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Assessment of the Cod Stock in NAFO Division 3M

by

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Abstract

An assessment of the status of the cod stock in NAFO Division 3M is performed. A new Bayesian model, briefly presented to NAFO Scientific Council in 2007 is developed in detail and used to peform the assessment. Comparisons with the survey-based method, used to assess the stock since 2003, and XSA using catch data until 2001, are provided. Results indicate another reasonable recruitment value in 2007 and a fairly substantial increase in SSB, although this large increase does not have a similar counterpart in terms of abundances (numbers). Three year projections indicate that fishing at the low Fbar level seen in recent years should allow SSB to increase to higher levels than estimated for the late 1980's, although in terms of abundances the stock will remain at lower values. If fishing mortality were to return to the levels seen until 1995, stock recovery would become very improbable.

1. INTRODUCTION

This stock is in fishing moratorium since 1999 following its collapse, which has been attributed to three possible factors: a stock decline due to overfishing, an increase in catchability at low abundance levels and a series of very poor recruitment levels starting in 1993. The assessments performed since the collapse of the stock confirmed the poor situation, with SSB at very low levels, well below Blim (Vázquez and Cerviño, 2005). Nevertheless, SSB was estimated to have increased a bit in 2004, 2005 and 2006 (Fernández, Cerviño and Vázquez, 2007) and above average recruitment levels were estimated for 2005 and 2006. The new data from 2007 indicate another increase in SSB in 2007 as well as a reasonable recruitment value in that year.

Since 1974, when a TAC was established for the first time, estimated catches ranged from 48000 tons in 1989 to a minimum value of 5 tons in 2004. Annual catches were about 30000 tons in the late 1980's (notwithstanding the fact that the fishery was under moratorium in 1988-1990) and diminished since then as a consequence of the stock decline. Since 1998 yearly catches have been less than 1000 tons and from 2000 to 2005 they were under 100 tons, mainly attributed to by-catches from other fisheries. Estimated commercial catches in 2006 and 2007 are 339 and 345 tons, respectively, which represent more than a ten-fold increase over the average yearly catch during the period 2000-2005.

A VPA based (XSA) assessment of the cod stock in Flemish Cap was approved by NAFO Scientific Council (SC) in 1999 for the first time and was annually updated until 2002. However, most recent catches were very small undermining the VPA based assessment, as its results are based on catches and are quite sensitive to assumed natural mortality values when catches are at low levels. Cerviño and Vázquez (2003) developed a method which combines survey abundance indices at age with catchability at age, the latter estimated from the last reliable accepted XSA. The method estimates abundances at age with their associated uncertainty and allows to calculate the SSB distribution and, hence, the probability that SSB is above or below any reference value. The method has been used to assess the stock since 2003. In 2007 results from an alternative Bayesian model were also presented (Fernández, Cerviño and Vázquez, 2007) and NAFO SC recommended that the Bayesian model be further developed and its potential for the assessment of this stock explored. This is done in the present document.

This document presents a full assessment of the status of the stock using the new Bayesian model. A comparison with the survey-based method of Cerviño and Vázquez (2003) is also presented. A B_{lim} value of 14000 tons was proposed in year 2000 for this stock by NAFO SC. As requested by NAFO SC in 2007, the appropriateness of this value given the results from the new method used to assess the stock this year is examined, reaching the conclusion that it is still an appropriate choice. Three year stochastic projections for several Fbar levels are presented. Results indicate that fishing at the low Fbar level seen in recent years should allow SSB to increase to higher levels than estimated for the late 1980's, although in terms of abundances the stock will remain at lower values. If fishing mortality were to return to the levels seen until 1995, stock recovery would become very improbable.

2. COMMERCIAL CATCH DATA

Given the increase in catch in 2006, STACFIS **recommended** that *efforts be made to conduct commercial sampling for this stock.*

The estimated total catch for 2007 is 345 tons, similar to the value in 2006 (339 tons), both of which are over ten times the average yearly catch estimated for the period 2000-2005 (see Table 1 and Figure 1).

In 2006 length sampling was conducted by Portugal (Vargas *et al.* 2007) and Russia (Vaskov *et al.* 2007), whereas in 2007 it was conducted by Portugal (Vargas *et al.* 2008), Russia (Vaskov *et al.* 2008) and Spain (González *et al.* 2008). Even though the level of sampling was limited, an attempt has been made to derive catch numbers-at-age for these two years using the sampling information avalaible. The procedure followed is described in the sequel.

Length distributions:

In 2007 length sampling of catch was conducted by Spain, Portugal and Russia. Length frequencies for these three countries and for the EU survey are shown on the top panel of Figure 2. Length frequencies of Spain and Russia are rather similar, being both bimodal, with a narrower mode at around 55 cm and a much wider distribution approximately spanning the range 70-100 cm. In broad lines this is in correspondence with the length frequencies observed in the EU survey for the range above 50 cm. Portuguese length frequencies are quite different, concentrating on smaller lengths, between 50 and 80 cm. The combined commercial catch length frequencies, obtained by adding up the length distributions of the three countries taking their estimated respective landings into account, is shown on the bottom panel of Figure 2. These combined length frequencies are applied to catches from countries with no length sampling.

In 2006 length sampling of catch was conducted only by Portugal and Russia. Length frequencies for these two countries and for the EU survey are shown on the top panel of Figure 3. Length frequencies of Portugal and Russia in 2006 are rather different from each other, each of them being similar to the corresponding length frequencies in 2007. As Portuguese landings in 2006 are much larger than those from Russia, and since the Spanish and Russian length frequencies were quite similar in 2007, it was decided to apply the Russian length frequencies to the catches from all countries with no length sampling in 2006. This was to avoid that the Portuguese length frequencies entirely dominated the length frequencies of the total commercial catch. The result is displayed on the bottom panel of Figure 3.

Age distributions:

As no age-length keys (ALK) were available for the commercial catch, each year the corresponding ALK from the EU survey was applied in order to convert from length to age distributions of catches. This is the same procedure followed during 1999-2001, the last three years for which catch numbers-at-age were derived for this stock. The range of ages in the catch goes from 1 to 8+. Results are in Table 2.

Screening of catch numbers-at-age:

Figure 4 shows a bubble plot of catch proportions at age over time (with larger bubbles corresponding to larger values), indicating that the bulk of the catch is comprised of individuas of 3-5 years of age. In 2006, catches contained mostly age 4 individuals, whereas in 2007 there has been much more spread over the ages.

Figure 5 shows standardised catch proportions at age (each age standardised independently, to have zero mean and standard deviation 1 over the range of years considered). White and black values indicate values above and below the average, respectively, and the larger the bubble size the larger the magnitude of the value. Assuming that the selection pattern at age is not too variable over time, it should be possible to follow cohorts from such a figure. Some strong and weak cohorts can be followed, although the pattern is not too evident.

Mean weight-at-age:

In past assessments, mean weight-at-age in the catch has been computed separately from mean weight-at-age in the stock. For the 2006 and 2007 catch data, four weight-length keys were available, respectively arising from Portuguese sampling of commercial catch in 2006, Russian sampling of commercial catch in 2007 and sampling during the EU surveys in 2006 and 2007 (Figure 6). For lengths under approximately 95 cm, Portugal and Russia calculate weights which are respectively higher and lower than those from the EU surveys. Above that length, both Portugal and Russian weights are larger than those from the EU surveys. Taking the average of the Portuguese and Russian weight-length relantionships (red line in Figure 6) was felt to be a sensible compromise. This was applied to calculate weight-at-age in the catch both in 2006 and in 2007. Results are in Table 4 (middle panel).

Dividing the estimated total catch weight by the SOP (sum over the ages of the product of catch weight-at-age and numbers-at-age), results in a value of 1.09 both for 2006 and 2007.

3. EU SURVEY INDICES OF ABUNDANCE AT AGE

The EU bottom trawl survey of Flemish Cap has been carried out since 1988, targeting the main commercial species down to 730 m of depth. The surveyed zone includes the complete distribution area for cod, which rarely occurs at depths of more than 500 m. The fishing procedure has been kept constant throughout the entire period, although in 1989 and 1990 a different research vessel was used. Since 2003, the survey has been carried out with a new research vessel (R/V Vizconde de Eza, replacing R/V Cornide de Saavedra) and conversion factors to transform the values from the years before 2003 have been implemented (González-Troncoso and Casas, 2005).

The survey indices of abundance at age and their standard errors are presented in Table 3. Figure 7 displays the time series of biomass and abundance indices. Biomass and abudance levels show some increase since 2005, following an extremely low period starting in the mid 1990's. Figure 8 displays a bubble plot of the abundances at age, in logarithmic scale, with each age standardised separately (each age to have mean 0 and standard deviation 1 over the range of survey years). White and black bubbles indicate values above and below average, respectively, with larger sized bubbles corresponding to larger magnitudes. The picture indicates that the survey is able to detect strength of recruitment and to track cohorts through time very well. It clearly shows a series of consecutive (age 1) recruitment failures from 1996 to 2004, leading to very weak cohorts. Cohorts recruited in or after 2005 appear to be a bit stronger than average.

Mean weight-at-age in the stock, derived from the survey data, shows a strong increasing trend since the late 1990's (see top panel of Table 4 and Figure 9).

4. MATURITY AT AGE

New annual maturity ogives are provided, since maturity data for years 2001-2006 have been analysed. Until last year, the same maturity ogive was used for all years since 1998. Logistic regression models for proportion mature at age have been fitted independently for each of the years for which data are available (1990-1998, 2001-2006). For 1989 and 1989, the same maturity ogive fitted for 1990 is used. For 2007, for which no maturity data have yet been analysed, the ogive estimated for 2006 is used. For 1999 and 2000, maturity ogives computed as mixtures of those fitted for 1998 and 2001 are used. The maturity data for 1991 was of poor quality and did not allow for a good fit, so a mixture of the ogives fitted for 1990 and 1992 is used for that year. The new estimated maturity ogives together and 90% uncertainty limits are displayed in Figure 10. The figure also displays the old maturity ogives (used until last year) for comparison. There are no major differences between the new and old maturity ogives.

Figure 11 displays the evolution of the a50 (age at which 50% of fish are mature) through the years (estimate and 90% uncertainty limits), derived from the new maturity ogives. The figure shows a continuous decline of the a50 through time, from above 5 years of age in the late 1980's to just above 3 years of age since about year 2000.

Figure 12 displays the evolution of the l50 (length at which 50% of fish are mature) through the years, estimated applying logistic regression to proportion mature at length data, separately for each year. The figure shows a steep decline of the l50 until the mid 1990's, followed by a slower increase since then. This is not inconsistent with the idea of fish growing faster (Figure 9) while maturing at younger ages (Figure 11).

5. ASSESSMENT METHODOLOGY

STACFIS has **recommended** to *further develop and explore the potential of the Bayesian model for the assessment of this stock in 2008. This should include comparisons with standard XSA and the survey-based method.*

An assessment based on XSA using commercial catch numbers-at-age and the EU survey to provide a tuning index was approved for this stock in 1999 for the first time and was annually updated until 2002 (Vázquez and Cerviño, 2002). However, commercial catch from year 2000 onwards became very low (under 60 tons), so performing XSA became increasingly difficult (derivation of catch numbers-at-age became unfeasible since there was almost no biological sampling) and results were rather sensitive to the assumed natural mortality (due to the very low catch rates). In 2003 the XSA methodology was abandoned in favour of a new one, survey-based, developed by Cerviño and Vázquez (2003). The idea of the survey-based method is to combine survey catchabilities at age estimated from a previous XSA assessment with survey indices obtained every year to derive stock abundance at age estimates as the ratio of the observed survey indices to the catchability for that age. The method identifies and takes due account of uncertainty arising from two different sources: sampling variability in the observed survey indices (a measure of which is provided by the survey standard errors) and interannual variability in catchability, which causes year to year departures from the average catchability value over time. The method was used to assess the status of the stock from 2003 to 2007, more details can be found in the SCR presented yearly (Vázquez and Cerviño, 2004, 2005; Murua, Cerviño and Vázquez, 2006; Fernández, Cerviño and Vázquez, 2007). It has the advantage of not requiring catch information after the initial period used to estimate catchabilities. A weakness of the method is that it does not impose a cohort structure on the population, so there is no gurantee that abundance estimates decrease along cohorts. Perhaps more worryingly, and related to the previous point, survey year effects (if they exist) will go largely undetected, biasing the abundance estimates for such years (although it might be expected that survey year effects during the years used to estimate catchability are reflected as increased uncertainty in the abundance estimates of the entire time series).

In 2007 an alternative VPA-type Bayesian model for stock assessment was presented (Fernández, Cerviño and Vázquez, 2007), albeit only briefly and without providing a detailed description. The model imposed a cohort structure on the population and assumed (small) stochastic fishing mortality rates for the years without catch data (hence, it was capable of handling the situation of years without catch data). The EU survey series was used as a tuning index.

This year, the Bayesian model has been developed in a way that allows maximal incorporation of catch information. For the years with catch numbers-at-age, it works in the same way as the Bayesian model from last year (starting from cohort survivors and reconstructing cohorts backwards in time using catch numbers-at-age and the assumed natural mortality rate). For the other years, if an estimate of total catch weight is available, this information can be incorporated in the model by means of an observation equation relating (stochastically) the estimated catch weight to the underlying population abundances (hence aiding in the estimation of fishing mortalities). An advantage of the model is that it allows to combine years for which catch numbers-at-age are available with years where only estimates of total catch weight are had. Years with no information on commercial catch are also allowed. Of course, the more and the better the quality of the catch information, the more reliable the results will be. A detailed description of the model follows.

Input data:

Ages considered are $a = 1, 2, \ldots, A-1, A+$, where $A-1 = 7$ and $A+ = 8+$ is a plus group.

The assessment years are denoted $y = 1, ..., Y$ (1988 to 2007).

Commercial catch numbers at age data, $C(y, a)$, are available for the years $1988, \ldots, 2001$ (denoted as $y = 1, \ldots, Y_c(1)$) and for the years 2006 and 2007 (denoted $y = Y_c(2), \ldots, Y$). For years 2002 to 2005 ($y = Y_c(1)+1,\ldots,Y_c(2)-1$) only total catch in weight, $CW(y)$, is available.

The EU survey, conducted in the month of July, provides relative indices of abundance at age yearly for the entire time series ($y = 1,\ldots,Y$).

The natural mortality rate M is assumed to be the same for all years and ages.

Prior distributions of survivors from age a at the end of year y:

For (Y,a) pairs, $a = 1,\ldots,A-1$ (survivors from "true" ages at end of final year) and for $(y,A-1)$, $y = 1,\ldots,Y-1$ (survivors from last true age at end of previous years), a log-Normal prior distribution is assumed:

$$surv(y,a) \sim LN\left(\text{median} = medrec\,\exp\Big(-medM\,a - \sum_{age=1}^{a} medFsurv(age)\Big), \text{CV} = cvsurv\right),$$

where $medrec$ and $medFsurv(a)$ are values of recruitment and fishing mortality at age a chosen only for the purpose of defining the median of the prior distribution of survivors and $medM$ is a value for M. The prior distribution of survivors is assigned coefficient of variation (CV) equal to $cvsurv$. The values chosen for $medrec$, $medFsurv(a)$, $medM$ and $cvsurv$ are indicated in Table 5. For $medrec$, $medFsurv(a)$ and $medM$, values that were felt to be reasonable for this stock were chosen; $cvsurv$ was taken to be rather large (1 or larger), so as to obtain wide (little informative) prior distributions on survivors.

Abundances at age follow from cohort analysis:

A distinction is made between the years for which catch numbers-at-age are available and those years for which only total catch weight is available.

Years with catch numbers-at-age ($y = 1,\ldots,Y_c(1)$ and $y = Y_c(2),\ldots,Y$):

Use $C(y,a)$ and cohort analysis to reconstruct abundances at age starting from survivors.

For $a = 1,\ldots,A-1$:

If (y,a) corresponds to the last true age or final year, then numbers-at-age are obtained as

$$N(y,a) = surv(y,a)\exp(M) + C(y,a)\exp(M/2).$$

Otherwise:

$$N(y,a) = N(y+1,a+1)\exp(M) + C(y,a)\exp(M/2).$$

The total mortality rate and fishing mortality rate are obtained as:

$$Z(y,a) = \log(N(y,a)/surv(y,a)) \quad \text{or} \quad Z(y,a) = \log(N(y,a)/N(y+1,a+1)),$$

as appropriate, and

$$F(y,a) = Z(y,a) - M$$

For $a = A+$:

The age plus group contains individuals from different cohorts. In common with the standard XSA method, it is assumed that fishing mortality for this group is the same as for individuals aged $A-1$ and Baranov catch equation is used to determine the abundance:

$$\begin{aligned}
F(y, A+) &= F(y, A-1) \\
Z(y, A+) &= Z(y, A-1) \\
N(y, A+) &= \frac{C(y, A+)}{1-\exp(-Z(y, A+))} \frac{Z(y, A+)}{F(y, A+)}
\end{aligned}$$

Years without catch numbers-at-age ($y = Y_c(1)+1, \ldots, Y_c(2)-1$):

Use a prior distribution on $F(y, a)$ to reconstruct cohort abundances at age from survivors.

For $a = 1, \ldots, A-1$:

A log-Normal prior distribution for $F(y, a)$ is assumed:

$$F(y, a) \sim LN\Big(\text{median} = medF(a), \text{CV} = cvF\Big).$$

The values $medF(a)$ and cvF used are given in Table 5. Prior medians of fishing mortality have been chosen to be very low, as years without catch numbers-at-age correspond to very low catches. Prior CV has been chosen rather large ($cvF = 0.7$) so as to have relatively uninformative prior distributions.

If (y, a) corresponds to the last true age or final year, then:

$$N(y, a) = surv(y, a) \exp(Z(y, a));$$

Otherwise:

$$N(y, a) = N(y+1, a+1) \exp(Z(y, a)),$$

where

$$Z(y, a) = F(y, a) + M$$

For $a = A+$:

As before, it is assumed that fishing mortality for the age plus group is the same as for individuals aged $A-1$:

$$\begin{aligned}
F(y, A+) &= F(y, A-1) \\
Z(y, A+) &= Z(y, A-1)
\end{aligned}$$

Numbers at age $A+$ are determined by the equation

$$N(y, A+) = \Big(N(y-1, A-1) + N(y-1, A+)\Big) \exp(Z(y-1, A+))$$

Role of total catch weight, $CW(y)$:

From Baranov catch equation, total catch weight according to the model is:

$$CW_{\text{mod}}(y) = \sum_{a=1}^{A+} N(y,a)\Big(1 - \exp(-Z(y,a))\Big)\frac{F(y,a)}{Z(y,a)}\, wcatch(y,a),$$

where $wcatch(y,a)$ is the assumed mean weight in catch of age a in year y. Weight in stock or some other suitable proxy may be used as a proxy for $wcatch(y,a)$. In this assessment, the average of $wcatch(y,a)/wstock(y,a)$ (catch weight-at-age over stock weight-at-age) over years 2001, 2006 and 2007 was computed separately for each age. Then $wcatch(y,a)$ during the period 2002-2005 was obtained by multiplying this average ratio by $wstock(y,a)$ in the appropriate year.

A log-Normal observation equation is used to relate the estimated total catch weight to that derived from the model:

$$CW(y) \sim LN(\text{median} = CW_{\text{mod}}(y),\ \text{CV} = 0.05)$$

The CV of this observation equation is taken to be very low, 5%. In other words, the estimates of total catch weight are assumed to be very precise and, when fitting the model to the data, the fitted values $CW_{\text{mod}}(y)$ will be very close to $CW(y)$. Larger CV values could be used, but it would be somewhat contradictory fully to believe catch numbers-at-age in the years for which they are available while having less confidence in the total catch weight estimates in the other years. This observation equation will complement the abundance index coming from the EU survey, aiding in the estimation of fishing mortality during the period in which no catch numbers-at-age are available.

Observation equations for the EU survey abundance at age indices:

The abundance at age indices obtained from the EU survey are assumed to be related to the underlying population abundance via a log-Normal observation equation:

$$I(y,a) \sim LN(\text{median} = \mu(y,a), \text{CV} = (\exp(1/\psi(a)) - 1)^{1/2})$$

where

$$\mu(y,a) = q(a)\left\{N(y,a)\frac{\exp(-\alpha Z(y,a)) - \exp(-\beta Z(y,a))}{(\beta-\alpha)Z(y,a)}\right\}^{\gamma(a)},$$

with $\alpha = 0.5$ and $\beta = 0.58$ defining the portion of the year in which the survey takes place (July), so that the quantity within brackets is the average stock abundance during survey time.

If the parameter $\gamma(a) \neq 1$, the survey catchability depends on stock abundance. After conducting experimental runs with different settings, it was decided to fix $\gamma(a) = 1$ for ages $a \geq 3$. For $a = 1, 2$, the following Normal prior distribution is assumed:

$$\gamma(a) \sim N(\text{mean} = 1, \text{variance} = 0.25),$$

so that the prior probability that $\gamma(a)$ is in between 0 and 2 is 0.95.

For the parameter $q(a)$ (which represents surveys' catchabilities when $a \geq 3$ and is related to it when $a = 1, 2$) a log-Normal prior has been assumed independently for each age $a = 1, \ldots, A+$:

$$\log(q(a)) \sim N(\text{mean} = 0, \text{variance} = 5),$$

so the prior probability that $\log(q(a))$ is in between -4.4 and 4.4 is 0.95. For the precision of the survey index, each age a in the survey has been assigned the prior

$$\psi(a) \sim Gamma(\text{shape} = 2, \text{rate} = 0.07).$$

This prior on $\psi(a)$ implies a prior median value of 21% with a prior 95% uncertainty interval going from 11% to 58% for the CV of the survey index observation equation.

Uncertainty in natural mortality:

Most stock assessments are performed with a fixed value of M. For the 3M cod stock, past assessments used $M = 0.2$ and this value will be assumed in several of the runs performed in this document. However, due to the very low values estimated for F in recent years, concerns have been raised about the possibility that the results from the assessment are highly sensitive to the choice of value for M. To examine this issue, two additional runs were performed assuming log-Normal prior distributions for M as follows:

$$M \sim LN(\text{median} = medM, \text{CV} = cvM).$$

The first of these runs took $medM = 0.2$ and $cvM = 0.75$, which is a relatively little informative prior due to the very large CV assumed which implies high dispersion (although note that the prior mode is at 0.128, a fairly low value). The second of these runs assumed $medM = 0.218$ and $cvM = 0.3$, leading to a prior mode for M equal to 0.2. This second prior was felt to be more in agreement with the biological knowledge had about this stock.

6. ASSESSMENT RESULTS

Six runs were conducted, with prior settings as indicated in Table 5. The first four runs have $M = 0.2$ fixed, whereas the final two runs consider uncertainty in M.

Results from Run 1:

Figure 13 displays the assessment results regarding total biomass, SSB, recruitment and Fbar (ages 3-5). The continuous black lines in the figure are posterior medians and the dashed lines show the limits of 90% posterior credible intervals (capturing uncertainty in the estimates). The actual numbers leading to this figure are presented in Table 6. For comparison, the blue lines in the figure are the results from XSA ran using data until 1999 (light blue) and 2001 (dark blue) and with the same settings as in the last approved XSA assessment in 2002. The results from the Bayesian model match quite well those from the XSA assessments, which is not too surprising given that when catch numbers-at-age exist the Bayesian model works essentially as cohort analysis starting from survivors and tuning the analysis using the survey abundance index, similarly to what XSA does.

The panel relating to SSB includes also the year 2008. The results indicate that there has been a substantial increase in SSB in the last few years, with the largest increase happening during the year 2007. Whereas at the beginning of 2007, SSB is still well below the levels seen until 1995, the SSB estimate for the start of 2008 is similar to that of 1991, although the uncertainty associated with the 2008 value is much higher. This larger uncertainty arises from the fact that no information from the EU survey or commercial catch in 2008 is available at present. Neither is information yet had about weight-at-age or maturity-at-age for 2008 and random draws from the three last years for which there is weight and maturity information are used for 2008 (assuming always that maturity at age 1 is equal to 0, as there is no estimate of recruitment in 2008). The red horizontal line in the SSB panel represents $B_{\text{lim}} = 14000$. Whereas the probability that SSB is below B_{lim} is very high (above 0.95) at the beginning of 2007, by the beginning of 2008 this probability is estimated to be only 0.11.

Years 2005-2007 have seen an improvement in recruitment, although the actual recruitment levels for these years can not yet be precisely estimated (see the wide uncertainty limits in the figure and table). Recruitment estimates for these years will become more precise as information on more cohort ages is gathered during the next few years.

Fbar continues to be at very low levels, although an increase has been estimated for 2006. In 2007, Fbar has again fallen to a very low value.

Table 7 and Figure 14 provide more detailed information on the estimated F-at-age values, indicating that the increase in Fbar in 2006 is mostly due to fishing mortality at age 3. The figure indicates good agreement between Bayesian and XSA results over the common years, although for ages 6 and older XSA estimates higher fishing mortality than the Bayesian method.

Estimates of stock abundance at age for the assessment period and the following year (1988-2008) are presented in Table 8 and Figure 15, showing generally good agreement with XSA estimates. For 2008, only abundances of ages $a \geq 2$ can be estimated, as they are the survivors from individuals in the last assessment year (2007).

Figure 16 depicts the prior distribution (in red) and posterior (in black) of survivors at age at the end of the final year of the assessment, where by $survivors(2007, a)$ it is meant individuals of age $a + 1$ at the beginning of 2008 (in other words, $survivors(2007, a) = N(2008, a + 1)$). The plotting range for the horizontal axis is the 95% prior credible interval in all cases (the same procedure will be followed in all subsequent prior-posterior plots), to facilitate comparison between prior and posterior distributions. For survivors of ages 4 and older, there has been very substantial updating of the prior distribution. This is much less the case for younger ages, with prior and posterior distributions being much closer for those ages. Similarly to the comment made regarding uncertainty in recruitment estimates, the latter was to be expected as few ages of these cohorts have been observed to date.

Figures 17 and 18 display prior distributions (in red) and posterior distributions (in black) for survivors of the last true age at the end of every year. By $survivors(y, 7)$ it is meant individuals of age 8 (not 8+) at the beginning of year $y+1$. Whereas the prior distribution is the same every year, posterior distributions vary substantially depending on the year, displaying particularly low values between 2002 and 2005.

For the years without catch numbers-at-age, there are also prior distributions on F-at-age and the same prior distribution has been chosen in each of such years. Prior (in red) and posterior (in black) densities are diplayed in Figure 19, indicating that there is enough information to update the prior distribution.

Raw residuals (observed minus fitted values) for the EU survey abundance indices at age in logarithmic scale, are presented in Figure 20. Each panel in the figure corresponds to one age. The black lines are residuals from the Bayesian model, where the continuous lines correspond to posterior medians and dashed lines to the limits of 90% posterior credible intervals. XSA residuals are shown in blue. There is again good agreement between Bayesian and XSA values for the common years, with the exception of age 7, for which XSA residuals have much smaller magnitude. The very small magnitude of age 7 XSA residuals was actually commented on in the NAFO approved 2002 XSA assessment (Vázquez and Cerviño, 2002), where the corcern was expressed that age 7 indices might be dominating the fit. No obvious trends over time or any other particular patterns emerge from the residuals plot.

Standardised residuals (observed minus fitted values divided by estimated standard deviations) for the EU survey abundance at age indices in logarithmic scale, are displayed in Figure 21. As the residuals have been standardised, they should be mostly in the range $(-2, 2)$ if model assumptions about variance are not contradicted by the data. Most of the residuals are indeed in $(-2, 2)$ range.

Figure 22 shows again standardised residuals (posterior medians), now all plotted in a single graph, with a different colour line for each age. This graph should highlight year effects, identified as years in which most of the residuals are above or below zero. In 1988 all residuals are negative except for the one for age 7, whereas the opposite happens in 1996 and 1997, suggesting year effects (*i.e.* survey catchabilities that are below average in 1988 and above average in 1996 and 1997).

Results regarding the EU survey's catchabilities are displayed in Figures 23 and 24. The first of these figures shows results for the parameter $\log(\phi(a))$, which corresponds to log(catchability) for ages $a \geq 3$. For ages $a = 1, 2$ catchability depends also on stock abundance and this dependence is regulated via the parameter $\gamma(a)$, for which results are in Figure 24. The posterior probability that $\gamma(a) > 1$ for $a = 1, 2$ is very high, pointing towards an increase in survey catchabilities for the younger ages as abundance of those ages increases.

