methods that use the same data to be affected in a similar way (ICES 1991). Consistent over- or underestimation in the retrospective analysis indicates problems in the specification of the model; thus conventional model-based measures of uncertainty of management parameters are not realistic because they are based on the structural assumptions of the model being correct (National Research Council 1998).

Sensitivity of the models to age span used for tuning

It is common practise in tuning age-structured models with survey data to down-weight or exclude the youngest and oldest age groups due to their relatively higher variance. The data set used in this study is peculiar in the way that relatively higher residuals were observed for age group 2 than age 1, which is probably related to different spatial distribution of these age groups.

Including all age groups covered by the data in the tuning generally resulted in similar fishing mortality and stock size estimates for all the methods as when oldest and youngest ages were excluded. The observed difference in XSA and Adapt was the greatest for the survivor estimates of 8-year-olds in 1999 that, by following the particular cohort backwards, was also the main cause of the difference in spawning stock biomass in the latest years. The survey estimate for the 1991 year-class age 1 in 1992 was the second highest estimate in the data series, but then decreased sharply. This might be why this particular cohort is estimated higher in numbers while including the survey data for younger ages. In spite of the down weighting of older ages in 'cadapt', the consistency in the retrospective pattern improved while excluding older ages from the tuning but did not change remarkably by excluding the younger ages as well. Therefore, including older ages in the survey data, which have got relatively high variance and only a few observations, probably did not improve the assessment. By excluding age groups 1 and 2 based on relatively high variance in the abundance index for age 2 one might loose valuable information in the index of 1-year -olds.

Choice of the appropriate method

Retrospective analysis is one possibility when deciding which method should be used for assessing a particular stock. Retrospective analysis doesn't show the degree of departure from the "true" population but reflects the degree of consistency between years. Stock sizes and fishing mortalities from the retro years can be compared to the results from the final assessment year and the difference can be expressed by a single number of the average absolute residual (ICES 1991). This method provides a clear distinction between the retrospective behaviour from different methods by comparing single numbers instead of a visual impression of the behaviour of the retrospective pattern. Due to time constraints this analysis was not included in this study.

Retrospective patterns from the three assessments performed in this study show similar behaviour. In the most recent years the retrospective pattern for spawning stock biomass was slightly more consistent for AMCI compared to the other methods. Applying the Statistical Catch-at-Age model using AMCI theoretically has many advantages. It takes into account the error in catch-at-age data and provides the possibility of estimating uncertainty and running forward projections and retrospective analysis within the programme. In the case presented in this report the observed blocks of residuals of catch-at-age might indicate that the AMCI programme is not able to fit the catch data and the separability model might be incorrect. The separable model is not suitable if the fishery is targeting specific year-classes, which is presumably the case for the Icelandic herring. In this study the selection is allowed to change over the years by a certain factor but the model specification used might still not be correct.

In the assessment method that is officially used for assessing the Icelandic summer-spawning herring stock, the data on different age groups are pooled together for tuning. This is justified as the sampling of different age groups due to their variable behaviour and age reading is considered problematic according to information from the MRI staff. Therefore, it might be the most appropriate method to use for assessing the particular stock as down-weighting the poorly determined age groups may not be enough to avoid the noise in the assessment.

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FIGURES

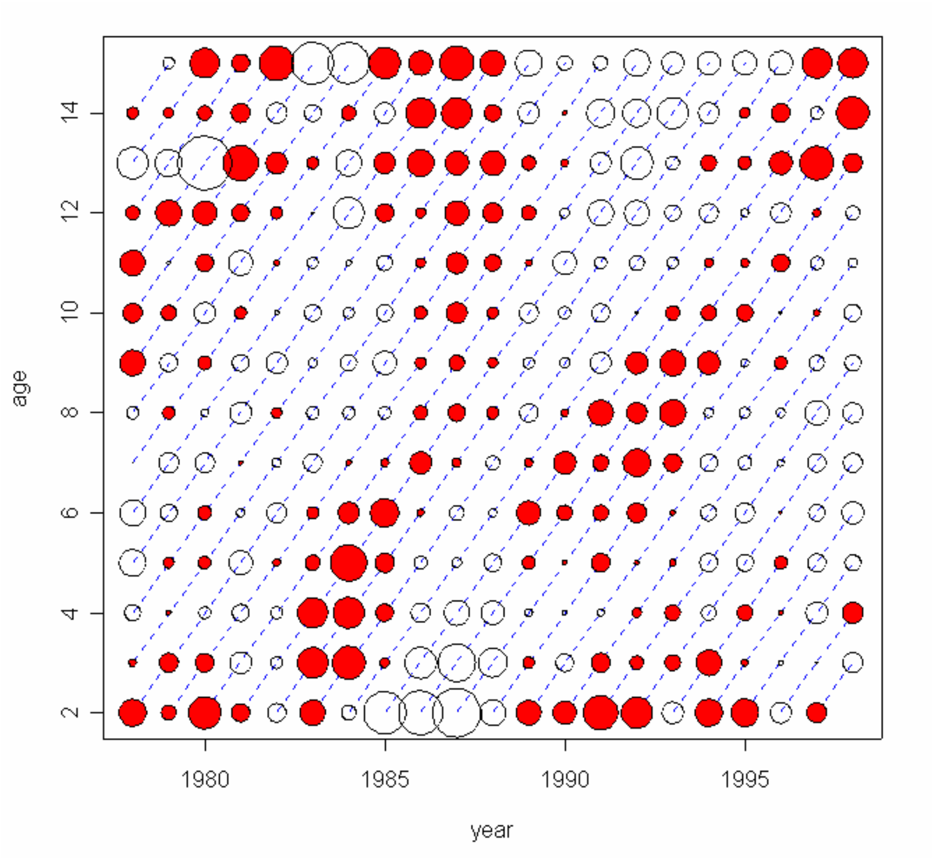

Figure 1: Relative log residuals (maximum value 4.2) from Shepherd-Nicholson model for catch -at-age data for ages 2-15 and for years 1978-1998 (filled circle-postive, open circle-negative).

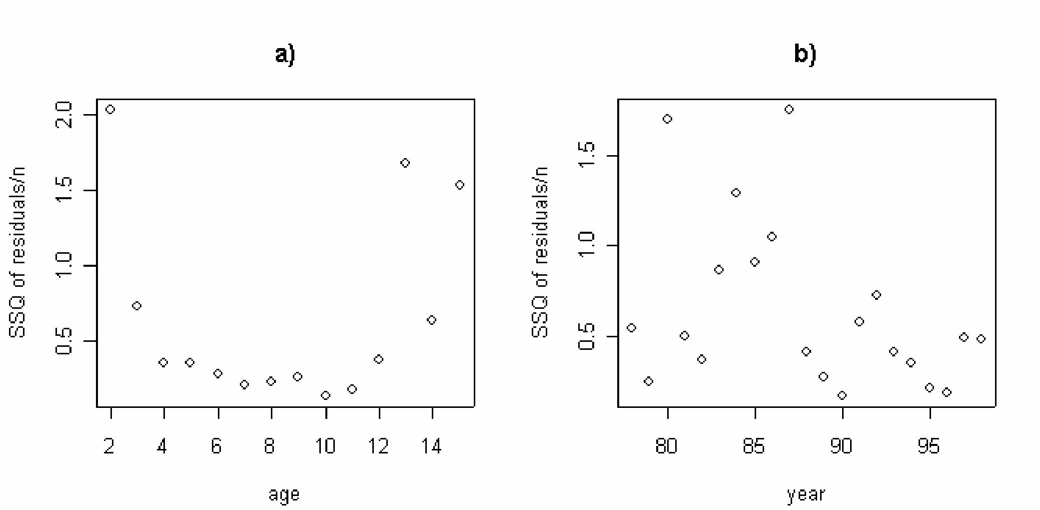

Figure 2: Sum of squared log residuals from Shepherd-Nicholson model for catch-at-age data by a) ages 2-15 and by b) years 1978-1998 divided by the number of data points (n).

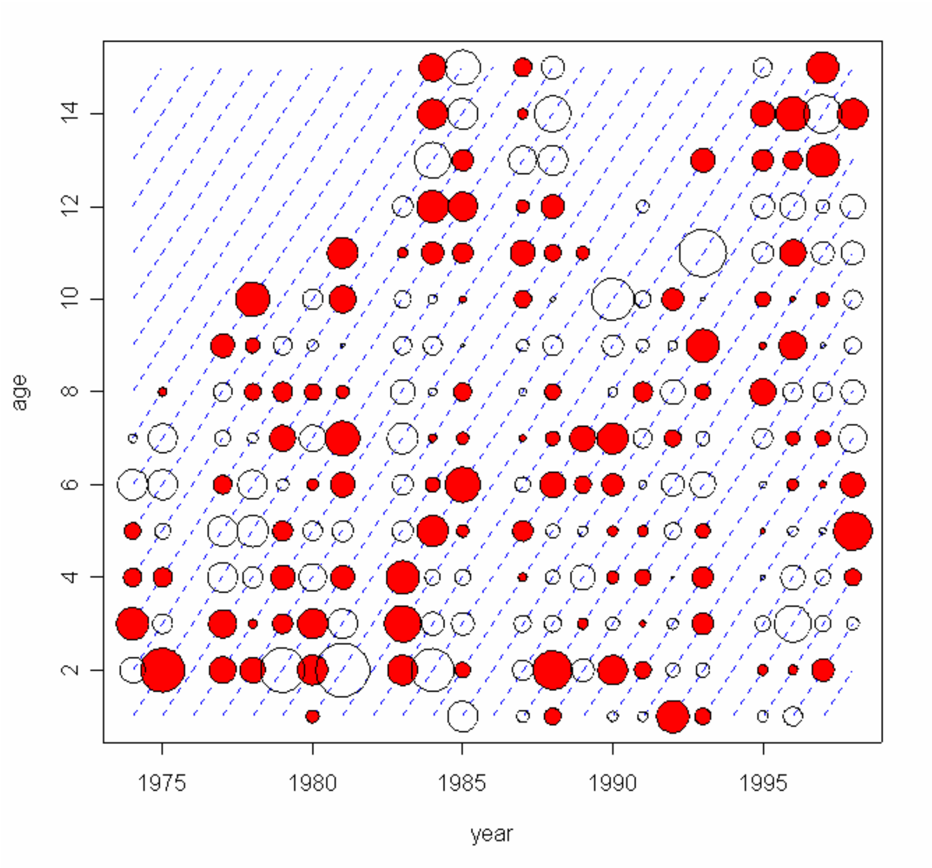

Figure 3: Relative log residuals (maximum value 2.33) from Shepherd-Nicholson model for acoustic survey data for ages 1-15 and years 1974-1998 (filled circle-postive, open circle-negative).

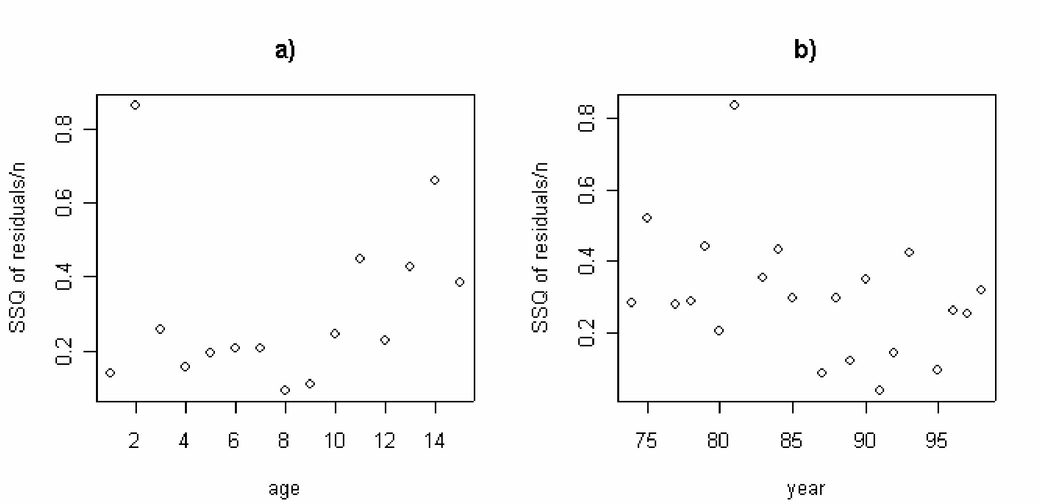

Figure 4: Sum of squared log residuals from Shepherd-Nicholson model for acoustic survey data by a) ages 1-15 and by b) years 1974-1998 divided by the number of data points (n).

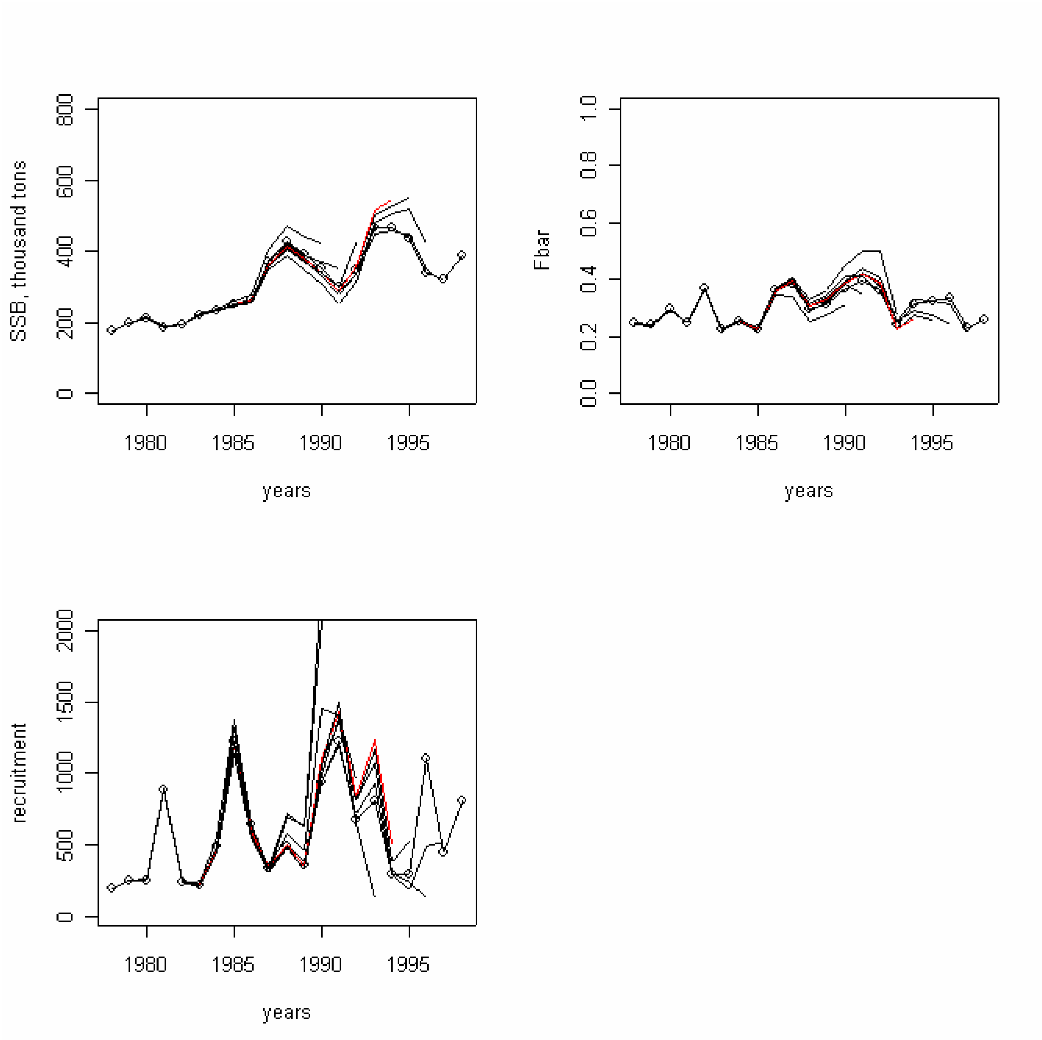

Figure 5: Retrospective analysis of spawning stock biomass (thousand tons), fishing mortality (weighted average of the ages 5-15) and recruitment (age 2, in millions) from the final run (tuned with ages 3-8, SE 0.5 applied as a weight on the shrinkage) of XSA (red line indicates to the year with no survey data).

