

Sensitivity of the current ICA assessment of western mackerel and short term prediction to the sampling error in the egg survey parameters.

E J Simmonds, D Beare, and D G Reid.

FRS Marine Laboratory, PO Box 101, Victoria Road, Torry,
Aberdeen, AB11 9DB, Scotland, UK

ABSTRACT

The assessment and deterministic short term projection of the North East Atlantic mackerel stock is based on an integrated catch at age model (ICA) assessment tuned with an egg survey derived biomass estimate. The egg survey biomass estimate is based on a calculation of the total annual egg production, converted to biomass using realised female fecundity. Currently western and southern spawning components are assessed together for management purposes. Ideally the present study would be best conducted on the combined stock but was restricted to the western component where there is a longer time series of egg survey data. The paper examines variability in the parameters estimated from the survey and their influence on both the assessment and predicted Total Allowable Catch (TAC) is calculated.

The variability in the estimates of egg abundance, fecundity and atresia were all estimated by bootstrap and are presented. The variability around the estimate of total annual egg production was found to be the dominant source of error. Therefore, it was thought unnecessary to examine each source of variability in the assessment individually and only the combination was tested in the assessment and predictions. The results are used to illustrate the influence of this data on the perception of the state of the stock and possible TAC if the western component was assessed and managed separately. As the western component dominates the North West Atlantic Mackerel stock complex the results are thought to be indicative of the sensitivity of the combined assessment. The analysis is conditional on the total catch in tonnes and a fixed natural mortality as well as the use of the ICA assessment method with the predefined weighting of the data used by the working group. The sensitivity of the assessment to its data sources is discussed.

John Simmonds FRS Marine Laboratory, PO Box 101, Victoria Road, Torry, Aberdeen, AB11 9DB, Scotland, UK [tel +44 1224 295366, Fax +44 1224 295511, Email j.simmonds@marlab.ac.uk]

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INTRODUCTION

Mackerel (*Scomber scombrus*) egg surveys have been carried out in the spawning area of the Atlantic mackerel on a triennial basis since 1977 (Augustin et al., 1998; Thompson et al., 1984). The aim of each survey is to cover the entire spawning season which begins in February and ends in July (Beare & Reid, 2000). The North East Atlantic mackerel (NAEM) stock has traditionally been divided and managed as three separate spawning components (Southern, Western and North Sea) although there is some debate as to whether such delineations are realistic (Uriarte & Lucio 2001). Initially, the International Council for the Exploration of the Sea (ICES) used the biomass estimate from the egg survey as an index for "tuning" the biomass of the western component only. More recently, however, the areal coverage of the overall assessment has been extended to involve quantification of the western and southern mackerel stock components combined.

The assessment of the Atlantic mackerel stock is based on an Integrated Catch at Age (ICA) model ((Patterson & Melvin, 1996 Patterson 1998 and Needle 2000), "tuned" using the biomass estimate from

the egg survey. The short term deterministic projections follow the standard ICES procedure using routines developed by L. Kell for the European Commission project EVARES (Beare et al., 2003). Currently, the western and southern stock components are assessed together for management purposes. Ideally, the current study would have been best conducted on the combined stock. Unfortunately, however, the availability of egg production, fecundity and atresia data restricted this study to the western component only.

Quantification of fish stocks typically involves a sequence of steps, each of which are potentially a source of variability. In the case of mackerel, total annual egg production (TAEP), fecundity and atresia measurements are all incorporated in the ICES stock assessment without explicit reference to the inherent sample variation involved with each step. Large error bounds may have implications for successful management of fish stocks such as mackerel. The goal of this paper, therefore, is to examine the variability in the ICES assessment of biomass and fishing mortality for the western component of the Atlantic mackerel stock due to the egg survey. This was done by calculating the variability in the estimates of each of the input components, (e.g. TAEP, fecundity and atresia) to the biomass estimate, which were then used to provide multiple realisations for the standard assessment. The output was then used for determining sensitivity to the egg survey of both the assessment of the stock and the recommended Total Allowable Catch (TAC).