Results from Runs 2-4:

In order to test the robustness of the assessment results to various settings in Run 1, three additional runs were performed with $M = 0.2$ (labelled Runs 2-4 in Table 5). Run 2 uses exactly the same settings as the Run 1 but uses only total catch in weight from 2002 onwards (*i.e.* it does not use catch numbers-at-age as derived for 2006-2007). Runs 3 and 4 use catch numbers-at-age for 2006 and 2007. These two runs introduce changes in the prior settings that are expected to have most influence on results, namely, the prior distributions of F-at-age in years with no catch numbers-at-age (Run 3) and the prior distributions of survivors (Run 4). The settings of these two runs are more pessimistic than those of Run 1 (larger prior median values of F-at-age); consequently, results from them would be expected to be more pessimistic.

Estimated trends in SSB, recruitment and Fbar are shown in Figures 25 to 27 and standardised residuals for the survey indices in Figures 28 to 30, for Runs 2-4, respectively. In comparsion with Run 1, Run 2 estimates SSB as being currently higher and there is no estimated increase in Fbar in 2006. As expected, Runs 3 and 4 give lower SSB estimates, although results from Run 4 are rather similar to those from the Main Run. Residuals from Run 3 look a bit worse than for the other runs (for example, for age 5 residuals since 1996 are all positive whereas they are mostly negative until 2005). This suggests than the settings of Run 3 are the ones in less agreement with the signal coming from the EU survey abundance indices.

While there is clearly some sensitivity of results to prior settings, all runs estimate very similar stock trends. They all show an increase in recruitment and SSB in the last three years. However, particularly for SSB, the magnitude of the increase varies between the different runs.

Results from Runs 5 and 6:

These two runs include uncertainty in M, by incorporating a (Log-Normal) prior distribution as explained earlier in this document. The rest of the prior settings are the same as those of Run 1 (see Table 5).

Run 5 has prior median of 0.2 for M with CV$= 0.75$, hence allowing a wide range of values for M a priori (prior 95% probability interval for M is (0.05,0.74)). The posterior distribution of M is concentrated in lower values, with a posterior median of 0.13. This estimate of M is not considered to be realistic for this stock, from a biological point of view. Despite estimating M to be below 0.2, estimates of F and SSB are quite similar to those obtained from Run 1, whereas recruitment is estimated to be a bit lower. Estimated trends from this run and standardised residuals are displayed in Figures 31 and 32.

Run 6 was chosen to have a prior distribution on M that was more in agreement with biological knowledge about this stock. The prior mode, rather than the median, was fixed at 0.2 and a prior CV of 0.3 was chosen. In this way, the run will incorporate a certain amount of uncertainty in the value of M without allowing for values that are considered to be unrealistic. The prior 95% probability interval for M is now (0.12,0.39). The posterior distribution is concentrated on slightly lower values, with a posterior median of 0.19.

Results from Run 6 are in Tables 9-11 and Figures 33-44. Estimates of F, SSB and recruitment are very similar to those obtained from Run 1. Results do not change any aspect of the assessment substantially with respect to Run 1, although the posterior distributions now diplay more uncertainty, reflected in wider posterior intervals.

Comparison with results from survey-based method:

The survey-based method in use since 2003 has also been applied. The method gives numbers-at-age estimates, and their associated uncertainty, at survey time (July). SSB is projected backwards to the beginning of the year (the time point to which B_{lim} is referred), applying natural plus fishing mortality rates. Fishing mortality at age estimates from XSA are used until year 2001. From 2002 onwards, fishing mortality at age was estimated in two steps, as follows: In the first step, yearly Fbar values are estimated. This is done by estimating a correction factor between the ratio of survey biomass index and total yearly catch weight, on the hand, and Fbar, on the other hand, based on XSA results until 2001. This factor is then applied to the ratio of survey biomass index and estimated total catch weight to obtain yearly Fbar estimates from 2002 onwards. In the second step, the average selection pattern pattern at age (computed from XSA results) from a number of years until 2001 is multiplied by the Fbar estimates from 2002. In this way, estimates of fishing mortality at age are obtained for all assessment years and the survey-based method results can be referred to the start of the year.

SSB estimates until 2007 from the survey method are shown in Figure 45, where the yearly estimates and 90% probability limits are shown as continuous and dashed lines, respectively. The two XSA assessments with which Bayesian results were compared are also shown in this figure (blue lines). The red horizontal line corresponds to $B_{\text{lim}} = 14000$ tons. The survey-based method shows less agreement with XSA than did the Bayesian one (Figure 13). This is not surprising, as the Bayesian method is using more strongly the information contained in catch numbers-at-age (like XSA does), whereas the survey-based method only uses catch numbers-at-age to estimate survey catchabilities and then computes abundance estimates relying much more directly on the observed survey indices. The survey-based method gives particularly large SSB estimates for 1989 and 1989, years for which survey residuals of the main ages contributing to SSB are mostly positive (see Figure 40). All residuals of ages 5 and older are positive in 2006 and 2007, explaining why the survey-based method gives higher SSB estimates than the Bayesian model on those years. Nevertheless, $SSB(2007)$ from the survey-based method is quite similar to the estimate obtained from the most optimistic of the Bayesian runs (Run 2). No estimate of SSB at the beginning of 2008 has been computed from the survey-based method, but given the SSB values in 2007, it is clear that, had it been computed, it would have been quite similar to the one obtained from the Bayesian Run 2.

Conclusion on the different models and settings considered in the assessment:

Results from Run 6 of the Bayesian model are proposed as the assessment results. Prior settings, including the allowed uncertainty in M, are considered to be the most realistic.

Consequently, the remainder of this document will be using only the results from the Run 6 of the Bayesian model.

7. RECONSIDERING THE $B_{\lim}$ VALUE

STACFIS **recommended** *to revisit candidates for Blim, as the current value in based on estimates of SSB and recruitment obtained from standard XSA, which is not the method currently being used to assess the status of this stock.*

Given that the Bayesian model used for the assesment of the stock this year gives very similar answers to XSA for the common period, the validity of the current value $B_{\lim} = 14000$ tons would not seem to be in question. Figure 46 shows a stock-recruitment plot, with the 14000 value indicated with a vertical red line. This value still appears as a reasonable choice for $B_{\lim}$: only low recruitments have been observed with SSB below this level whereas both low and high recruitments have been observed at higher SSB values.

8. PROJECTIONS

Stochastic projections of the stock dynamics over a 3 year period (2009-2011) have been performed. The variability in the input data is taken from the results of the Bayesian assessment (Run 6, including uncertainty in M). Input data for the projections were chosen on the basis of the last three assessment years (2005-2007), except when there was some reason to consider this unrealistic. Input data are as follows:

Numbers aged 2 to 8+ in 2008: estimates from the assessment

Recruitments for 2008-2011: Recruits per spawner were estimated for each of the assessment years (Figure 48). As the last 3 years have a much higher value than the average over the assessment years, using just the last 3 years was not considered realistic. Hence, in the projections, recruits per spawner were drawn randomly from the values in all of the assessment years (1988-2007).

Maturity ogive: Drawn randomly from the maturity ogives (with their associated uncertainty, see Figure 10) of years 2004, 2005 and 2006 (2007 was not used since no data were available to estimate an ogive for that year).

Weight-at-age in stock and weight-at-age in catch: Drawn randomly from the last 3 assessment years (Table 4).

PR at age for 2008-2011: Average of the PRs estimated for last 3 assessment years (Figure 49).

Fbar(ages 3-5): Three options were considered:

(1) Average of Fbar in 2005-2007 (median value at 0.08). Projection results are in Tables 12 and 13 and Figure 50.

(2) F0.1 (median value at 0.165). Projection results are in Tables 14 and 15 and Figure 51.

(3) Average of Fbar in 1988-1995 (median value at 0.93), as these years correspond to the period when SSB was above B_{lim}. Projection results are in Tables 16 and 17 and Figure 52.

Results for the 3 year projection period are presented in Tables 12-17 and Figures 50-52. They indicate that fishing at the very low Fbar value currently estimated for 2005-2007 or even fishing at F0.1 (which is higher than the average Fbar over the last 3 years), SSB has a very high probability of reaching levels higher than those estimated for the late 1980's. However, the huge increase seen in SSB does not have a counterpart in terms of population abundances, which is projected to remain at levels well below those of the late 1980's. This is largely due to the fact that weight-at-age and maturity-at-age used for the projection period, namely random draws from the last 3 assessment years, are much higher than those assumed to have applied at the end of the 1980's.

Projections option 3 corresponds to the level of fishing mortality seen during the late 1980's and beginning of the 1990's. Results indicate that recovery of the stock under such fishing pressure would be very improbable.

The projected values for the period 2009-2011 are heavily reliant on the relatively abundant three most recent cohorts, namely those recruited in 2005-2007, rather than on healthy population abundances across all ages, making the stock status much more fragile than suggested by SSB values alone.

As a redfish fishery has developed in recent years in depths shallower than 350 m, and as cod is a bycatch species of that fishery, it may be surmised that catch levels of cod will continue to rise during the next few years.

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Table 1: Total cod catch in Flemish Cap. Reported nominal catches since 1959 and estimated total catch since 1988 in tons.

Year	Estimated	Faroes	Japan	Korea	Norway	Portugal	Russia	Spain	UK	France	Poland	Others	Total
1959					11		6470	466				2	6949
1960		260			166	9	11595	607			2	96	12735
1961		246			116	2155	12379	851	600	2626	336	1548	20857
1962		188	1		95	2032	11282	1234	93		888	363	16176
1963		969	35		212	7028	8528	4005	2476	9501	1875	853	35482
1964		1518	333		1009	3668	26643	862	2185	3966	718	1172	42074
1965		1561			713	1480	37047	1530	6104	2039	5073	771	56318
1966		891			125	7336	5138	4268	7259	4603	93	259	29972
1967		775			200	10728	5886	3012	5732	6757	4152	802	38044
1968		852	223		697	10917	3872	4045	1466	13321	71	235	35699
1969		750	30		1047	7276	283	2681		11831		42	23940
1970		379	34		1347	9847	494	1324	3	6239	53	1	19721
1971		708	6		926	7272	5536	1063		9006	19	1647	26183
1972		6902			952	32052	5030	5020	4126	2693	35	693	57503
1973		7754			417	11129	1145	620	1183	132	481	39	22900
1974		1872			383	10015	5998	2619	3093		700	258	24938
1975		3288			111	10430	5446	2022	265		677	136	22375
1976		2139			1188	10120	4831	2502		229	898	359	22266
1977		5664	24		867	6652	2982	1315	1269	5827	843	1576	27019
1978		7922	22		1584	10157	3779	2510	207	5096	615	1239	33131
1979		7484	74		1310	9636	4743	4907		1525	5	26	29710
1980		3259	37		1080	3615	1056	706		301	33	381	10468
1981		3874	9		1154	3727	927	4100		79		3	13873
1982		3121	10	4	375	3316	1262	4513	33	119			12753
1983		1499	1		111	2930	1264	4407				3	10215
1984		3058	9		47	3474	910	4745				459	12702
1985		2266	5		405	4376	1271	4914				438	13675
1986		2192	6			6350	1231	4384				355	14518
1987		916	269			2802	706	3639		2300			10632
1988	28899	1100	5	6		421	39	141				6	1718
1989	48373		38	321		170	10	378					917
1990	40827	1262	24	815		551	22	87				1	2762
1991	16229	2472	54	82	897	2838	1	1416	26			1203	8989
1992	25089	747	2	18		2201	1	4215	5			6	7226
1993	15958	2931		3		3132		2249				1	8316
1994	29916	2249			1	2590		1952					6885
1995	10372	1016				1641		564					3221
1996	2601	700				1284		176	129			16	2305
1997	2933					1433		1	23				1457
1998	705					456							456
1999	353					2							2
2000	55					30	6						36
2001	37					56							56
2002	33					32	1						33
2003	16					7						9	16
2004	5					18	2					3	23
2005	19	7				16						3	26
2006	339					51	1	16				55	123
2007	345		10			58	6	33				18	125

Table 2: Catch numbers-at-age for the assessment years.

	1	2	3	4	5	6	7	8+
1988	1	3500	25593	11161	1399	414	315	162
1989	0	52	15399	23233	9373	943	220	205
1990	7	254	2180	15740	10824	2286	378	117
1991	1	561	5196	1960	3151	1688	368	76
1992	0	15517	10180	4865	3399	2483	1106	472
1993	0	2657	14530	3547	931	284	426	213
1994	0	1219	25400	8273	386	185	14	182
1995	0	0	264	6553	2750	651	135	232
1996	0	81	714	311	1072	88	0	0
1997	0	0	810	762	143	286	48	0
1998	0	0	8	170	286	30	19	2
1999	0	0	15	15	96	60	3	1
2000	0	10	54	1	1	4	1	0
2001	0	9	0	4	2	0	2	2
2002								
2003								
2004								
2005								
2006	0	22	19	81	2	10	2	0
2007	0	2	30	1	27	1	14	5

Table 3: EU bottom trawl survey abundance at age indices ('000s), in upper panel, and their standard errors, in lower panel.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1988	4850	78920	49050	13370	1450	210	220	60	0	0	0	0	0	0
1989	22100	12100	106400	63400	23800	1600	200	100	0	0	0	0	0	0
1990	2660	14020	5920	19970	18420	5090	390	170	90	30	0	0	0	0
1991	146100	29400	20600	2500	7800	2100	300	100	0	0	0	0	0	0
1992	75480	44280	6290	2540	410	1500	270	10	0	0	10	0	0	0
1993	4600	156100	35400	1300	1500	200	600	100	0	0	0	0	0	0
1994	3340	4550	31580	5760	150	70	10	120	0	10	0	0	0	0
1995	1640	13670	1540	4490	1070	40	30	0	20	10	0	0	0	0
1996	41	3580	7649	1020	2766	221	9	6	0	0	0	0	0	0
1997	42	171	3931	5430	442	1078	24	0	0	0	0	6	0	0
1998	27	94	106	1408	1763	87	165	0	6	0	0	0	0	0
1999	7	96	128	129	792	491	21	7	0	0	0	0	0	0
2000	186	16	343	207	100	467	180	11	17	0	0	5	0	5
2001	487	2048	15	125	81	15	146	101	6	6	6	0	0	0
2002	0	1340	609	24	68	36	28	96	33	0	6	0	0	0
2003	665	53	610	131	22	47	7	8	37	25	0	0	0	0
2004	0	3379	25	602	168	5	10	3	5	16	0	0	0	0
2005	8069	16	1118	78	708	136	0	17	8	8	0	0	0	0
2006	19710	3883	62	1481	86	592	115	7	0	7	14	0	7	0
2007	3910	11620	5020	21	1138	58	425	74	13	20	0	0	0	0

1988	1575	12388	5903	2357	399	64	77	37	0	0	0	0	0	0
1989	3358	1973	12593	6035	2871	264	54	75	10	9	0	0	0	0
1990	590	1676	728	2636	2373	689	99	72	50	23	0	0	0	0
1991	49587	5178	3614	397	1692	424	74	33	22	9	14	0	0	0
1992	16130	10717	1746	934	190	499	89	13	0	0	10	0	0	0
1993	2307	60189	7422	348	558	88	151	39	0	0	0	0	0	0
1994	707	1712	8003	1416	50	33	9	44	0	10	0	0	0	0
1995	407	5547	319	837	232	19	18	0	18	9	0	0	0	0
1996	22	426	1411	187	424	53	10	9	0	0	0	0	0	0
1997	25	57	870	906	81	138	13	0	0	0	0	9	0	0
1998	17	35	31	145	229	28	48	0	10	0	0	0	0	0
1999	9	36	50	43	140	76	14	9	0	0	0	0	0	0
2000	46	15	145	52	31	87	45	11	14	0	0	10	0	10
2001	149	199	9	44	30	6	47	32	12	10	9	0	0	0
2002	0	89	62	14	22	14	13	24	14	0	6	0	0	0
2003	360	29	90	41	18	24	10	10	23	19	0	0	0	0
2004	0	320	10	95	38	5	7	3	5	10	0	0	0	0
2005	727	10	204	36	151	53	0	14	7	7	0	0	0	0
2006	7753	881	28	349	30	138	41	8	0	10	13	0	10	0
2007	996	8163	1725	14	293	27	145	36	14	16	0	0	0	0

Table 4: Upper panel: weight-at-age (kg) in stock; Middle panel: weight-at-age (kg) in catch; Lower panel: Maturity-at-age (median values of ogives with uncertainty).

	1	2	3	4	5	6	7	8+
1988	0.03	0.1	0.31	0.68	1.97	3.59	5.77	6.93
1989	0.04	0.24	0.54	1.04	1.6	2.51	4.27	6.93
1990	0.04	0.17	0.34	0.85	1.5	2.43	4.08	5.64
1991	0.05	0.17	0.5	0.86	1.61	2.61	4.26	7.69
1992	0.05	0.25	0.49	1.38	1.7	2.63	3.13	6.69
1993	0.04	0.22	0.66	1.21	2.27	2.37	3.45	5.89
1994	0.06	0.21	0.59	1.32	2.26	4.03	4.03	6.72
1995	0.05	0.24	0.47	0.96	1.85	3.16	5.56	8.48
1996	0.04	0.25	0.53	0.8	1.32	2.27	4	5.03
1997	0.08	0.32	0.64	1	1.31	2.1	2	9.57
1998	0.07	0.36	0.75	1.19	1.66	1.99	3.1	7.4
1999	0.1	0.37	0.92	1.3	1.85	2.44	3.51	4.89
2000	0.1	0.58	0.96	1.61	1.91	2.83	3.47	5.28
2001	0.08	0.48	1.25	1.7	2.56	3.42	3.91	5.22
2002	0	0.42	1.12	1.43	2.47	3.59	4.86	5.31
2003	0.05	0.33	0.9	1.5	2.86	3.52	5.52	5.8
2004	0.07	0.6	1.42	2.07	3.22	5.31	5.88	7.84
2005	0.02	0.64	1.37	2.44	3.13	4.54	5.82	6.21
2006	0.09	0.7	1.06	2.49	3.57	4.69	5.76	9.55
2007	0.05	0.59	1.6	3.4	4.01	5.69	6.27	8.76

	1	2	3	4	5	6	7	8+
1988	0.06	0.2	0.44	0.82	2.19	3.39	5.27	7.97
1989	0	0.21	0.58	0.92	1.43	2.29	4.72	7.65
1990	0.08	0.15	0.5	0.89	1.61	2.52	3.55	7.17
1991	0.12	0.23	0.5	0.79	1.74	2.62	3.47	6.82
1992	0	0.3	0.41	0.59	1.09	1.7	2.62	3.87
1993	0	0.21	0.51	0.89	1.83	2.23	3.37	4.84
1994	0.14	0.29	0.5	0.79	1.92	2.72	2.16	4.24
1995	0	0	0.42	0.79	1.45	2.27	3.96	5.5
1996	0	0.29	0.79	1.05	1.54	2.43	4	5.03
1997	0	0	0.4	0.64	0.87	1.2	1.34	
1998	0	0.34	0.72	1.02	1.47	1.8	2.25	3.86
1999	0	0	0.92	1.3	1.85	2.44	3.51	4.89
2000	0	0.58	0.67	1.75	2.05	2.84	3.62	
2001	0	0.48	1.25	1.7	2.56	3.42	3.91	5.22
2002	0	0.65	1.46	1.52	2.73	3.91	5.32	5.49
2003	0	0.51	1.17	1.59	3.16	3.83	6.04	5.99
2004	0	0.93	1.85	2.19	3.56	5.78	6.43	8.1
2005	0	0.99	1.78	2.59	3.46	4.94	6.37	6.42
2006	0	1.08	1.46	2.28	3.97	5.04	6.33	10.40
2007	0	0.97	1.86	3.39	4.06	6.13	6.81	9.44

	1	2	3	4	5	6	7	8+
1988	0.05	0.09	0.16	0.28	0.43	0.6	0.75	0.89
1989	0.05	0.09	0.16	0.28	0.43	0.6	0.75	0.89
1990	0.05	0.09	0.16	0.28	0.43	0.6	0.75	0.89
1991	0.02	0.04	0.1	0.24	0.45	0.69	0.86	0.96
1992	0	0.01	0.05	0.18	0.49	0.81	0.95	0.99
1993	0	0.01	0.05	0.28	0.74	0.96	0.99	1
1994	0	0	0.07	0.65	0.98	1	1	1
1995	0	0	0.03	0.8	1	1	1	1
1996	0	0	0.04	0.63	0.99	1	1	1
1997	0	0.01	0.12	0.66	0.97	1	1	1
1998	0	0.01	0.18	0.87	1	1	1	1
1999	0	0	0.18	0.89	1	1	1	1
2000	0	0	0.19	0.91	1	1	1	1
2001	0	0	0.2	0.97	1	1	1	1
2002	0	0.02	0.62	0.99	1	1	1	1
2003	0	0.05	0.52	0.96	1	1	1	1
2004	0	0	0.15	0.96	1	1	1	1
2005	0.04	0.17	0.5	0.83	0.96	0.99	1	1
2006	0	0.02	0.37	0.95	1	1	1	1
2007	0	0.02	0.37	0.95	1	1	1	1

Table 5: Prior settings for the runs performed (for Runs 2-6, only differences with Run 1 are indicated).

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6
Years with catch numbers-at-age	1988-2001 2006-2007	1988-2001				
medrec	15000					
$medFsurv(1)$	0.0001					
$medFsurv(2)$	0.1			0.15		
$medFsurv(3)$	0.5					
$medFsurv(a)$, $a = 4, \ldots, 7$	0.7			0.8		
cvsurv	1			1.5		
$medF(1)$	0.0001					
$medF(2)$	0.005		0.05			
$medF(a)$, $a = 3, 4, 5$	0.01		0.1			
$medF(a)$, $a = 6, 7$	0.005		0.1			
cvF	0.7		1			
Mean of $\gamma(a)$, $a = 1, 2$	0.7					
Variance of $\gamma(a)$, $a = 1, 2$	0.25					
Mean of $\log(q(a))$, $a = 1, \ldots, A+$	0					
Variance of $\log(q(a))$, $a = 1, \ldots, A+$	5					
Shape of $\psi(a)$, $a = 1, \ldots, A+$	2					
Rate of $\psi(a)$, $a = 1, \ldots, A+$	0.07					
M	fixed				uncertain	uncertain
median M	0.2					0.218
modal M	0.2				0.128	
cvM	0				0.75	0.3

Table 6: Posterior results from Run 1:

	SSB quantiles:			Recruitment quantiles:			Fbar quantiles:		
Year	50%	5%	95%	50%	5%	95%	50%	5%	95%
1988	20185	16432	25072	17028	16936	17222	0.479	0.447	0.5
1989	34666	28453	41954	22224	22111	22480	0.826	0.779	0.849
1990	26594	22849	30893	27703	27636	27852	0.86	0.83	0.876
1991	19198	16120	23494	69059	68873	69482	0.472	0.449	0.483
1992	21989	19337	25237	63303	62677	64546	1.496	1.444	1.526
1993	11721	9697	15456	3457	3299	3788	0.985	0.941	1.007
1994	23519	20255	29260	5587	4538	7537	0.917	0.896	0.93
1995	20241	19124	21998	2692	2432	3058	1.31	1.164	1.409
1996	3992	3462	4845	190	137	274	0.558	0.458	0.653
1997	4109	3297	5374	181	126	261	0.598	0.483	0.724
1998	4657	3310	6728	260	199	350	0.227	0.171	0.306
1999	3408	2241	5264	42	32	58	0.216	0.166	0.281
2000	3119	1903	5195	457	310	677	0.15	0.108	0.209
2001	2338	1590	3379	824	561	1184	0.027	0.02	0.039
2002	2555	1826	3553	83	55	128	0.014	0.007	0.025
2003	2836	2148	3777	1389	923	2091	0.01	0.006	0.016
2004	4103	3242	5250	96	69	146	0.003	0.002	0.005
2005	4330	3542	5318	6378	3594	11228	0.006	0.004	0.01
2006	4471	3509	5671	14282	6677	30675	0.201	0.144	0.276
2007	7408	5389	10254	10467	3936	29437	0.029	0.02	0.042
2008	18556	11849	29676						

Table 7: F-at-age (posterior median) from Run 1:

Year/Age	1	2	3	4	5	6	7	8+
1988	0	0.061	0.411	0.526	0.504	0.664	1.042	1.042
1989	0	0.004	0.414	0.829	1.239	0.776	0.945	0.945
1990	0	0.016	0.238	1.021	1.328	1.312	0.853	0.853
1991	0	0.028	0.497	0.35	0.57	0.751	0.763	0.763
1992	0	0.361	0.976	1.331	2.189	1.346	2.253	2.253
1993	0	0.058	0.689	1.216	1.054	1.653	0.904	0.904
1994	0	0.646	1.208	1.17	0.379	0.604	0.293	0.293
1995	0	0	0.275	1.346	2.325	2.98	1.344	1.344
1996	0	0.041	0.237	0.607	0.839	0.447	0	0
1997	0	0	0.728	0.428	0.633	0.559	0.471	0.471
1998	0	0	0.072	0.321	0.281	0.257	0.063	0.063
1999	0	0	0.147	0.187	0.302	0.087	0.036	0.036
2000	0	0.385	0.42	0.013	0.017	0.018	0.002	0.002
2001	0	0.027	0	0.048	0.032	0	0.011	0.011
2002	0	0.006	0.013	0.01	0.011	0.005	0.011	0.011
2003	0	0.005	0.008	0.009	0.01	0.005	0.003	0.003
2004	0	0.001	0.005	0.001	0.002	0.004	0.001	0.001
2005	0	0.005	0.004	0.008	0.005	0.003	0.003	0.003
2006	0	0.005	0.401	0.126	0.066	0.04	0.015	0.015
2007	0	0	0.008	0.02	0.056	0.05	0.069	0.069

Table 8: N-at-age (posterior median) from Run 1:

Year/Age	1	2	3	4	5	6	7	8+
1988	17028	65202	83935	30146	3905	943	538	271
1989	22224	13940	50217	45561	14581	1931	398	364
1990	27703	18196	11366	27182	16278	3457	728	222
1991	69059	22675	14668	7333	8014	3533	762	155
1992	63303	56540	18057	7306	4231	3710	1365	562
1993	3457	51828	32251	5572	1580	388	791	389
1994	5587	2830	40030	13257	1353	451	61	786
1995	2692	4575	1214	9788	3369	758	202	339
1996	190	2204	3745	755	2085	270	32	1
1997	181	156	1731	2420	337	738	141	1
1998	260	148	128	684	1292	146	345	36
1999	42	213	121	97	407	799	93	31
2000	457	35	174	86	66	246	600	1
2001	824	374	19	94	69	53	198	197
2002	83	675	298	16	73	55	44	320
2003	1389	68	548	240	13	59	45	295
2004	96	1137	55	445	194	10	48	279
2005	6378	78	930	45	364	159	8	270
2006	14282	5220	64	758	37	296	130	24
2007	10467	11693	4254	35	547	28	233	78
2008		8570	9571	3456	28	424	22	283

Table 9: Posterior results from Run 6:

	SSB quantiles:			Recruitment quantiles:			Fbar quantiles:		
Year	50%	5%	95%	50%	5%	95%	50%	5%	95%
1988	19689	15722	24731	16178	12779	22062	0.488	0.436	0.531
1989	34066	27566	41754	21268	17423	27731	0.837	0.767	0.892
1990	26112	22194	30857	26623	22185	33840	0.873	0.802	0.93
1991	18642	15505	23073	66664	56784	82455	0.478	0.436	0.512
1992	21636	18901	24867	60947	51387	76386	1.511	1.417	1.582
1993	11406	9397	14792	3321	2794	4230	0.998	0.914	1.063
1994	23015	19736	28693	5148	3677	8067	0.929	0.869	0.974
1995	19944	18552	22011	2531	1979	3598	1.339	1.176	1.459
1996	3833	3280	4704	174	109	298	0.586	0.47	0.693
1997	3868	3063	5129	165	101	278	0.635	0.491	0.783
1998	4278	2995	6240	239	164	384	0.245	0.174	0.34
1999	3093	2049	4825	39	27	63	0.231	0.168	0.315
2000	2837	1740	4756	422	249	742	0.161	0.109	0.23
2001	2191	1470	3302	763	458	1278	0.029	0.02	0.043
2002	2411	1731	3475	76	44	132	0.014	0.007	0.027
2003	2713	2057	3692	1282	793	2161	0.01	0.006	0.017
2004	3961	3119	5145	92	61	149	0.003	0.002	0.005
2005	4222	3426	5225	5962	3173	11424	0.006	0.004	0.011
2006	4327	3403	5520	13904	6330	31123	0.205	0.148	0.289
2007	7190	5200	10128	10088	3770	27657	0.03	0.021	0.043
2008	17683	11072	29523						

Table 10: F-at-age (posterior median) from Run 6:

Year/Age	1	2	3	4	5	6	7	8+
1988	0	0.063	0.418	0.533	0.517	0.69	1.12	1.12
1989	0	0.004	0.421	0.839	1.257	0.805	1.017	1.017
1990	0	0.016	0.243	1.036	1.34	1.365	0.916	0.916
1991	0	0.028	0.504	0.354	0.579	0.76	0.833	0.833
1992	0	0.368	0.988	1.345	2.208	1.389	2.358	2.358
1993	0	0.059	0.698	1.231	1.067	1.714	0.978	0.978
1994	0	0.666	1.223	1.181	0.383	0.616	0.318	0.318
1995	0	0	0.285	1.374	2.379	3.051	1.399	1.399
1996	0	0.043	0.252	0.633	0.877	0.476	0	0
1997	0	0	0.761	0.463	0.674	0.603	0.511	0.511
1998	0	0	0.076	0.341	0.31	0.279	0.069	0.069
1999	0	0	0.158	0.197	0.322	0.096	0.04	0.04
2000	0	0.41	0.449	0.014	0.018	0.019	0.002	0.002
2001	0	0.029	0	0.052	0.034	0	0.012	0.012
2002	0	0.006	0.014	0.01	0.011	0.005	0.011	0.011
2003	0	0.005	0.008	0.009	0.01	0.005	0.003	0.003
2004	0	0.001	0.005	0.002	0.002	0.004	0.001	0.001
2005	0	0.005	0.004	0.009	0.005	0.003	0.003	0.003
2006	0	0.005	0.411	0.131	0.068	0.04	0.015	0.015
2007	0	0	0.008	0.021	0.058	0.052	0.069	0.069

Table 11: N-at-age (posterior median) from Run 6:

Year/Age	1	2	3	4	5	6	7	8+
1988	16178	63187	82236	29638	3818	916	515	260
1989	21268	13419	49247	44914	14406	1876	379	347
1990	26623	17645	11086	26804	16104	3380	694	211
1991	66664	22081	14410	7211	7879	3490	713	145
1992	60947	55318	17806	7222	4196	3645	1345	553
1993	3321	50526	31764	5499	1559	381	750	369
1994	5148	2752	39518	13108	1332	443	57	731
1995	2531	4262	1172	9642	3335	752	197	331
1996	174	2099	3524	729	2020	256	29	1
1997	165	144	1668	2267	321	694	131	1
1998	239	137	120	647	1180	136	314	33
1999	39	198	113	92	382	717	85	28
2000	422	33	164	80	63	229	538	1
2001	763	350	18	87	65	51	186	186
2002	76	633	282	15	68	52	42	304
2003	1282	63	522	230	12	56	43	284
2004	92	1060	52	428	188	10	46	271
2005	5962	76	880	43	354	155	8	263
2006	13904	4935	62	725	35	291	128	24
2007	10088	11449	4054	34	526	27	230	77
2008		8325	9452	3338	28	410	21	237

Table 12: Projection results with Fbar=Fbar(average 2005-2007):

	SSB quantiles:			$P(SSB < B_{\text{lim}})$	Yield quantiles:		
Year	50%	5%	95%		50%	5%	95%
2008	17683	11072	29523	0.200	2292	1295	4226
2009	35207	21996	62578	0.000	3350	1910	6278
2010	50295	30449	87434	0.000	4210	2233	8765
2011	60167	34102	122401	0.000	5431	2468	14399

Table 13: N-at-age in prediction years (medians) with Fbar=Fbar(average 2005-2007):

Year/Age	1	2	3	4	5	6	7	8+
2008	1443	8325	9452	3338	28	410	21	237
2009	4131	1258	6694	7188	2553	21	316	199
2010	7159	3215	1000	5103	5510	1939	16	394
2011	8159	5945	2601	758	3912	4167	1491	314

Table 14: Projection results with Fbar=F0.1:

	SSB quantiles:			$P(SSB < B_{\text{lim}})$	Yield quantiles:		
Year	50%	5%	95%		50%	5%	95%
2008	17683	11072	29523	0.200	4469	2411	8420
2009	32658	20480	56722	0.002	6081	3277	11907
2010	43701	26200	76319	0.000	7285	3521	15759
2011	48882	26518	102155	0.000	8665	3655	24870

Table 15: N-at-age in prediction years (medians) with Fbar=F0.1:

Year/Age	1	2	3	4	5	6	7	8+
2008	1443	8325	9452	3338	28	410	21	237
2009	4350	1188	6493	6578	2358	19	292	182
2010	6337	3607	924	4544	4672	1635	14	335
2011	7745	5235	2831	644	3217	3257	1163	245

Table 16: Projection results with Fbar=Fbar(average 1988-1995):

	SSB quantiles:			$P(SSB < B_{\text{lim}})$	Yield quantiles:		
Year	50%	5%	95%		50%	5%	95%
2008	17683	11072	29523	0.200	18430	11760	31428
2009	16781	10326	29430	0.278	14157	8519	26442
2010	12648	7117	25772	0.601	10070	4762	29992
2011	9001	3925	32375	0.732	9292	2903	48587

Table 17: N-at-age in prediction years (medians) with Fbar=Fbar(average 1988-1995):

Year/Age	1	2	3	4	5	6	7	8+
2008	1443	8325	9452	3338	28	410	21	237
2009	4131	1120	5141	3086	1152	9	147	86
2010	3562	3179	657	1662	1060	361	3	77
2011	2532	2907	1937	216	570	331	130	26