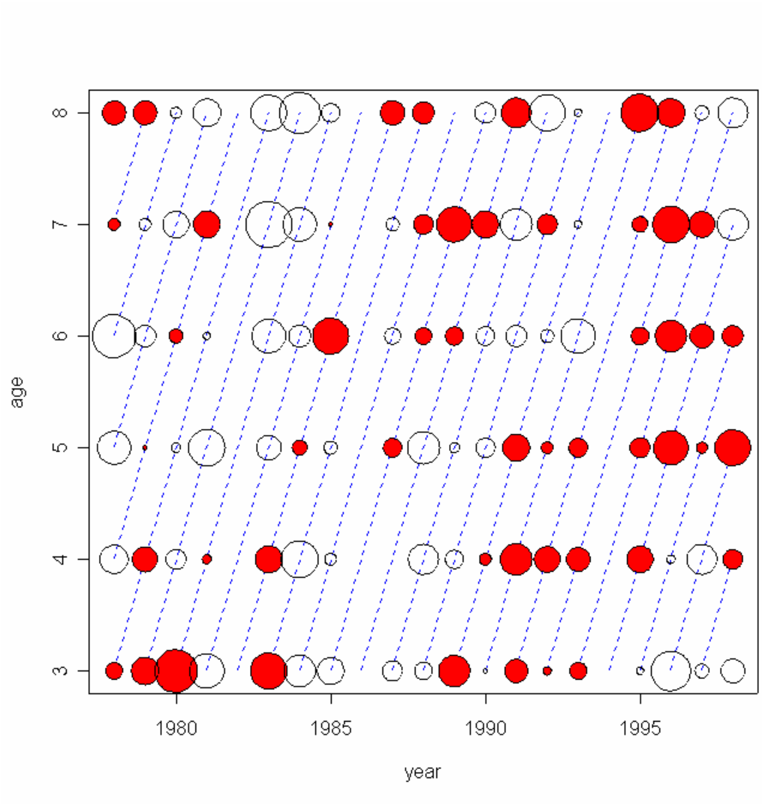

Figure 6: Relative log catchability residuals (max value 1.21) for ages 3-8 in 1978-1998 from the final run (tuned with ages 3-8, SE 0.5 applied as a weight on the shrinkage) of XSA (filled circle- positive, open circle-negative).

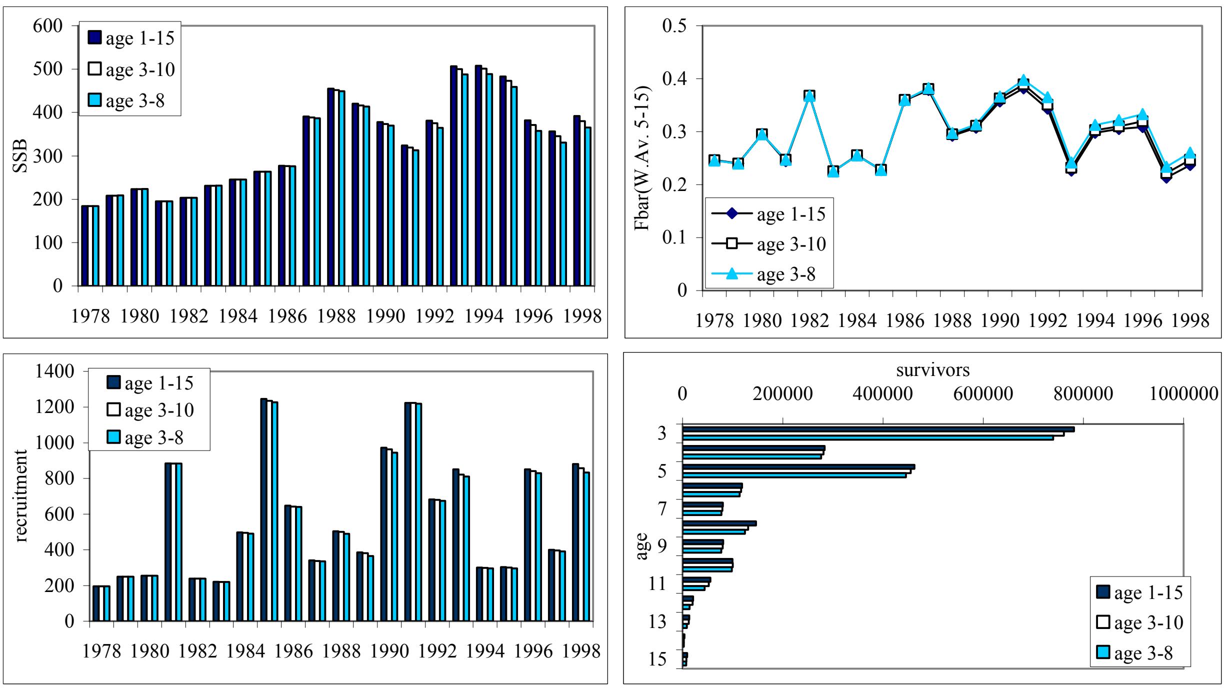

Figure 7: Spawning stock biomass (in thousand tons), reference fishing mortality (weighted average of ages 5-15), recruitment (age 2, in millions) and survivor estimates in 1999 (in thousands) from three runs of XSA tuned with ages 1-15, 3-10 and 3-8, respectively.

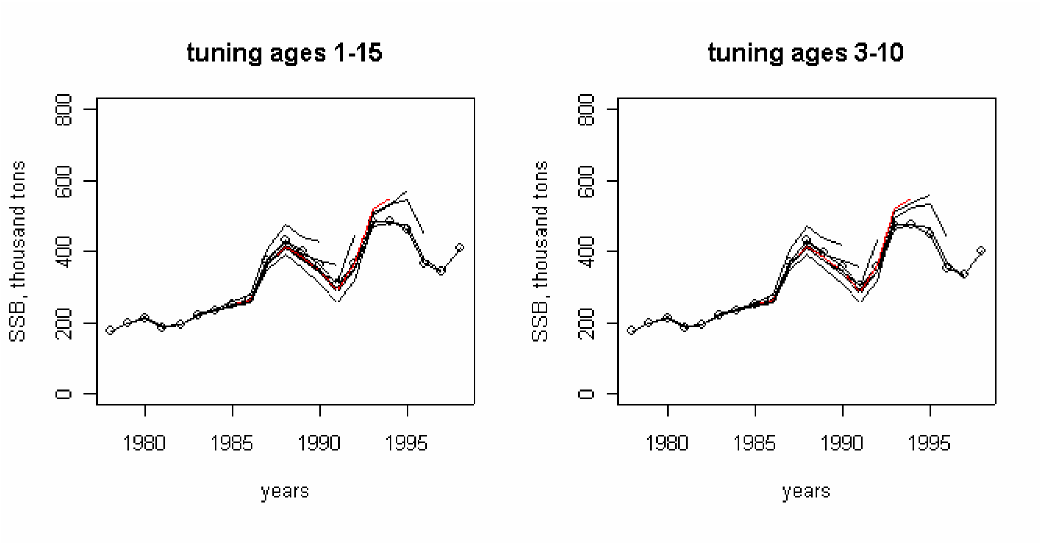

Figure 8: Retrospective analysis of SSB (thousand tons) from XSA tuned with ages 1-15 and 3-10 (red line indicates to the year with no survey data).

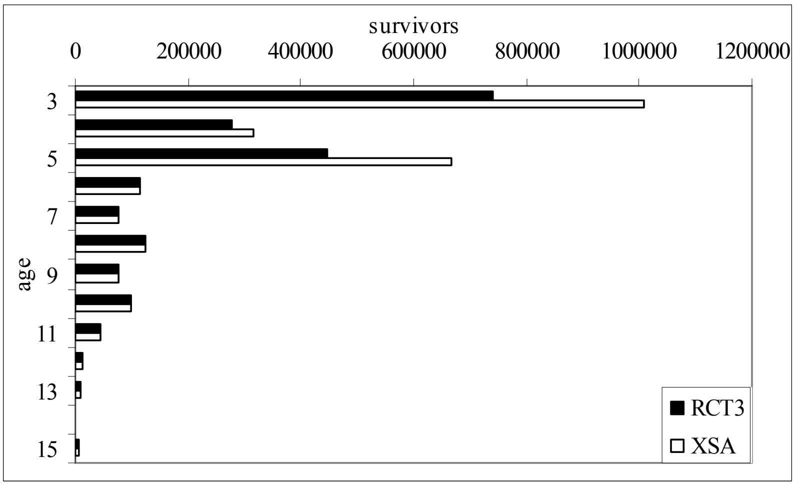

Figure 9: Survivor estimates in 1999 (in thousands) from two XSA assessments tuned with ages 3-8 and using for recruitment (age 2) estimates in 1996-1998 1) RCT3 2) 2-year-olds from XSA run including survey information for age 1.

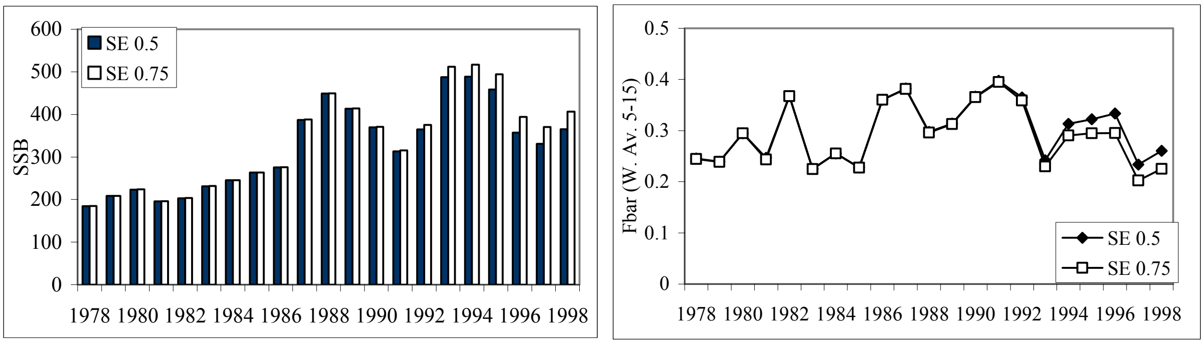

Figure 10: Spawning stock biomass (thousand tons) and reference fishing mortality (weighted average of ages 5-15) from two XSA runs (tuned with ages 3-8) giving weight on the shrinkage as standard errors 0.5 and 0.75, respectively.

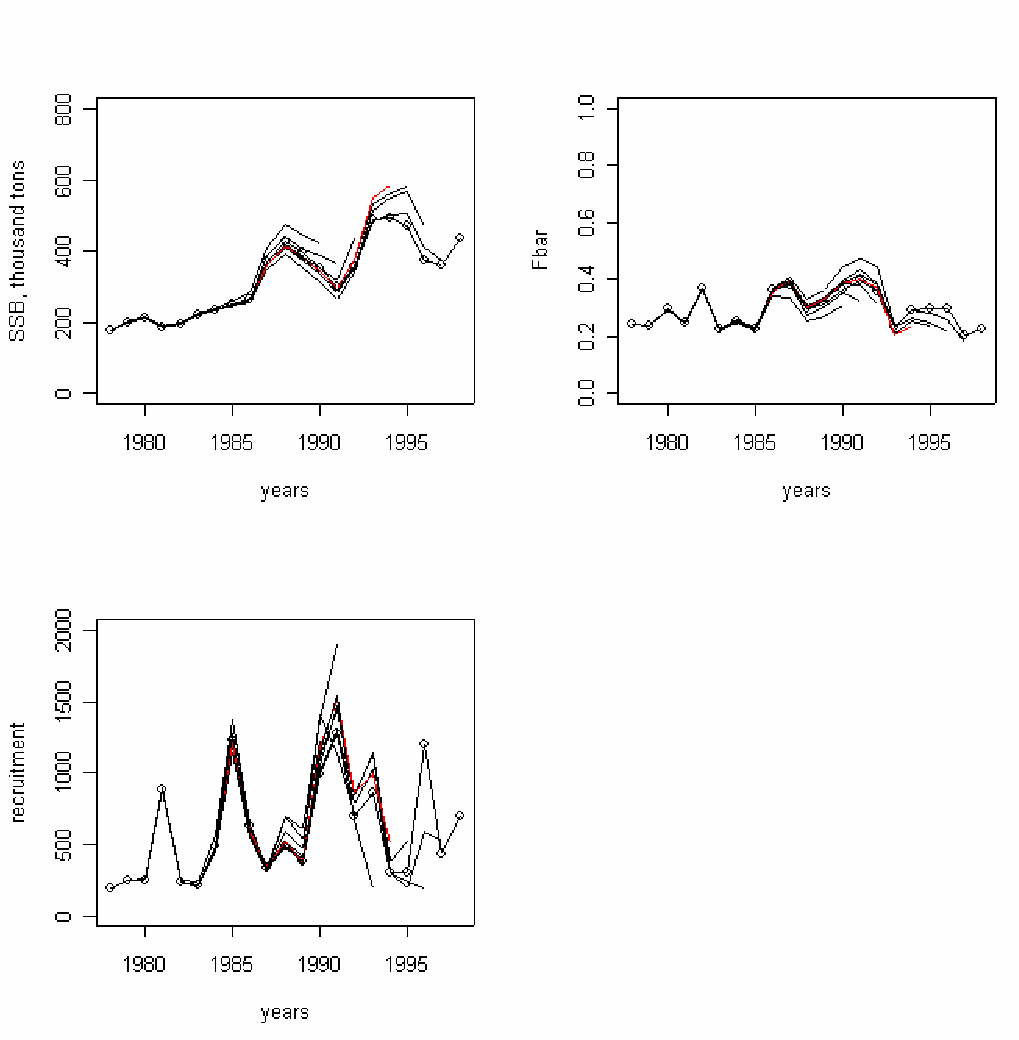

Figure 11: Retrospective analysis of spawning stock biomass (thousand tons), fishing mortality (weighted average of ages 5-15) and recruitment (age 2, in millions) from XSA run (tuned with ages 3-8) giving weight on the shrinkage as standard error 0.75 (red line indicates to the year with no survey data).

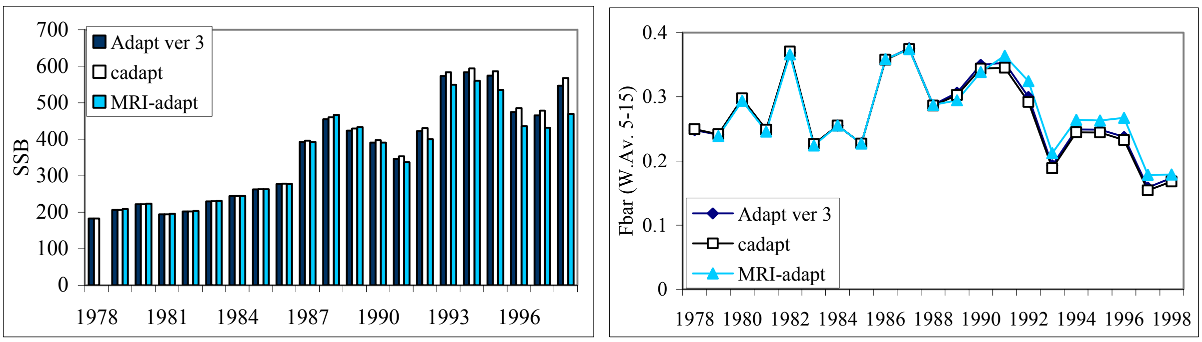

Figure 12: Spawning stock biomass (thousand tons) and reference fishing mortality (weighted average of ages 5-15) from the Adapt ver 3, 'cadapt' and MRI-adapt (Adapt ver 3 and 'cadapt' runs tuned with ages 3-10).

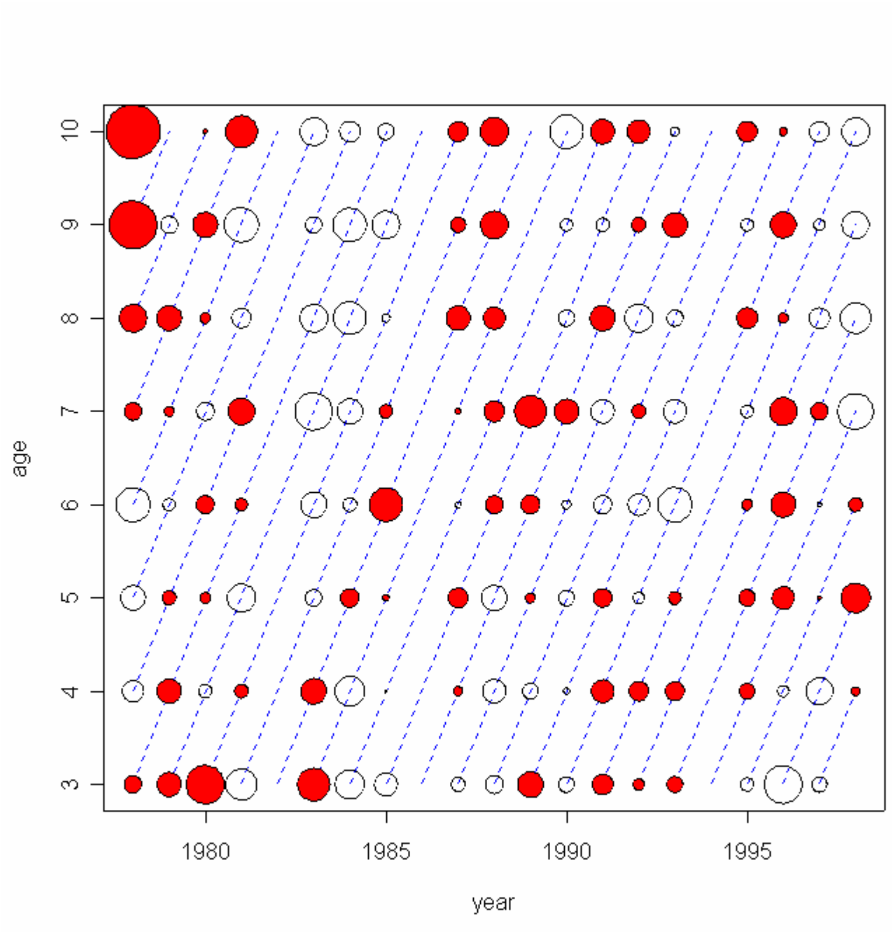

Figure 13: Relative log residuals (maximum value 2.23) from final (tuned with ages 3-10) adapt-type assessment by 'cadapt' (filled cirle-positive, open circle-negative).