METHODS

Egg survey

In order to carry out a stock assessment using an egg survey for tuning purposes it is necessary to estimate egg production by adult females over the entire range of the spawning area of the particular stock of interest. Depending on the various characteristics of the species in question and constraining economic factors, two main methods for estimating fish biomass have been used:

- The Annual Egg Production Method (AEPM, ((Armstrong et al., 1998))) and;
- the Daily Egg production Method (DEPM, (Arkhipov, Andrianov & Lisovenko, 1991) (Parker, 1980) Parker, 1980)).

For the Atlantic mackerel the Annual Egg Production Method is used. The egg data are collected using a Gulf III plankton sampler (Brander, Milligan & Nichols, 1993) deployed on double oblique tows, at *circa* 5 knots, from the surface to the predefined sampling depth (200m or 2m from the bottom, or 10m below the thermocline). Once the Gulf III is on board ship the sample is fixed in formaldehyde, washed from the net, the fish eggs separated from the rest of the plankton and sorted to species. The eggs are then sorted into one of five developmental stages (I, II, III, IV and V) according to a standard scheme (Lockwood, Nichols & Coombs, 1977)). The goal of the mackerel egg survey is to get representative samples over the entire range of spawning in space and in time, although this is difficult to achieve in reality because of the large area that must be covered. The egg survey data are converted into estimates of egg production by first converting stage I egg counts to numbers of eggs per m² of sea surface per day (Lockwood et al., 1977; Lockwood, Nichols & Dawson, 1981). The estimated egg density m⁻² d⁻¹ data are then raised to the area of the rectangle in which they were sampled. These data are then used to calculate the total annual egg production (TAEP), and the variance of that estimate. Historically this has been done using a simple routine based on linear interpolation in space and time, referred to as the "Traditional Method". Recently, more modern non-parametric regression (Augustin et al., 1998) and geostatistical techniques (Bez & Rivoirard, 2000) have been used to estimate TAEP, although they've not yet been accepted by ICES. Once the total annual egg production estimate (here the Traditional Estimator was used) has been obtained, spawning stock biomass is estimated according to the following equation:

$$\text{Spawning stock biomass (SSB)} = \frac{(\text{SR})\text{TAEP}}{\text{TF}-\text{AL}}$$

Where TAEP = Total Annual Egg Production (Eggs m⁻² d⁻¹);
TF = Total Fecundity (Eggs gramme⁻¹ per female;
AF = Atretic Loss (Oocytes gramme⁻¹ per female;
SR = Sex ratio (1:1 is assumed so SR =2)

In 1998, for example, total annual egg production by the western spawning component of mackerel was estimated to be 1.37×10^{15} eggs $\text{m}^{-2} \text{d}^{-1}$. The total fecundity was 1206 eggs gramme^{-1} per female while atretic loss (Armstrong et al., 1998; Rideout, Burton & Rose, 2000) was estimated to be 203 oocytes gramme^{-1} per female. The spawning stock biomass was, assuming a sex ratio of 1:1, equal to $(1.37 \times 10^{15} / 1003) \times 2 / (1000 \times 1000) = 2731805$ tonnes.

Variability in Egg abundance, Fecundity and Atresia

For the Traditional TAEP Estimator (R. Fryer, Fisheries Research Services) method, variance estimation is usually carried out as follows. First the mean egg production squared in each statistical rectangle is divided by the number of times that rectangle was sampled in that period. The variance for the TAEP is then equal to the sum of the variances for those rectangles multiplied by the number of days of the survey. In order to maintain compatibility with the ICES Working Group a simple parametric bootstrap method for estimating variance around the Traditional Estimator was used. It worked by assuming that the sample data can be approximated using a Normal distribution. Parameters from the Normal Distribution (mean and standard deviation) are then used to generate 1000 different TAEP estimates based on the original data for each egg survey (1977 to 2001). Variance estimates for fecundity and atresia data were also calculated by bootstrap. Fecundity and atresia (eggs g^{-1}) data were read into the statistical package “R” and resampled 1000 times using the Uniform distribution. The mean was then calculated for each of the 1000 datasets and stored for later use in the calculation of SSB. This procedure represents a somewhat crude, and probably exaggerated estimate of variance for both the fecundity and atresia datasets since we ignored potentially important explanatory information such as dependence on fish size, location or season. Notwithstanding this, the study showed that the variance in the TAEP estimate was much more important (see below) and so the potential overestimate in variance in the other parameters was probably not critical.