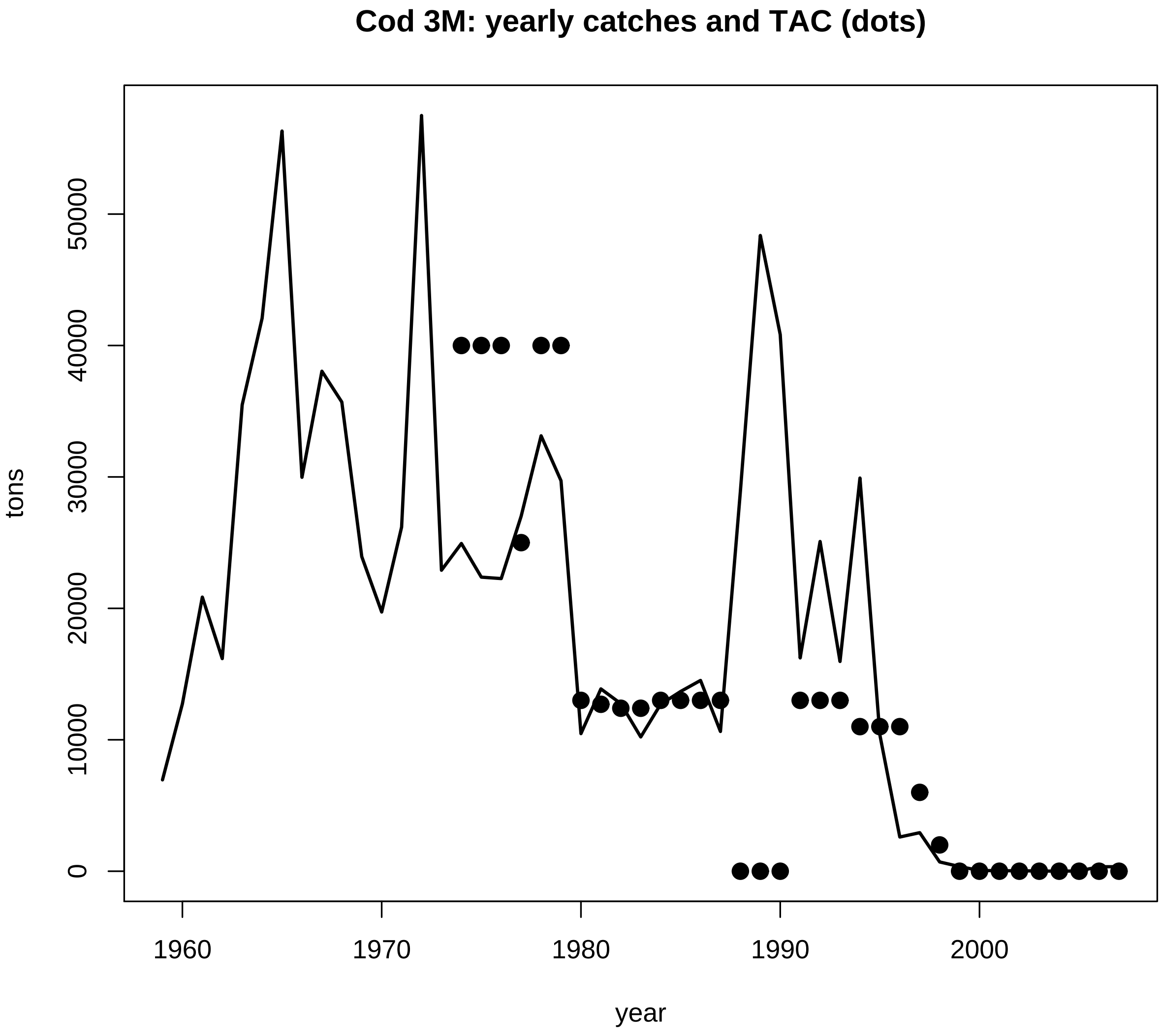

Figure 1: Catch and TAC

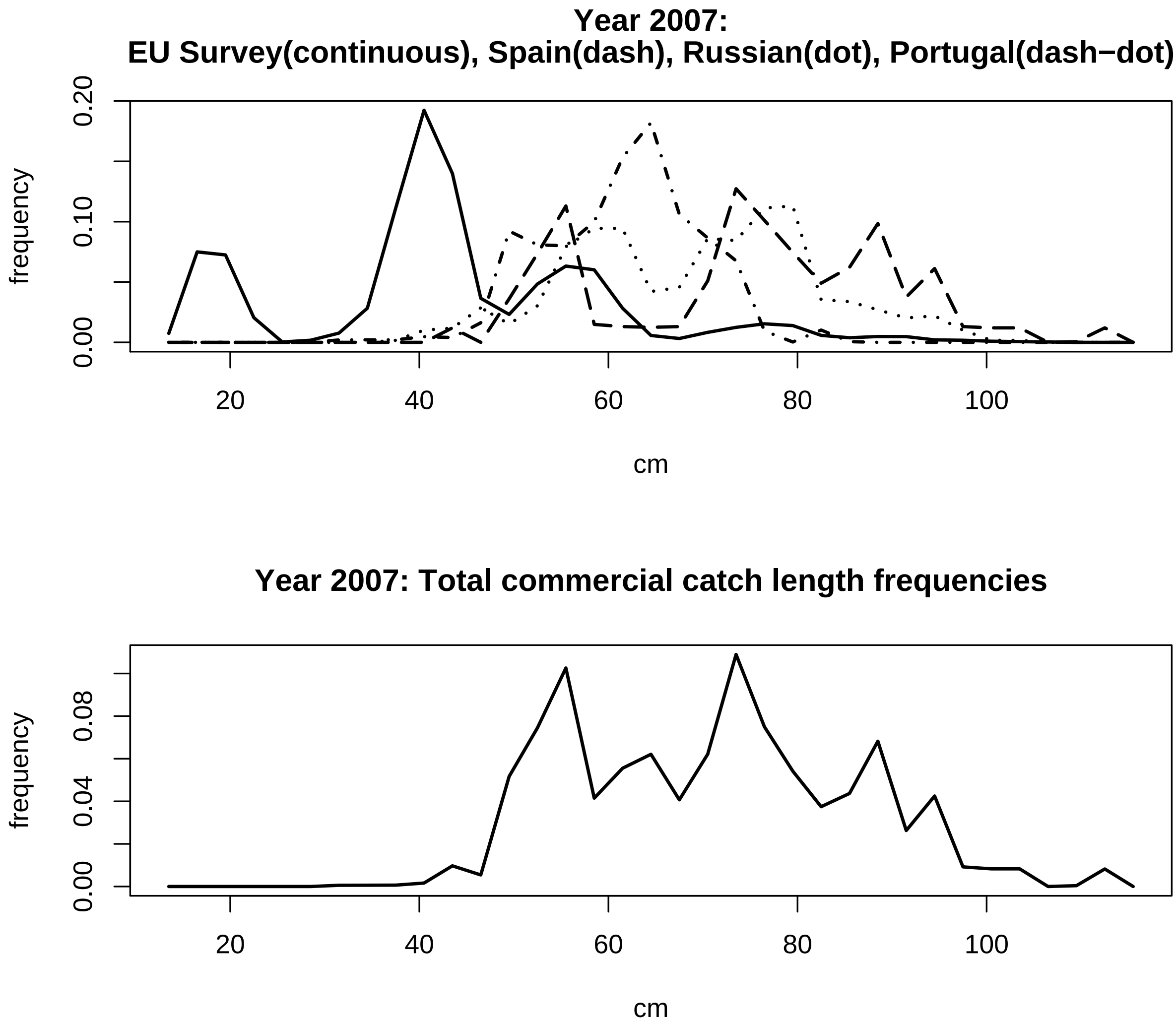

Figure 2: Length frequencies in 2007

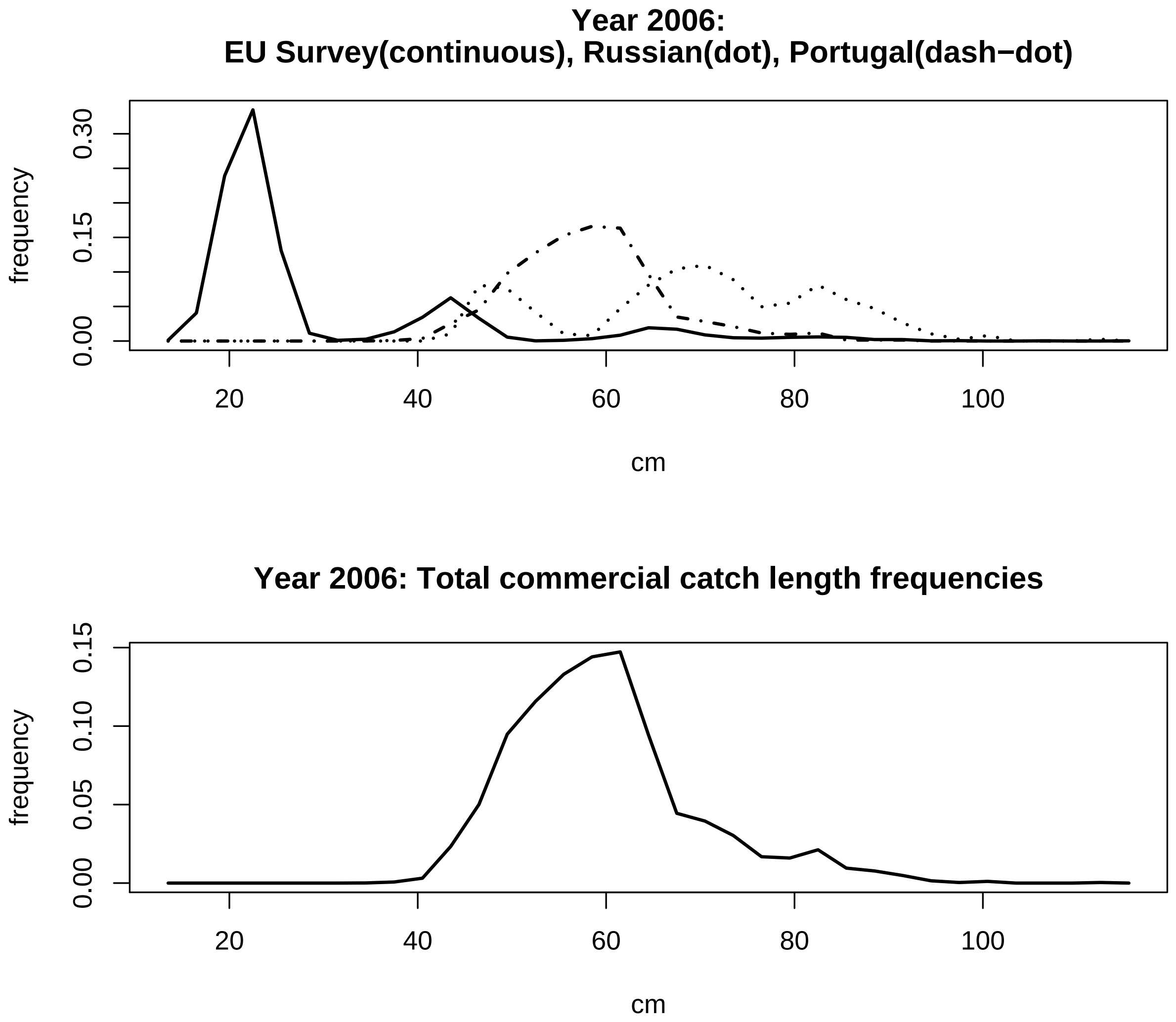

Figure 3: Length frequencies in 2006

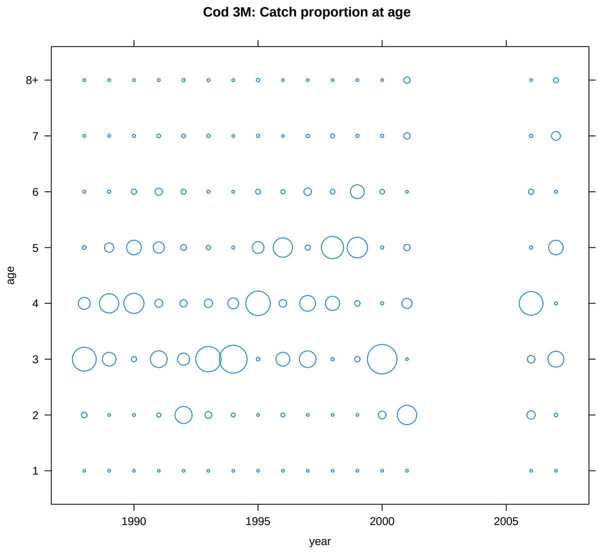

Figure 4: Commercial catch proportions at age

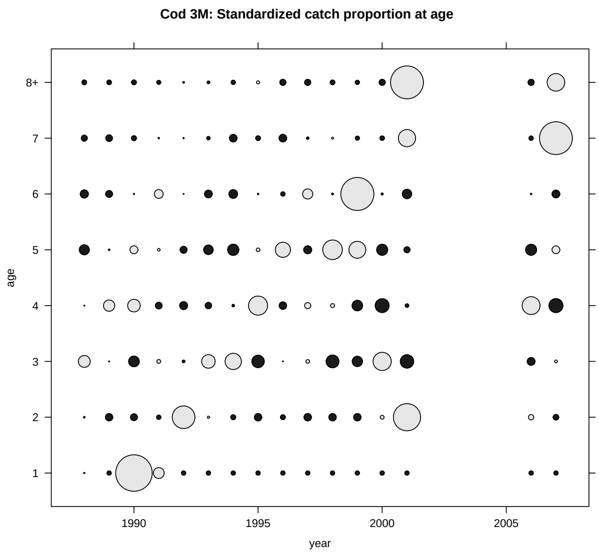

Figure 5: Commercial catch standardised proportions at age

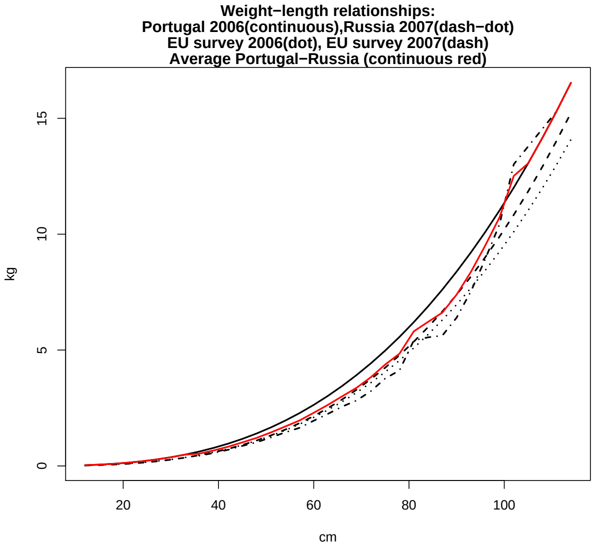

Figure 6: Weight-length relationships

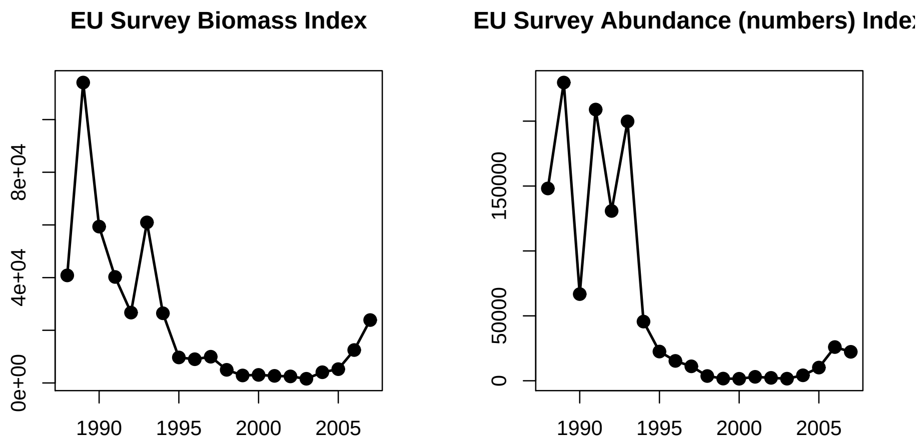

Figure 7: Indices from EU survey

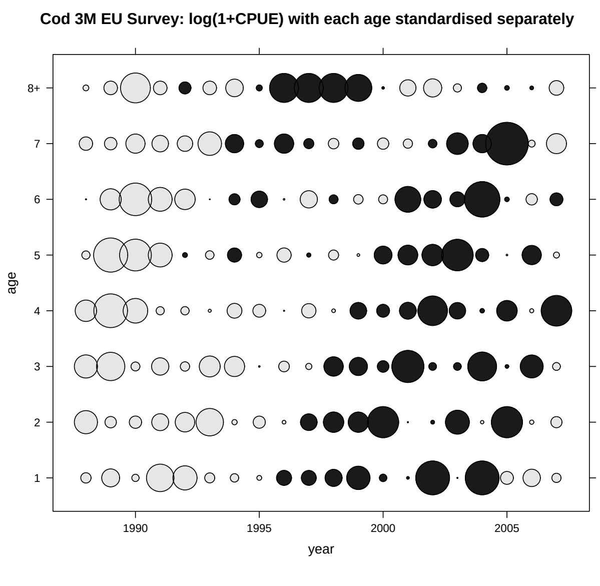

Figure 8: Standardised log(abundance at age) indices from EU survey

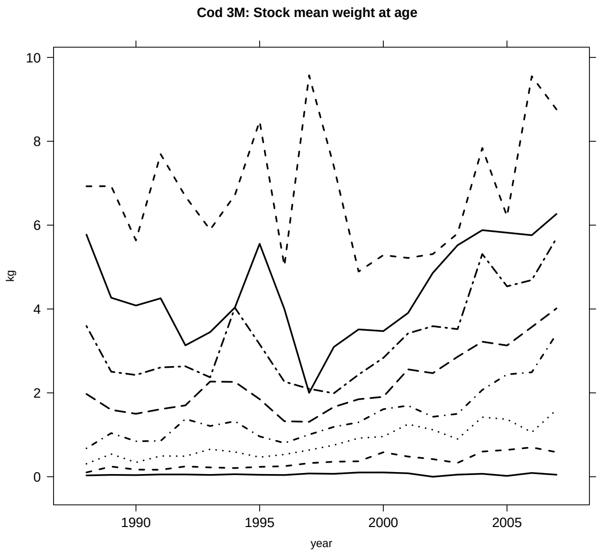

Figure 9: Stock mean weight at age

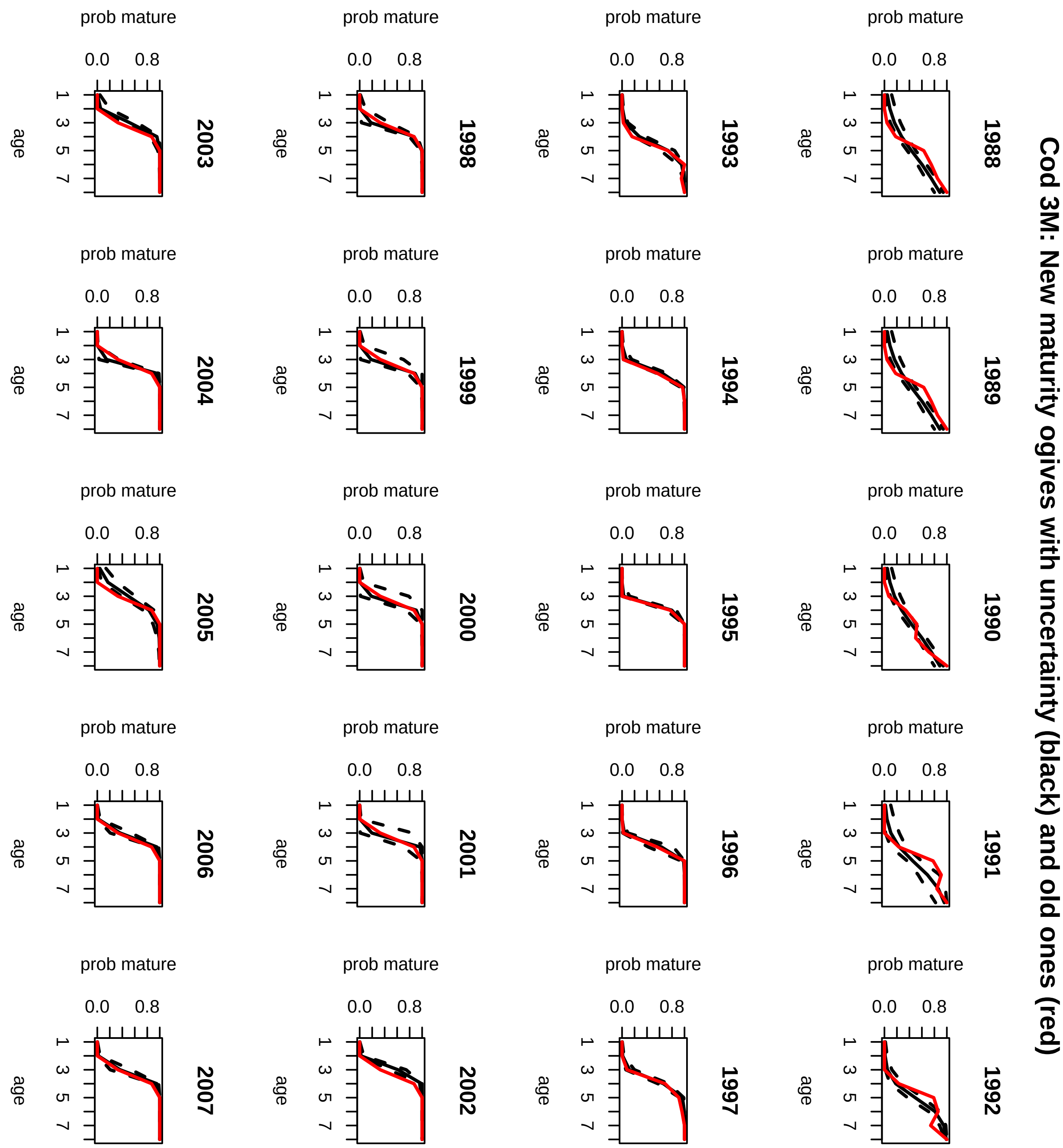

Figure 10: Maturity ogives

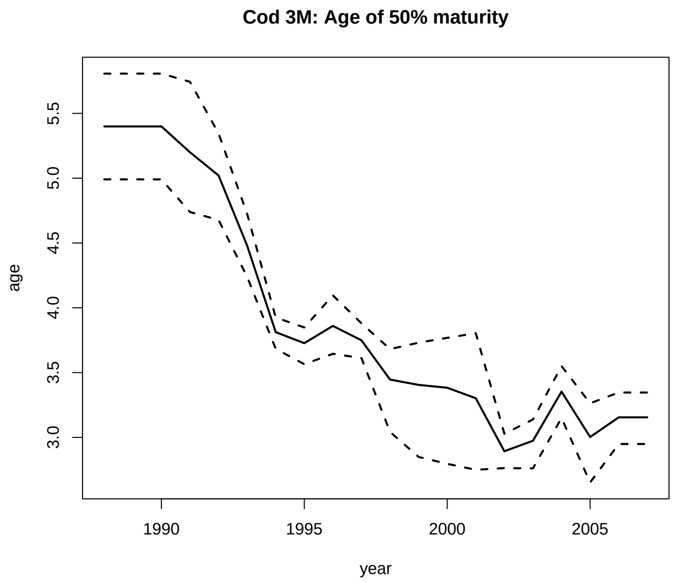

Figure 11: Age at which 50% of fish are mature

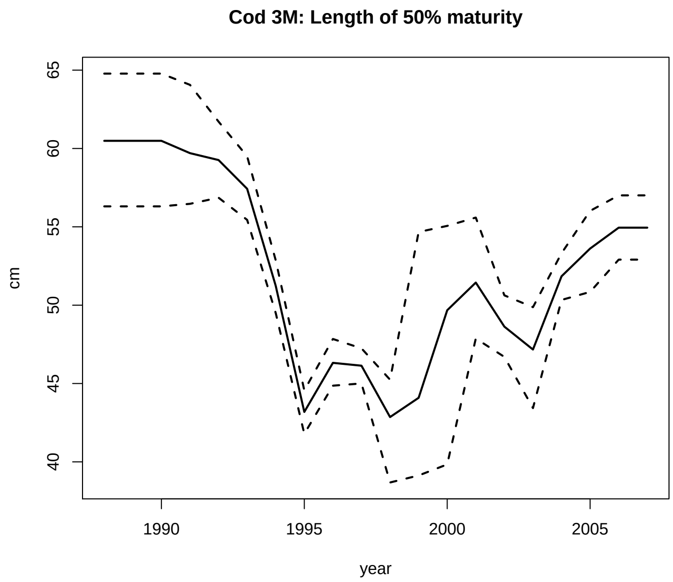

Figure 12: Length at which 50% of fish are mature

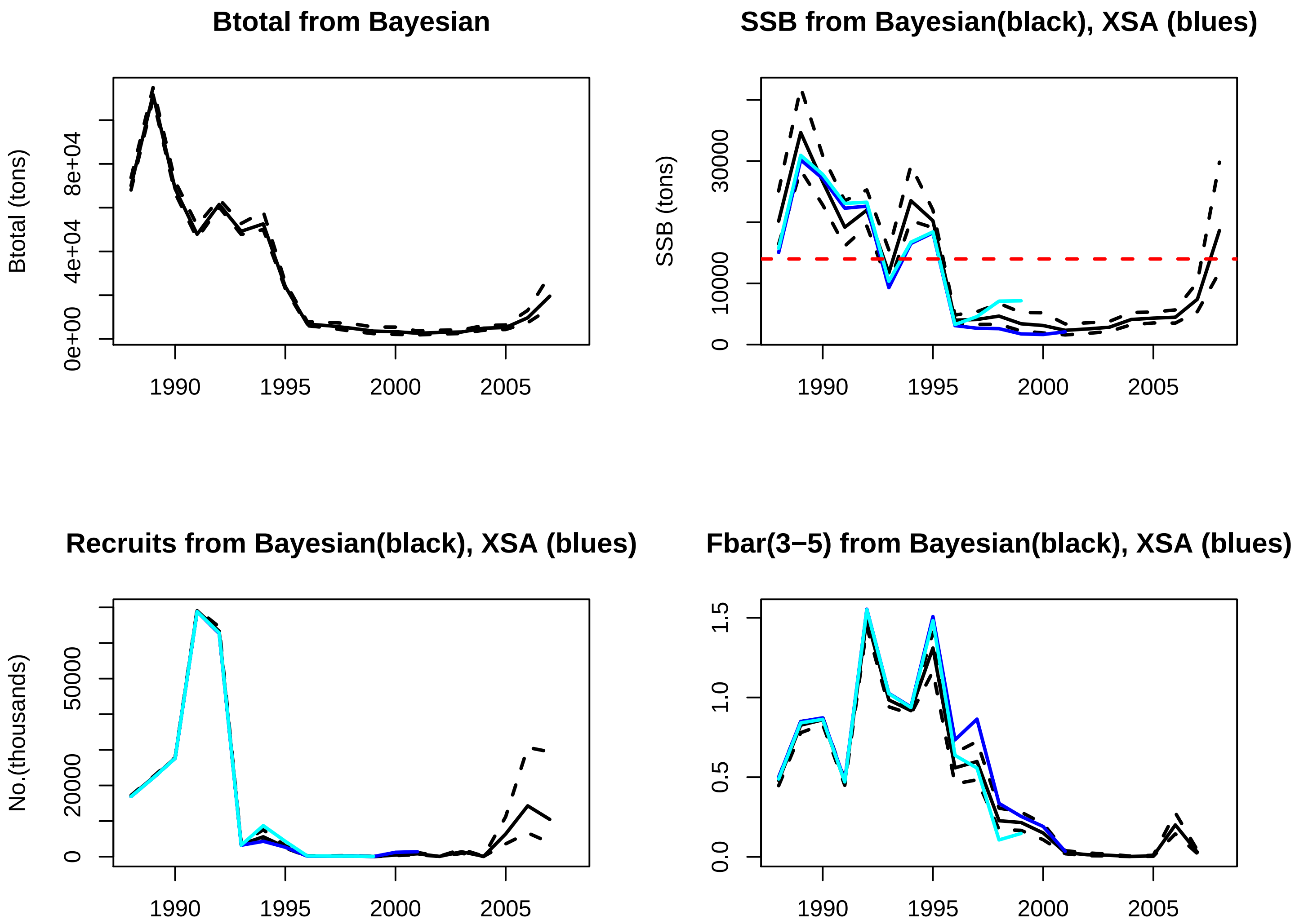

Figure 13: Run 1: Estimated trends in SSB, recruitment and Fbar

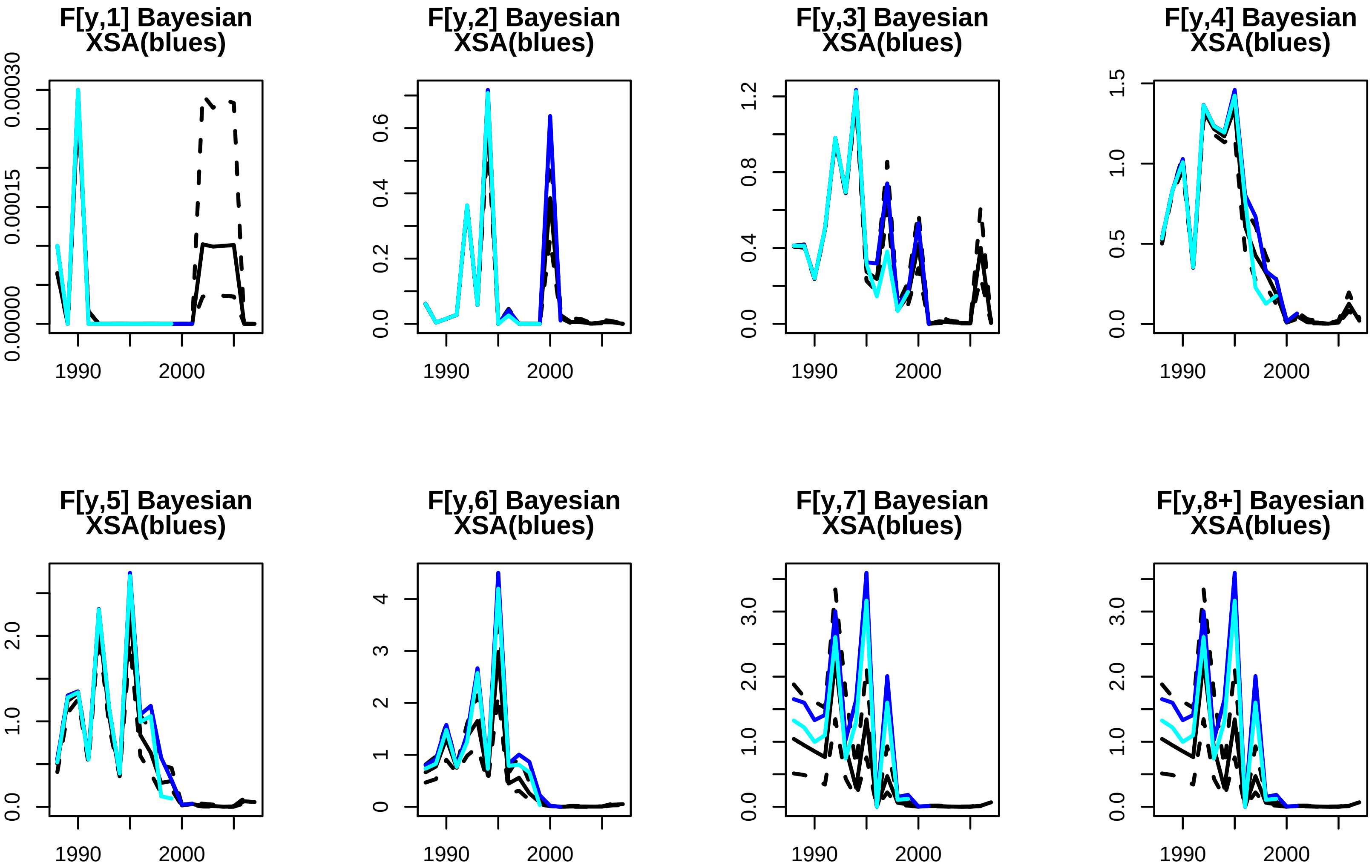

Figure 14: Run 1: Estimated fishing mortality at age

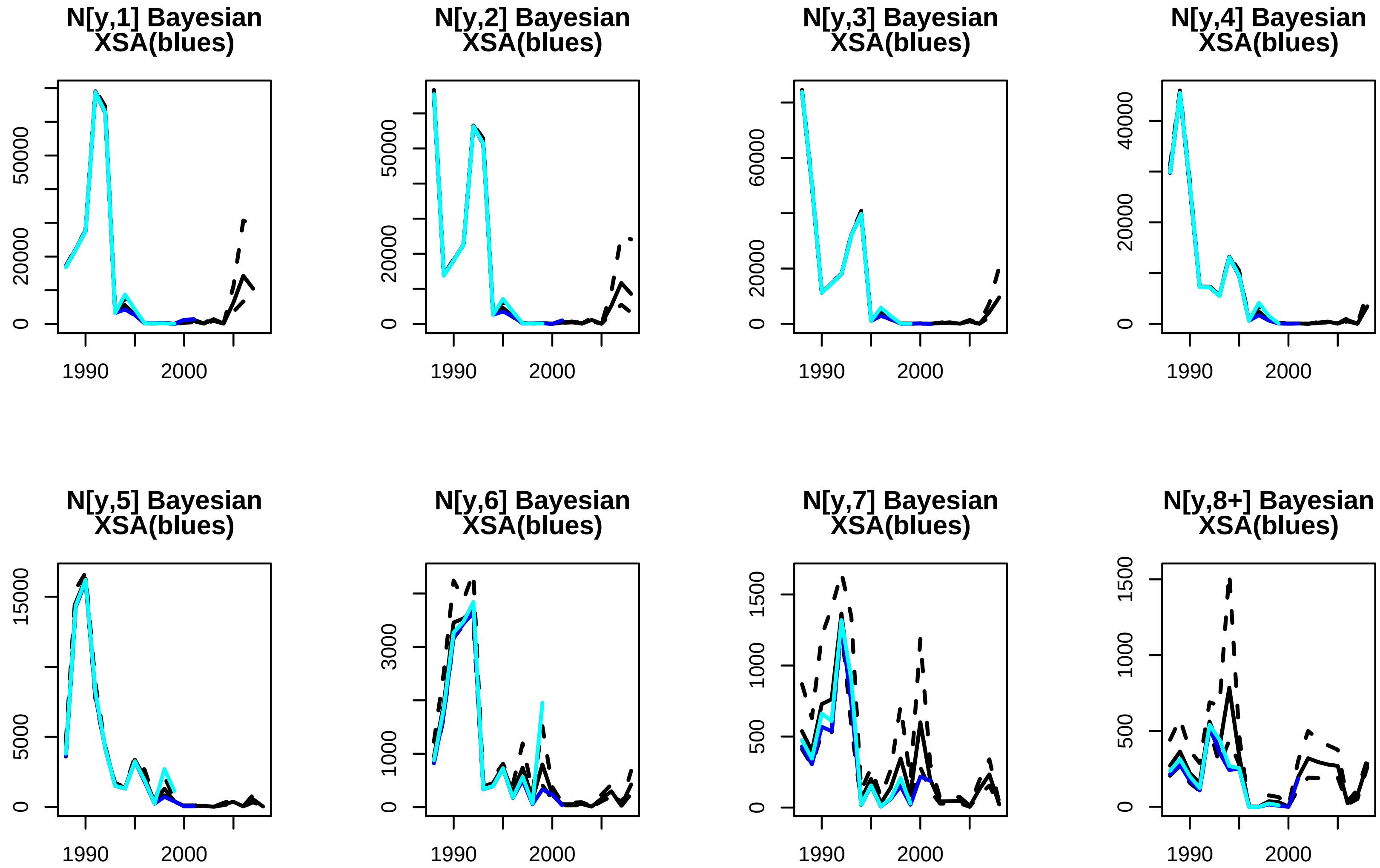

Figure 15: Run 1: Estimated numbers at age

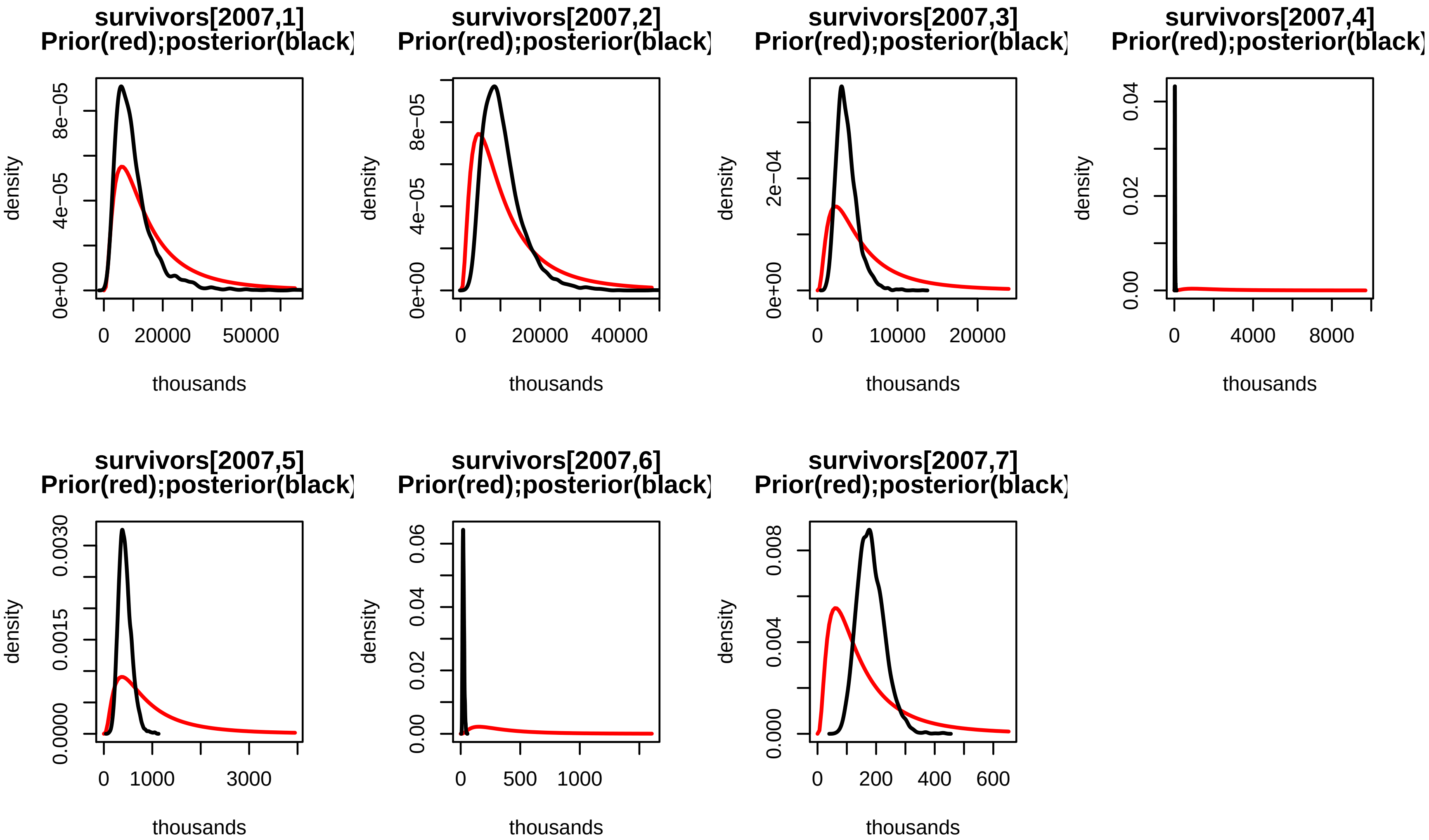

Figure 16: Run 1: Survivors at age at the end of 2007 ($survivors(2007, a)$) are individuals of age $a + 1$ at the beginning of 2008)

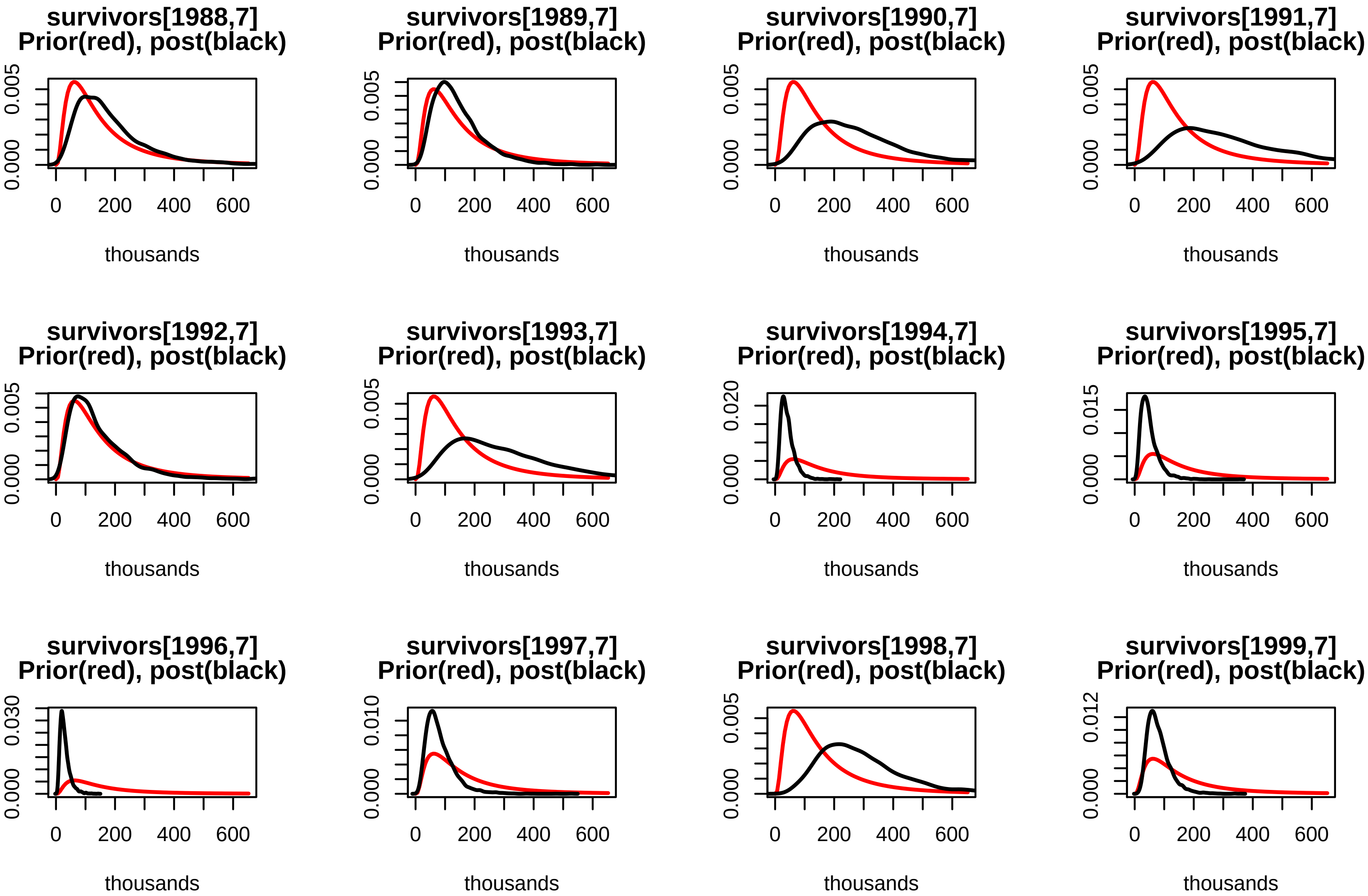

Figure 17: Run 1: Survivors from age 7 in each year ($survivors(y, 7)$) are individuals of age 8 at the beginning of year $y + 1$.

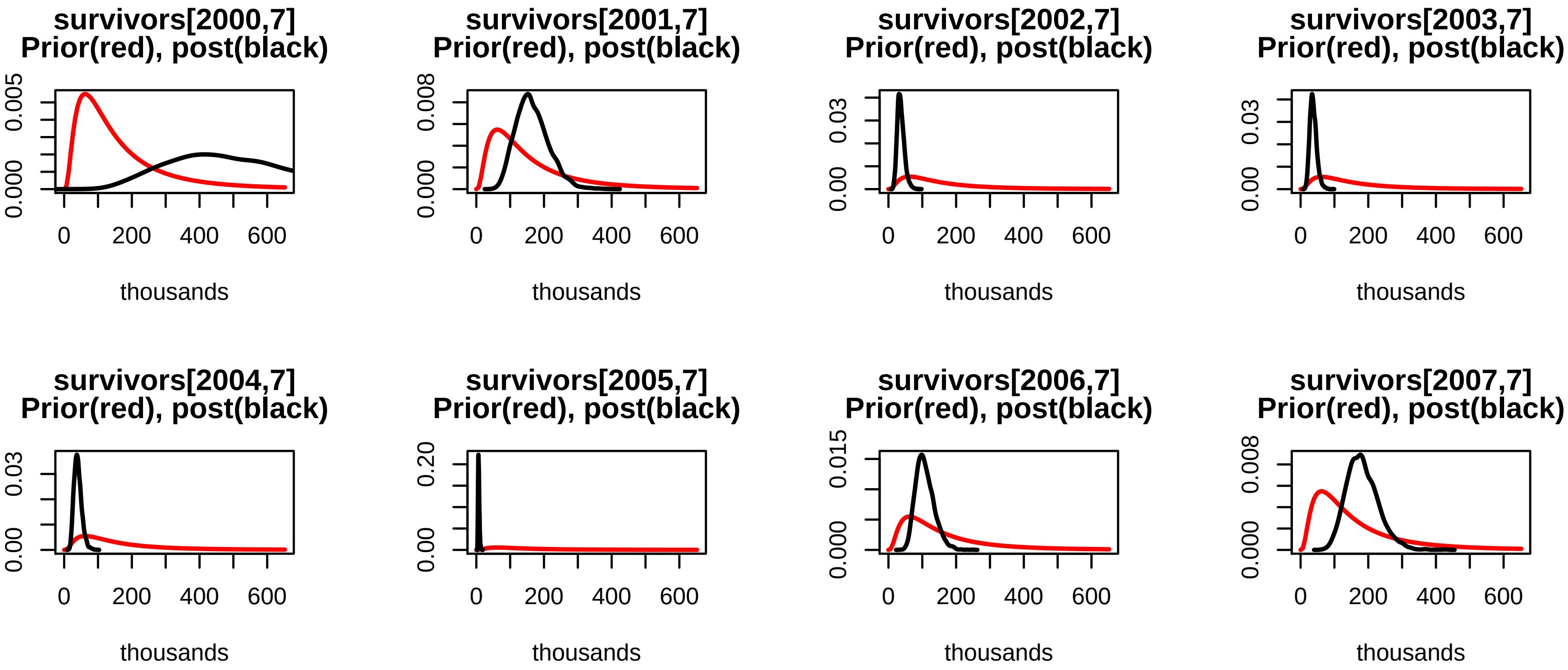

Figure 18: Run 1: Survivors from age 7 in each year ($survivors(y, 7)$) are individuals of age 8 at the beginning of year $y + 1$.

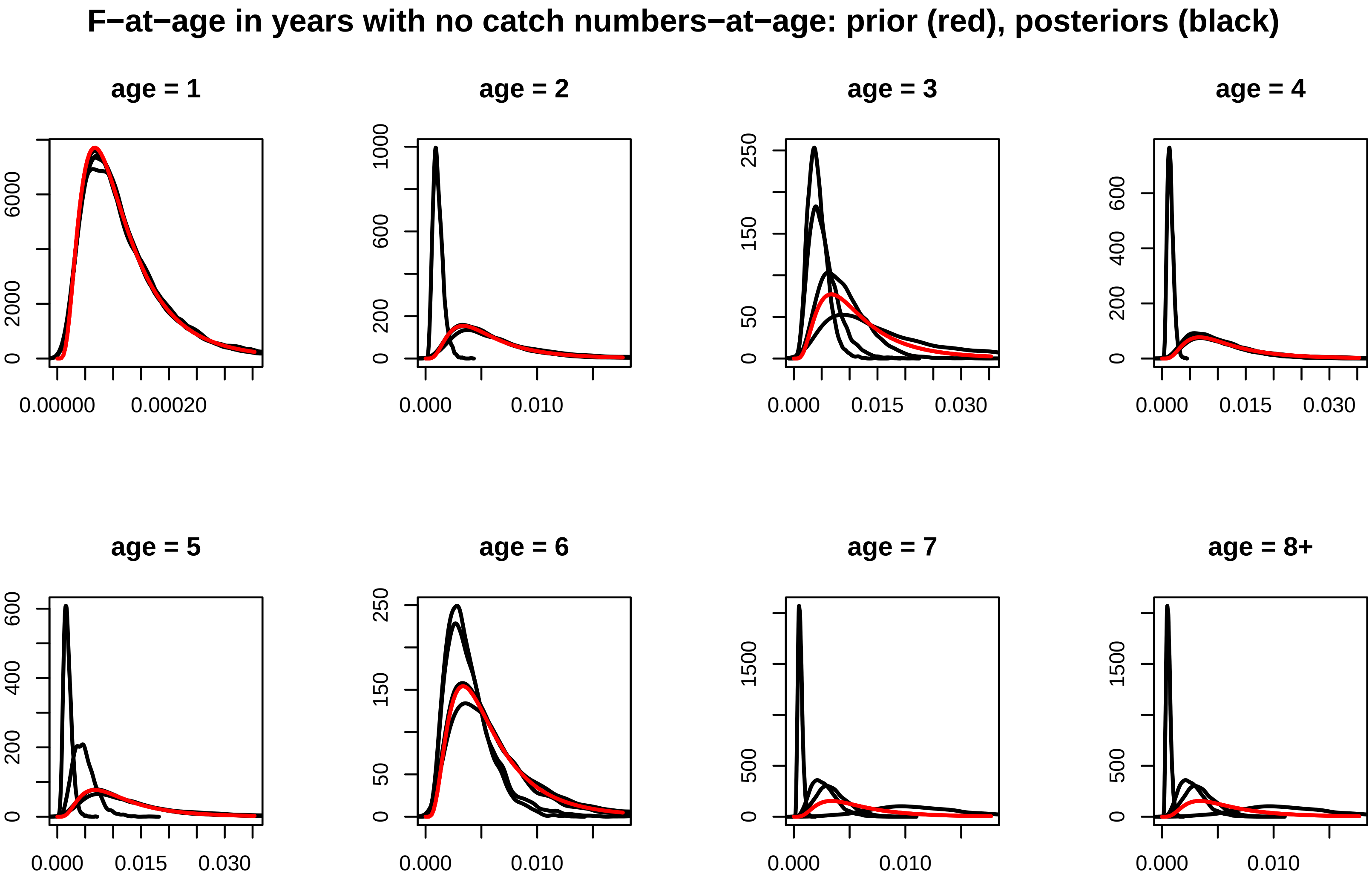

Figure 19: Run 1: F-at-age in years without catch numbers-at-age.