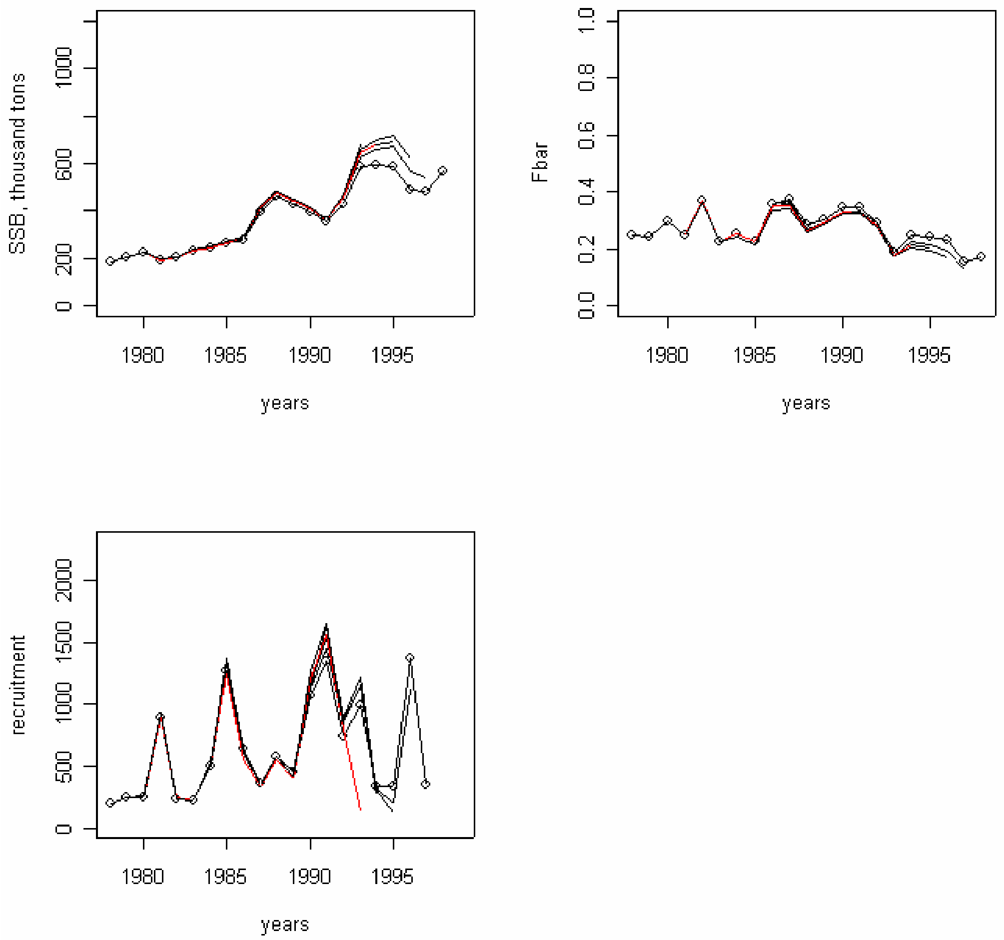

Figure 14: Retrospective analysis of spawning stock biomass (thousand tons), fishing mortality (weighted average of ages 5-15) and recruitment (age 2, in millions) from final (tuned with ages 3-10) adapt-type assessment by 'cadapt' (red line shows the year with no survey data).

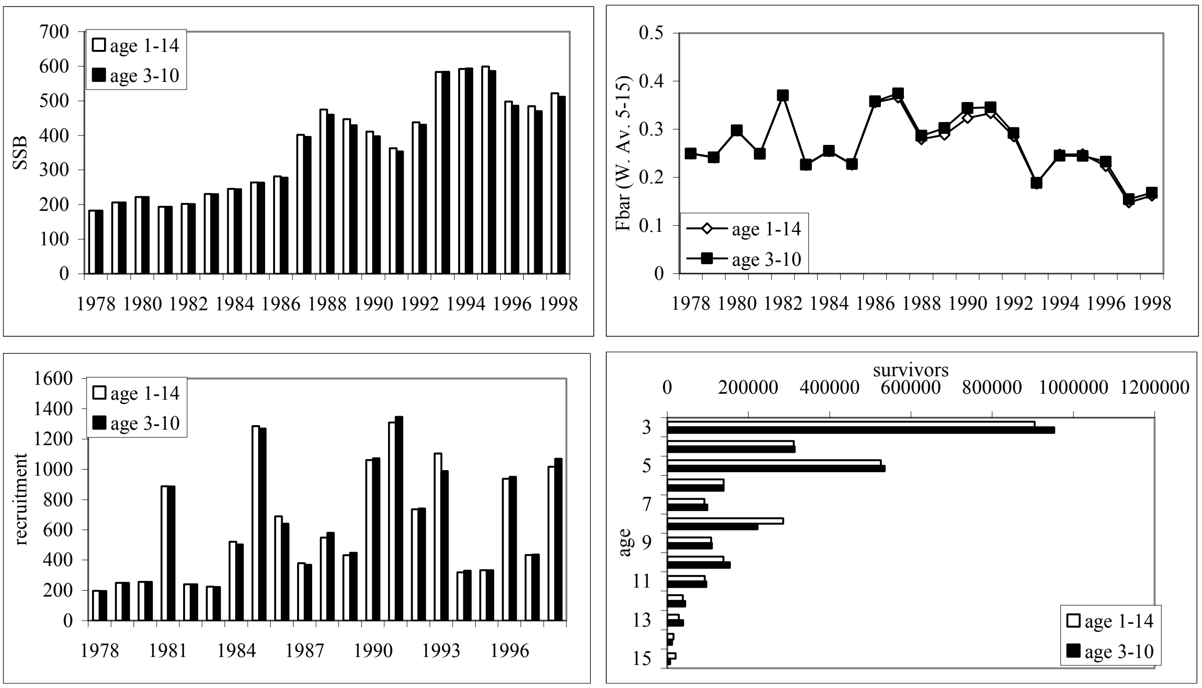

Figure 15: Spawning stock biomass (thousand tons), reference fishing mortality (weighted average of ages 5-15), recruitment (age 2, in millions) and survivor estimates in 1999 (thousands) from 'cadapt' tuned with survey data for ages 1-14 and 3-10.

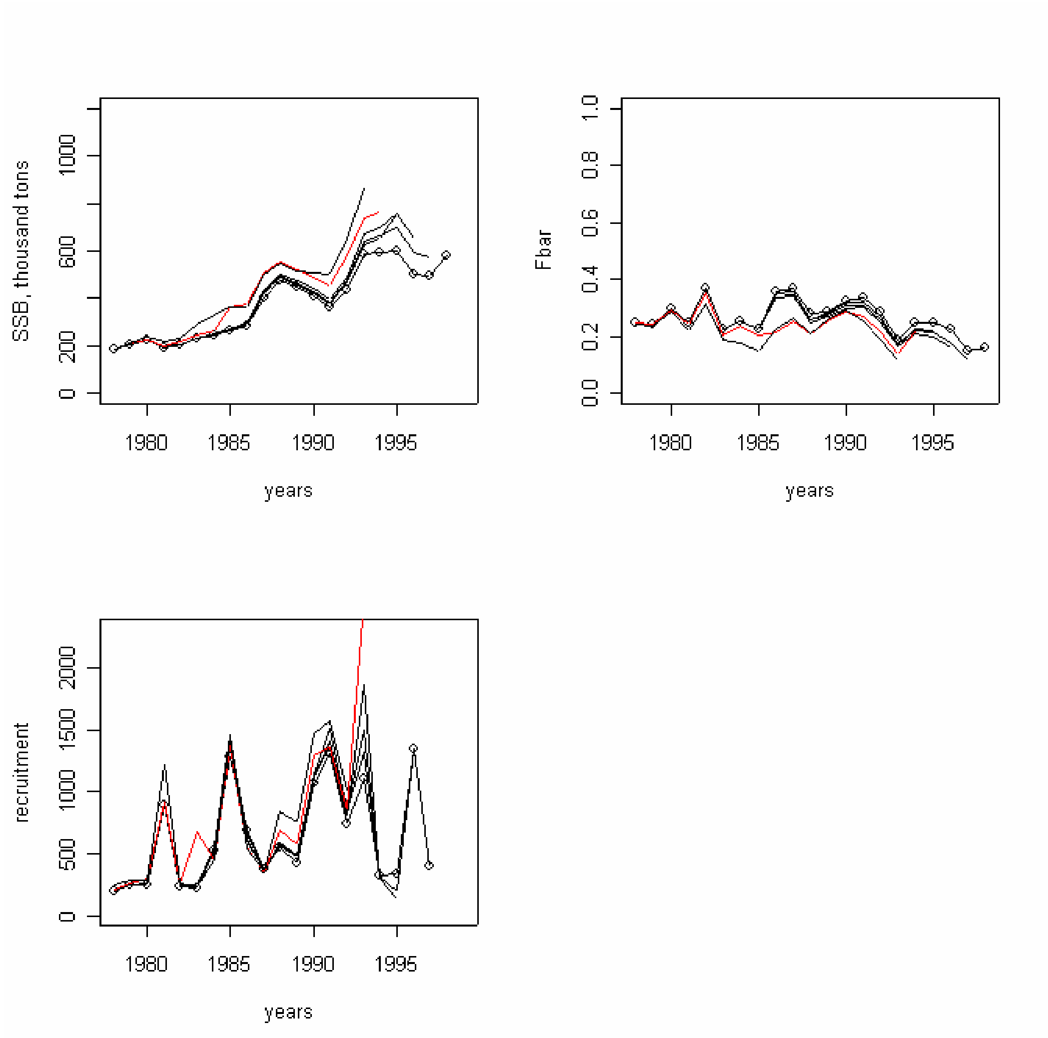

Figure 16: Retrospective analysis of spawning stock biomass (thousand tons), fishing mortality (weighted average of ages 5-15) and recruitment (age 2, in millions) from adapt-type assessment (by 'cadapt') tuned with survey data for ages 1-14 (red line shows the year with no survey data).

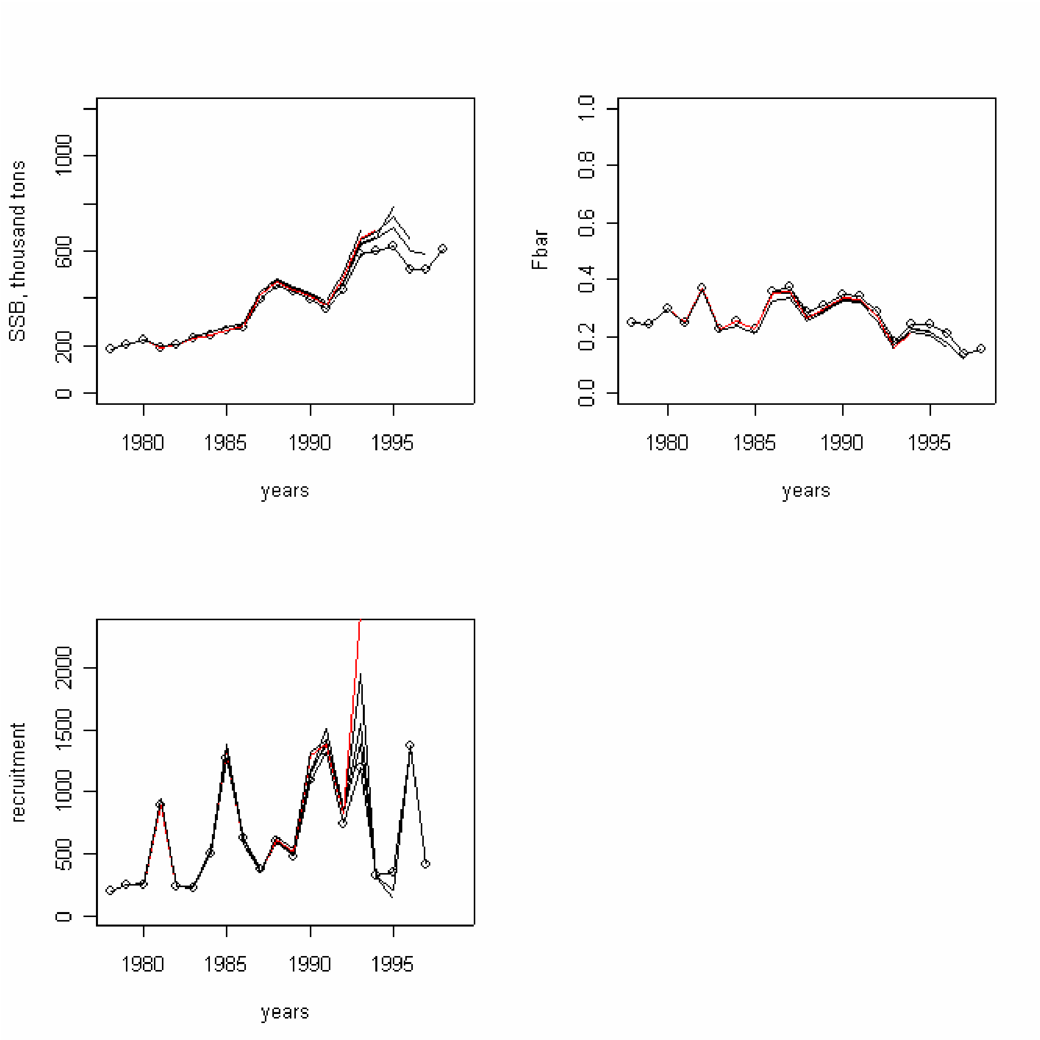

Figure 17: Retrospective analysis of spawning stock biomass (thousand tons), fishing mortality (weighted average of ages 5-15) and recruitment (age 2, in millions) from adapt-type assessment (by 'cadapt') tuned with survey data for ages 1-10 (red line shows the year with no survey data).

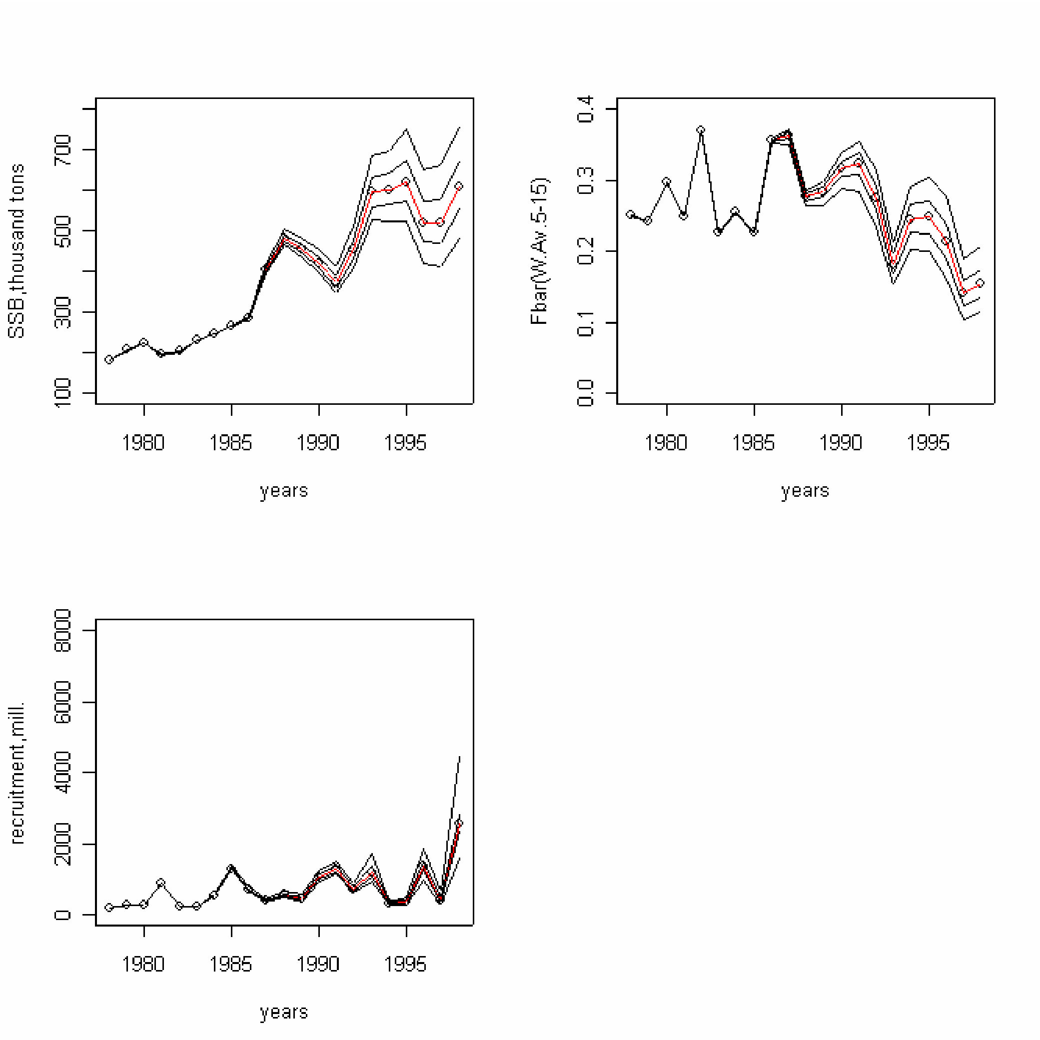

Figure 18: Confidence intervals (5%, 25%, 50%, 75% and 95% percentiles) for spawning stock biomass, reference fishing mortality (weighted average of ages 5-15) and recruitment (age 2) from adapt-type assessment (by 'cadapt') tuned with survey data for ages 1-14.