Stock Assessment and Prediction

The assessments were carried out using the Integrated Catch-at-Age model (ICA) (Patterson & Melvin, 1996). The ICA programs are intended to provide a method for analysing time-series of catch-at-age and research vessel survey information simultaneously, see (Deriso, Quinn & Neal, 1985; Gudmundsson, 1994; Kimura, 1986).

ICA models are fitted using maximum log likelihood methods via an optimisation routine (Needle, 2000).

For the western mackerel stock under investigation in this study, the most important underlying assumptions are:

- Fishing mortality is ‘separable’ to account for changes in fishing pattern for a range of recent years. This period has changed historically and was set at 13 years in the most recent assessment.
- The assessment working group considered the egg survey biomass as absolute up to 1999, and then as relative until 2002.
- Natural mortality is assumed to be known and independent of age and time (year).
- The model is fitted to the data by non-linear minimisation of a sum of squares of log residuals. By treating this as a likelihood estimate, it is implicitly assumed that the errors in the data are independent and log-normally distributed.
- Catch data by age are weighted equally by age and by year (at a value of 1) for the separable period see (Deriso et al., 1985) with the exception of catches of 0 group mackerel (0.02 for all years). Mackerel are fully recruited to the fishery by age 4.
- The weighting for data series of the egg survey tuning index is set (arbitrarily) to 5 –although this has varied over the last ten years.
- For the years prior to the separable period, a conventional Virtual Population Analysis (VPA) is carried out.
- It should be noted that the WG assessment uses all age groups from 0 to 11 and with a plus group at 12. In this study we used 0 to 8 with a plus group at 9, this was compared for a single 2001 assessment and the differences are expected to be small.

The short term projection method used was the same procedure that is used by ICES to predict recommended catch for different levels of Fishing Mortality (F). The input parameters were the numbers at age in the assessment year, and the exploitation pattern in the fishery. The fishery was assumed to be at status quo F for the intervening year, and F for the TAC year was computed following

the management rule applied over the last few years that follows the management regime for NE Atlantic mackerel agreed by the EU, Norway and Faroes (Coastal States Agreement). This agreement allows a fishing mortality of 0.15 to 0.19 when SSB is above 2.3M tonnes. When the stock is below this threshold, F must be reduced. In practice $F=0.13$ was selected. These two values of F were implemented as the rule for setting the TAC. The Bpa threshold used for the western mackerel was set to 2.0M tonnes. The selection pattern used in the ICA was a pattern fitted to catch data from the last 13 years. This pattern forming the basis for the F at age in the projection. Mean weights at age in the population were assumed to be the average of the last two years.

One hundred assessments and projections were run for each of 8 terminal years from 1994 to 2001 inclusive.

Results

The variability of the total annual egg production (TAEP), the fecundity (FEC) and the atresia (ATR) and all three components combined assuming independent errors are shown as box and whisker plots in Figure 1 and as coefficients of variation in Table 1. It can be seen that the egg production was found to completely dominate the variability so individual components were not examined separately in the later stages of the analysis, only the combination was tested in the assessment and predictions.

Table 1. Variability in the estimate of SSB from triennial egg surveys 1977 to 2001, expressed as coefficient of variation (%) for Atresia (Atr), Fecundity (Fec), Total Annual Egg Production (TAEP) and all sources combined.

Source	1977	1980	1983	1986	1989	1992	1995	1998	2001
Atr	1.1%	1.1%	1.1%	1.1%	1.4%	0.8%	1.0%	1.4%	0.8%
Fec	3.1%	3.0%	3.0%	3.0%	3.0%	2.8%	3.0%	3.4%	3.2%
TAEP	19.6%	13.2%	14.2%	9.7%	8.8%	14.1%	9.1%	14.7%	9.2%
Comb	19.9%	13.4%	14.5%	10.1%	9.3%	14.6%	9.6%	15.1%	9.9%

The results of 100 assessments at each of eight terminal years expressed as the estimates of terminal SSB, F and predicted TAC are presented as box and whisker plots in Figure 2 and as CVs in Table 2. These show that the variability in SSB and F expressed as a CV were rather similar, but there was a larger variability in the prediction of TAC. For all three parameters lower values of CV occur for assessments that have an egg survey in the terminal year ie. 1995, 1998 & 2001. For recent years the CV on the SSB and F is approximately 1.5 times the CV in the egg survey (Tables 1 and 2) and the CV on the TAC is twice the CV on the egg survey.