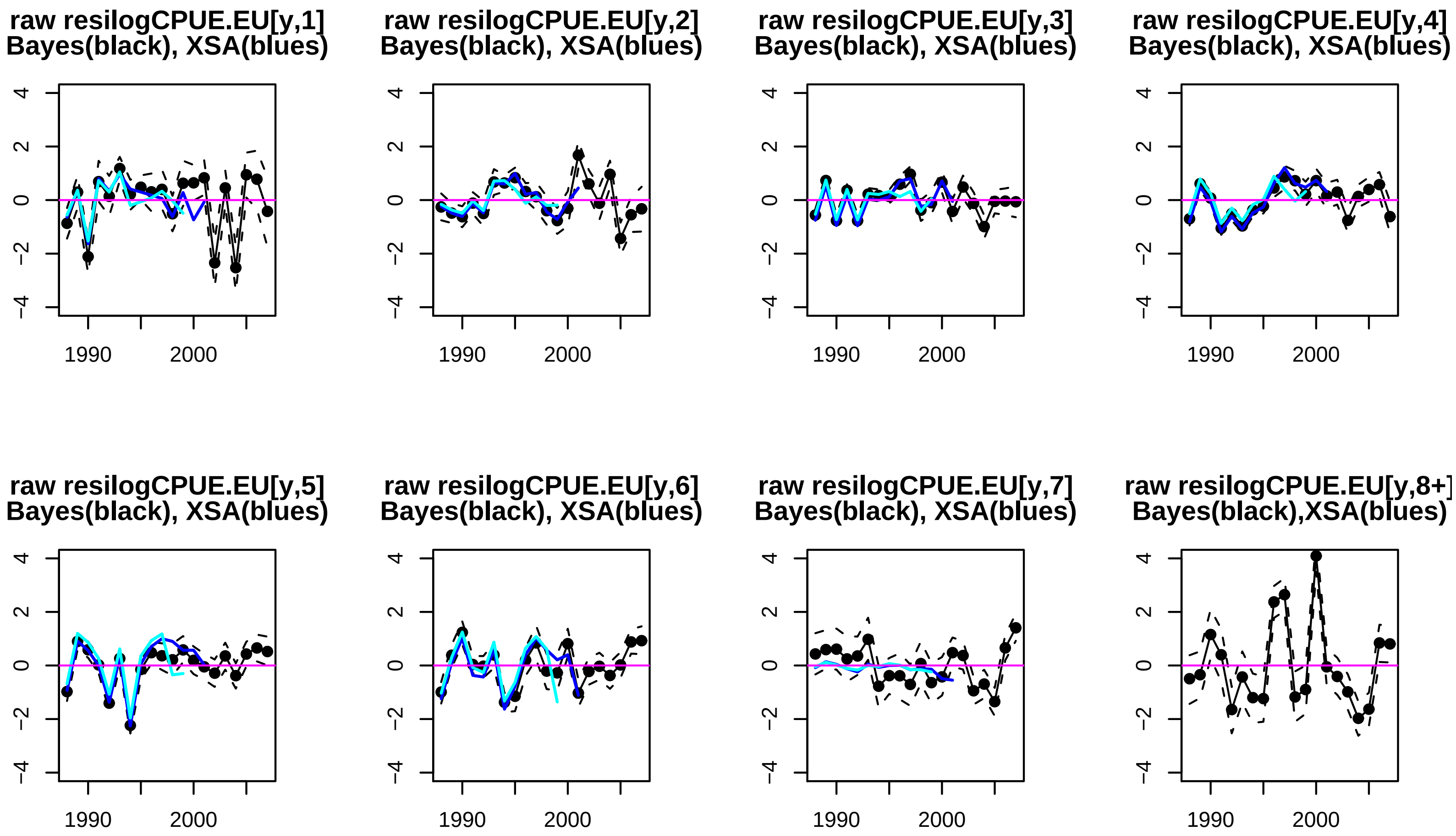

Figure 20: Run 1: Raw residuals (observed minus fitted value) in logarithmic scale of EU survey abundance indices at age. Each panel corresponds to one age. Bayesian residuals (in black) are given as posterior medians (continuous line) and limits of 90% posterior credible interval (dashed lines)

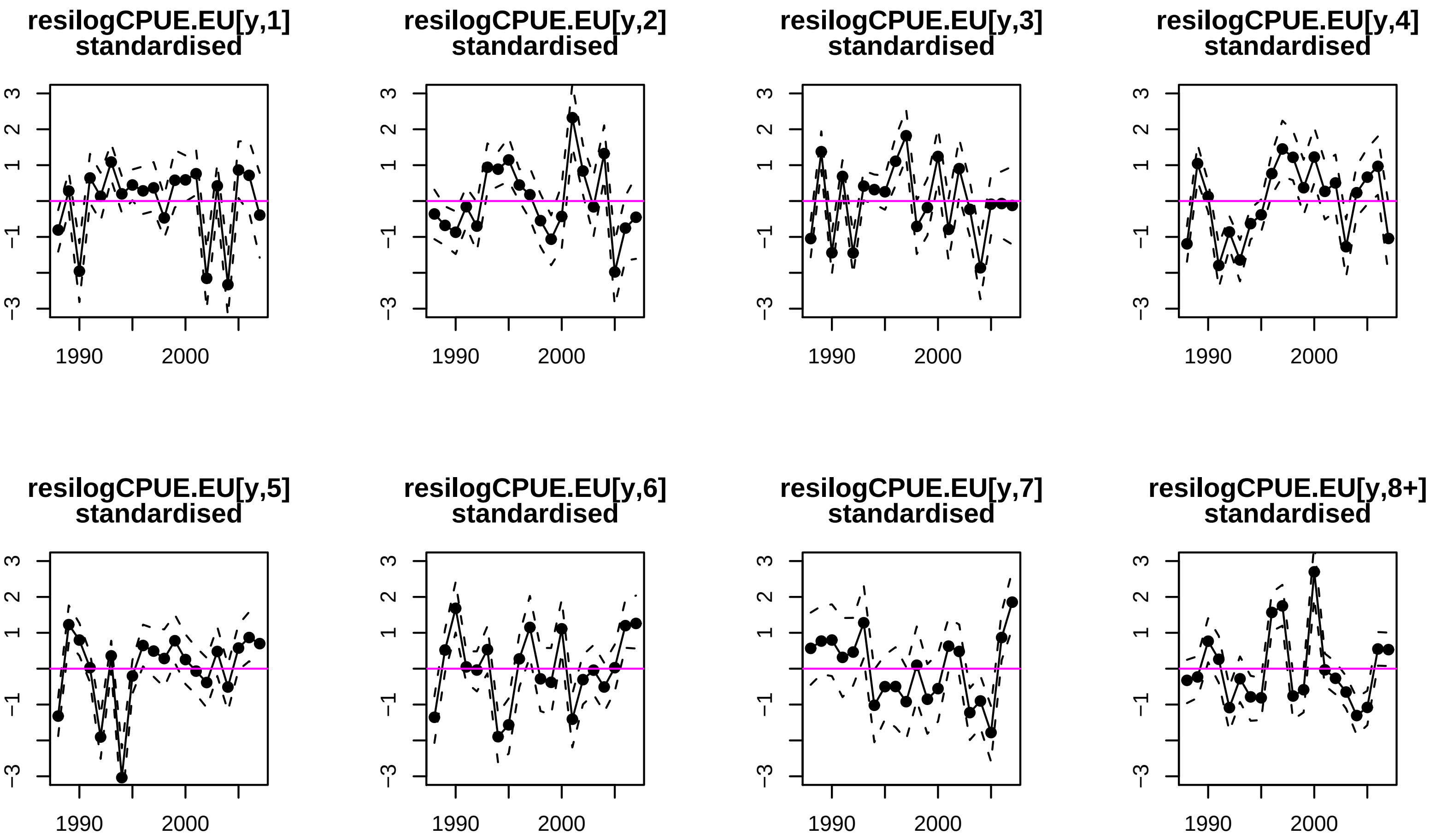

Figure 21: Run 1: Standardised residuals (observed minus fitted value divided by estimated standard deviation) in logarithmic scale of EU survey abundance indices at age. Each panel corresponds to one age. Bayesian residuals (in black) are given as posterior medians (continuous line) and limits of 90% posterior credible interval (dashed lines)

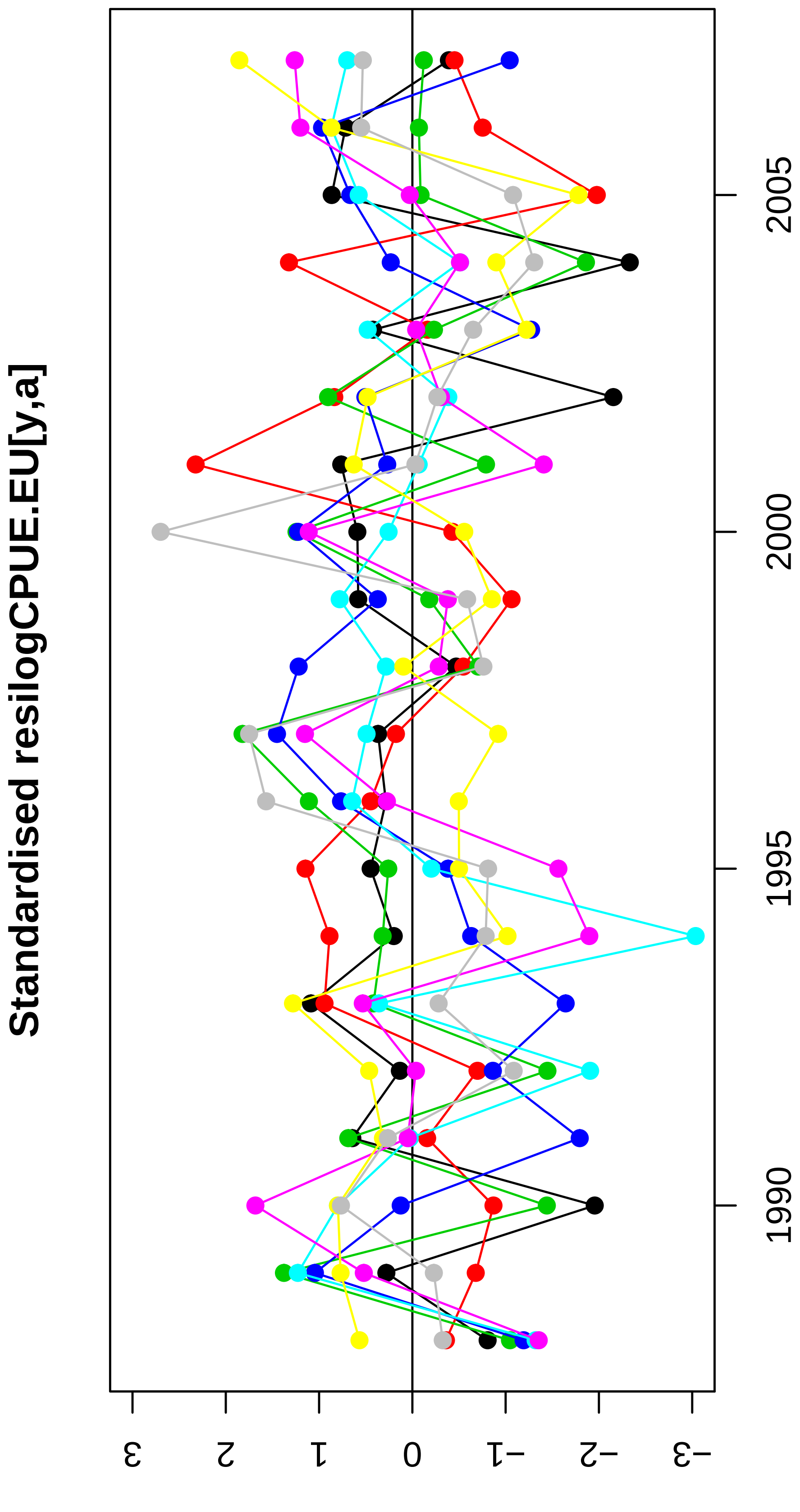

Figure 22: Run 1: Standardised residuals (observed minus fitted value divided by estimated standard deviation) in logarithmic scale of EU survey abundance indices at age. Each colour corresponds to one age. The residuals shown correspond to posterior medians from the Bayesian model

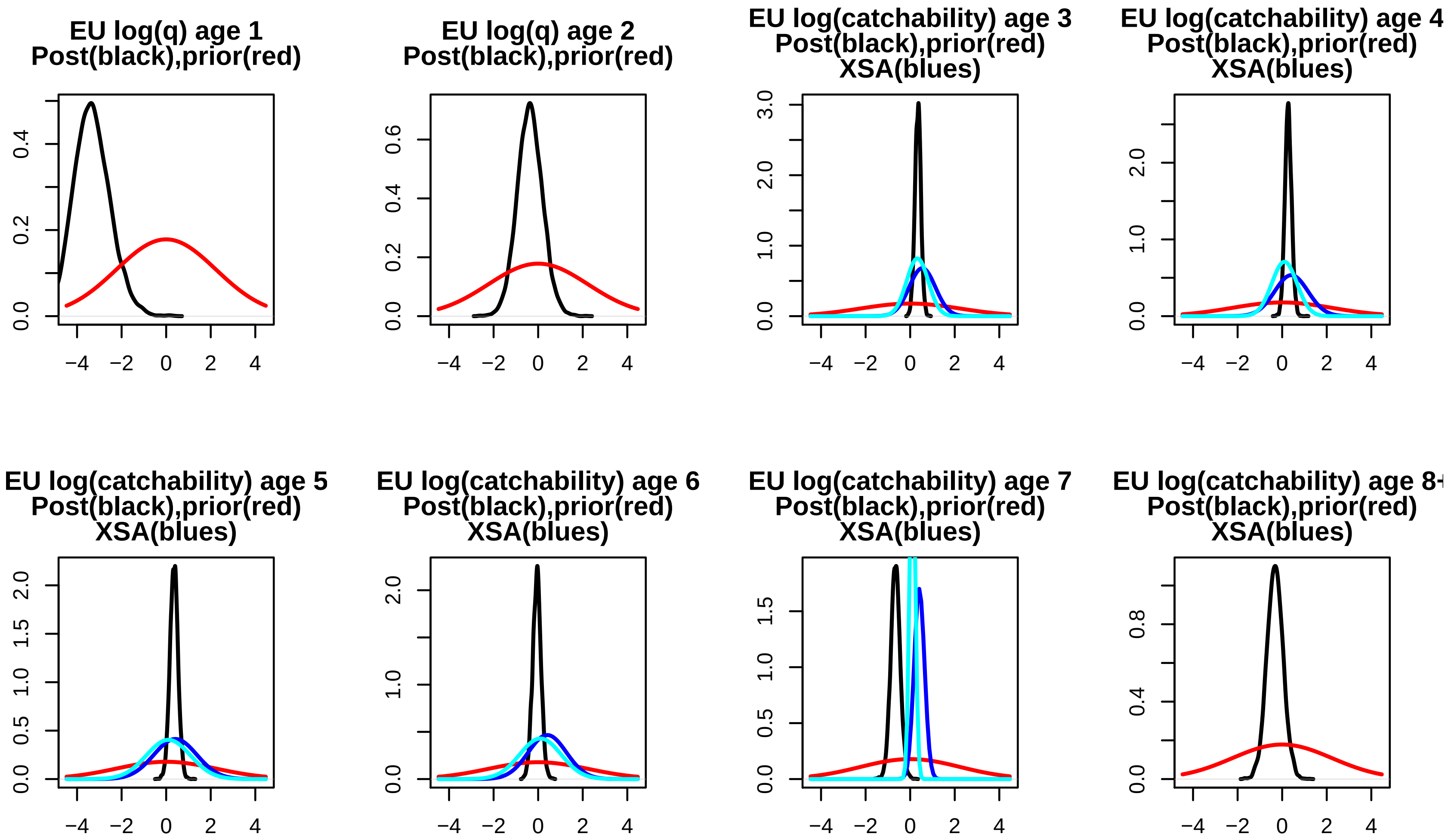

Figure 23: Run 1: Results for $\log(q(a))$ of EU abundance at age indices.

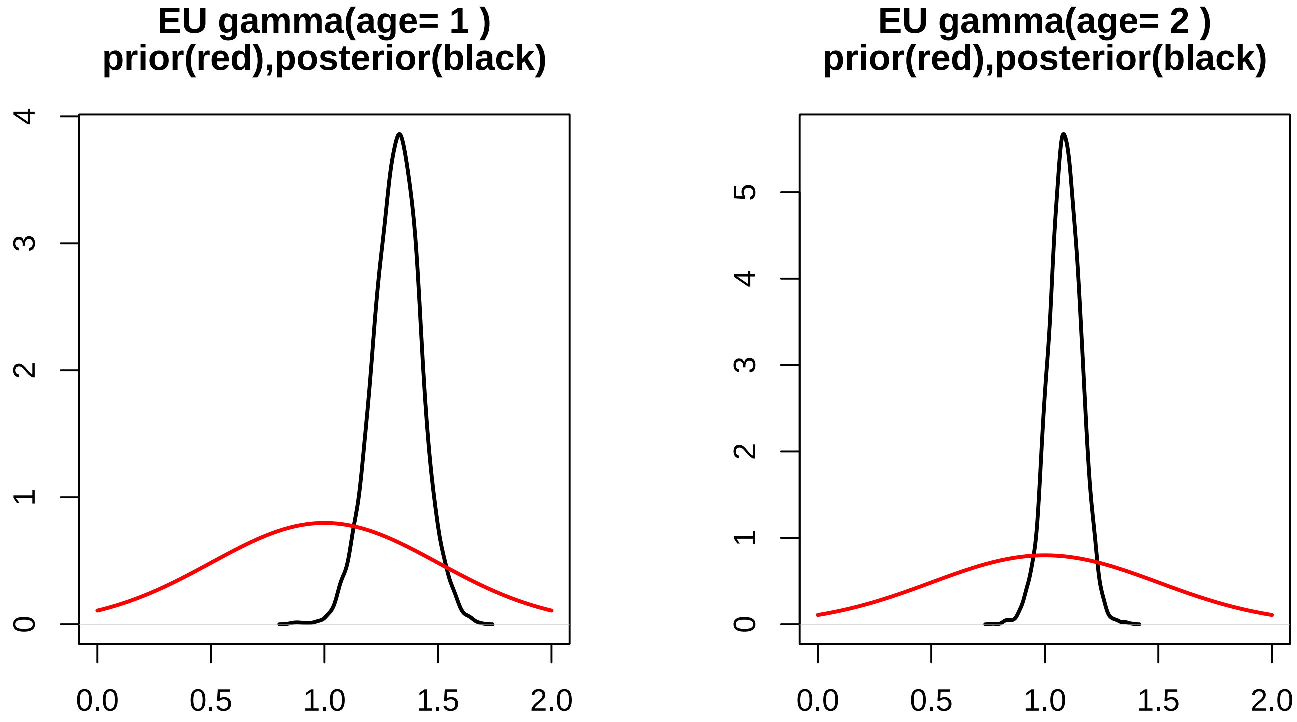

Figure 24: Run 1: Results for $\gamma(a)$ of EU abundance at age indices.

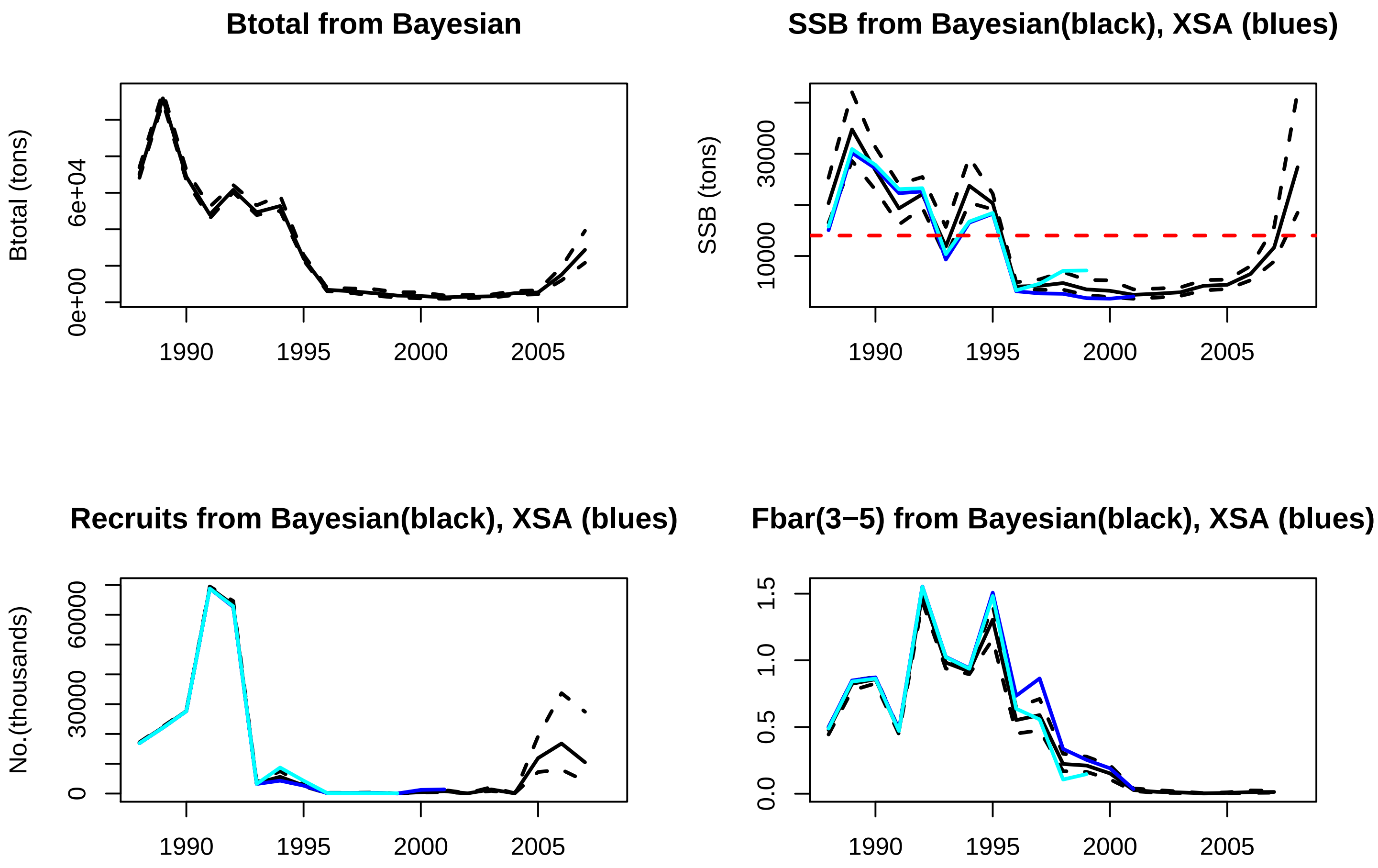

Figure 25: Run 2: Estimated trends in SSB, recruitment and Fbar.

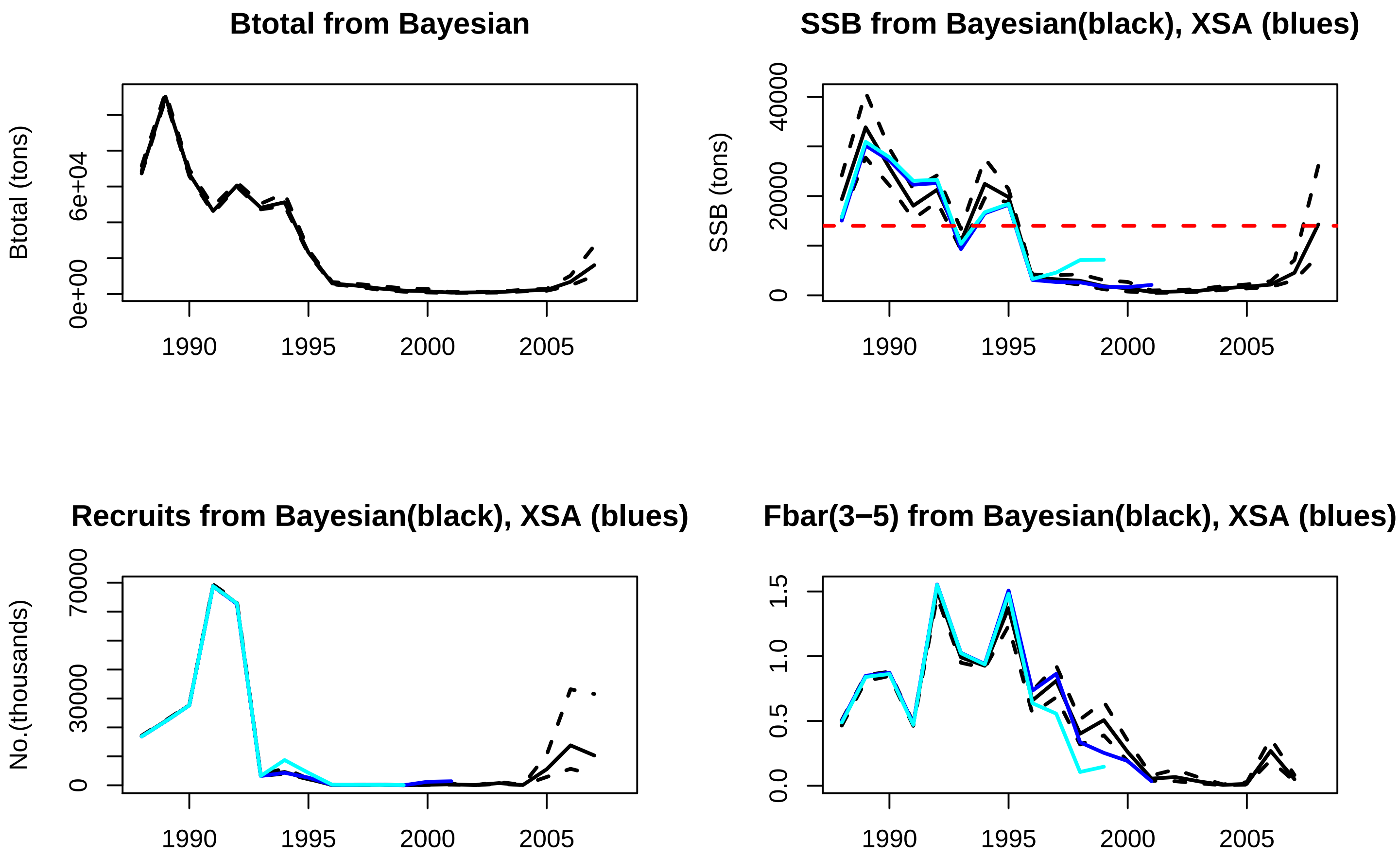

Figure 26: Run 3: Estimated trends in SSB, recruitment and Fbar.

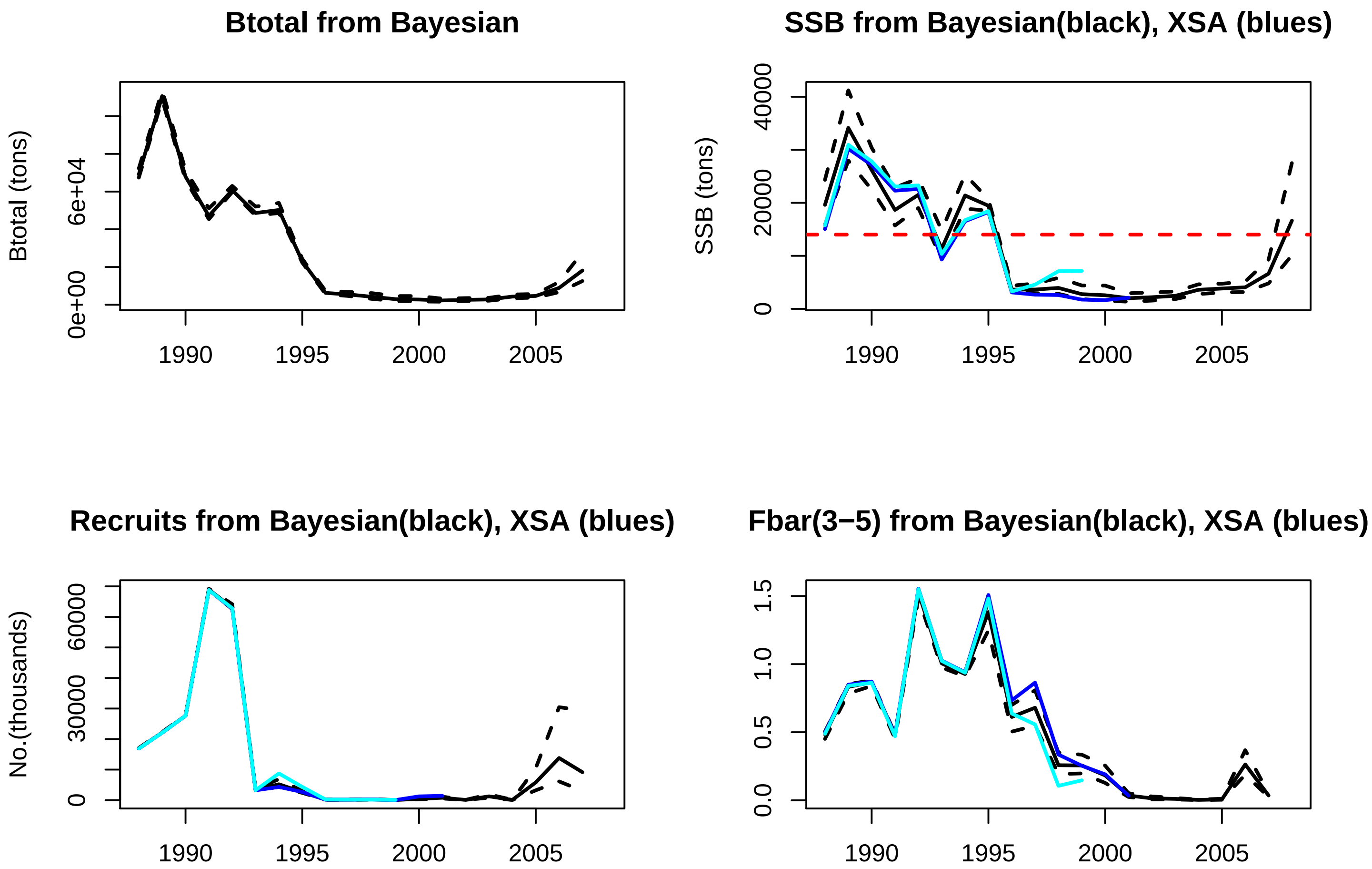

Figure 27: Run 4: Estimated trends in SSB, recruitment and Fbar.