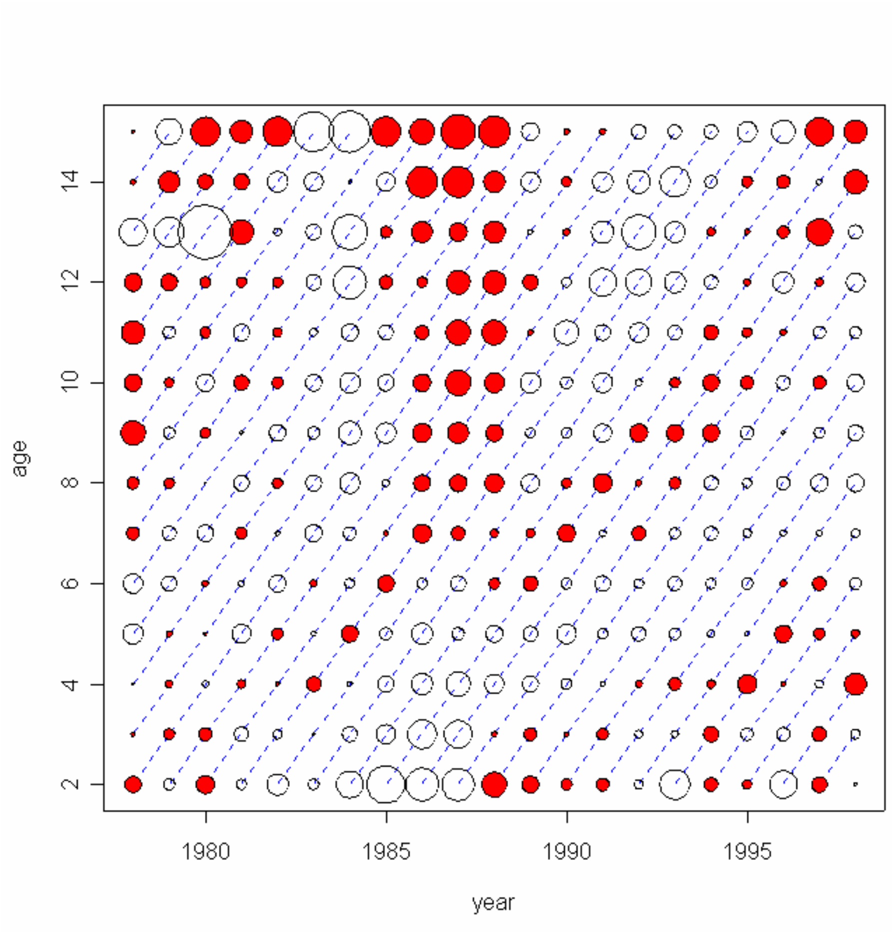

Figure 19: Relative log residuals (maximum value 5.13, open circle-negative, filled circle-positive) of catch-at-age from AMCI final run (tuned with ages 3-10; 0.6, 0.8 and 10 applied as weights on the objective funtions of catch-at-age, survey and yield, respectively and selection allowed to change in time by a certain factor).

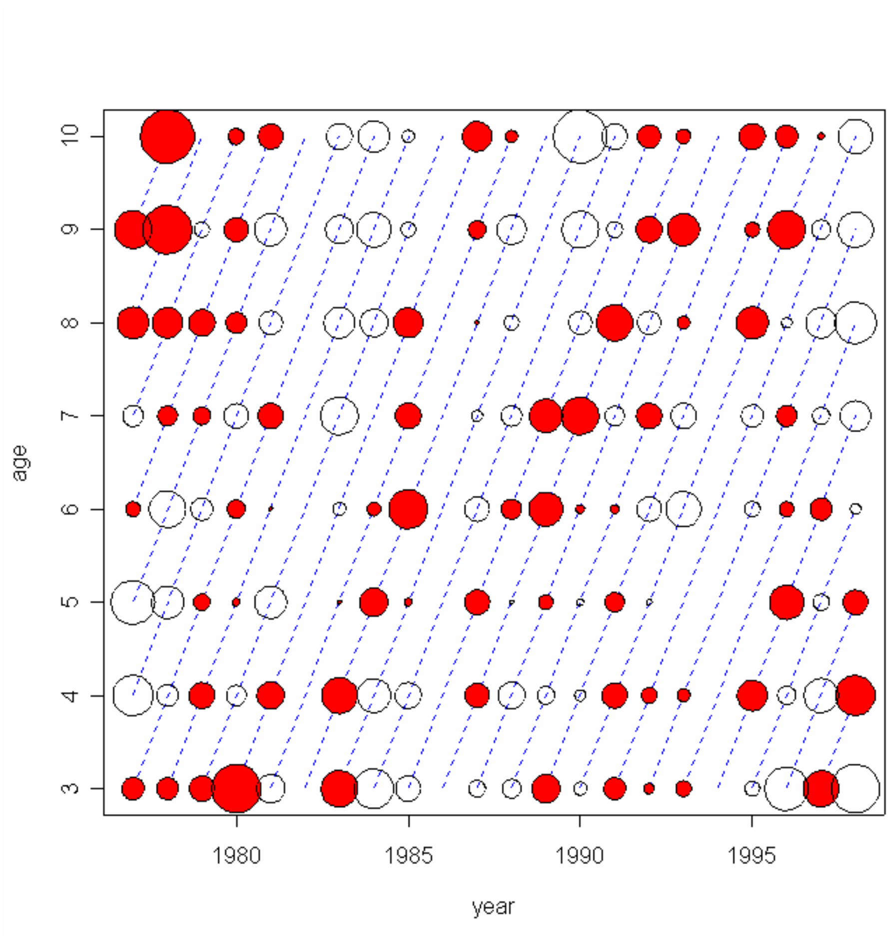

Figure 20: Relative log residuals (maximum value 1.86, open circle-negative, filled circle-positive) of survey indices from AMCI final run (tuned with ages 3-10; 0.6, 0.8 and 10 applied as weights on the objective funtions of catch-at-age, survey and yield, respectively and selection allowed to change in time by a certain factor). Ages correspond to the end of a particular year.

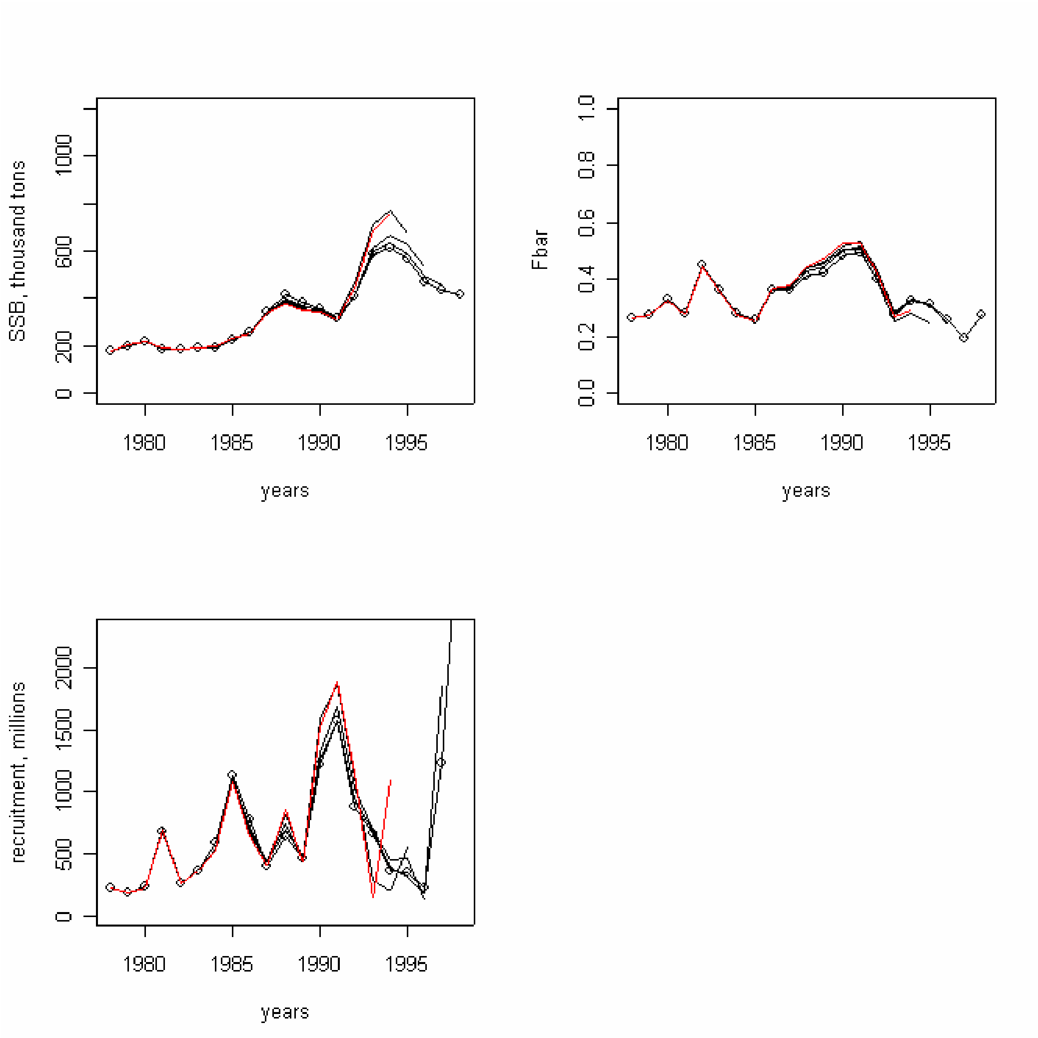

Figure 21: Retrospective analysis of spawning stock biomass (thousand tons), fishing mortality (weighted average of ages 5-15) and recruitment (age 2, in millions) from final AMCI assessment (tuned with ages 3-10; 0.6, 0.8 and 10 applied as weights on the objective funtions of catch-at-age, survey and yield, respectively and selection allowed to change in time by a certain factor) (red line indicates to the year with no survey data).

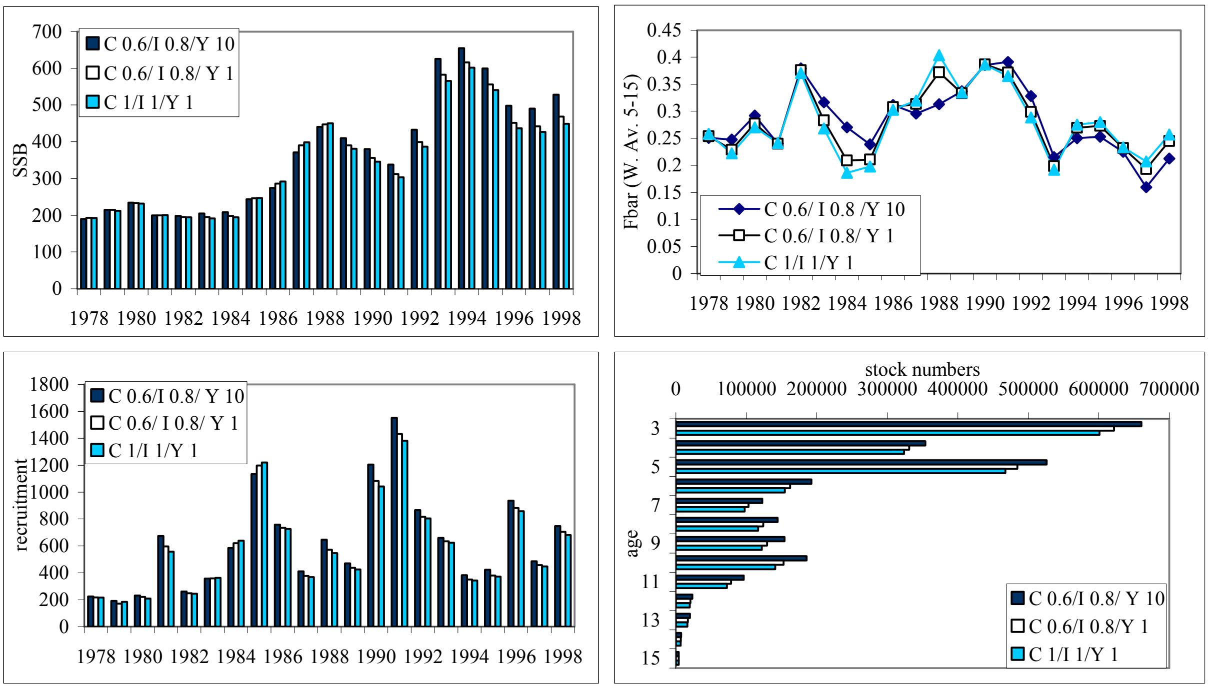

Figure 22: Spawning stock biomass (thousand tons), reference fishing mortality (weighted average of ages 5-15), recruitment (age 2, in millions) and stock in numbers in 1999 (thousands) from three AMCI runs applying weights 1) 0.6, 0.8 and 10, 2) 0.6, 0.8 and 1 and 3) 1, 1, 1 on catch-at-age (C), survey index (I) and yield (Y) objective functions, respectively.

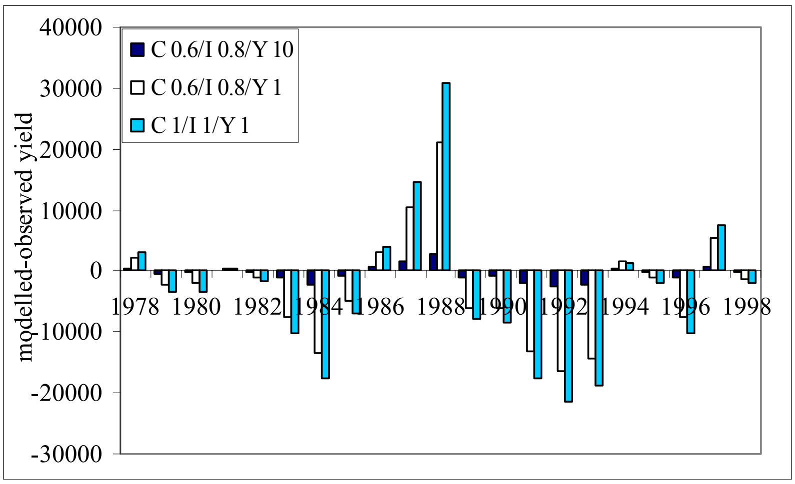

Figure 23: Difference between modelled and observed yield (in tons) from three AMCI runs applying weights 1) 0.6, 0.8 and 10, 2) 0.6, 0.8 and 1 and 3) 1, 1, 1 on catch-at-age (C), survey index (I) and yield (Y) objective functions, respectively.

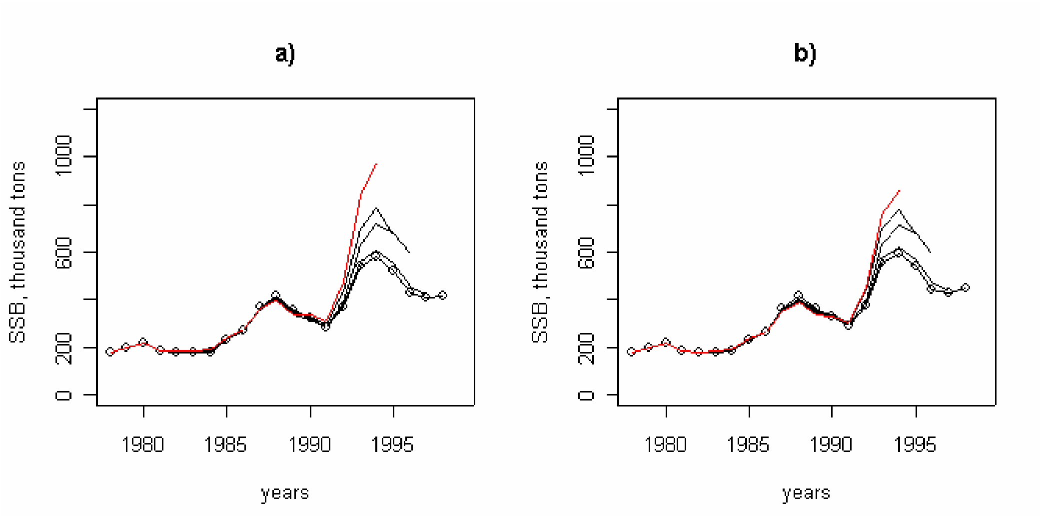

Figure 24: Retrospective analysis of spawning stock biomass from AMCI by applying a) 1, 1, 1; b) 0.6, 0.8 and 1 as weights to the catch-at-age, survey and yield objective functions, respectively (red line indicates to the year with no survey data).

