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Assessment of the Cod Stock in NAFO Division 3M

by

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Abstract

An assessment of the cod stock in NAFO Division 3M is performed. A Bayesian model, as used in the last assessments, was used to perform the analysis. The data set was extend to 1972 and a new tuning survey is used, the Canadian survey during 1978-1985. As there are inconsistencies with total catch of the last two years, a prior was added for 2011 and 2012 catch. Results indicate a fairly substantial increase in SSB, reaching a value well above B_{lim}. The six-years retrospective plots show an underestimation in the recruitment the last two years after several years of underestimation. Three year projections indicate that fishing at the $F_{statusquo}$ level should allow SSB to increase slowly in the short term.

Introduction

This stock had been on fishing moratorium since 1999 to 2009 following its collapse, which has been attributed to three simultaneous circumstances: a stock decline due to overfishing, an increase in catchability at low abundance levels and a series of very poor recruitments starting in 1993. The assessments performed since the collapse of the stock confirmed the poor situation, with SSB at very low levels, well below B_{lim} (Vázquez and Cerviño, 2005). Nevertheless, Spawning Stock Biomass (SSB) was estimated to increase a bit in 2004, 2005 and 2006 (Fernández, *et al.*, 2007) and above average recruitment levels were estimated for 2005 and 2006. Another large increase in SSB in 2007-2009, largely due to the recruitments in 2005-2006, has happened, reaching in 2011 the highest value of the studied series. The recruitment in 2010 and 2011 were the fourth and the third higest of the series, only below the recruitments of the years 1991 and 1992 (González-Troncoso *et al.*, 2012).

Since 1974, when a TAC was established for the first time, estimated catches ranged from 48 000 tons in 1989 to a minimum value of 5 tons in 2004. Annual catches were about 30 000 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 1 000 tons and from 2000 to 2005 they were under 100 tons, mainly attributed to by-catches from other fisheries. Estimated commercial catches in 2006, 2007, 2008 and 2009 are 339, 345, 889 and 1 161 tons (Table 1 and Figure 1), respectively, which represent more than a ten-fold increase over the average yearly catch during the period 2000-2005. The results of the 2009 assessment led to a reopening of the fishery with 5 500 tons of catch in 2010. With the results of the 2010-2012 assessments TACs of 10 000 tons in

2011, 9 280 tons in 2012 and 14 113 tons in 2013 were established. The estimated catch by the Scientific Council for 2010 was 9 291 tons, which almost double the TAC. In 2011 and 2012 there are not available estimated catches by the Scientific Council. The STATLANT 21A catch was 9 794 for 2011 and 9 003 for 2012.

A VPA based 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, catches between 2002 and 2005 were very small undermining the VPA based assessment, as its results are quite sensitive to assumed natural mortality 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 calculating the SSB distribution and, hence, the probability that SSB is above or below any reference value. The method was used to assess the stock since 2003. In 2007 results from an alternative Bayesian model were also presented (Fernández *et al.*, 2007) and in 2008 this Bayesian model was further developed and approved by the NAFO SC (Fernández *et al.*, 2008), having been used since then in the assessment of this stock.

An assessment of this stock using the Bayesian model used last years is presented. A B_{lim} of 14 000 tons was proposed by the NAFO Scientific Council in 2000. The appropriateness of this value given the results from the new method used to assess the stock was examined in 2008, concluding that it is still an appropriate reference.

Material and Methods

Used data

Commercial data

Total Catch

In 2012 there were catches of 3M cod from Cuba, Estonia, Faroe Islands (Denmark), Latvia, Lithuania, Norway, Portugal, Russia, Spain and United Kingdom with a total amount of 9 003 tons of STATLANT 21A catch (Table 1, Figure 1).

Length distributions

In 2012 length sampling of catch was conducted by Estonia (*pers. com.*), Lithuania (*pers. com.*), Norway (*pers. com.* from Canada), Portugal (SCR 13/05), Russia (SCS 13/09) and Spain (SCS 13/07). Length frequency distributions from the commercial catch and from the EU survey (Casas and González-Troncoso, 2013) are shown in Figure 2.

It must be noted that countries with a high proportion of TAC and catch, as Norway (22.3% of the TAC) and UK (9.3% of the TAC), have not reported length frequencies for the catch in 2012.

Estonia has measured 48 individuals in a range of 23-73 cm and found three modes in 46, 57 and 59 cm. Lithuania has measured 600 individuals between 28 and 125 cm with a mode in 85 cm. Norway has a 2325 individuals sample in a range of 31-124. The modal length is 64 cm, ranging 58-63 cm the most frequent fish. The number of sampled individuals for Portugal was 11018, the highest sample. The mode of this length distribution is clearly at 54 cm in a range of 15-105 cm. For Russia the number of measured individuals was 4453 in a range of 30-124 cm. The mode was in the range of 60-78 cm. Spain has measured 4094 individuals in a range of 22-129 cm. The mode was at 63 cm. The EU survey has a well-defined mode around 19 cm, followed with another mode in 33-38. The range is from 9 to 125 cm.