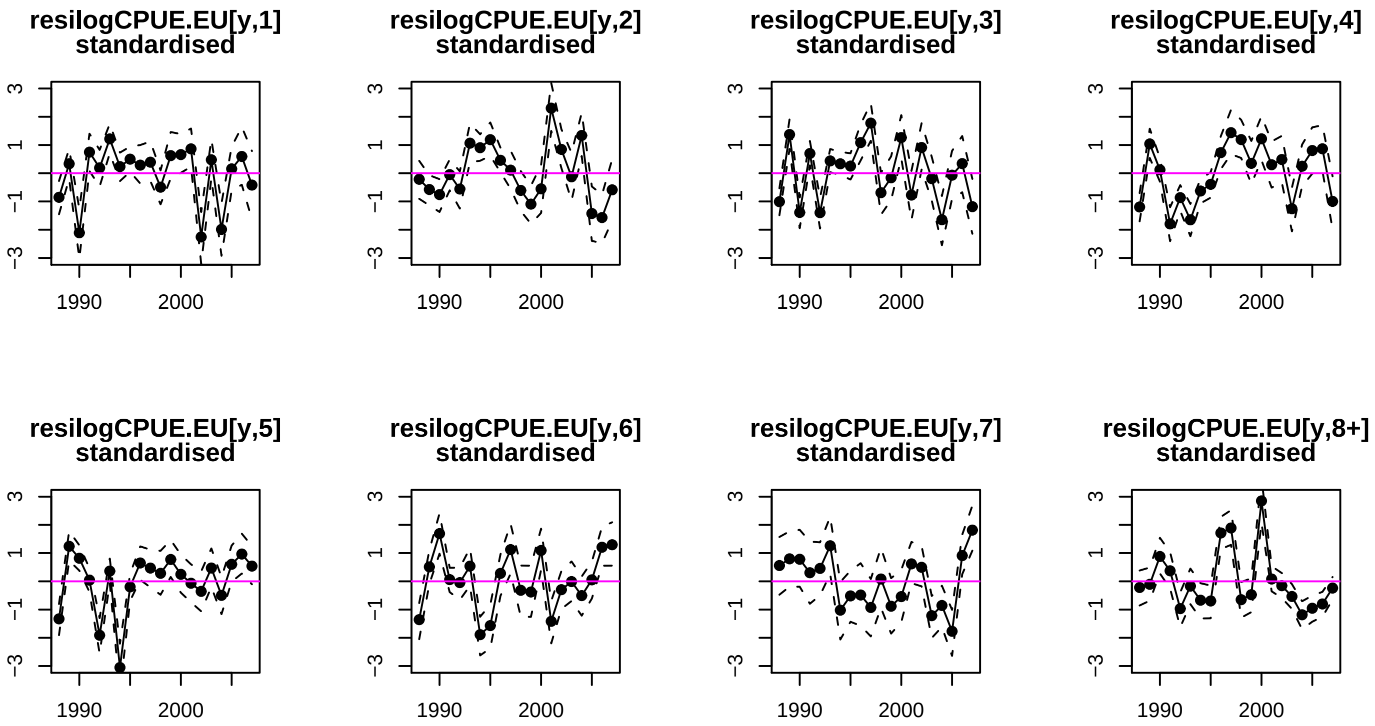

Figure 28: Run 2: Standardised survey residuals.

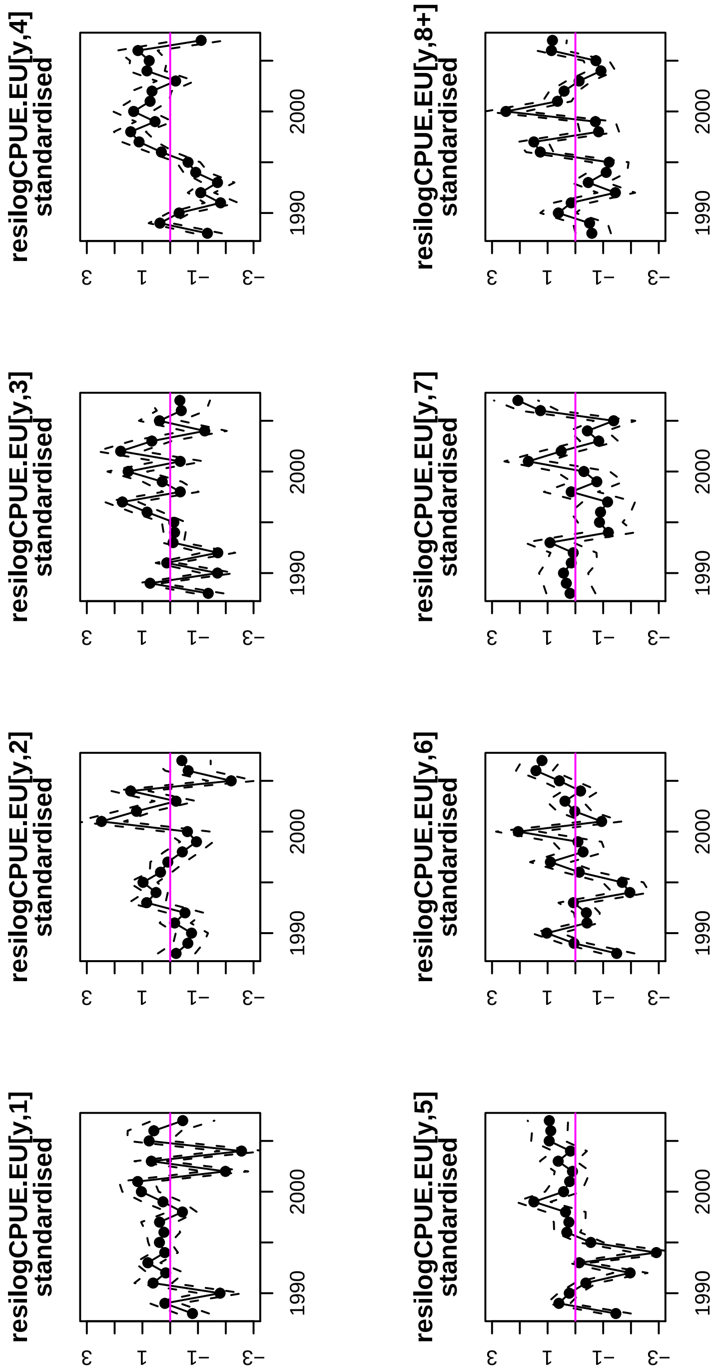

Figure 29: Run 3: Standardised survey residuals.

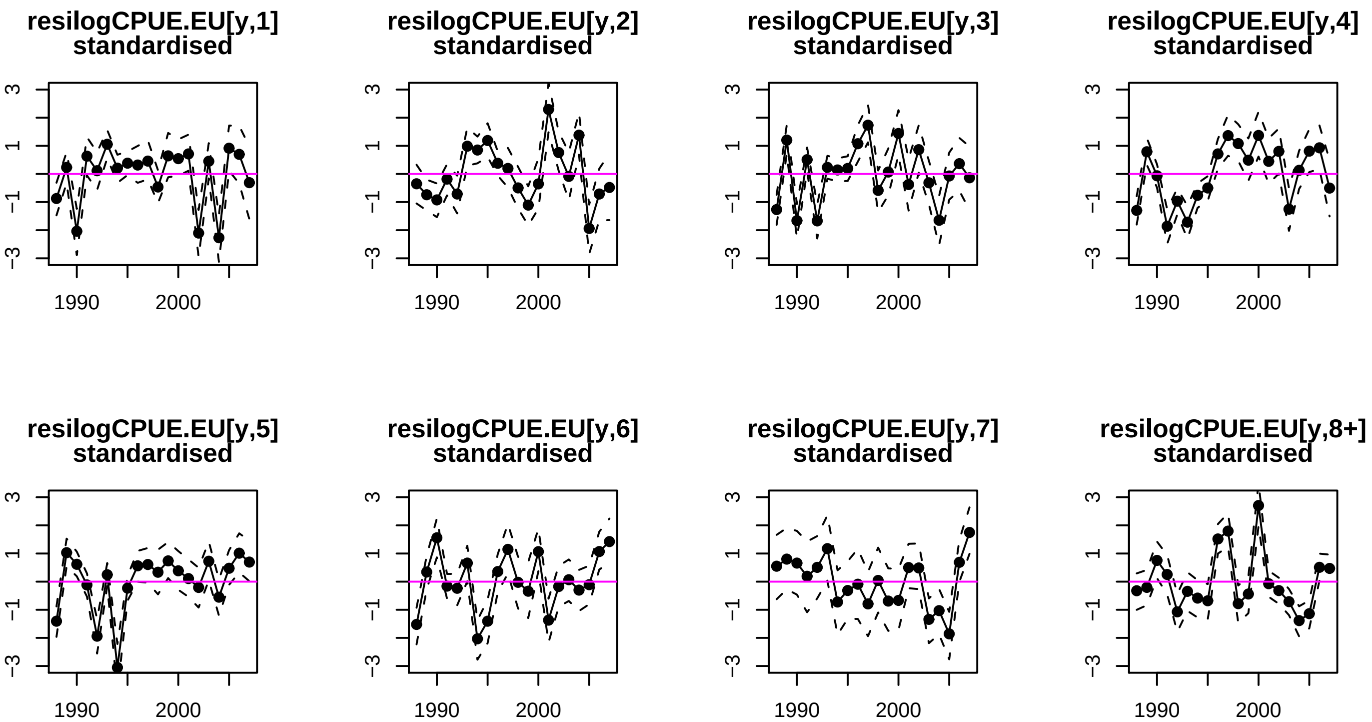

Figure 30: Run 4: Standardised survey residuals.

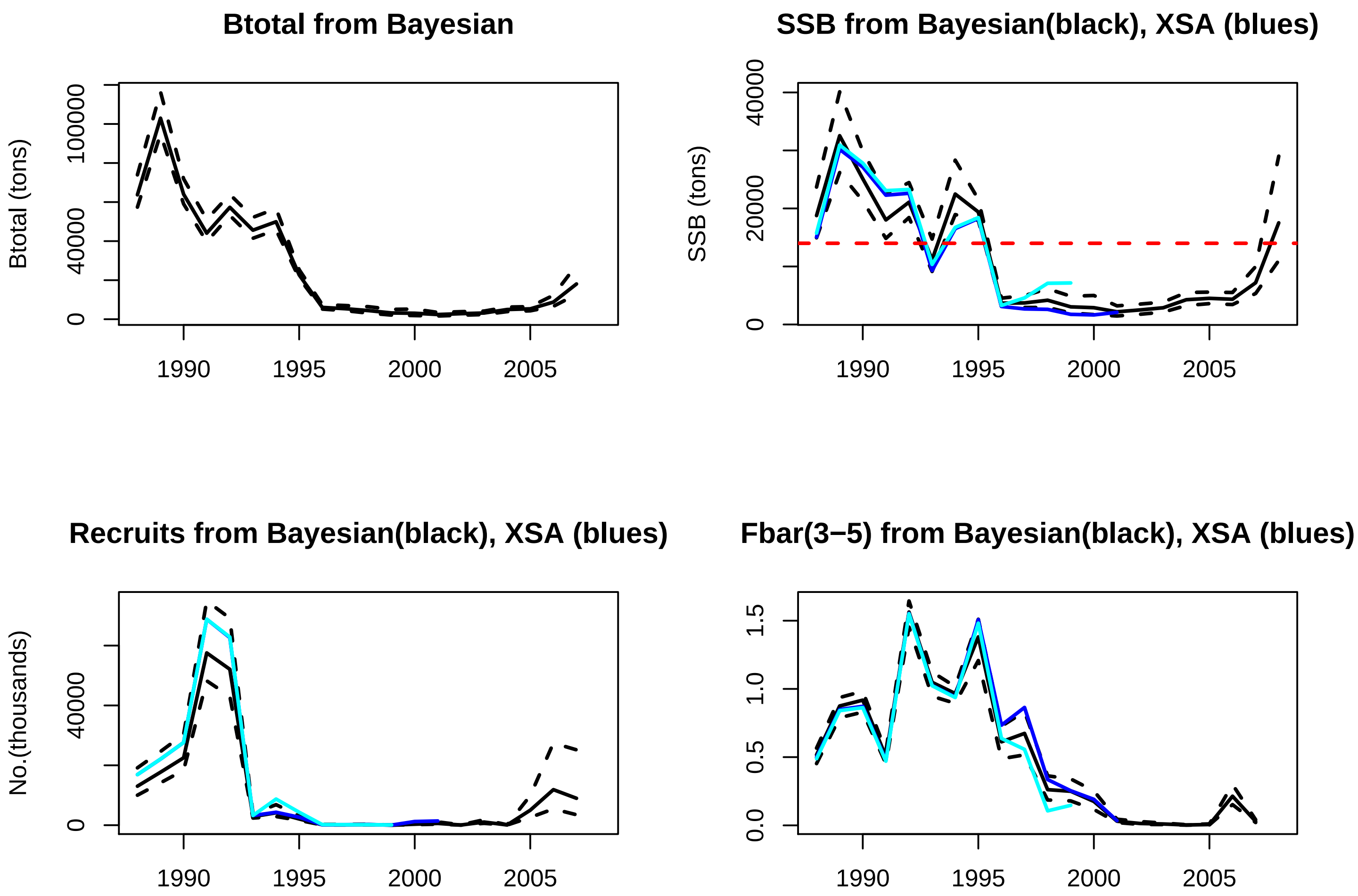

Figure 31: Run 5: Estimated trends in SSB, recruitment and Fbar

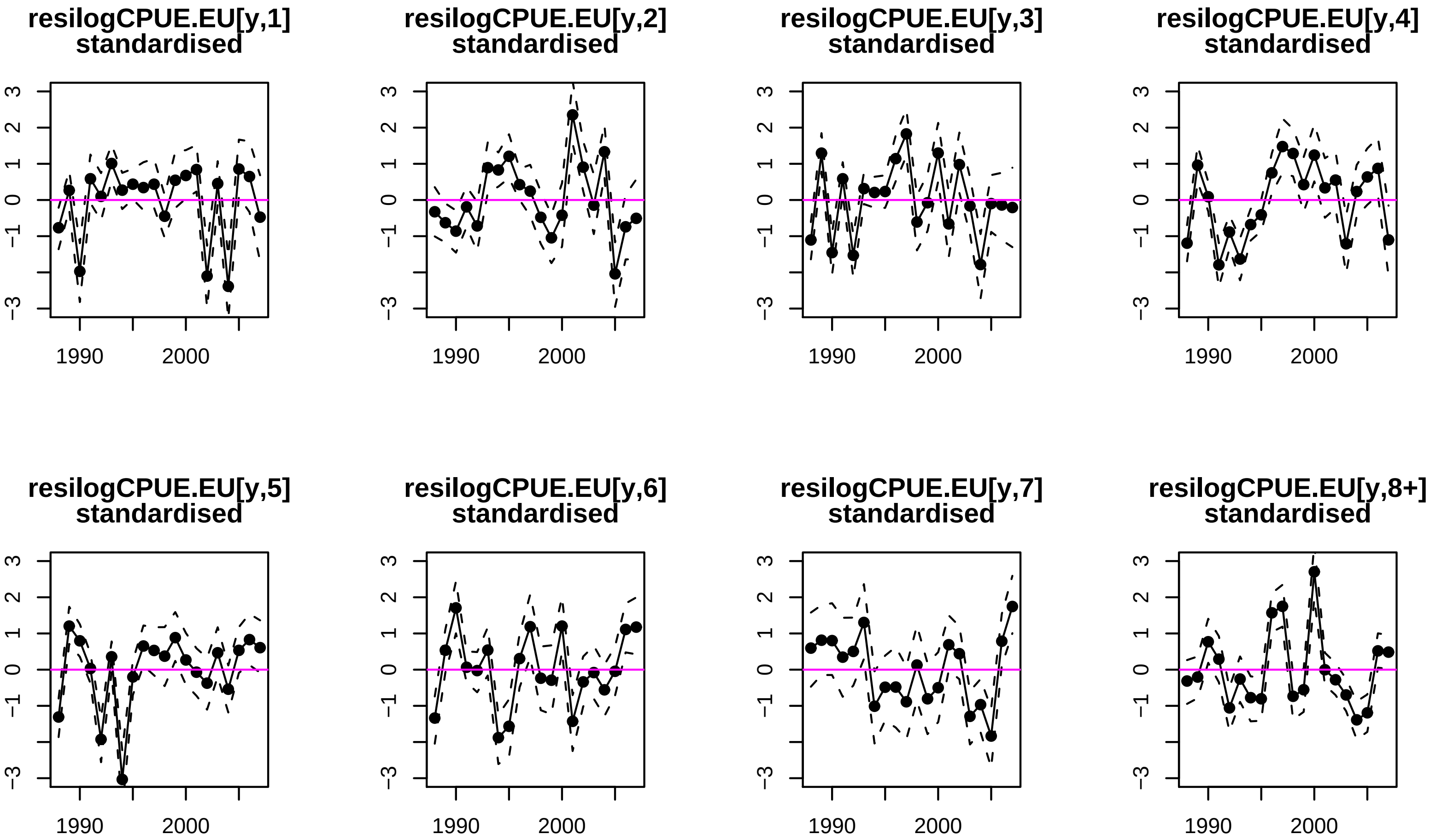

Figure 32: Run 5: Standardised residuals (observed minus fitted value divided by estimated standard deviation) in logarithmic scale of EU survey abundance indices at age. Each panel corresponds to one age. Bayesian residuals (in black) are given as posterior medians (continuous line) and limits of 90% posterior credible interval (dashed lines)