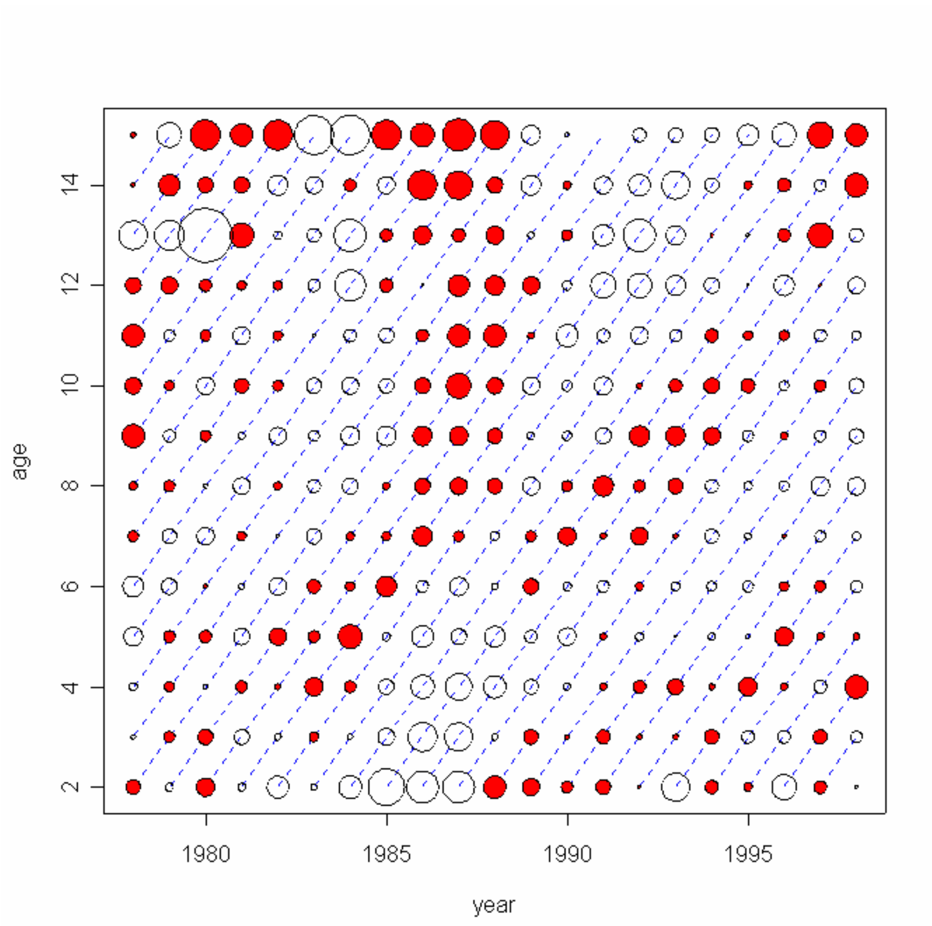

Figure 25: Relative log residuals (maximum value 5.1) of catch-at-age from AMCI run applying weight 10 on catch-at-age and yield and 0.8 on survey objective functions (open circle-negative, filled circle-positive).

Figure 26: Retrospective analysis of spawning stock biomass from AMCI run tuned with survey data for ages 1-14 (red line shows the year with no survey data).

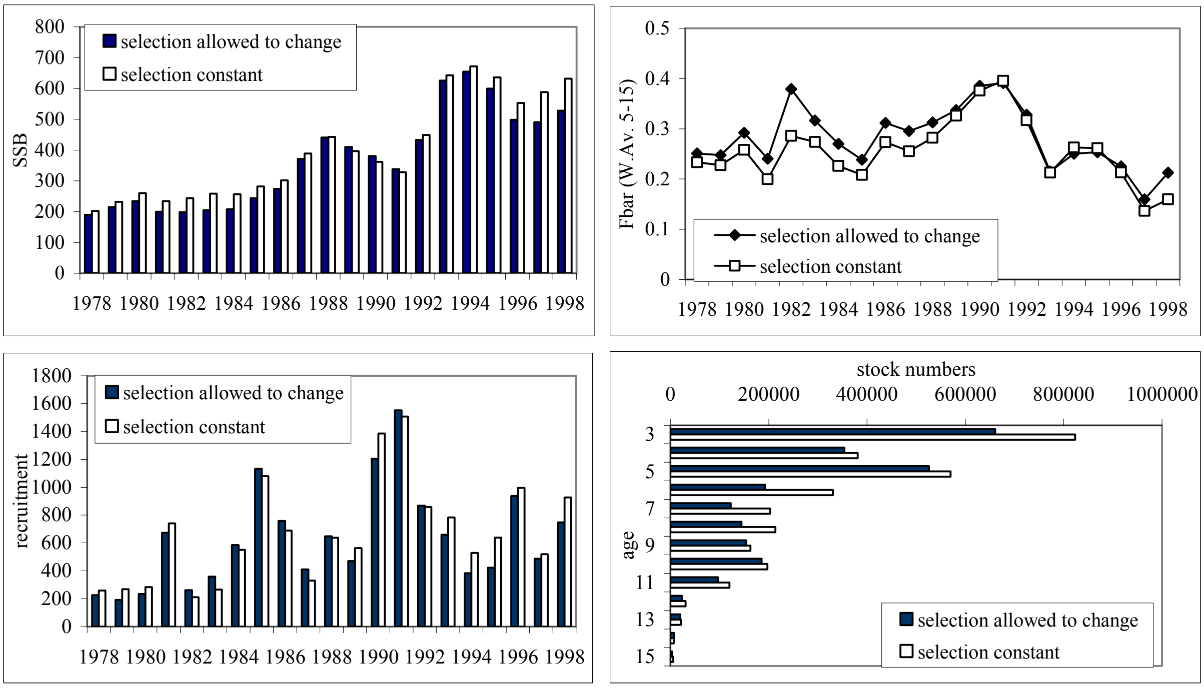

Figure 27: Spawning stock biomass (thousand tons), reference fishing mortality (weighted average of ages 5-15), recruitment (age 2, in millions) and stock numbers in 1999 (thousands) from final AMCI run allowing selection to change over time and from the run keeping selection constant. The other options in the two runs were kept equal.

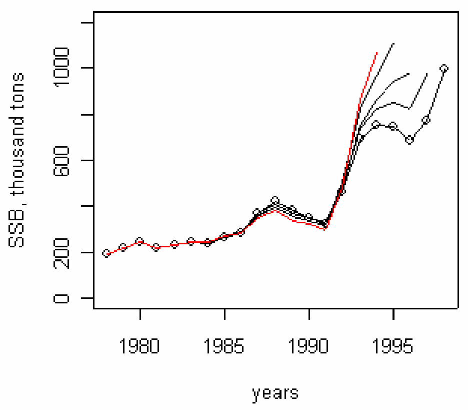

Figure 28: Retrospective analysis of spawning stock biomass from AMCI run keeping selection pattern constant over time (red line shows the year with no survey data).

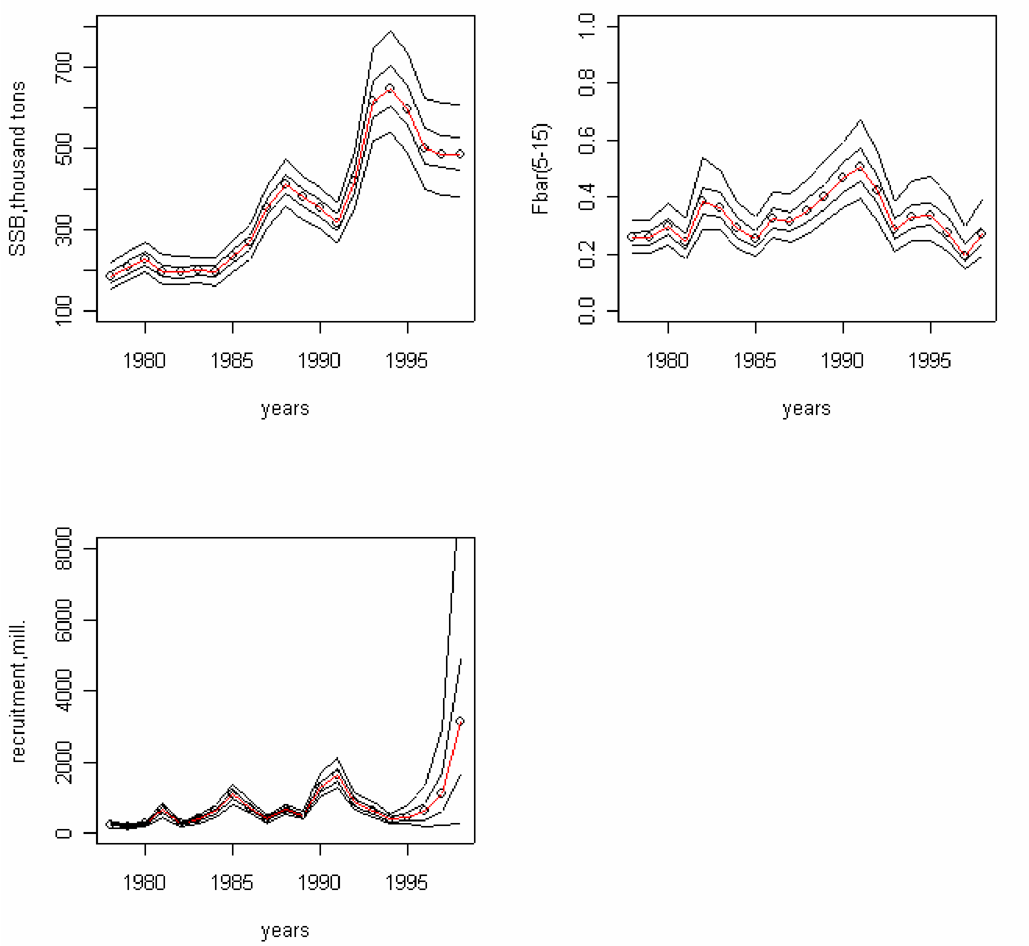

Figure 29: Confidence intervals (5%, 25%, 50%, 75% and 95% percentiles) for spawning stock biomass (thousand tons) , fishing mortality (average of ages 5-15) and recruitment (age 2, in millions) from AMCI assessment including survey data for ages 1-14.

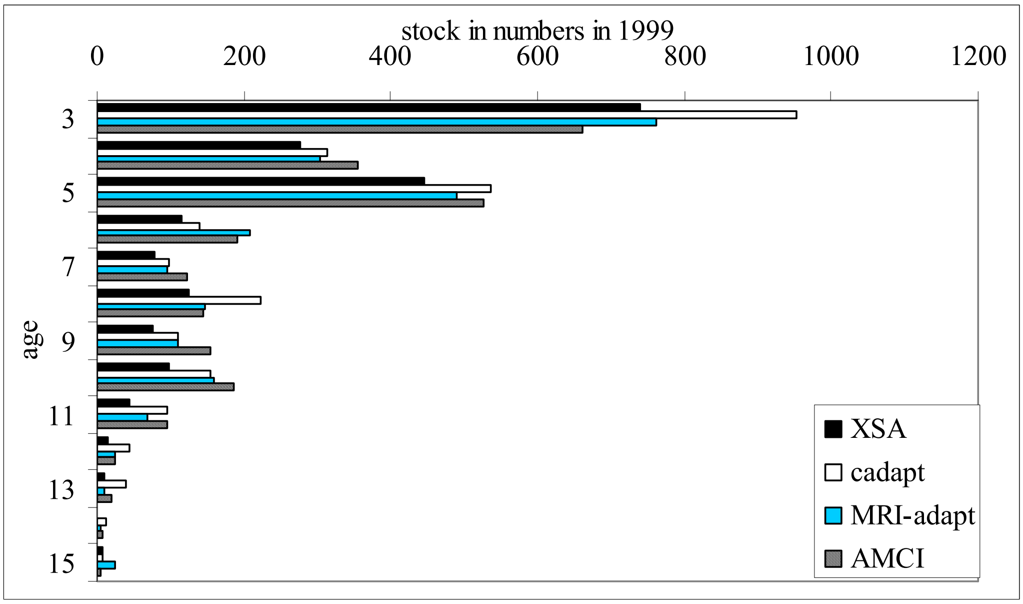

Figure 30: Stock in numbers (in millions) in 1999 from the final runs of XSA, 'cadapt', MRI-adapt and AMCI.

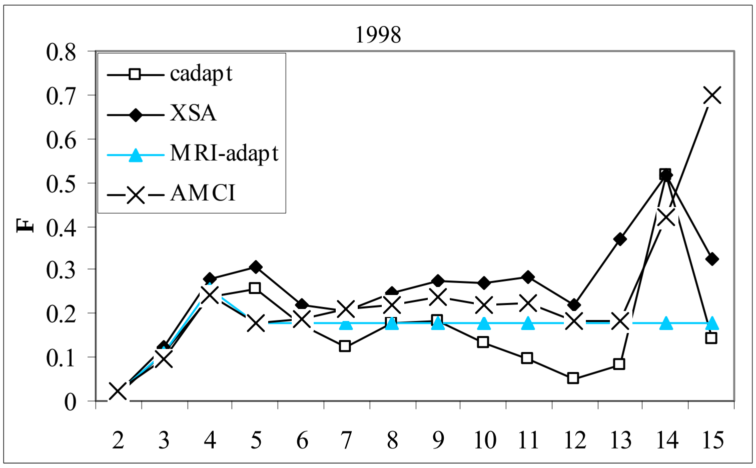

Figure 31: Fishing pattern in 1998 from the final runs of XSA, ´cadapt', MRI-adapt and AMCI.

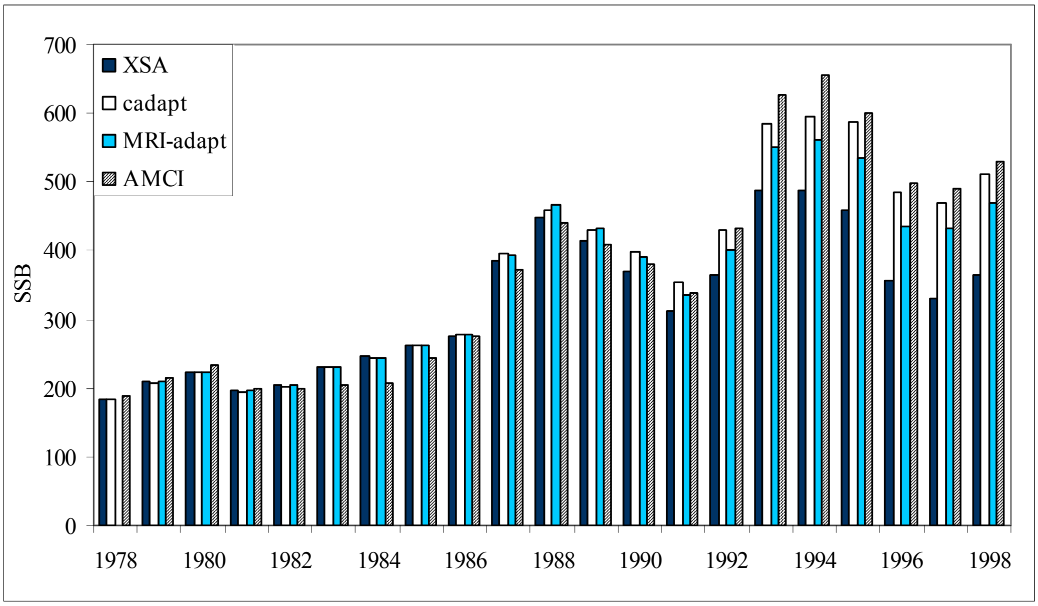

Figure 32: Spawning stock biomass (thousand tons) from the final runs of XSA, 'cadapt', MRI-adapt and AMCI.