Table 2. Variability in the assessment (SSB and Terminal F 4-7) and prediction (TAC @ $F=F_{pa}$) due to variability in the egg surveys for eight terminal years from 1994 to 2001 inclusive. Precision of SSB and F were similar but the TAC predictions had a higher CV.

	1994	1995	1996	1997	1998	1999	2000	2001
SSB	30%	17%	19%	17%	15%	22%	22%	16%
F4-7	35%	17%	21%	16%	16%	22%	22%	16%
TAC	41%	20%	22%	21%	19%	26%	26%	19%

Figure 3 shows the ninety percentiles on the historic assessment due to variability in the egg survey index. Figure 3a shows historic mean fishing mortality for ages 4-7 and Figure 3b shows historic SSB. The final assessment (data year 2001) is shown in thicker lines. This assessment suggests that the stock is relatively stable or that data available are not sufficiently precise to determine any significant change in SSB during the last 20 years from 1982 to 2001. During this period the stock has remained close to 3.7M tonnes and CVs on the assessment suggest that changes in SSB of $\pm 25\%$ will be detectable. Almost all assessments from previous years provide evaluations within current error bounds, suggesting a reasonably consistent result when the egg survey is used to tune the ICA model. The error bounds on terminal years without an egg survey are wider and include the error bounds for terminal years with a survey suggesting that assessments in these years do not contain improved information on the state of the stock. This adds weight to the WG view that this stock should be managed on a 3 year basis. For estimates of fishing mortality, the assessment does indicate changes, this can be clearly seen to have been lower from 1982 to 1991, to have risen through 1993 to 1995 and declined again in 1996.

The current level is uncertain but the best estimate is that it is near the higher level of 1993-5. The analysis presented here deals only with errors in the egg survey as a tuning index and is conditional on the total catch in tonnes and the fixed natural mortality as well as the use of the ICA assessment method with the predefined weighting of the data used by the working group. Errors in catch data and miss-specification of the model would add to this error.