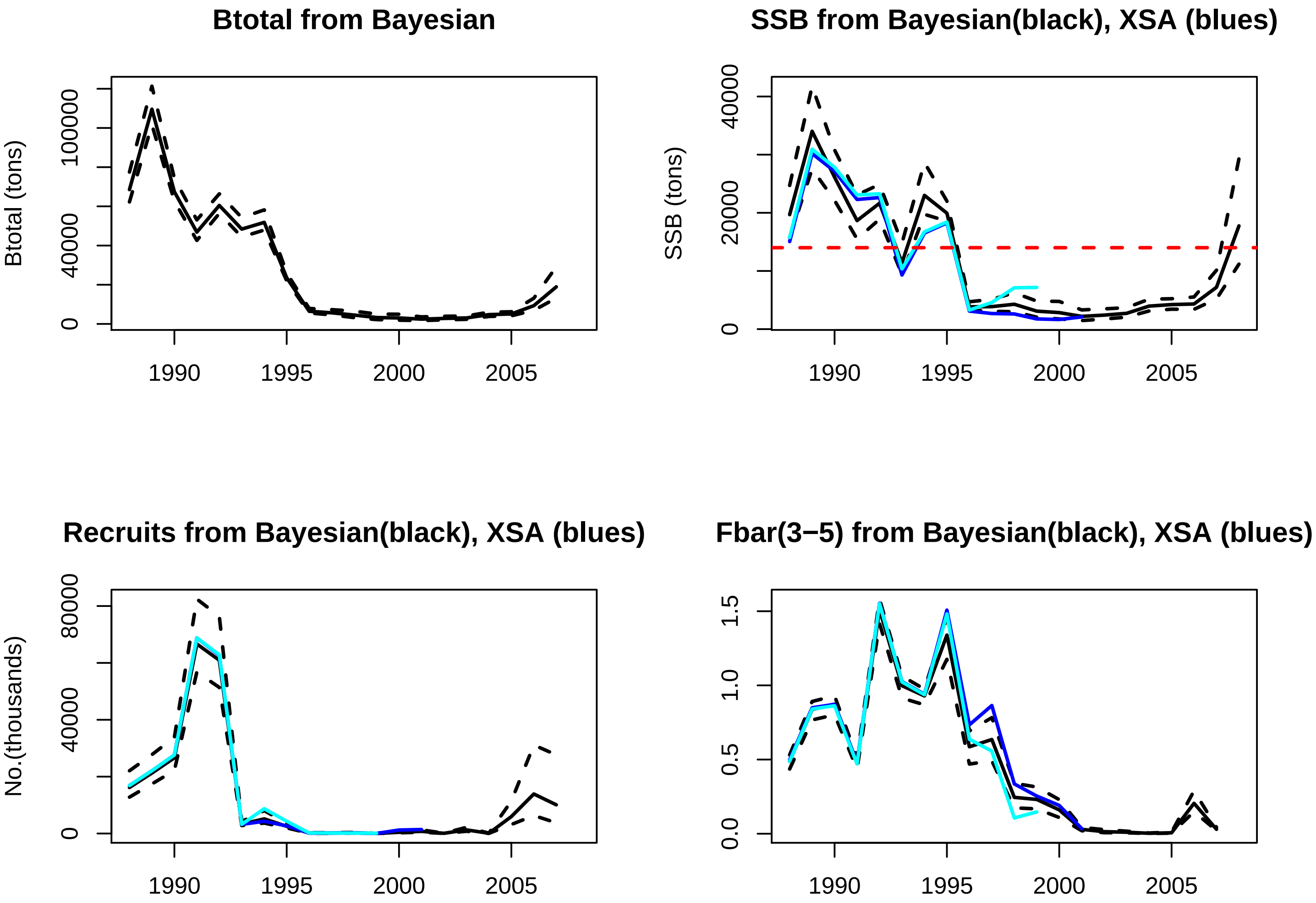

Figure 33: Run 6: Estimated trends in SSB, recruitment and Fbar

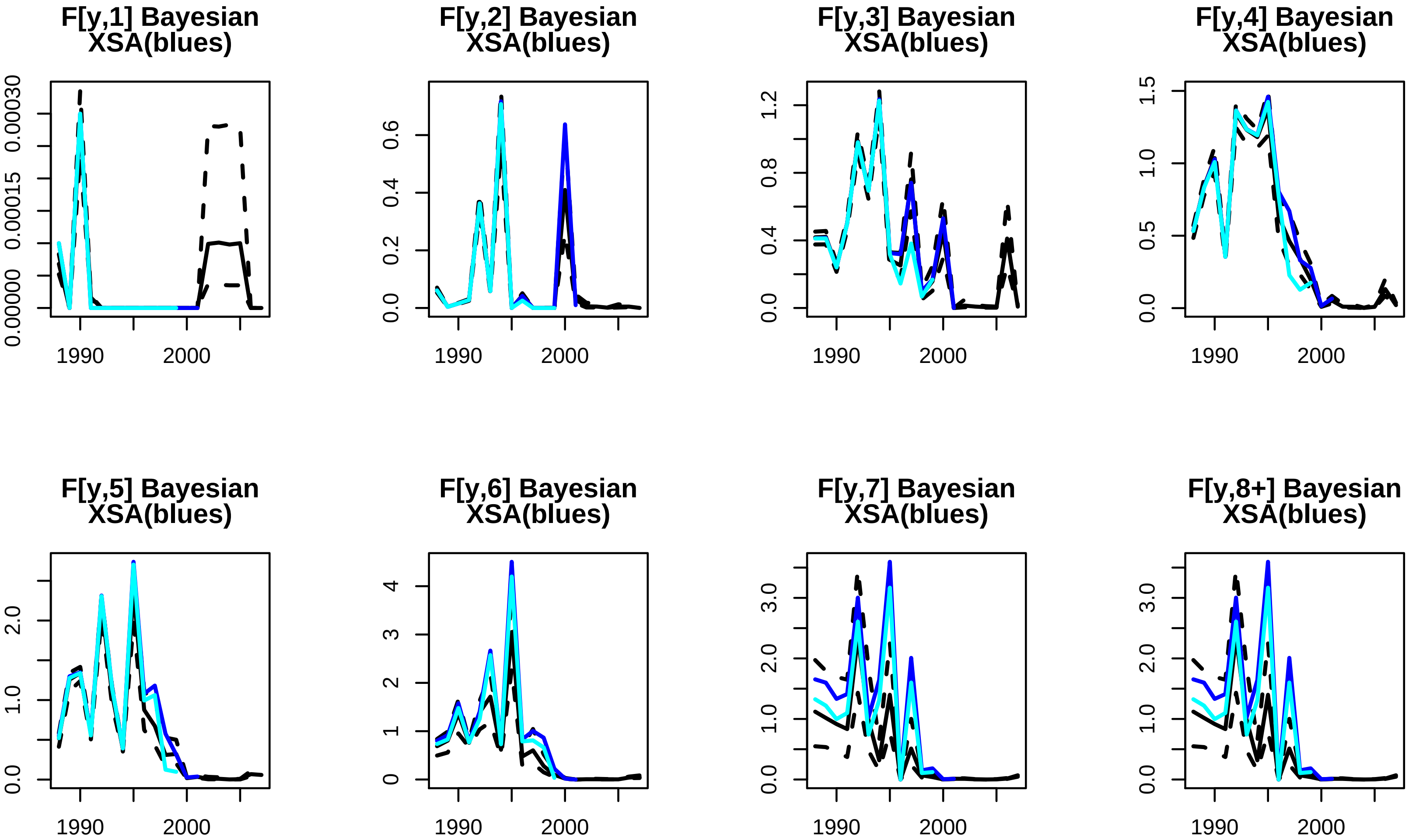

Figure 34: Run 6: Estimated fishing mortality at age

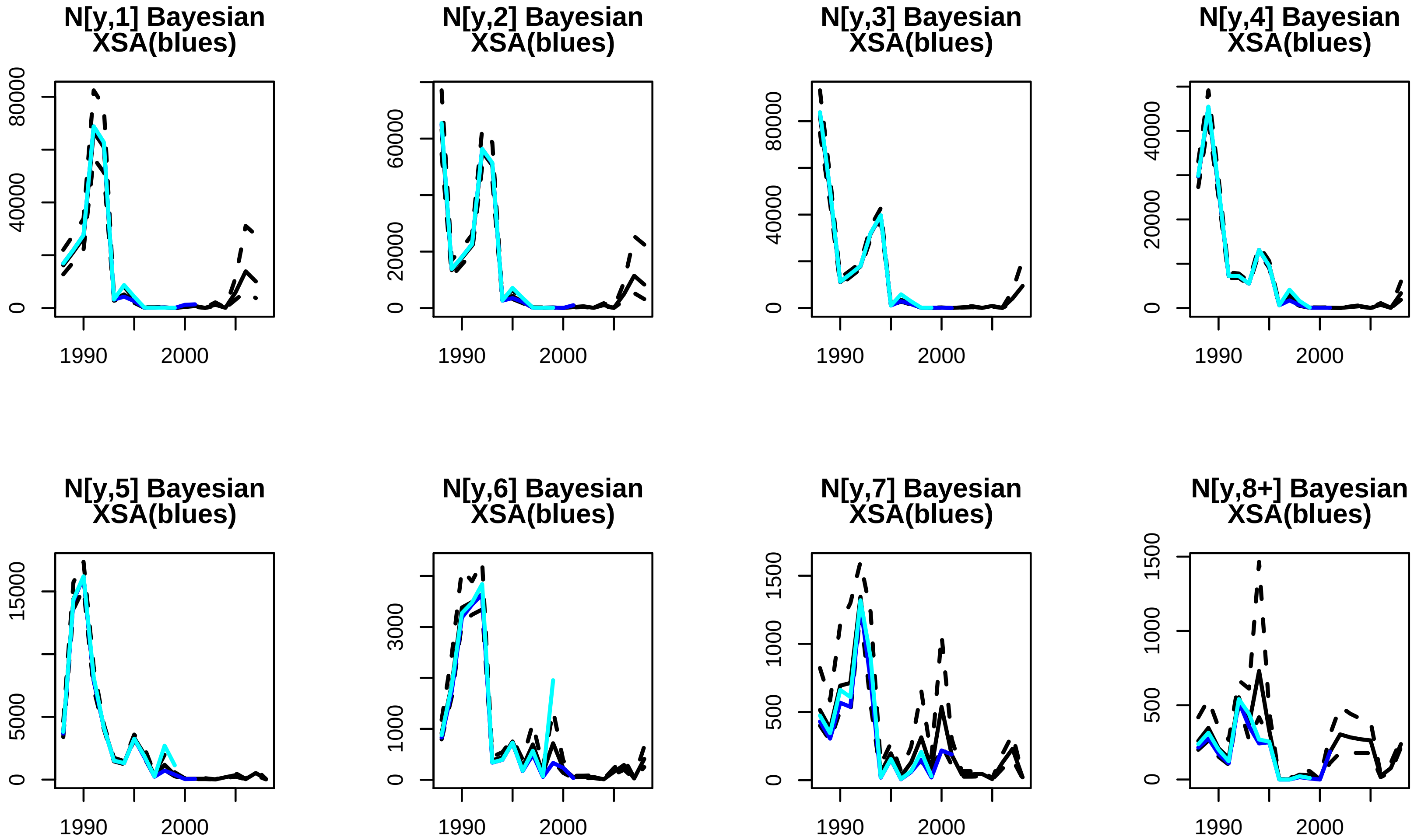

Figure 35: Run 6: Estimated numbers at age

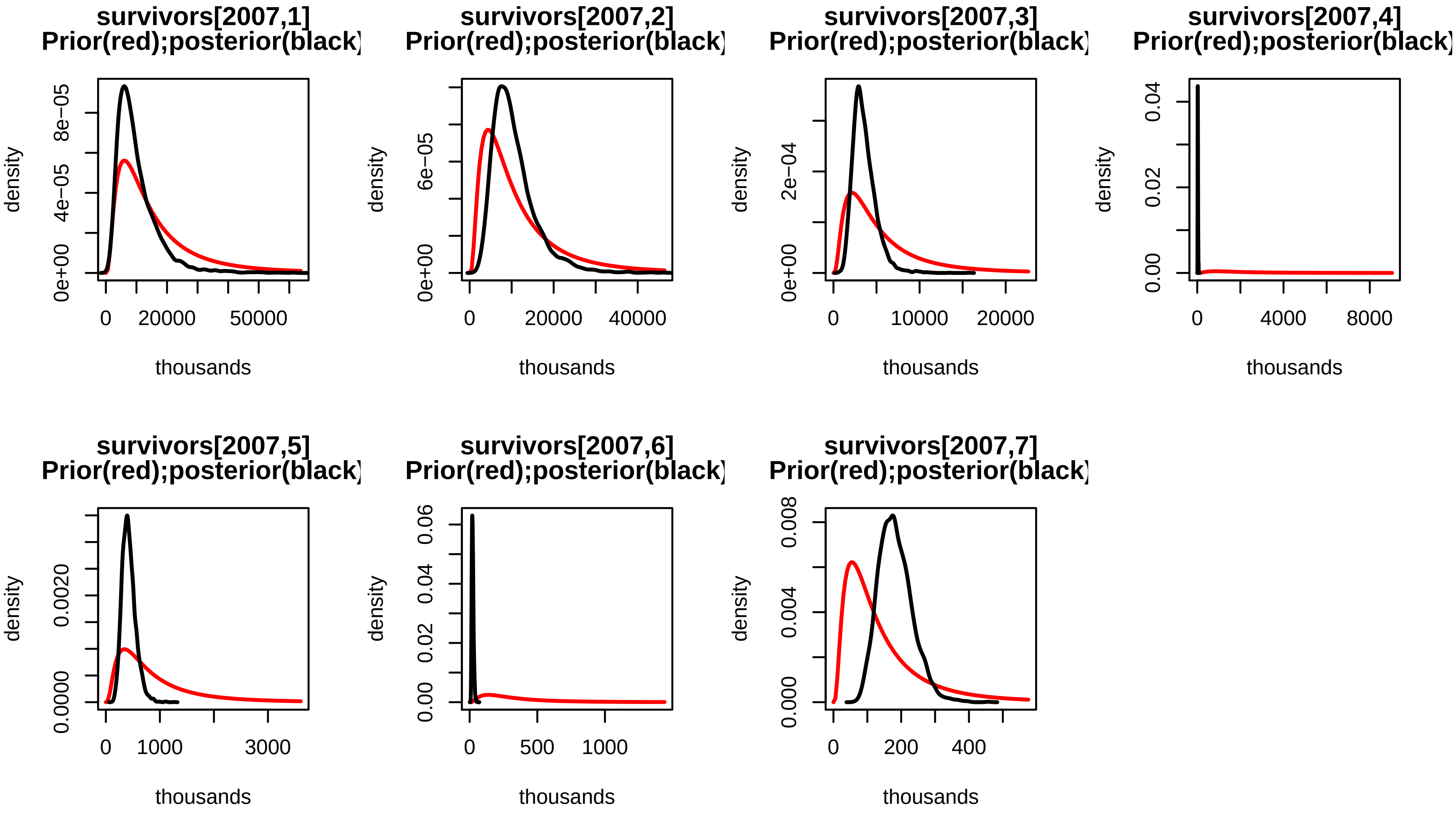

Figure 36: Run 6: Survivors at age at the end of 2007 ($survivors(2007, a)$ are individuals of age $a + 1$ at the beginning of 2008)

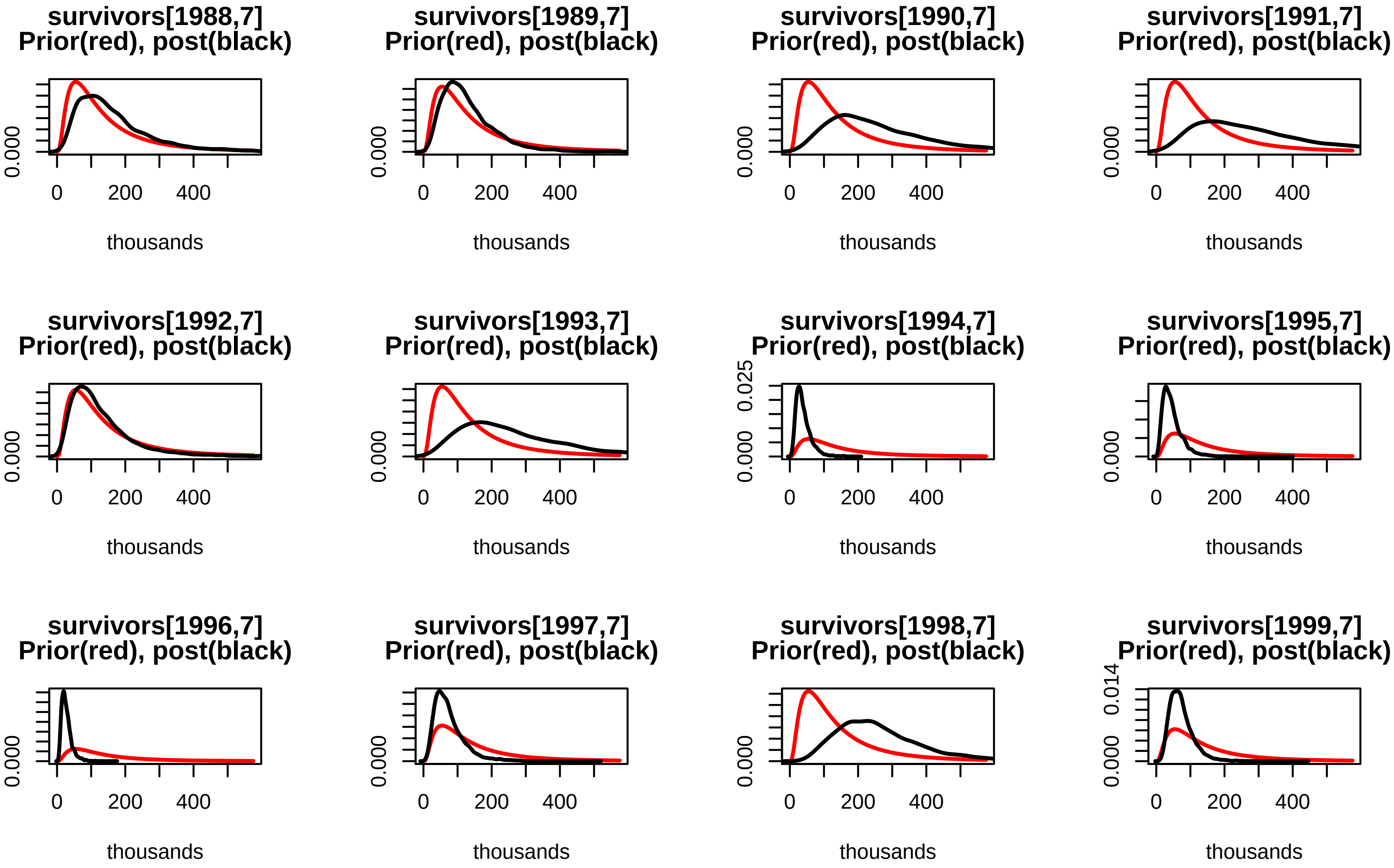

Figure 37: Run 6: Survivors from age 7 in each year ($survivors(y, 7)$ are individuals of age 8 at the beginning of year $y + 1$).

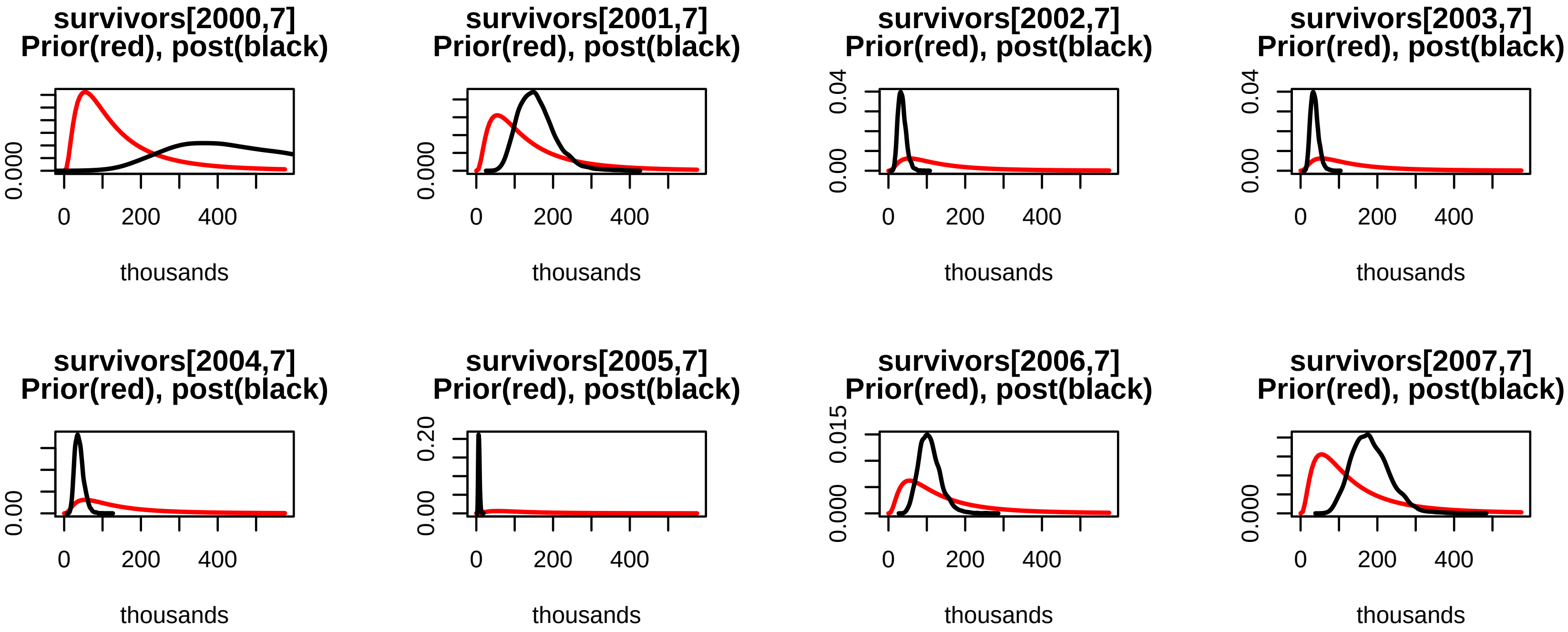

Figure 38: Run 6: Survivors from age 7 in each year ($survivors(y,7)$) are individuals of age 8 at the beginning of year $y+1$.

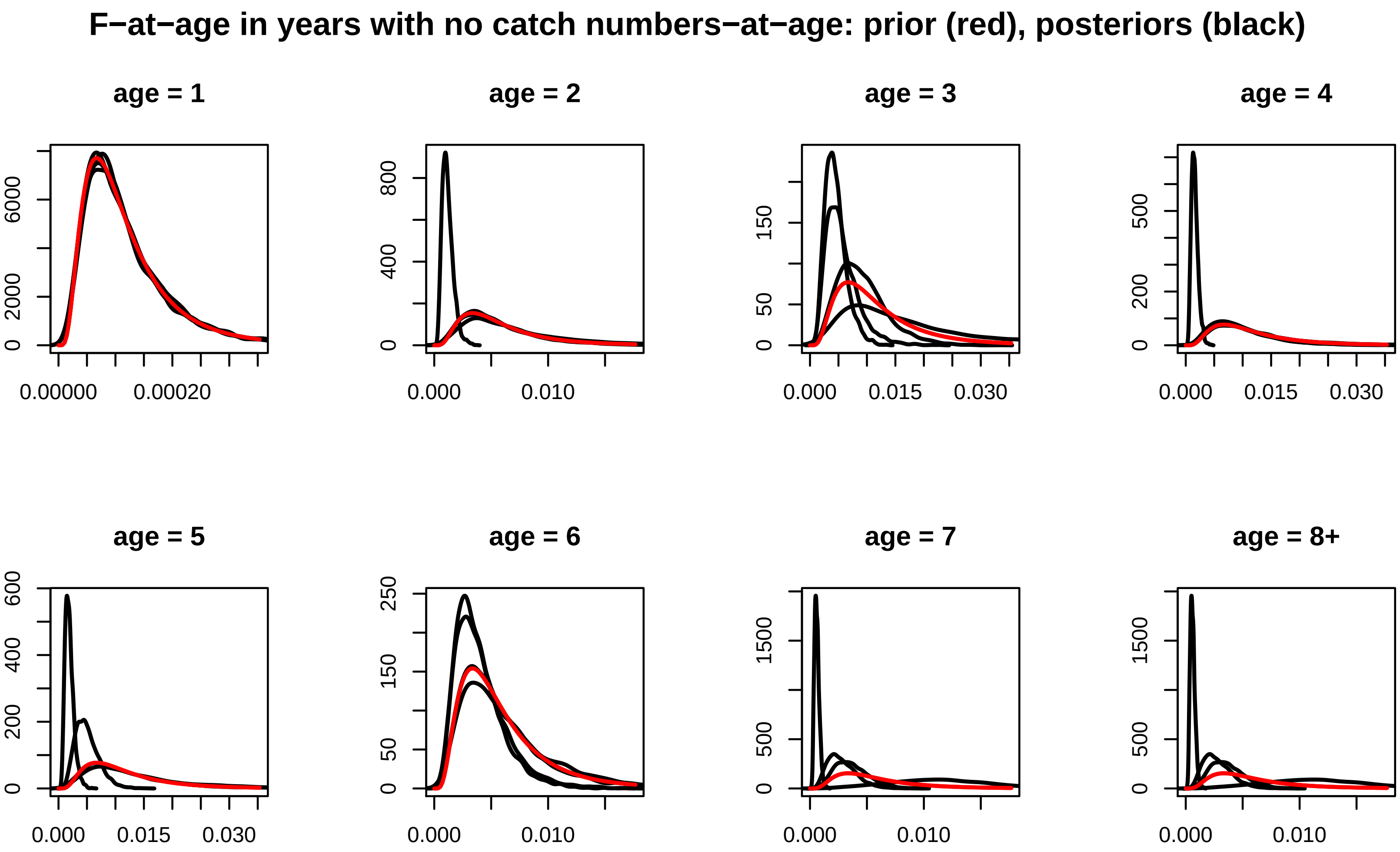

Figure 39: Run 6: F-at-age in years without catch numbers-at-age.

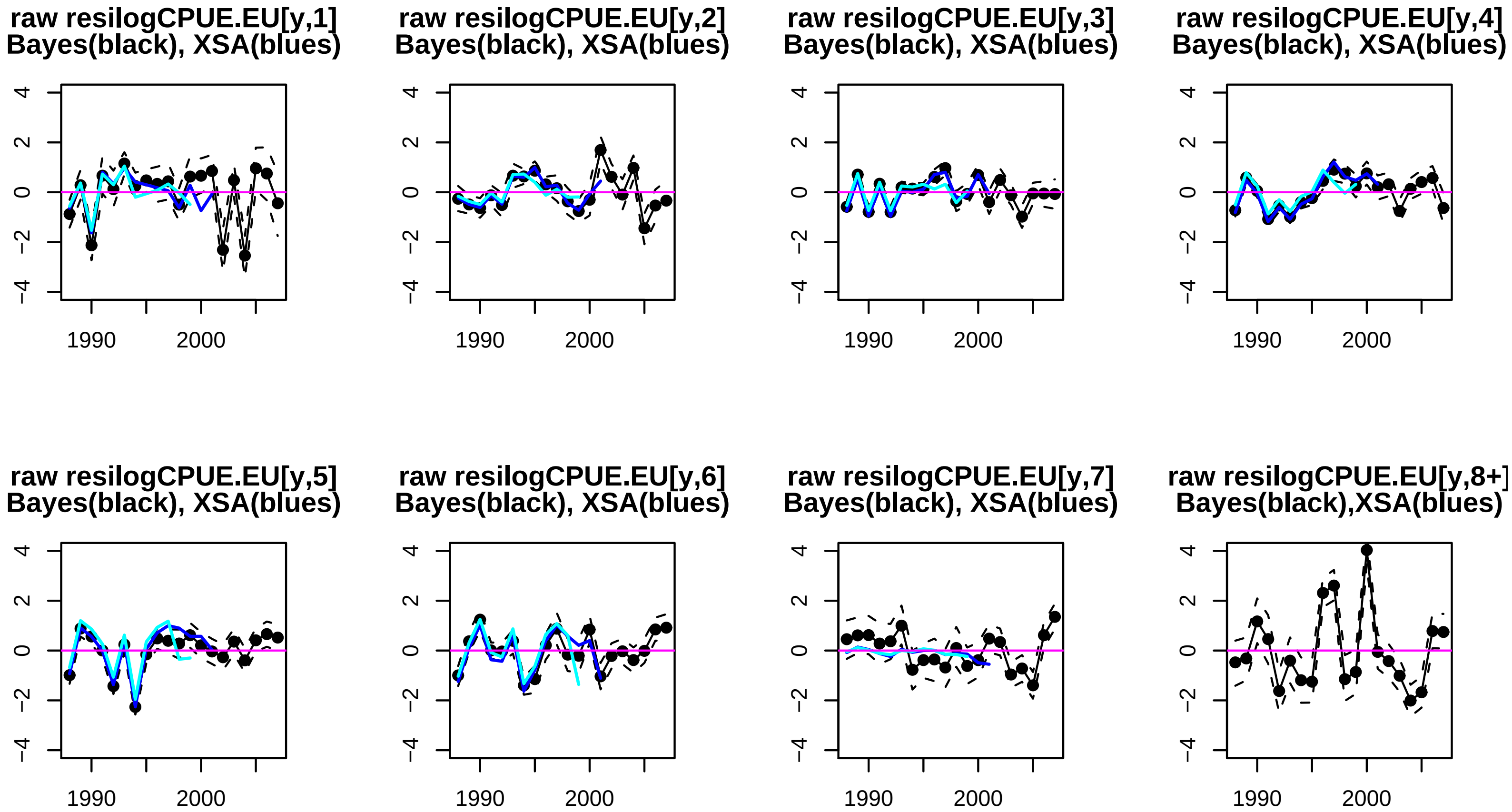

Figure 40: Run 6: Raw residuals (observed minus fitted value) in logarithmic scale of EU survey abundance indices at age. Each panel corresponds to one age. Bayesian residuals (in black) are given as posterior medians (continuous line) and limits of 90% posterior credible interval (dashed lines)

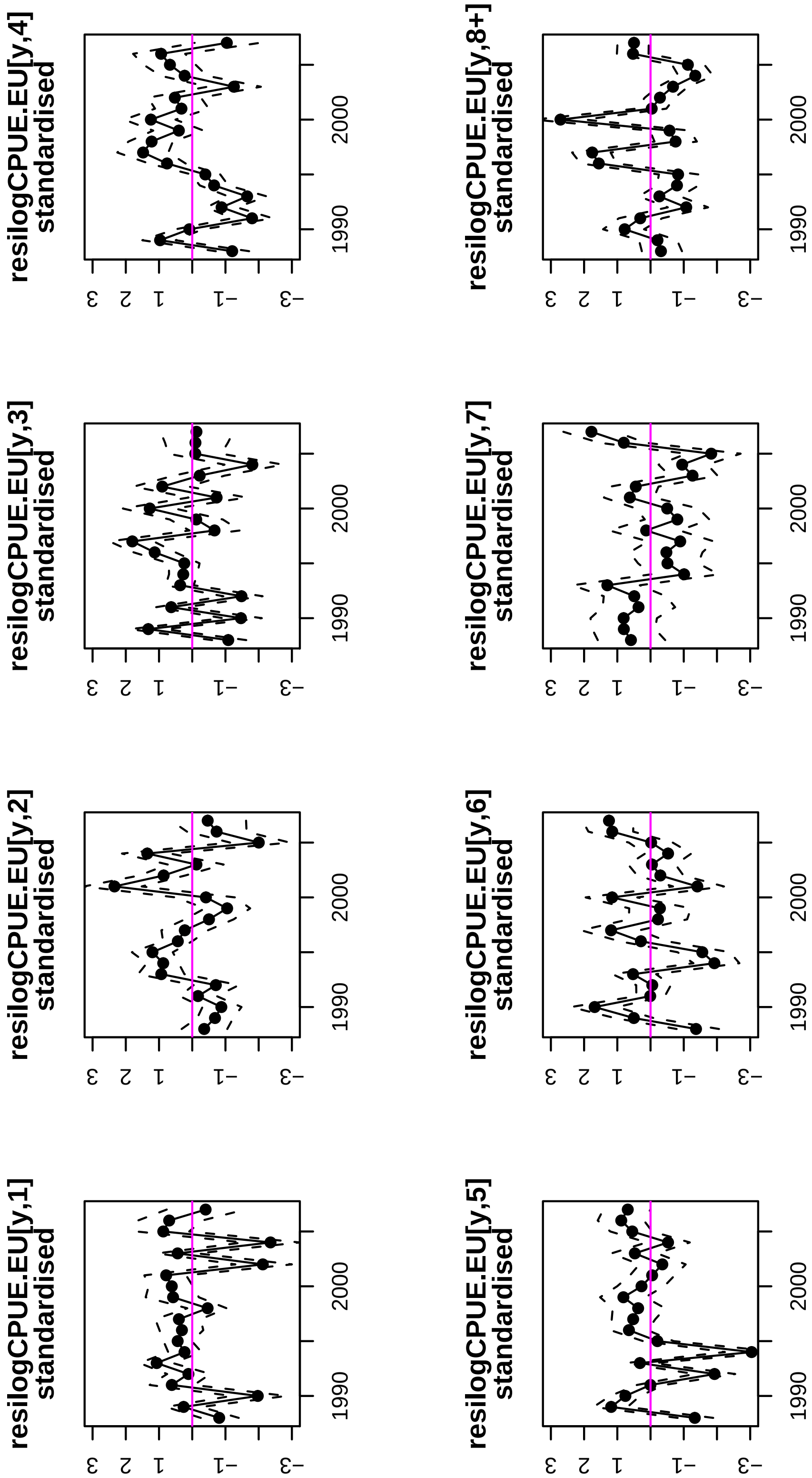

Figure 41: Run 6: Standardised residuals (observed minus fitted value divided by estimated standard deviation) in logarithmic scale of EU survey abundance indices at age. Each panel corresponds to one age. Bayesian residuals (in black) are given as posterior medians (continuous line) and limits of 90% posterior credible interval (dashed lines)

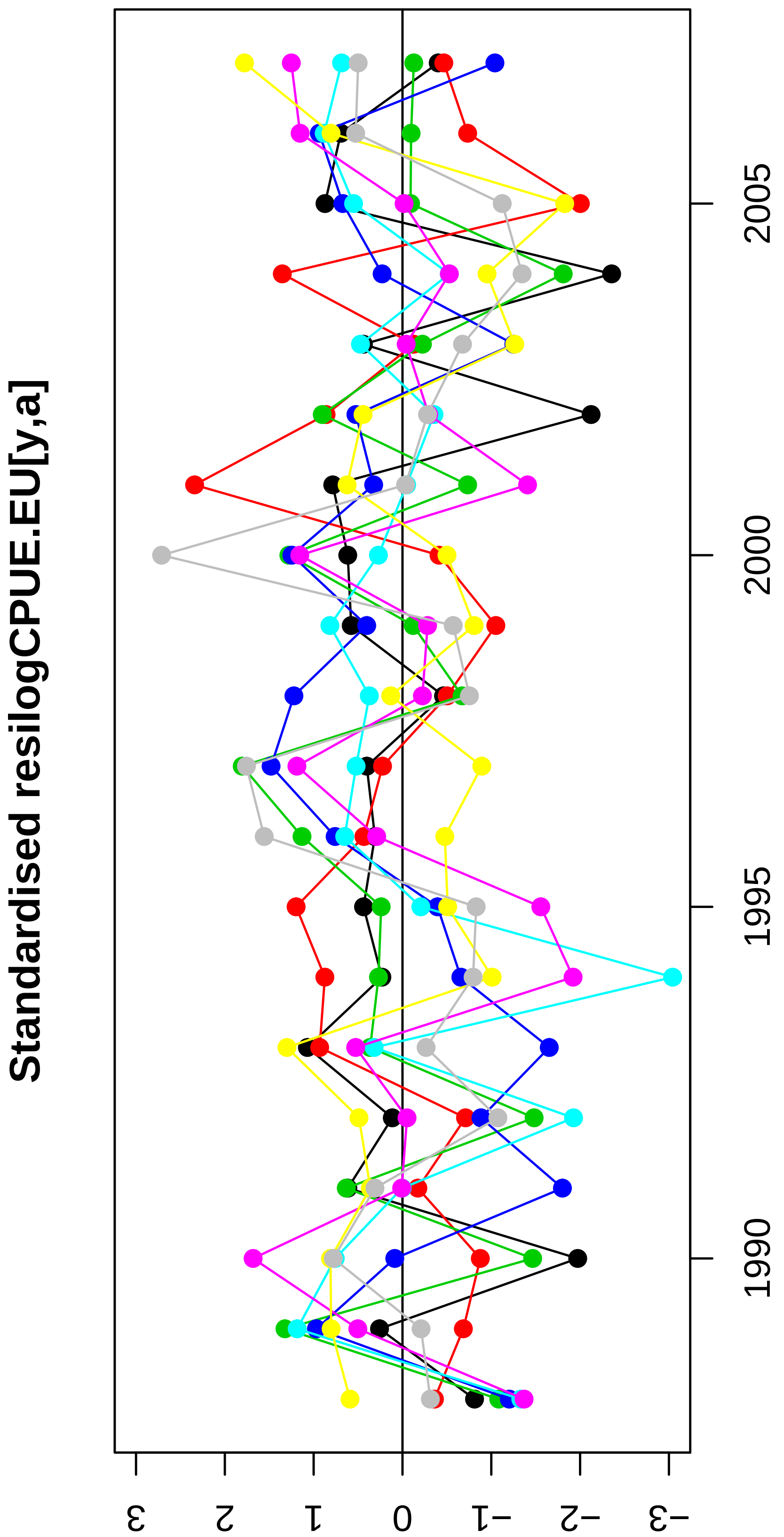

Figure 42: Run 6: Standardised residuals (observed minus fitted value divided by estimated standard deviation) in logarithmic scale of EU survey abundance indices at age. Each colour corresponds to one age. The residuals shown correspond to posterior medians from the Bayesian model

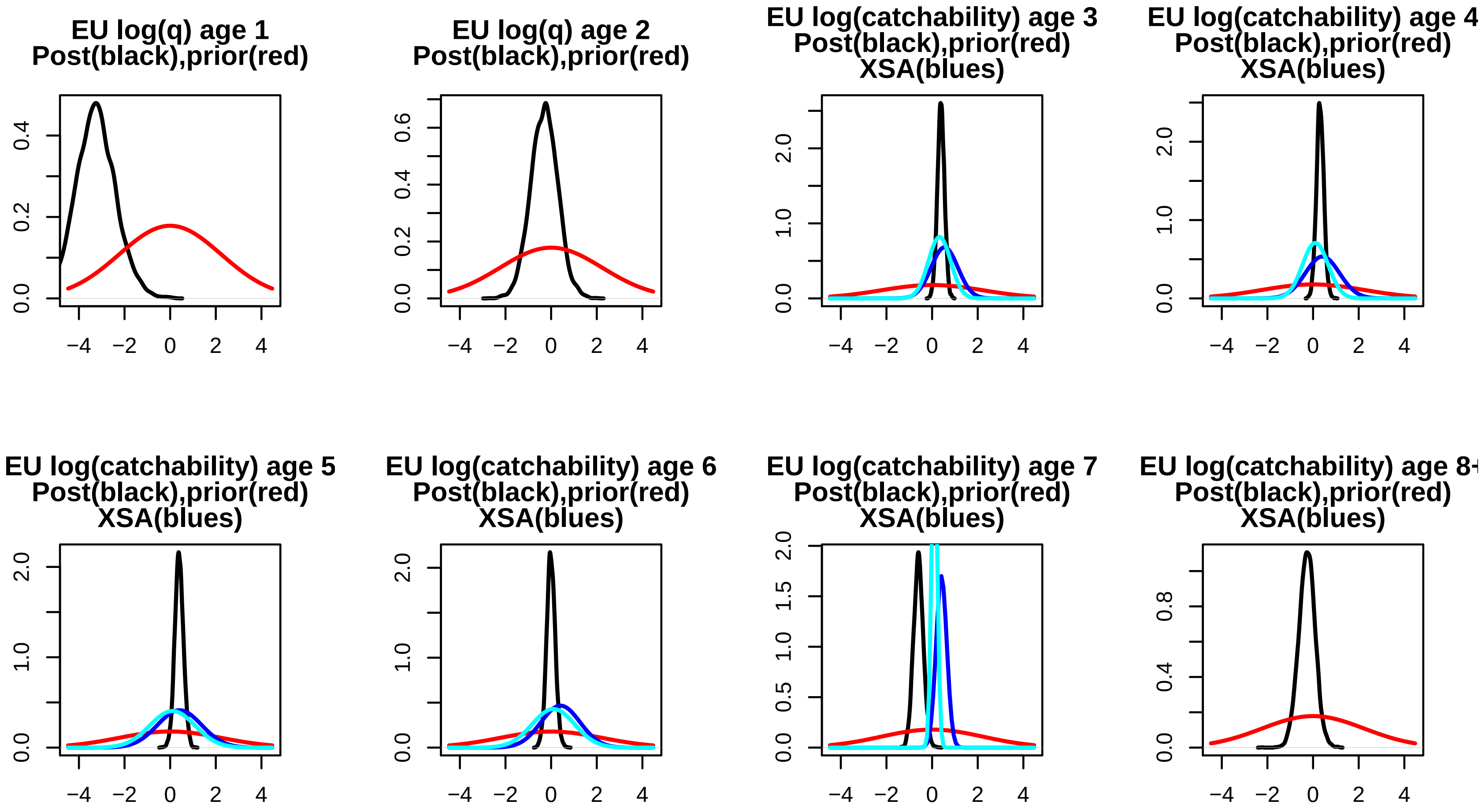

Figure 43: Run 6: Results for $\log(q(a))$ of EU abundance at age indices.