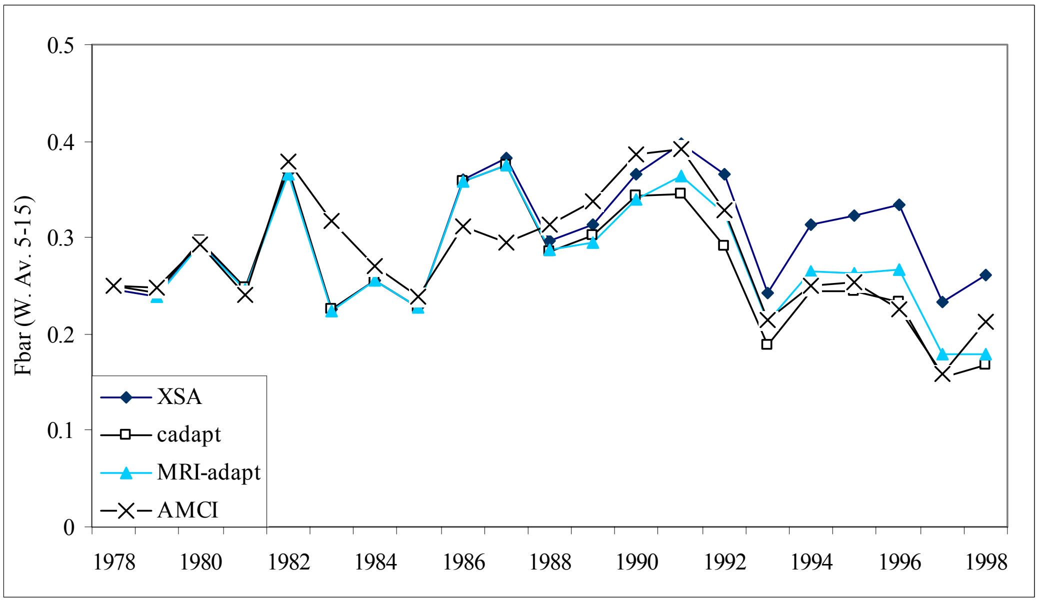

Figure 33: Reference fishing mortality (weighted average of ages 5-15) from the final runs of XSA, 'cadapt', MRI-adapt and AMCI.

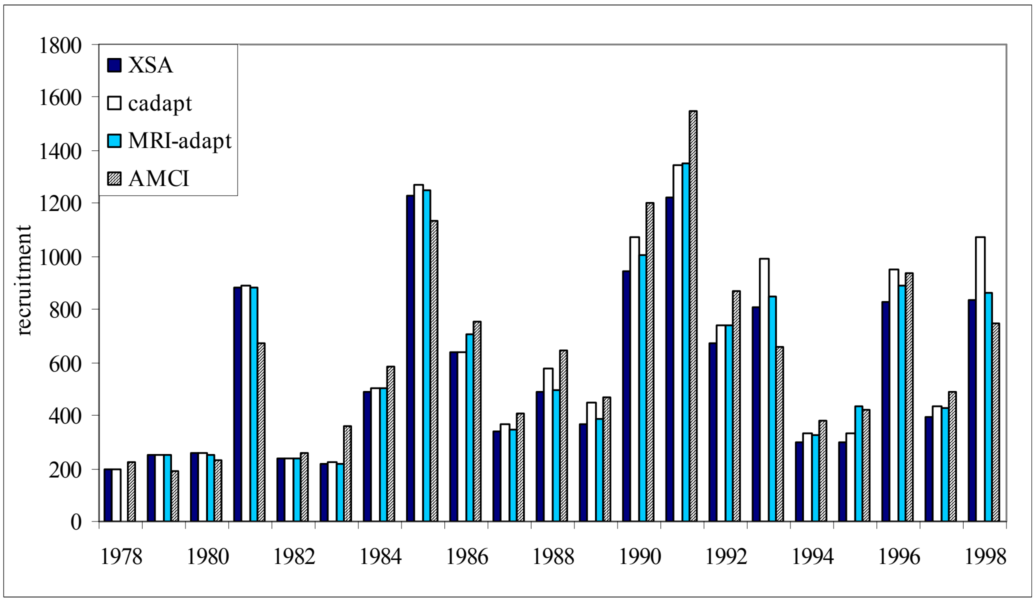

Figure 34: Recruitment (age 2, in millions) from the final runs of XSA, 'cadapt', MRI-adapt and AMCI (recruitment estimated by thr RCT3 programme for all methods).

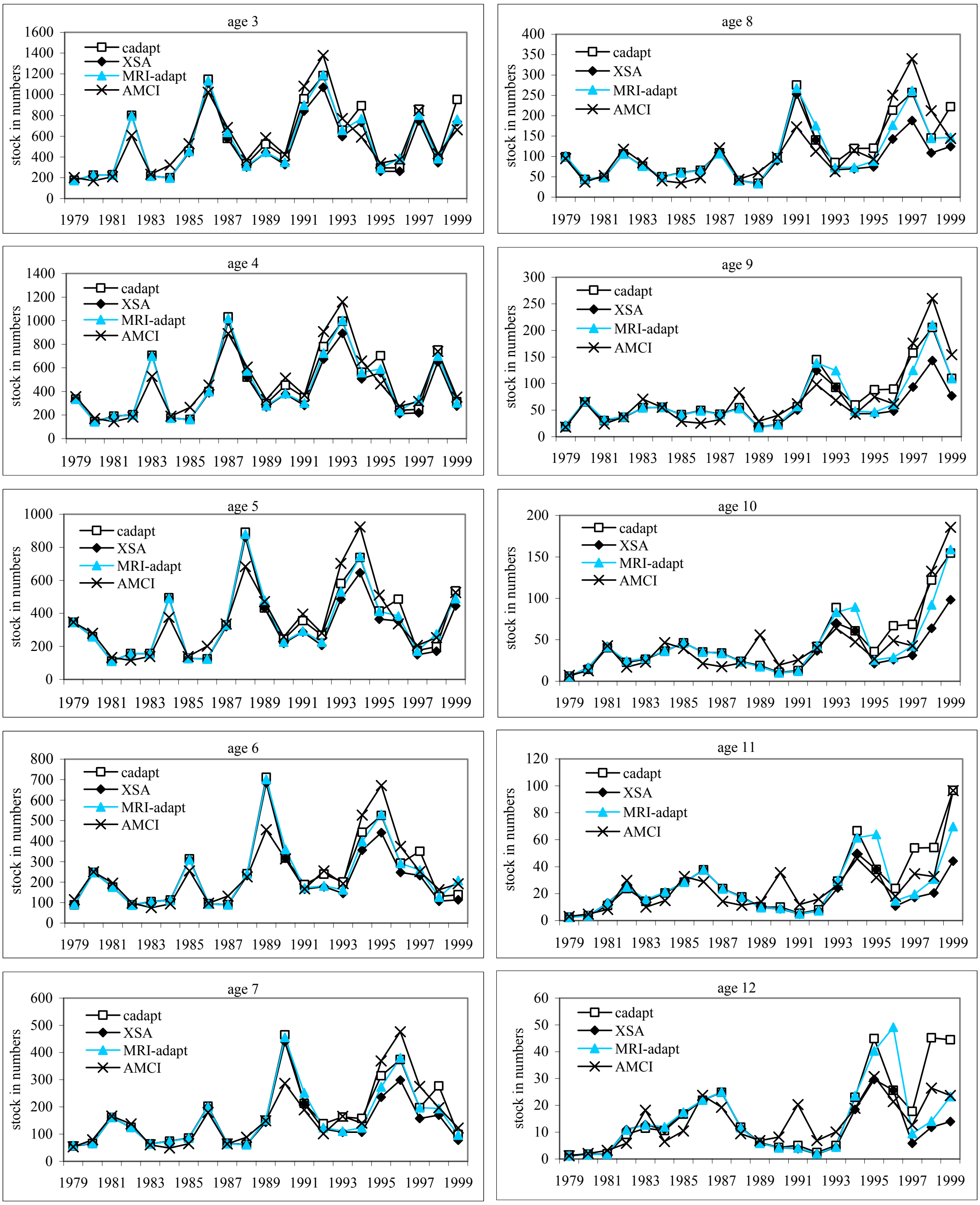

Figure 35: Stock in numbers (in millions) for ages 3-12 in 1979-1999 from the final runs of XSA, ´cadapt', MRI-adapt and AMCI.

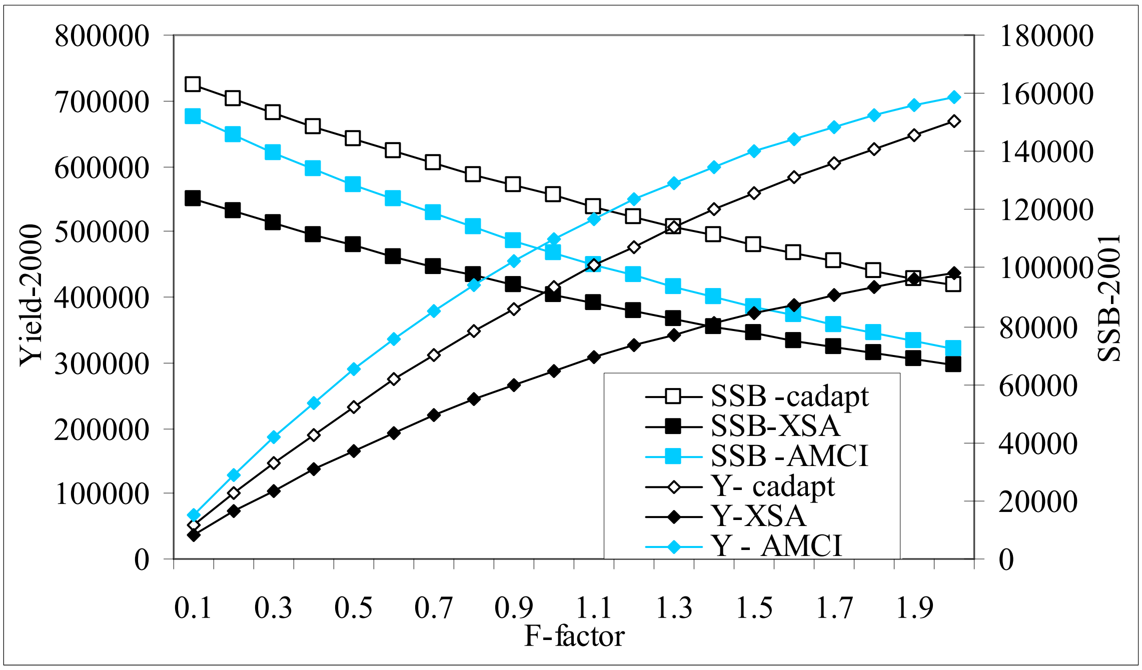

Figure 36: Predicted yield (tons) in 2000 and spawning stock biomass (tons) in 2001 for different levels of fishing mortality for XSA, 'cadapt' and AMCI. F-factor 1 corresponds to the current reference fishing mortality.

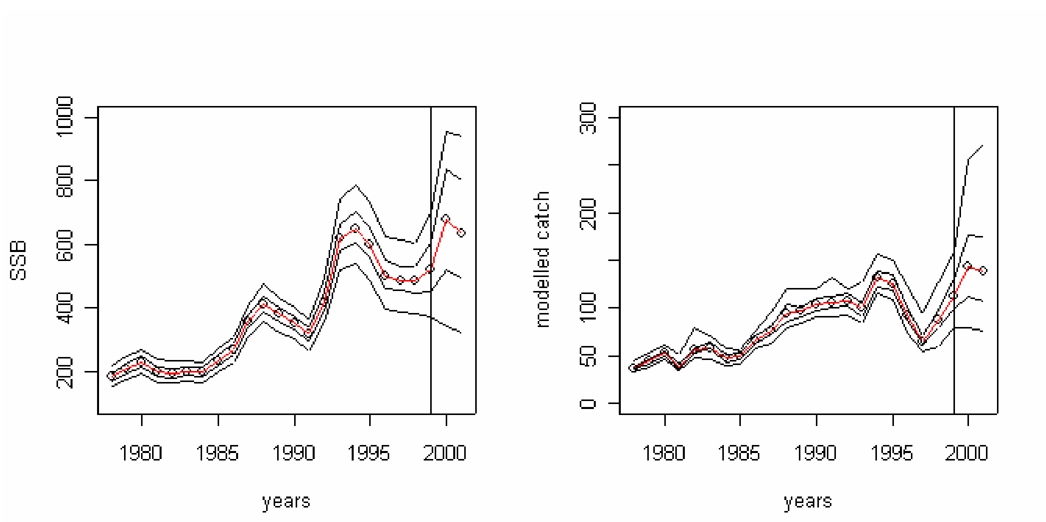

Figure 37: Confidence intervals (5%, 25%, 50%, 75% and 95% percentiles) for spawning stock biomass (thousand tons) and modelled catch (thousand tons) from AMCI assessment predicted until 2001 (including tuning data for ages 1-14).

APPENDIX A: DATA ON THE ICELANDIC SUMMER-SPAWNING HERRING USED IN THE STOCK ASSESSMENT MODELS

Table A1: Catch in numbers (thousands) and total catch in weight (tons).

year/age	1978	1979	1980	1981	1982	1983	1984
2	2634	929	3147	2283	454	1475	421
3	22551	15098	14347	4629	19187	22499	18015
4	50995	47561	20761	16771	28109	151718	32244
5	13846	69735	60727	12126	38280	30285	141354
6	8738	16451	65328	36871	16623	21599	17043
7	39492	8003	11541	41917	38308	8667	7113
8	7253	26040	9285	7299	43770	14065	3916
9	6354	3050	19442	4863	6813	13713	4113
10	1616	1869	1796	13416	6633	3728	4517
11	926	494	1464	1032	10457	2381	1828
12	400	439	698	884	2354	3436	202
13	17	32	1	760	594	554	255
14	25	54	110	101	75	100	260
15	51	6	79	62	211	3	3
Yield	37333	45072	53268	39544	56528	58867	50304

year/age	1985	1986	1987	1988	1989	1990	1991
2	112	100	29	879	3974	11009	35869
3	12872	8172	3144	4757	22628	14345	92758
4	24659	33938	44590	41331	26649	57024	51047
5	21656	23452	60285	99366	77824	34347	87606
6	85210	20681	20622	69331	188654	77819	33436
7	11903	77629	19751	22955	43114	152236	54840
8	5740	18252	46240	20131	8116	32265	109418
9	2336	10986	15232	32201	5897	8713	9251
10	4363	8594	13963	12349	7292	4432	3796
11	4053	9675	10179	10250	4780	4287	2634
12	2773	7183	13216	7378	3449	2517	1826
13	975	3682	6224	7284	1410	1226	516
14	480	2918	4723	4807	844	1019	262
15	581	1788	2280	1957	348	610	298
Yield	49368	65500	75439	92828	101000	105097	109489

year/age	1992	1993	1994	1995	1996	1997	1998
2	12006	869	6225	7411	1100	9323	16161
3	79782	35560	110079	26221	18723	27072	37787
4	131543	170106	99377	159170	45304	28397	151853
5	43787	87363	150310	86940	92948	29451	42833
6	56083	25146	90824	105542	69878	42267	19872
7	41932	28802	23926	74326	86261	35285	30280
8	36224	18306	20809	20076	37447	28506	22572
9	44765	24268	19164	13797	13207	21828	32779
10	9244	14318	17973	8873	6854	8160	14366
11	2259	3639	16222	9140	4012	3815	4802
12	582	878	2955	7079	1672	1696	2199
13	305	300	1433	2376	4179	6570	1084
14	203	200	345	927	1672	1378	5081
15	102	100	345	124	100	1802	3036
Yield	108504	102741	134003	125851	95882	64395	86999

Table A2: Weight-at-age (g).

Age/Year	1978	1979	1980	1981	1982	1983	1984
2	73	75	69	61	65	59	49
3	128	145	115	141	141	132	131
4	196	182	202	191	186	180	189
5	247	231	233	246	217	218	217
6	295	285	269	269	274	260	245
7	314	316	317	298	293	309	277
8	339	334	352	330	323	329	315
9	359	350	360	356	354	357	322
10	360	367	380	368	385	370	351
11	376	368	383	405	389	407	334
12	380	371	393	382	400	437	362
13	425	350	390	400	394	459	446
14	425	350	390	400	390	430	417
15	425	450	390	400	420	472	392

Age/Year	1985	1986	1987	1988	1989	1990	1991
2	53	60	60	75	63	75	74
3	146	140	168	157	131	119	139
4	219	200	200	221	206	199	188
5	266	252	240	239	246	244	228
6	285	282	278	271	261	273	267
7	315	298	304	298	291	286	292
8	335	320	325	319	331	309	303
9	365	334	339	334	338	329	325
10	388	373	356	354	352	351	343
11	401	380	378	352	369	369	348
12	453	394	400	371	389	387	369
13	469	408	404	390	380	422	388
14	433	405	424	409	434	408	404
15	447	439	430	437	409	437	396

Age/Year	1992	1993	1994	1995	1996	1997	1998
2	63	74	67	69	78	62	78
3	144	150	135	129	140	137	147
4	190	212	204	178	166	197	184
5	232	245	249	236	209	234	213
6	277	288	269	276	258	270	246
7	317	330	302	292	294	299	286
8	334	358	336	314	312	323	315
9	346	373	368	349	324	343	341
10	364	387	379	374	360	358	351
11	392	401	398	381	349	363	354
12	444	425	387	401	388	373	351
13	399	387	421	409	403	412	372
14	419	414	402	438	385	394	400
15	428	420	390	469	420	429	437

Table A3: Proportion mature-at-age.