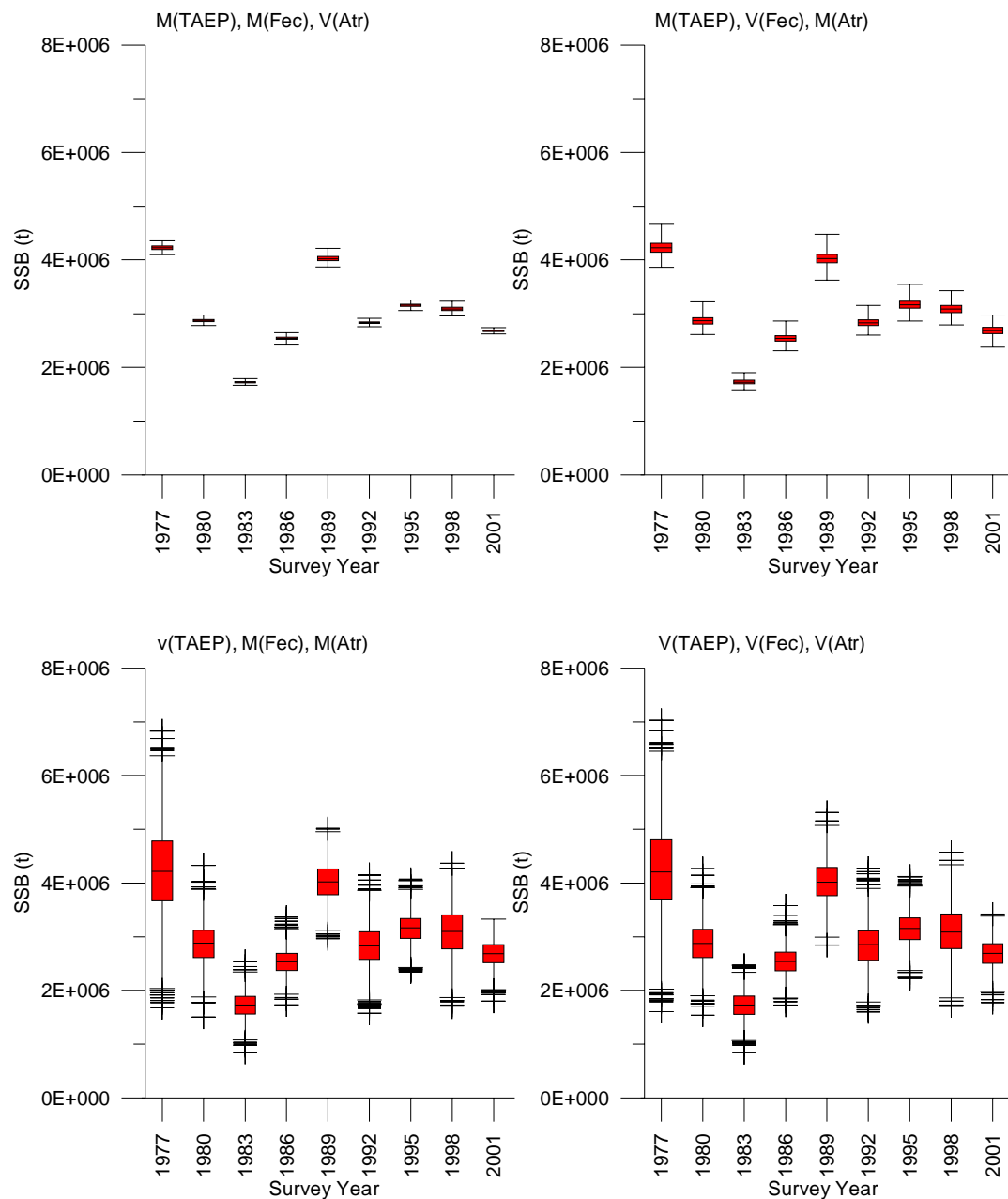


Figure 1. Box and whisker plots with outliers showing the sources of variability in the mackerel egg survey estimate of spawning stock biomass. The magnitude of the variability derived from bootstrap estimates for the three sources, Atresia (Atr), Fecundity (Fec) and Total Annual Egg Production (TAEP) are shown separately and then as a combined set which are used in the assessment.