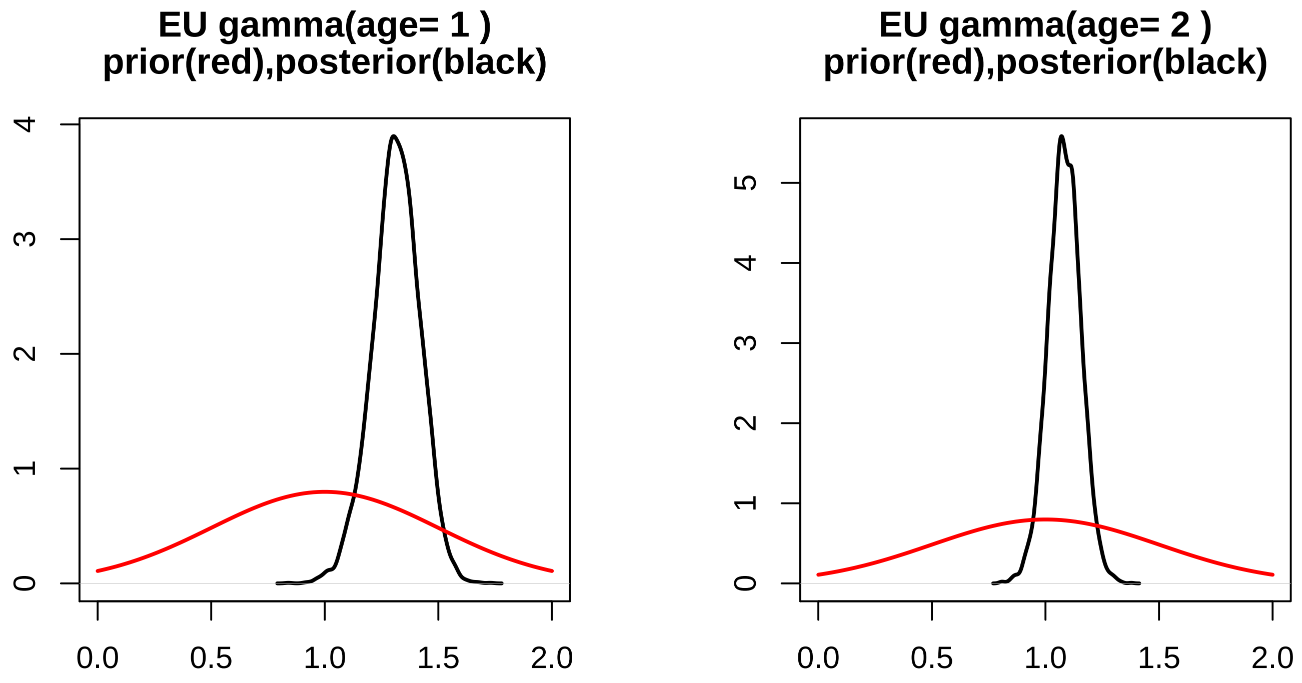

Figure 44: Run 6: Results for $\gamma(a)$ of EU abundance at age indices.

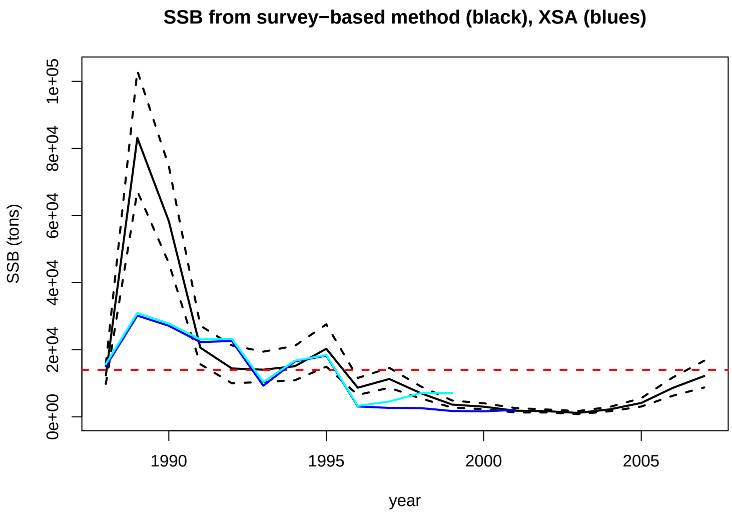

Figure 45: SSB estimates from survey-based method. The red horizontal line is at $B_{\lim} = 14000$ tons.

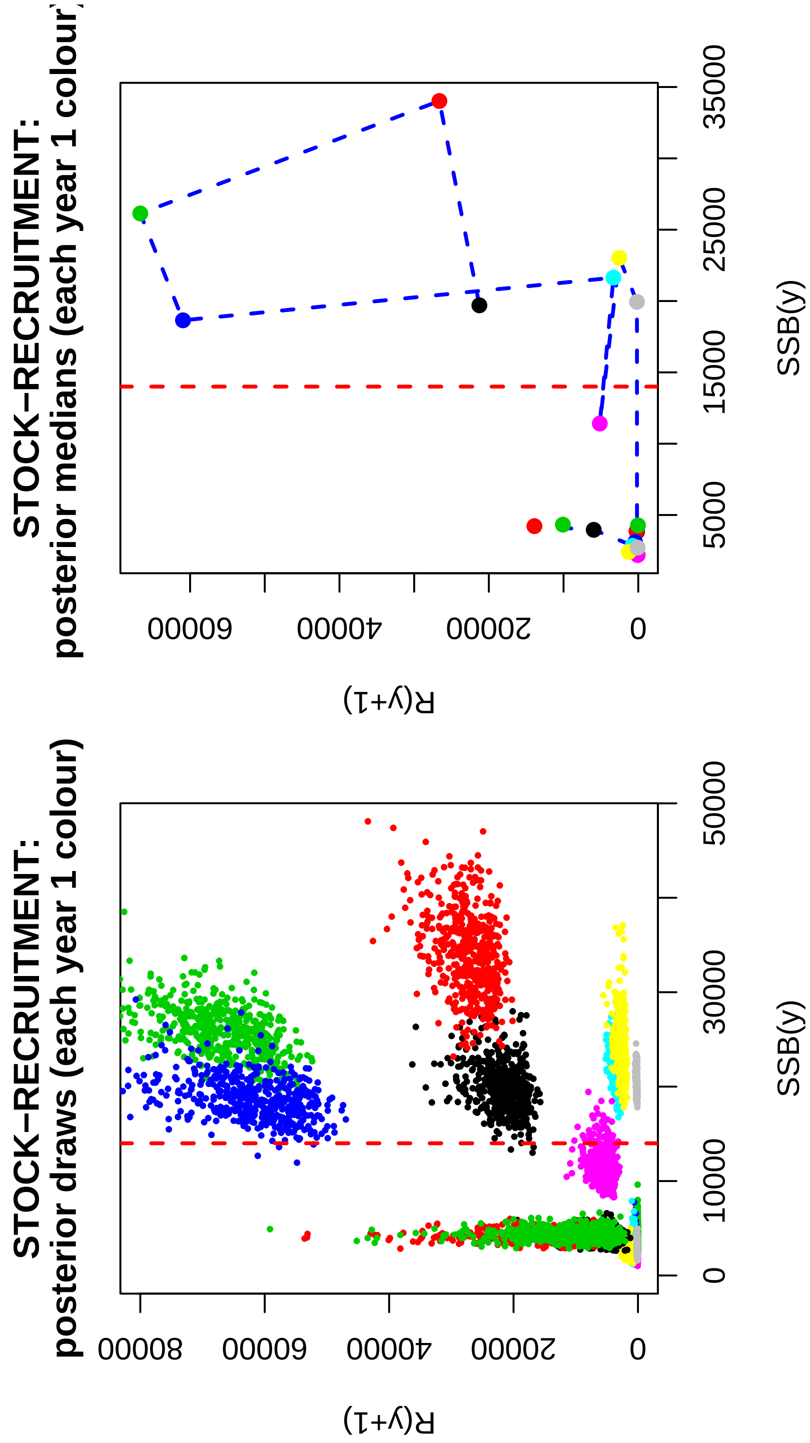

Figure 46: Run 6: Stock-Recruitment plots from the Bayesian model. $B_{\text{lim}} = 14000$ is shown as the red vertical line.

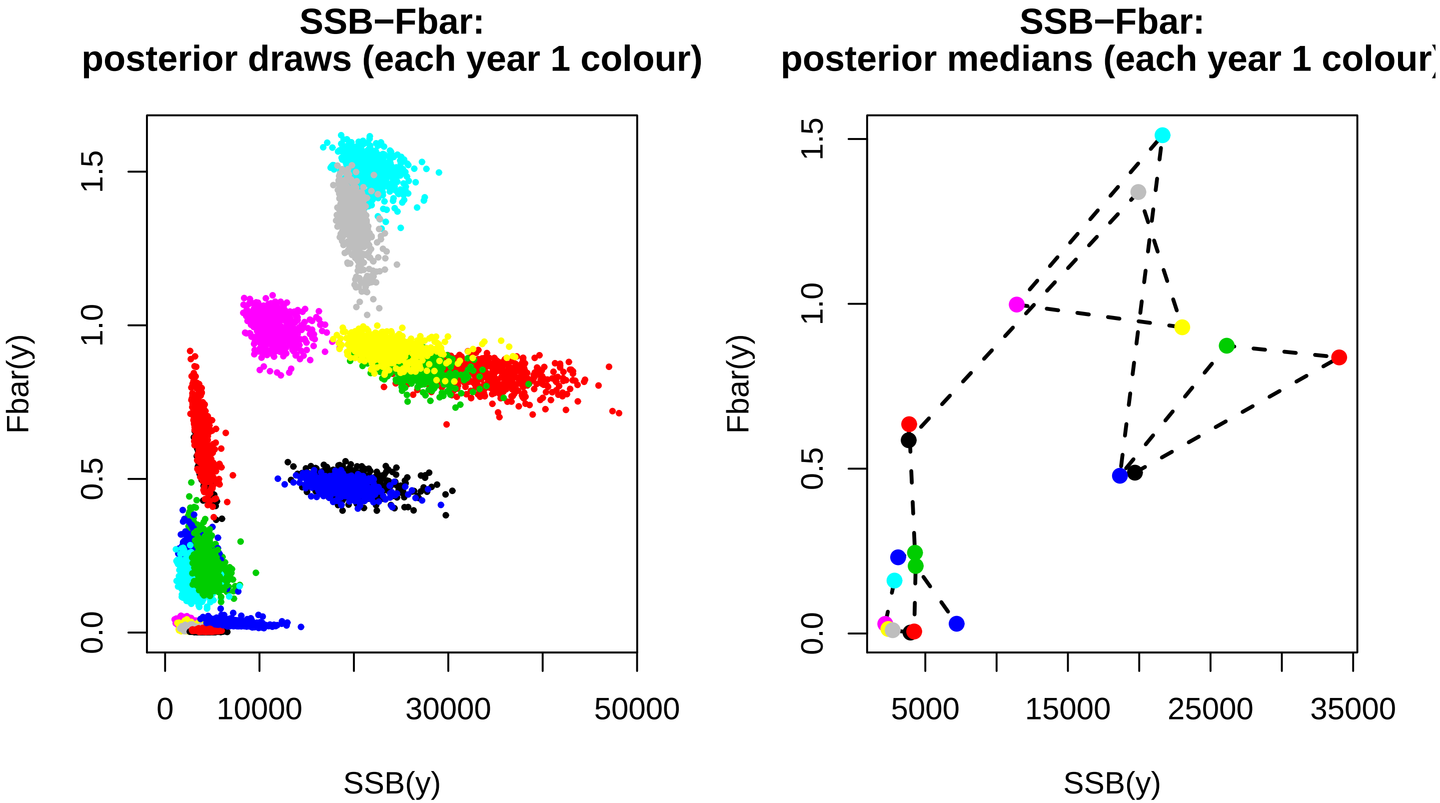

Figure 47: Run 6: Fbar versus SSB.

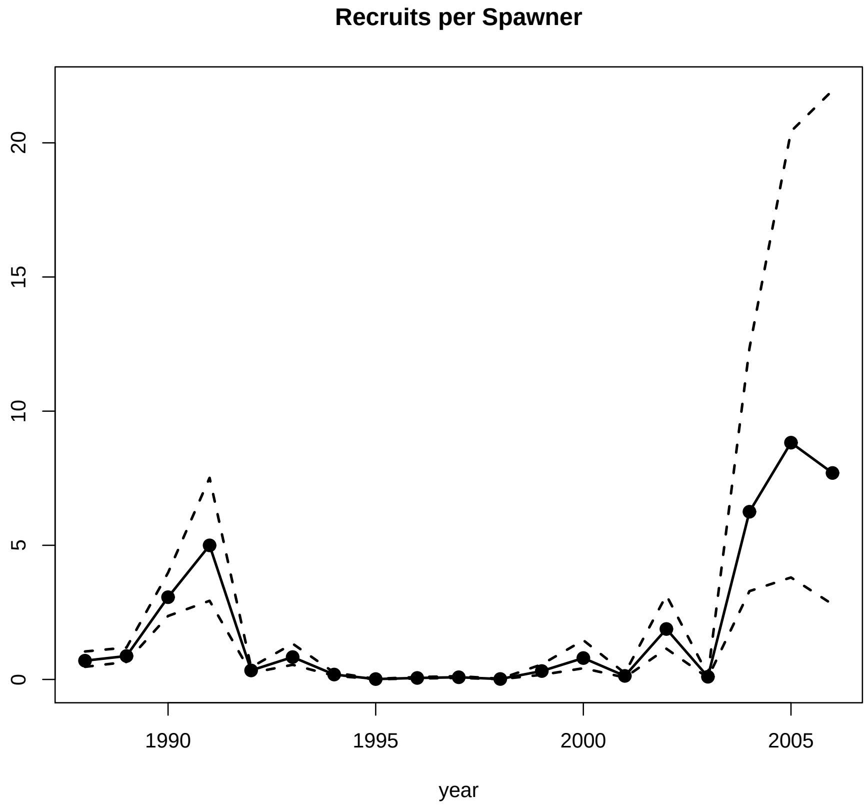

Figure 48: Estimated recruits per spawner

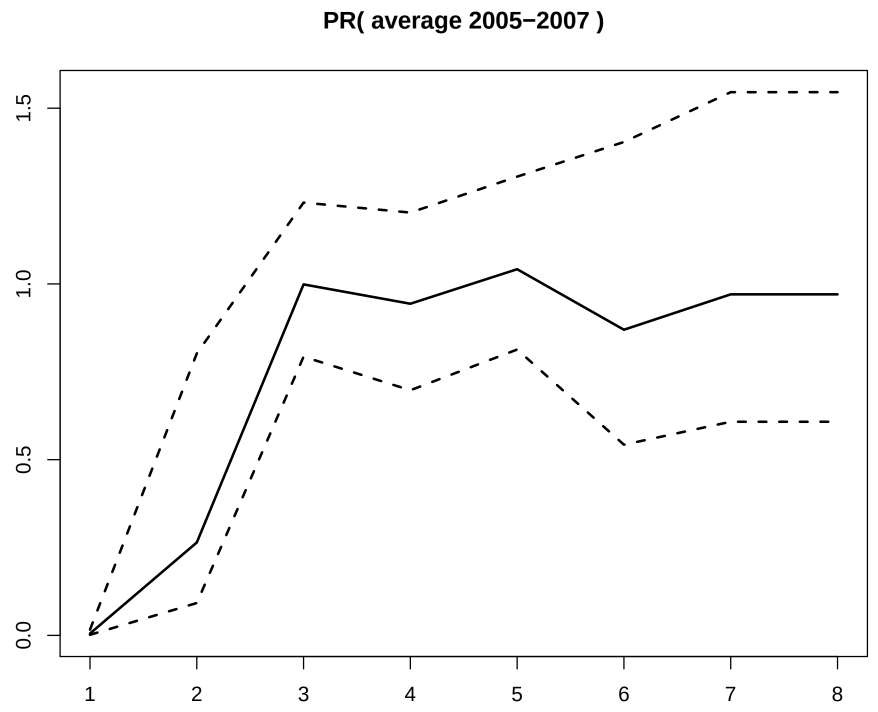

Figure 49: Estimated PR, averaged over the years 2005-2007

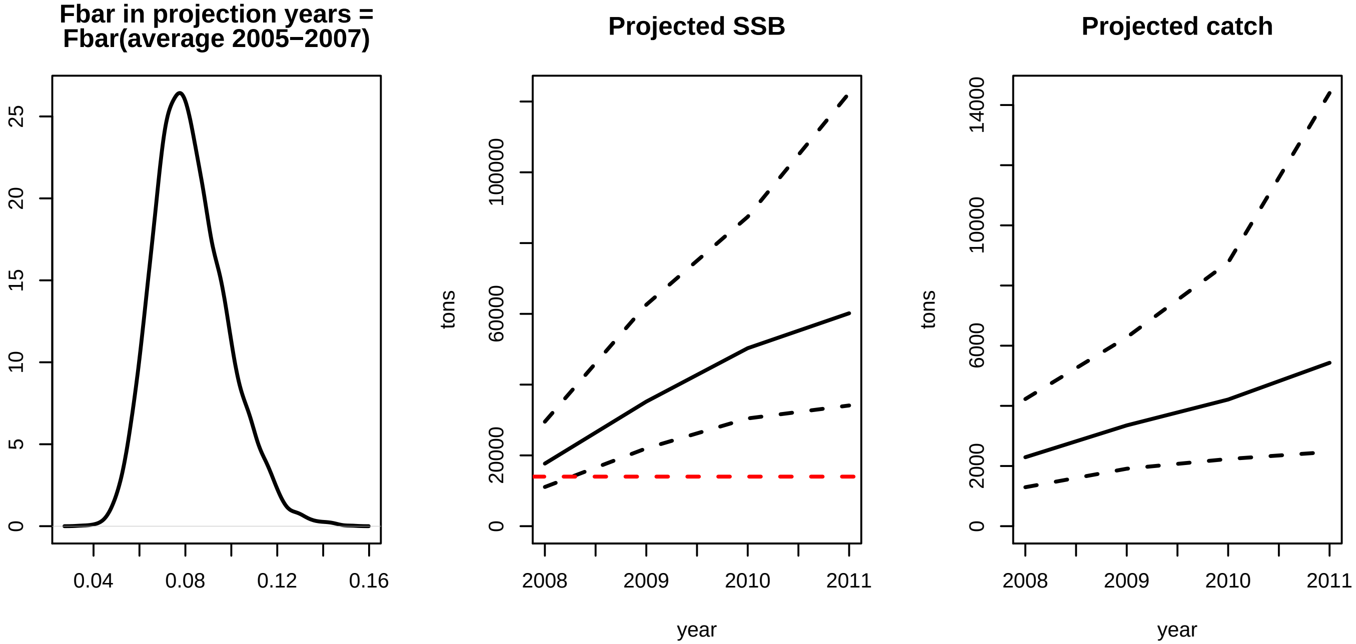

Figure 50: Projections with Fbar = Fbar(average of 2005-2007)

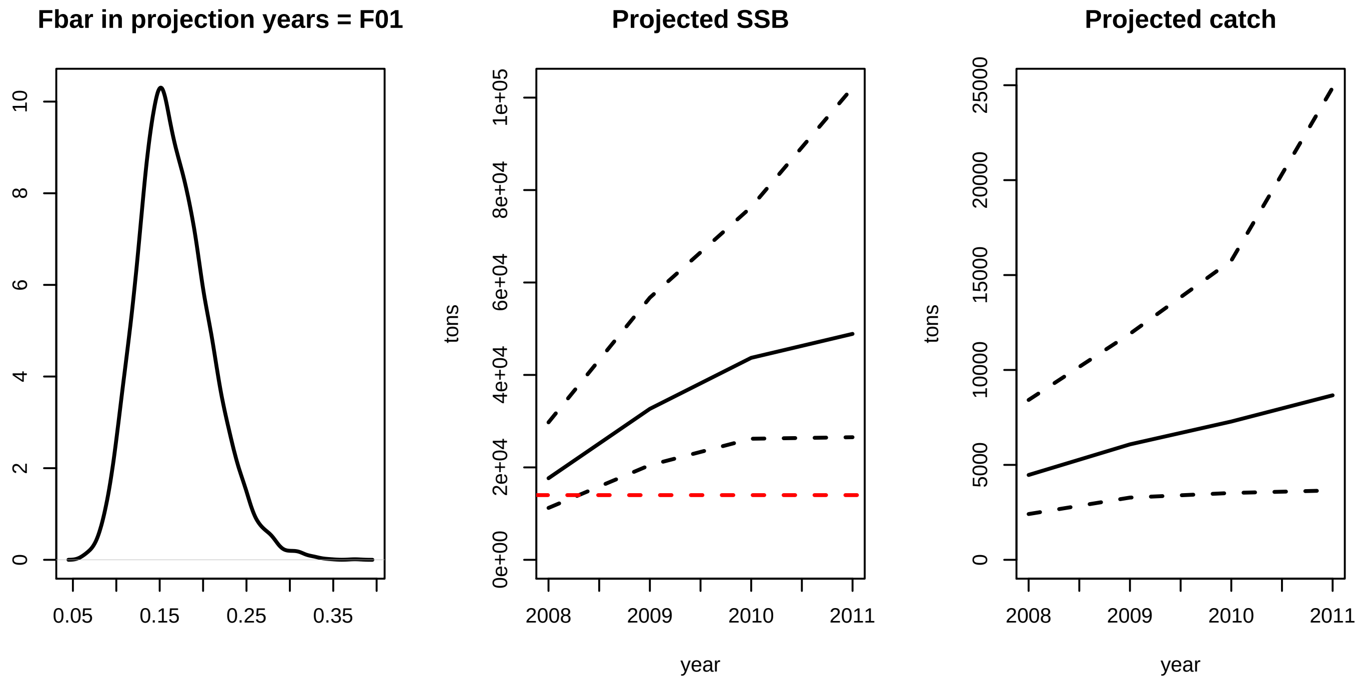

Figure 51: Projections with Fbar = F0.1

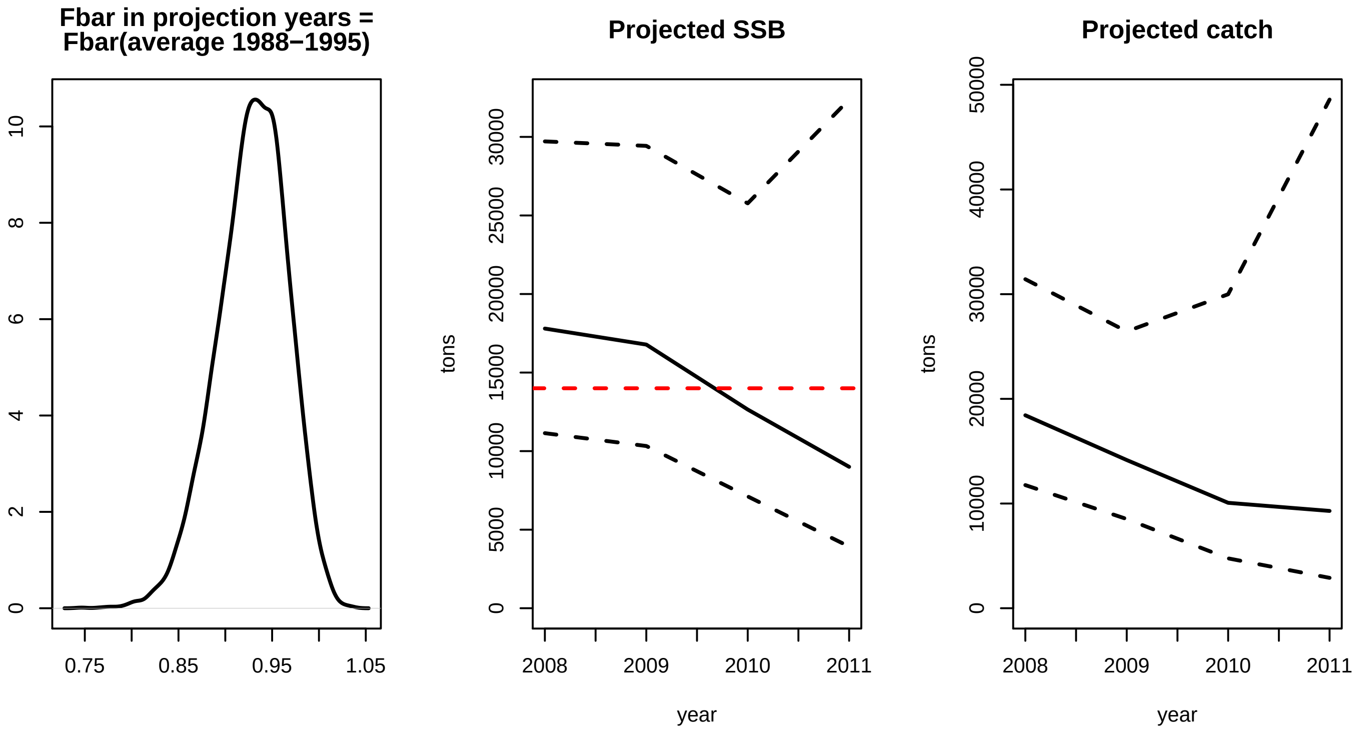

Figure 52: Projections with Fbar = Fbar(average of 1988-1995)