Age/Year	1978	1979	1980	1981	1982	1983	1984
2	0.000	0.000	0.000	0.000	0.020	0.000	0.000
3	0.040	0.070	0.050	0.030	0.050	0.000	0.010
4	0.780	0.650	0.920	0.650	0.850	0.640	0.820
5	1.000	0.980	1.000	0.990	1.000	1.000	1.000
6	1.000	1.000	1.000	1.000	1.000	1.000	1.000
7	1.000	1.000	1.000	1.000	1.000	1.000	1.000
8	1.000	1.000	1.000	1.000	1.000	1.000	1.000
9	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10	1.000	1.000	1.000	1.000	1.000	1.000	1.000
11	1.000	1.000	1.000	1.000	1.000	1.000	1.000
12	1.000	1.000	1.000	1.000	1.000	1.000	1.000
13	1.000	1.000	1.000	1.000	1.000	1.000	1.000
14	1.000	1.000	1.000	1.000	1.000	1.000	1.000
15	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Age/Year	1985	1986	1987	1988	1989	1990	1991
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.030	0.010	0.045	0.060	0.000	0.013
4	0.900	0.890	0.870	0.900	0.930	0.780	0.720
5	1.000	1.000	1.000	1.000	1.000	1.000	1.000
6	1.000	1.000	1.000	1.000	1.000	1.000	1.000
7	1.000	1.000	1.000	1.000	1.000	1.000	1.000
8	1.000	1.000	1.000	1.000	1.000	1.000	1.000
9	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10	1.000	1.000	1.000	1.000	1.000	1.000	1.000
11	1.000	1.000	1.000	1.000	1.000	1.000	1.000
12	1.000	1.000	1.000	1.000	1.000	1.000	1.000
13	1.000	1.000	1.000	1.000	1.000	1.000	1.000
14	1.000	1.000	1.000	1.000	1.000	1.000	1.000
15	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Age/Year	1992	1993	1994	1995	1996	1997	1998
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.020	0.049	0.054	0.157	0.049	0.160	0.265
4	0.930	0.999	1.000	0.982	0.990	0.925	0.935
5	1.000	1.000	0.992	0.998	1.000	0.989	0.995
6	1.000	1.000	1.000	1.000	1.000	1.000	1.000
7	1.000	1.000	1.000	1.000	1.000	1.000	1.000
8	1.000	1.000	1.000	1.000	1.000	1.000	1.000
9	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10	1.000	1.000	1.000	1.000	1.000	1.000	1.000
11	1.000	1.000	1.000	1.000	1.000	1.000	1.000
12	1.000	1.000	1.000	1.000	1.000	1.000	1.000
13	1.000	1.000	1.000	1.000	1.000	1.000	1.000
14	1.000	1.000	1.000	1.000	1.000	1.000	1.000
15	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table A4: Acoustic survey data (numbers in millions). The surveys are conducted in October-December or January. The indices for different ages are used in XSA as given in the table below. In Adapt and Statistical Catch-at-Age the numbers referring to age *a* in year *y* in the table are used as age *a+1* for the year *y+1* (-1 indicates missing data).

Age/Year	1978	1979	1980	1981	1982	1983	1984
1	-1	-1	625	-1	-1	-1	-1
2	158	19	361	17	-1	171	28
3	334	177	462	75	-1	310	67
4	215	360	85	159	-1	724	56
5	49	253	170	42	-1	80	360
6	20	51	182	123	-1	39	65
7	111	41	33	162	-1	15	32
8	30	93	29	24	-1	27	16
9	30	10	58	8	-1	26	17
10	20	-1	10	46	-1	10	18
11	-1	-1	-1	10	-1	5	9
12	-1	-1	-1	-1	-1	12	7
13	-1	-1	-1	-1	-1	-1	4
14	-1	-1	-1	-1	-1	-1	5
15	-1	-1	-1	-1	-1	-1	5

Age/Year	1985	1986	1987	1988	1989	1990	1991
1	201	-1	406	370	-1	710	465
2	652	-1	126	725	178	805	745
3	208	-1	352	181	593	227	850
4	110	-1	836	249	177	304	353
5	86	-1	287	381	302	137	273
6	425	-1	53	171	538	176	94
7	67	-1	37	42	185	387	81
8	41	-1	76	23	-1	40	210
9	17	-1	25	30	-1	10	32
10	27	-1	21	16	-1	2	11
11	26	-1	14	10	18	-1	-1
12	16	-1	17	9	-1	-1	17
13	6	-1	8	5	-1	-1	-1
14	6	-1	6	3	-1	-1	-1
15	1	-1	3	2	-1	-1	-1

Age/Year	1992	1993	1994	1995	1996	1997	1998
1	1418	183	-1	845	266	1629	-1
2	254	234	-1	98	792	237	-1
3	858	533	-1	165	65	716	188
4	687	860	-1	515	139	100	790
5	160	443	-1	316	459	116	240
6	99	55	-1	361	280	240	101
7	87	69	-1	166	410	161	73
8	44	43	-1	110	150	130	47
9	92	86	-1	52	101	97	77
10	39	55	-1	29	50	35	47
11	-1	2	-1	16	35	15	10
12	-1	-1	-1	27	15	11	10
13	-1	6	-1	19	65	43	-1
14	-1	-1	-1	8	32	8	22
15	-1	-1	-1	2	-1	15	-1

APPENDIX B: STOCK IN NUMBERS AND FISHING MORTALITY FROM THE FINAL XSA ASSESSMENT

Table B1: Stock in numbers (thousands) from the final XSA assessment.

Age/Year	1978	1979	1980	1981	1982	1983	1984
2	195758	249172	254959	883655	238690	220182	490651
3	394843	174623	224577	227703	797393	215544	197826
4	436517	335817	143644	189558	201631	703260	173631
5	113886	346469	258619	110226	155566	155705	492017
6	71978	89878	247164	176243	88202	104349	112080
7	153215	56817	65676	161502	124398	63996	73873
8	31276	101069	43797	48448	106260	76120	49662
9	13180	21400	66681	30797	36894	54513	55498
10	4382	5881	16462	41842	23241	26903	36281
11	2164	2428	3544	13187	25098	14719	20796
12	768	1077	1727	1814	10951	12763	11054
13	407	315	557	899	800	7670	8280
14	53	352	254	503	90	159	6413
15	132	24	267	125	359	10	49

Age/Year	1985	1986	1987	1988	1989	1990	1991
2	1228026	640409	336316	489726	365206	943544	1219804
3	443559	1111058	579371	304284	442286	326672	843282
4	161864	389104	997553	521246	270803	378673	281940
5	126436	123004	319793	860208	432328	219683	288394
6	310735	93804	88991	232016	683829	317158	166105
7	85202	200111	65205	60906	143987	439300	212952
8	60077	65772	107224	40212	33274	89274	252684
9	41211	48900	42151	53036	17236	22388	50087
10	46304	35067	33796	23650	17358	9987	11969
11	28532	37747	23555	17298	9653	8770	4821
12	17079	21961	24952	11631	5902	4188	3858
13	9810	12816	13039	10006	3506	2059	1395
14	7249	7949	8094	5877	2125	1831	697
15	5555	6103	4417	2831	746	1120	688

Age/Year	1992	1993	1994	1995	1996	1997	1998	1999
2	673735	811011	296057	296884	829000	391000	834000	600000
3	1069605	598200	733006	261962	261582	749064	344929	739271
4	674799	891928	507448	558541	212091	218880	652049	276212
5	206552	485456	645240	364628	353982	148813	171038	445947
6	177617	145245	356156	440858	247229	231881	106637	114019
7	118493	107366	107503	235869	298510	157232	169609	77588
8	140522	67330	69752	74514	142722	188049	108705	124667
9	124556	92692	43510	43320	48326	93520	143038	76891
10	36520	70121	60787	21140	26073	31164	63857	98248
11	7219	24252	49829	37906	10688	17072	20437	44116
12	1856	4383	18482	29656	25604	5854	11819	13924
13	1754	1126	3131	13913	20100	21577	3684	8603
14	771	1297	734	1470	10329	14212	13274	2302
15	382	505	983	336	448	7755	11549	7178

Table B2: Fishing mortality from the final XSA assessment.

Age/Year	1978	1979	1980	1981	1982	1983	1984
2	0.014	0.004	0.013	0.003	0.002	0.007	0.001
3	0.062	0.095	0.070	0.022	0.026	0.116	0.101
4	0.131	0.161	0.165	0.098	0.159	0.257	0.217
5	0.137	0.238	0.284	0.123	0.299	0.229	0.360
6	0.137	0.214	0.326	0.248	0.221	0.245	0.174
7	0.316	0.160	0.204	0.319	0.391	0.154	0.107
8	0.279	0.316	0.252	0.172	0.568	0.216	0.087
9	0.707	0.162	0.366	0.182	0.216	0.307	0.081
10	0.491	0.407	0.122	0.411	0.357	0.157	0.140
11	0.598	0.241	0.570	0.086	0.576	0.186	0.097
12	0.793	0.559	0.553	0.718	0.256	0.333	0.019
13	0.045	0.113	0.002	2.199	1.515	0.079	0.033
14	0.681	0.176	0.607	0.237	2.076	1.080	0.044
15	0.523	0.300	0.372	0.734	0.961	0.368	0.067
Av. 5-15	0.428	0.262	0.332	0.494	0.676	0.305	0.110
W. Av. 5-15	0.245	0.239	0.295	0.247	0.368	0.225	0.255
Age/Year	1985	1986	1987	1988	1989	1990	1991
2	0.000	0.000	0.000	0.002	0.012	0.012	0.031
3	0.031	0.008	0.006	0.017	0.055	0.047	0.123
4	0.175	0.096	0.048	0.087	0.109	0.172	0.211
5	0.199	0.224	0.221	0.130	0.210	0.180	0.385
6	0.340	0.264	0.279	0.377	0.343	0.298	0.238
7	0.159	0.524	0.383	0.505	0.378	0.453	0.316
8	0.106	0.345	0.604	0.747	0.296	0.478	0.607
9	0.061	0.269	0.478	1.017	0.446	0.526	0.216
10	0.104	0.298	0.570	0.796	0.583	0.628	0.406
11	0.162	0.314	0.606	0.975	0.735	0.721	0.854
12	0.187	0.421	0.814	1.099	0.953	0.999	0.688
13	0.110	0.360	0.697	1.449	0.550	0.983	0.493
14	0.072	0.488	0.951	1.965	0.541	0.880	0.503
15	0.117	0.368	0.782	1.298	0.675	0.850	0.608
Av. 5-15	0.147	0.352	0.580	0.942	0.519	0.636	0.483
W. Av. 5-15	0.228	0.360	0.382	0.297	0.314	0.366	0.398
Age/Year	1992	1993	1994	1995	1996	1997	1998
2	0.019	0.001	0.022	0.027	0.001	0.025	0.021
3	0.082	0.065	0.172	0.111	0.078	0.039	0.122
4	0.229	0.224	0.231	0.356	0.254	0.147	0.280
5	0.252	0.210	0.281	0.289	0.323	0.233	0.306
6	0.403	0.201	0.312	0.290	0.353	0.213	0.218
7	0.465	0.331	0.267	0.402	0.362	0.269	0.208
8	0.316	0.337	0.376	0.333	0.323	0.174	0.246
9	0.475	0.322	0.622	0.408	0.339	0.282	0.276
10	0.309	0.242	0.372	0.582	0.324	0.322	0.270
11	0.399	0.172	0.419	0.292	0.502	0.268	0.284
12	0.400	0.236	0.184	0.289	0.071	0.363	0.218
13	0.202	0.329	0.656	0.198	0.247	0.386	0.370
14	0.324	0.177	0.682	1.087	0.187	0.108	0.515
15	0.330	0.234	0.460	0.492	0.267	0.280	0.324
Av. 5-15	0.352	0.254	0.421	0.424	0.300	0.263	0.294
W. Av. 5-15	0.365	0.242	0.313	0.322	0.333	0.233	0.260

APPENDIX C: STOCK IN NUMBERS AND FISHING MORTALITY FROM THE MRI ADAPT-TYPE ASSESSMENT

Table C1: Stock in numbers (millions) from the MRI Adapt-type assessment.

Age/Year	1979	1980	1981	1982	1983	1984	1985
2	248.289	254.092	880.753	238.200	219.841	503.210	1253.125
3	174.318	223.780	226.974	794.435	215.225	197.741	454.488
4	335.020	143.435	188.796	200.906	700.386	173.414	161.735
5	345.360	258.060	110.044	154.882	155.064	490.111	126.303
6	90.487	246.309	175.949	88.048	103.821	111.590	309.399
7	58.331	66.235	161.030	124.237	63.936	73.454	84.761
8	100.602	45.156	48.970	105.910	76.111	49.644	59.720
9	21.209	66.365	32.045	37.383	54.412	55.489	41.218
10	5.798	16.288	41.644	24.365	27.363	36.255	46.302
11	2.314	3.488	13.033	24.982	15.755	21.226	28.519
12	1.163	1.644	1.780	10.810	12.720	11.991	17.465
13	0.353	0.637	0.851	0.780	7.549	8.250	10.656
14	0.389	0.289	0.575	0.087	0.151	6.306	7.222
15	0.028	0.301	0.157	0.425	0.011	0.043	5.460

Age/Year	1986	1987	1988	1989	1990	1991	1992
2	703.163	345.139	494.538	389.967	1004.531	1352.931	738.232
3	1133.893	636.901	312.546	447.225	349.013	898.706	1190.210
4	399.084	1017.814	573.418	278.314	383.010	302.206	724.844
5	122.972	329.037	878.673	479.438	226.501	292.382	225.002
6	93.661	88.940	240.609	700.933	359.824	172.216	181.465
7	199.264	65.084	60.883	152.044	455.508	251.543	124.058
8	65.420	106.872	40.152	33.347	96.657	267.846	175.496
9	48.602	41.881	52.965	17.317	22.465	56.893	138.714
10	35.089	33.571	23.473	17.560	10.081	12.073	42.699
11	37.758	23.591	17.161	9.582	8.986	4.932	7.323
12	21.968	24.983	11.715	5.857	4.157	4.074	1.973
13	13.173	13.074	10.127	3.647	2.048	1.389	1.957
14	8.716	8.425	5.945	2.312	1.966	0.696	0.769
15	6.081	5.125	3.162	0.869	1.292	0.817	0.382

Age/Year	1993	1994	1995	1996	1997	1998	1999
2	850.294	326.821	436.770	888.000	425.000	860.000	600.000
3	657.080	768.609	289.864	388.156	802.450	384.556	762.796
4	1001.131	560.487	590.862	237.321	333.422	700.353	304.045
5	531.103	744.628	412.735	383.593	171.642	274.625	489.628
6	162.083	397.803	531.065	290.849	258.936	127.410	207.765
7	110.948	122.745	273.679	380.271	196.922	194.140	96.391
8	72.512	73.044	88.333	177.143	262.142	144.721	146.875
9	124.414	48.219	46.343	60.892	124.706	210.163	109.487
10	83.047	89.534	25.476	28.849	42.568	92.108	158.997
11	29.850	61.523	63.919	14.655	19.591	30.788	69.683
12	4.486	23.551	40.302	49.137	9.457	14.098	23.292
13	1.233	3.225	18.507	29.738	42.889	6.950	10.666
14	1.482	0.832	1.562	14.486	22.952	32.577	5.258
15	0.503	1.151	0.426	0.539	11.521	19.461	24.646

Table C2: Fishing mortality from the MRI Adapt-type assessment.