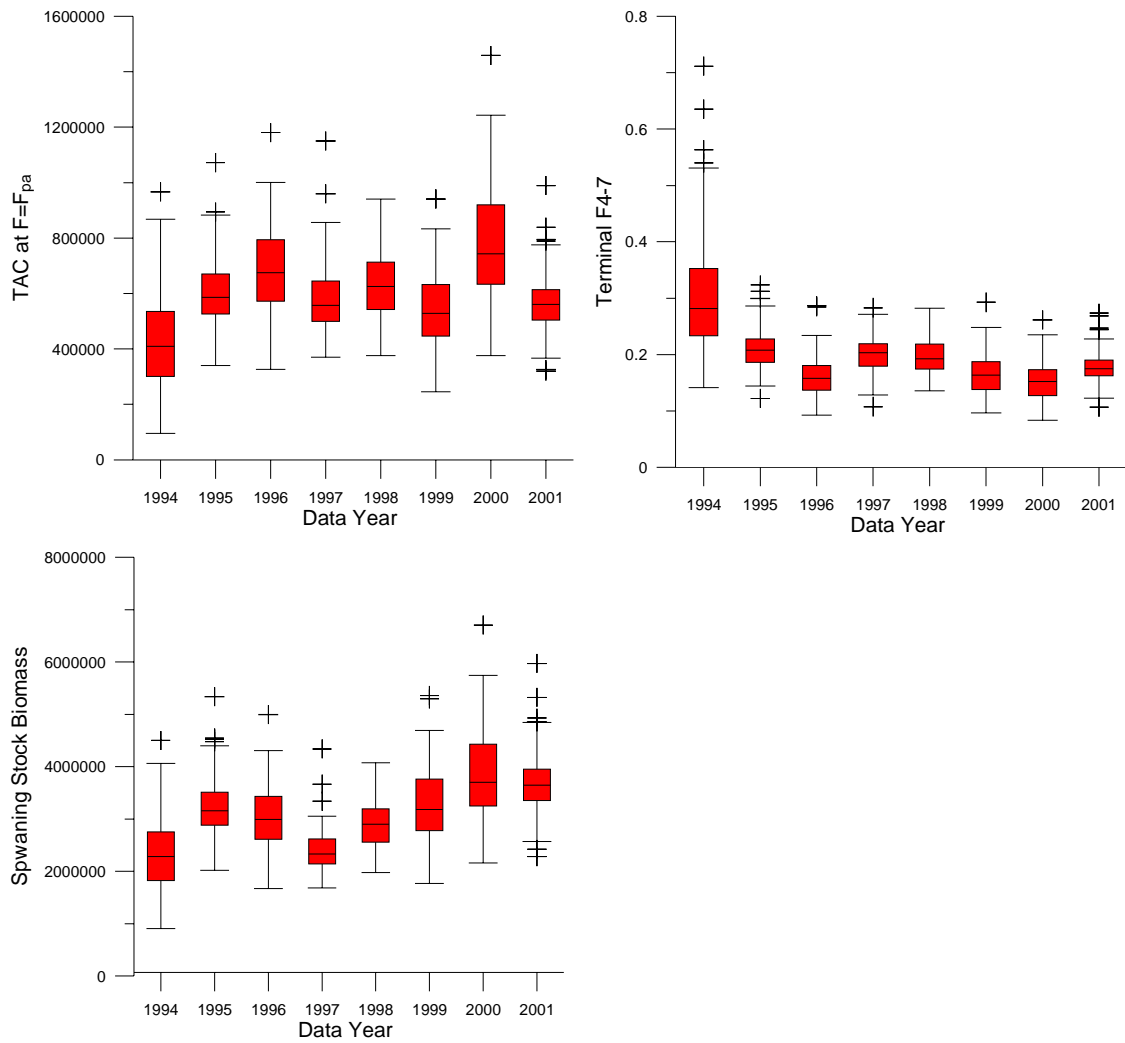


Figure 2. Box and whisker plots showing the variability in the assessment parameters: terminal SSB and terminal F ages 4-7 for eight terminal years from 1994 to 2001 and the predicted TAC two years later assuming exploitation at $F=0.17$