Age/Year	1979	1980	1981	1982	1983	1984	1985
2	0.004	0.013	0.003	0.002	0.007	0.001	0.000
3	0.095	0.070	0.022	0.026	0.116	0.101	0.030
4	0.161	0.165	0.098	0.159	0.257	0.217	0.174
5	0.238	0.283	0.123	0.300	0.229	0.360	0.199
6	0.212	0.325	0.248	0.220	0.246	0.175	0.340
7	0.156	0.202	0.319	0.390	0.153	0.107	0.159
8	0.316	0.243	0.170	0.566	0.216	0.086	0.106
9	0.164	0.366	0.174	0.212	0.306	0.081	0.061
10	0.408	0.123	0.411	0.336	0.154	0.140	0.104
11	0.242	0.573	0.087	0.575	0.173	0.095	0.161
12	0.502	0.558	0.725	0.259	0.333	0.018	0.182
13	0.100	0.002	2.183	1.540	0.080	0.033	0.101
14	0.157	0.509	0.203	1.966	1.158	0.044	0.072
15	0.256	0.322	0.534	0.731	0.322	0.076	0.119
Av. 5-15	0.250	0.319	0.471	0.645	0.306	0.110	0.146
W. Av. 5-15	0.239	0.294	0.246	0.366	0.224	0.255	0.227

Age/Year	1986	1987	1988	1989	1990	1991	1992
2	0.000	0.000	0.002	0.011	0.012	0.028	0.017
3	0.008	0.005	0.016	0.055	0.044	0.115	0.073
4	0.093	0.047	0.079	0.106	0.170	0.195	0.211
5	0.224	0.213	0.126	0.187	0.174	0.377	0.228
6	0.264	0.279	0.359	0.331	0.258	0.228	0.392
7	0.523	0.383	0.502	0.353	0.431	0.260	0.437
8	0.346	0.602	0.741	0.295	0.430	0.558	0.244
9	0.270	0.479	1.004	0.441	0.521	0.187	0.413
10	0.297	0.571	0.796	0.570	0.615	0.400	0.258
11	0.313	0.600	0.975	0.735	0.691	0.816	0.390
12	0.419	0.803	1.067	0.951	0.996	0.633	0.370
13	0.347	0.688	1.377	0.518	0.979	0.492	0.178
14	0.431	0.880	1.823	0.482	0.778	0.500	0.324
15	0.368	0.626	1.036	0.543	0.680	0.481	0.327
Av. 5-15	0.346	0.557	0.891	0.491	0.596	0.448	0.324
W. Av. 5-15	0.359	0.374	0.287	0.294	0.339	0.364	0.325

Age/Year	1993	1994	1995	1996	1997	1998
2	0.001	0.020	0.018	0.001	0.001	0.020
3	0.059	0.163	0.100	0.052	0.036	0.112
4	0.196	0.206	0.332	0.224	0.094	0.258
5	0.189	0.238	0.250	0.293	0.198	0.179
6	0.178	0.274	0.234	0.290	0.188	0.179
7	0.318	0.229	0.335	0.272	0.208	0.179
8	0.308	0.355	0.272	0.251	0.121	0.179
9	0.229	0.538	0.374	0.258	0.203	0.179
10	0.200	0.237	0.453	0.287	0.224	0.179
11	0.137	0.323	0.163	0.338	0.229	0.179
12	0.230	0.141	0.204	0.036	0.208	0.179
13	0.294	0.625	0.145	0.159	0.175	0.179
14	0.153	0.569	0.964	0.129	0.065	0.179
15	0.233	0.377	0.364	0.216	0.179	0.179
Av. 5-15	0.224	0.355	0.342	0.230	0.182	0.179
W. Av. 5-15	0.212	0.264	0.263	0.267	0.179	0.179

APPENDIX D: COMPATIBILITY OF PARAMETER ESTIMATES FROM ADAPT VER 3 AND 'CADAPT'

Table D1: Estimated stock in numbers for ages 4-15 in 1999 and catchability for ages 4 and 5 + and standard errors of the parameters from Adapt ver 3 and 'cadapt' (estimated in the logarithmic scale) and relationship between the estimates of the two programs.

Parameter	**Adapt 3**		**cadapt**			**Relation**
	Estimate	Stand. Err.	ln (Estimate)	stdev	exp(Estimate)	**Adapt3/cadapt**
N[1999 4]	240440	139797	12.4	0.51	240386	1.00
N[1999 5]	847667	268828	13.6	0.28	845768	1.00
N[1999 6]	139330	37132	11.8	0.29	138690	1.00
N[1999 7]	99275	25957	11.5	0.23	98913	1.00
N[1999 8]	222746	58663	12.3	0.27	221904	1.00
N[1999 9]	112472	33881	11.6	0.31	109864	1.02
N[1999 10]	158490	51613	11.9	0.31	154508	1.03
N[1999 11]	98848	33408	11.5	0.31	96568	1.02
N[1999 12]	44450	15987	10.7	0.32	44489	1.00
N[1999 13]	38913	15774	10.6	0.37	38754	1.00
N[1999 14]	11867	8496	9.4	0.59	12038	0.99
N[1999 15]	7010	10982	8.9	1.14	7177	0.98
q [4]	0.000782	0.000110	-7.2	0.12	0.000782	1.00
q [5+]	0.000878	0.000050	-7.0	0.05	0.000880	1.00

APPENDIX E: STOCK IN NUMBERS AND FISHING MORTALITY FROM THE FINAL ADAPT-TYPE ASSESSMENT BY 'CADAPT'

Table E1: Stock in numbers (thousand) from the final adapt-type assessment by 'cadapt'.

Age/Year	1978	1979	1980	1981	1982	1983	1984
2	196203	249733	255347	886889	240121	221934	502923
3	394575	175026	225084	228054	800319	216839	199411
4	436303	335575	144008	190017	201949	705907	174802
5	113192	346275	258399	110556	155982	155993	494413
6	71144	89250	246989	176044	88500	104725	112340
7	151125	56062	65108	161343	124218	64266	74213
8	28547	99177	43114	47934	106116	75958	49906
9	13254	18932	64969	30179	36430	54383	55350
10	4385	5949	14229	40293	22682	26482	36163
11	2552	2430	3605	11166	23697	14214	20416
12	736	1428	1729	1869	9122	11495	10596
13	376	285	875	901	850	6015	7133
14	50	324	228	791	92	204	4915
15	115	22	242	101	619	12	90

Age/Year	1985	1986	1987	1988	1989	1990	1991
2	1269450	640404	368639	580347	448276	1072540	1345020
3	454663	1148540	579366	333530	524283	401836	960002
4	163298	399152	1031470	521242	297266	452867	349951
5	127496	124302	328885	890896	432324	243628	355528
6	312903	94763	90165	240242	711596	317154	187772
7	85438	202072	66073	61968	151431	464426	212949
8	60385	65985	108999	40998	34236	96009	275419
9	41432	49179	42344	54642	17947	23257	56181
10	46171	35267	34048	23825	18812	10630	12756
11	28425	37627	23736	17526	9811	10085	5402
12	16734	21865	24843	11795	6108	4331	5047
13	9396	12504	12951	9907	3654	2246	1524
14	6211	7574	7812	5798	2036	1965	866
15	4200	5164	4078	2576	674	1039	809

Age/Year	1992	1993	1994	1995	1996	1997	1998	1999
2	740057	988317	331198	333770	950000	437000	1070000	600000
3	1182910	658211	893440	293759	294958	858550	386551	952812
4	780411	994450	561748	703707	240862	249079	751114	313869
5	268091	581018	738005	413761	485333	174847	198364	535535
6	238361	200928	442624	524796	291686	350733	130193	138743
7	138098	162331	157887	314109	374460	197459	277151	98901
8	140519	85069	119485	120103	213516	256771	145104	221973
9	145127	92689	59560	88321	89577	157577	205221	109824
10	42035	88735	60784	35663	66792	68490	121818	154511
11	7931	29241	66671	37904	23829	53916	54210	96560
12	2383	5028	22997	44896	25602	17745	45156	44484
13	2830	1602	3714	17998	33889	21576	14443	38767
14	888	2271	1165	1998	14025	26689	13273	12038
15	535	611	1864	726	926	11100	22839	7176

Table E2: Fishing mortality from the final adapt-type assessment by 'cadapt'.

Age/Year	1978	1979	1980	1981	1982	1983	1984
2	0.014	0.004	0.013	0.003	0.002	0.007	0.001
3	0.062	0.095	0.069	0.022	0.026	0.115	0.100
4	0.131	0.161	0.164	0.097	0.158	0.256	0.216
5	0.138	0.238	0.284	0.123	0.298	0.228	0.357
6	0.138	0.215	0.326	0.249	0.220	0.244	0.174
7	0.321	0.163	0.206	0.319	0.392	0.153	0.106
8	0.311	0.323	0.257	0.174	0.568	0.216	0.086
9	0.701	0.186	0.378	0.186	0.219	0.308	0.081
10	0.490	0.401	0.142	0.431	0.367	0.160	0.141
11	0.480	0.240	0.557	0.102	0.623	0.194	0.099
12	0.847	0.390	0.552	0.688	0.316	0.377	0.020
13	0.049	0.125	0.001	2.180	1.325	0.102	0.038
14	0.737	0.192	0.709	0.144	1.938	0.722	0.057
15	0.584	0.322	0.395	0.945	0.417	0.288	0.034
Av. 5-15	0.436	0.254	0.346	0.504	0.608	0.272	0.109
W. Av. 5-15	0.250	0.242	0.297	0.249	0.370	0.226	0.255

Age/Year	1985	1986	1987	1988	1989	1990	1991
2	0.000	0.000	0.000	0.002	0.009	0.011	0.028
3	0.030	0.008	0.006	0.015	0.046	0.038	0.107
4	0.173	0.094	0.047	0.087	0.099	0.142	0.166
5	0.197	0.221	0.214	0.125	0.210	0.160	0.300
6	0.337	0.261	0.275	0.362	0.327	0.298	0.207
7	0.158	0.517	0.377	0.493	0.356	0.423	0.316
8	0.105	0.344	0.591	0.726	0.287	0.436	0.541
9	0.061	0.268	0.475	0.966	0.424	0.501	0.190
10	0.105	0.296	0.564	0.787	0.523	0.577	0.375
11	0.162	0.315	0.599	0.954	0.718	0.592	0.719
12	0.191	0.424	0.819	1.072	0.900	0.944	0.479
13	0.116	0.370	0.704	1.482	0.520	0.853	0.440
14	0.085	0.519	1.010	2.052	0.572	0.788	0.383
15	0.149	0.425	0.819	1.426	0.726	0.884	0.460
Av. 5-15	0.151	0.360	0.586	0.950	0.506	0.587	0.401
W. Av. 5-15	0.227	0.358	0.375	0.286	0.303	0.344	0.345

Age/Year	1992	1993	1994	1995	1996	1997	1998
2	0.017	0.001	0.020	0.024	0.001	0.023	0.016
3	0.074	0.058	0.139	0.099	0.069	0.034	0.108
4	0.195	0.198	0.206	0.272	0.220	0.128	0.238
5	0.188	0.172	0.241	0.250	0.225	0.195	0.257
6	0.284	0.141	0.243	0.238	0.290	0.135	0.175
7	0.384	0.206	0.174	0.286	0.277	0.208	0.122
8	0.316	0.256	0.202	0.193	0.204	0.124	0.179
9	0.392	0.322	0.413	0.179	0.168	0.157	0.184
10	0.263	0.186	0.372	0.303	0.114	0.134	0.132
11	0.356	0.140	0.295	0.292	0.195	0.077	0.098
12	0.297	0.203	0.145	0.181	0.071	0.106	0.053
13	0.120	0.219	0.520	0.149	0.139	0.386	0.082
14	0.275	0.097	0.373	0.669	0.134	0.056	0.515
15	0.212	0.179	0.205	0.187	0.114	0.177	0.143
Av. 5-15	0.281	0.193	0.289	0.266	0.176	0.160	0.176
W. Av. 5-15	0.292	0.189	0.245	0.244	0.233	0.154	0.168

APPENDIX F: STOCK IN NUMBERS AND FISHING MORTALITY FROM THE FINAL AMCI ASSESSMENT

Table F1: Stock in numbers (thousands) from the final AMCI assessment.

Age/Year	1978	1979	1980	1981	1982	1983	1984
2	225241	191078	232771	673468	260382	358188	585371
3	416987	202166	171765	208880	606695	234608	322336
4	439549	355825	170830	145028	182449	526954	190427
5	157893	346717	279475	132566	116689	138205	375099
6	76922	114510	249873	194286	97530	75758	93853
7	136986	53184	79489	166130	137308	60723	49087
8	26068	94712	36889	53303	117684	84837	40467
9	10267	18023	64665	24107	37300	70651	55087
10	4327	7099	12473	42701	16935	22995	46472
11	1637	2991	4854	8237	29760	10081	14851
12	1057	1132	2071	3207	5816	18149	6514
13	294	731	760	1318	2179	3331	11327
14	237	203	513	521	922	1323	2180
15	496	206	112	152	171	228	367

Age/Year	1985	1986	1987	1988	1989	1990	1991
2	1132569	757200	410363	647906	469239	1204705	1551778
3	528209	1023444	684490	371131	585955	422184	1081353
4	265085	453744	891292	607179	331354	513490	368384
5	138764	201684	335538	684096	471235	258395	395711
6	254762	97675	132067	225556	455167	312735	167471
7	65023	179742	63836	88706	148886	286270	188885
8	34962	47540	121184	43803	59978	98224	172597
9	28609	25437	31966	82653	29121	39955	62196
10	39472	21172	17416	22036	55781	19469	25807
11	32730	28735	14224	11399	13950	35523	11946
12	10405	23702	19268	9422	6858	8169	20275
13	4542	7424	15630	12617	5813	3962	4481
14	8174	3349	5034	10732	8374	3801	2468
15	658	2389	1143	1275	2292	1993	920

Age/Year	1992	1993	1994	1995	1996	1997	1998	1999
2	867270	659477	382295	423492	937000	486000	747000	600000
3	1377615	771131	592646	341495	376909	846787	430888	660550
4	906785	1159046	659337	464133	274984	315466	740471	353983
5	281120	702452	923062	510312	337053	206251	253934	525909
6	254585	193268	527430	671591	373812	250953	163260	192240
7	101290	165365	140016	368925	476298	275437	197032	122628
8	112277	62353	115096	93857	250535	340091	212332	144347
9	98230	68347	42189	74764	61905	175836	259835	154177
10	40352	63827	47541	26992	48879	42767	132698	185552
11	15971	26616	45955	32019	18029	34673	32717	96505
12	6833	10094	18941	30703	21397	12643	26441	23650
13	11407	4305	7224	13106	21339	15763	9943	19942
14	2826	7884	3270	5296	9649	16145	12391	7485
15	550	681	2192	1202	1537	2835	5342	3964

Table F2: Fishing mortality from the final AMCI assessment.

Age/Year	1978	1979	1980	1981	1982	1983	1984
2	0.008	0.007	0.008	0.004	0.004	0.006	0.003
3	0.059	0.068	0.069	0.035	0.041	0.109	0.096
4	0.137	0.142	0.154	0.117	0.178	0.240	0.217
5	0.221	0.228	0.264	0.207	0.332	0.287	0.287
6	0.269	0.265	0.308	0.247	0.374	0.334	0.267
7	0.269	0.266	0.300	0.245	0.382	0.306	0.239
8	0.269	0.282	0.325	0.257	0.410	0.332	0.247
9	0.269	0.268	0.315	0.253	0.384	0.319	0.233
10	0.269	0.280	0.315	0.261	0.419	0.337	0.251
11	0.269	0.268	0.315	0.248	0.395	0.337	0.256
12	0.269	0.299	0.352	0.286	0.457	0.372	0.261
13	0.269	0.254	0.277	0.257	0.399	0.324	0.226
14	0.269	0.337	0.408	0.342	0.512	0.405	0.335
15	0.269	0.256	0.455	0.488	0.930	0.682	0.471
Av. 5-15	0.265	0.273	0.330	0.281	0.454	0.367	0.279
W. Av. 5-15	0.251	0.248	0.292	0.240	0.379	0.316	0.270

Age/Year	1985	1986	1987	1988	1989	1990	1991
2	0.001	0.001	0.001	0.001	0.006	0.008	0.019
3	0.052	0.038	0.020	0.013	0.032	0.036	0.076
4	0.173	0.202	0.165	0.154	0.149	0.161	0.170
5	0.251	0.323	0.297	0.307	0.310	0.334	0.341
6	0.249	0.325	0.298	0.315	0.364	0.404	0.403
7	0.213	0.294	0.277	0.291	0.316	0.406	0.420
8	0.218	0.297	0.283	0.308	0.306	0.357	0.464
9	0.201	0.279	0.272	0.293	0.303	0.337	0.333
10	0.218	0.298	0.324	0.357	0.351	0.388	0.380
11	0.223	0.300	0.312	0.408	0.435	0.461	0.459
12	0.238	0.316	0.323	0.383	0.449	0.500	0.475
13	0.205	0.288	0.276	0.310	0.325	0.373	0.361
14	0.290	0.485	0.527	0.626	0.616	0.729	0.709
15	0.562	0.829	0.841	0.951	0.941	1.095	1.190
Av. 5-15	0.261	0.367	0.366	0.414	0.429	0.490	0.503
W. Av. 5-15	0.239	0.312	0.296	0.313	0.337	0.385	0.391

Age/Year	1992	1993	1994	1995	1996	1997	1998
2	0.018	0.007	0.013	0.017	0.001	0.020	0.023
3	0.073	0.057	0.144	0.117	0.078	0.034	0.097
4	0.155	0.128	0.156	0.220	0.188	0.117	0.242
5	0.275	0.187	0.218	0.211	0.195	0.134	0.178
6	0.332	0.222	0.257	0.244	0.205	0.142	0.186
7	0.385	0.262	0.300	0.287	0.237	0.160	0.211
8	0.396	0.291	0.331	0.316	0.254	0.169	0.220
9	0.331	0.263	0.347	0.325	0.270	0.182	0.237
10	0.316	0.229	0.295	0.304	0.243	0.168	0.219
11	0.359	0.240	0.303	0.303	0.255	0.171	0.225
12	0.362	0.235	0.268	0.264	0.206	0.140	0.182
13	0.269	0.175	0.211	0.206	0.179	0.141	0.184
14	0.546	0.342	0.393	0.399	0.352	0.238	0.423
15	0.951	0.637	0.726	0.660	0.509	0.454	0.699
Av. 5-15	0.411	0.280	0.332	0.320	0.264	0.191	0.269
W. Av. 5-15	0.328	0.215	0.251	0.253	0.225	0.159	0.212