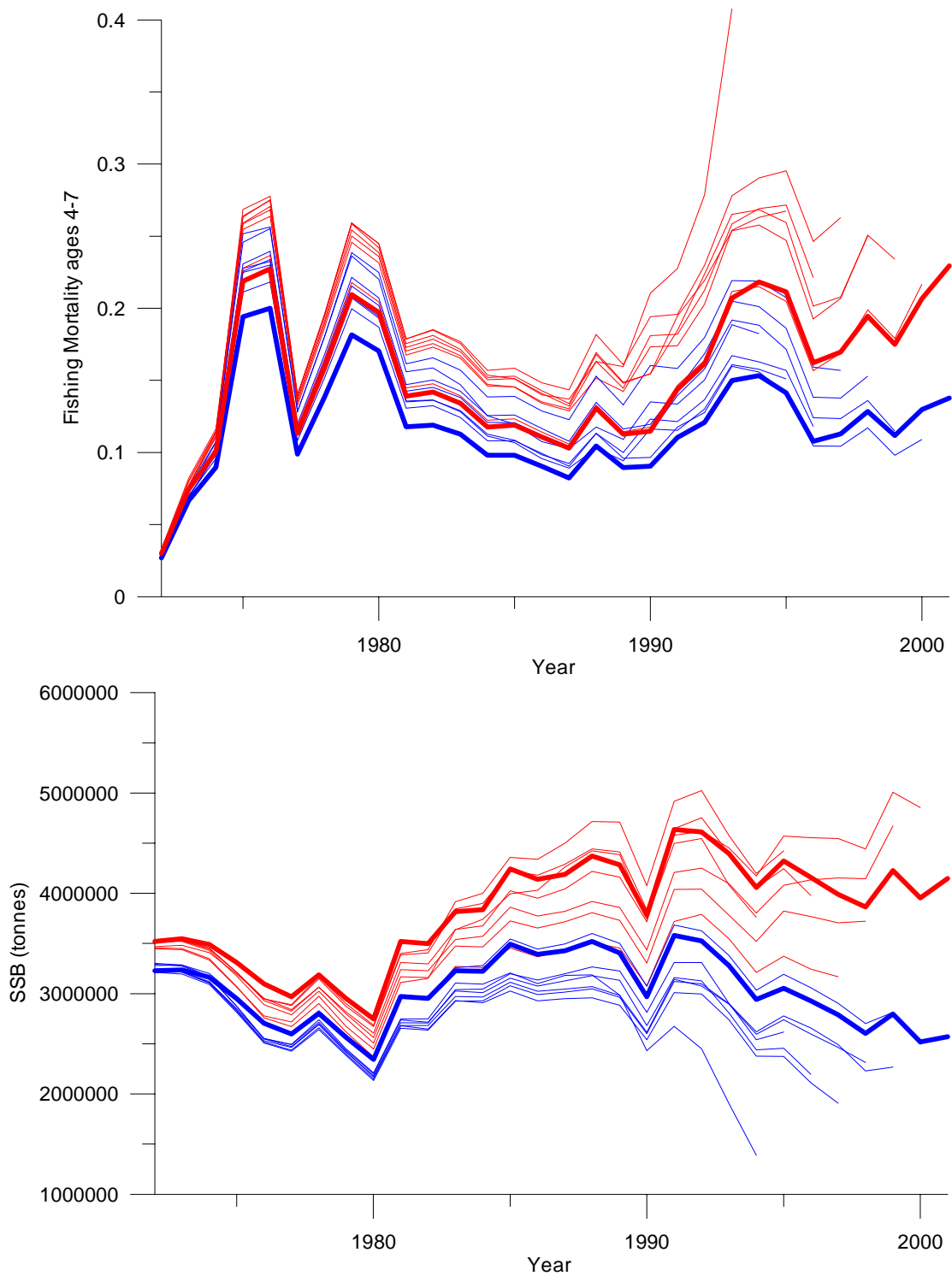


Figure 3 Ninety percentiles on the Fishing Mortality (upper panel) and SSB (lower panel) from 1972 to each terminal year for eight terminal years from 1994 to 2001. Blue lines are lower bound red lines are upper bounds. The current intervals are shown as bold lines

DISCUSSIONS AND CONCLUSIONS

The results illustrate the influence of the three sources of variability in the egg survey data: total egg production, fecundity and atresia and they show that variability in the egg production estimate dominates the sources of error. It should be noted that the variance in the fecundity estimate, while low, may be overestimated, as there was no correction for fish size, location or season. Even so, the perception from this analysis remains that little important variability was introduced from this source. This information should be of use to the ICES Working Group on Mackerel Egg Surveys, as it would suggest that greatest effort should be directed at reducing the TAEP estimate variability.

The variability in the assessment of the western stock is shown to be greater than the variability in the egg surveys themselves. It is not intuitively obvious why this should be the case, but it may be an indication that the model may be over parameterised. Unsurprisingly the assessments in years with egg surveys carried out in the terminal year show slightly lower CVs than the intervening years. In some years the error bounds on terminal years without an egg survey (for example 1999/2000) are wider and include the error bounds for terminal years with a survey (1998) suggesting that assessments in years without egg survey data do not contain improved information on the state of the stock. This again may be the result of over parameterisation in the model. This effect adds weight to the WG view that this stock should be managed on a 3 year basis. The SSB for this component of the mackerel stock appears to be rather stable. Useful management information is available from these assessments; significant fluctuations in the historic fishing mortality can be observed, and median terminal F for the most recent assessments presented here is comparable with the slightly higher level of F seen in the period 1993 to 1995. As the western component dominates the North Western Atlantic Mackerel stock complex the results from this study are thought to be indicative of the sensitivity of the combined western and southern mackerel assessment to the sources of error in the egg survey.

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