Catch-at-age

Catch-at-age is presented in Table 2. The data from 1972 to 1987 were taken from the 1999 assessment, in which a review of those data were made (Vázquez *et. al*, 1999). As no age-length keys (ALK) were available for commercial catch from 1988 to 2008, each year the corresponding ALKs from the EU survey were applied in order to calculate annual catch-at-age. A commercial ALK was available for 2009-2011 from the Portuguese commercial data and was applied to the total commercial length distribution. In 2012 otholits were no collected by the Portuguese fleet. There is available a commercial ALK from the Spanish fleet, but as the reader of these otholits is different as last years reader it is considered no consistent. So, the commercial 2011 ALK was applied to the total commercial length distribution. In 2011 and 2012, as no consistent catch is available, the percentage of each age is presented.

The range of ages in the catch goes from 1 to 8+. No catch-at-age was available for 2002-2005 due to the lack of length distribution information because of low catches.

Figure 3 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 (including 2012 catch) is comprised of 3-5 years age cod. In years 2006 and 2009 catches containing mostly age 4 individuals. In 2007 there has been much more spread over the ages; in 2008 the greatest presence was at ages 2 to 4 and in 2010 ages 3 and 4. In 2011 and 2012 the most caught age was 3.

Figure 4 shows standardised catch proportions at age (each age standardised independently to have zero mean and standard deviation 1 over the range of years considered). Assuming that the selection pattern at age is not too variable over time, it should be possible to follow cohorts from such figure. Figure 5 shows the same figure for the last complete cohort taking into account that the plus group is at age 8 (2006-2012, as there are no 2005 data). Some strong and weak cohorts can be followed, although the pattern is not too evident. The biggest circle corresponds to the recruitment (age 1) of year 1987, the biggest caught, by far, of the entire series. The corresponding cohort was weak. It is remarkable the catch over the recruitment in the last three years.

<u>Mean weight-at-age</u>

There are available data of mean weight-at-age in catch for years 1972-1987 from the 1999 assessment (Vázquez *et. al*, 1999). For 1988-2011, the same data as last year assessment were taken.

For 2012, mean weight-at-age has been computed separately for the catch and for the stock, using length-weight relationships from the commercial sampling and from the EU survey, respectively. In the commercial case, there are four length-weight relationships available in 2012: Estonian, Lithuanian, Portuguese and Spanish. All of them are presenting in Figure 6 with the survey one. There are no significant differences between them. The Portuguese length-weight relationship was applied to the commercial data to calculate weight-at-age in the catch as it lead from the biggest sample. Results are showed in Table 3. Since 2005 there are a general decrease in the trend of the mean-weight for the ages between 2 and 6 years old. Ages 1, 7 and 8+ present a stable trend over these years. It must be noted that all the mean-weight-at-age are now higher than the ones at the beginning of the time series.

The SOP (sum over ages of the product of catch weight-at-age and numbers at age) for the commercial catch differs in 6.7% from the estimated total catch.

<u>Survey data</u>

<u>Canadian survey</u>

Canada conducted research vessel surveys on Flemish Cap from 1978-1985. Surveys were done with the R/V *Gadus Atlantica*, a stern trawler of 74 m in length, fishing with a lined Engels 145 otter trawl. The surveys were conducted in January-February of each year from 1978 to 1985, using a stratified random design. Fishing sets were usually of 30 minutes duration, over a distance of 1.75 nautical miles, and covered depths between 130 and 728 m. All strata were surveyed each year, with the exception of 1982, when 4 deeper strata were omitted (Brodie and Bowering, 1992).

Survey indices of abundance at age are presented in Table 4. Figure 7 displays the estimated biomass and abundance indices over the time series. From a high value in 1978, a general decrease in both indices can be seen until 1985. Figure 8 shows 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). Grey and black bubbles indicate values above and below average, respectively, with larger sized bubbles corresponding to larger magnitudes. The plot indicates that the survey was able to detect strength of recruitment and to track cohorts through time very well. It clearly shows a series of consecutive recruitment failures from 1978 to 1980, leading to very weak cohorts, specially the 1979 one (age 1 at 1980). The 1981 cohort was quite good.

EU survey

The EU bottom trawl survey on 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 deeper than 500 m. The survey procedures have 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 results of the survey for the years 1988-2012 are present in Casas and González-Troncoso, 2013.

Survey indices of abundance at age are presented in Table 5. Figure 7 displays the estimated biomass and abundance indices over time. There are differences between the level of biomass and abundance in the Canadian survey and in the EU one, probably due to the difference in the gear. Biomass and abundance show a high increase since 2005, higher in biomass than in abundance except for 2011, following an extremely low period starting in the mid 1990's. The large number in 2011 is due to a big presence of individuals of age 1. It must be noted that 2009-2010 biomass is at the level of the first years of the assessment but abundance in these years is roughly the same as in 1994. In 2010 the biomass has suffered a bit decrease, probably due to the opening of the fishery, but a new huge increase can be seen in 2011 and 2012, reaching a value very near the highest of the series, that occurred in 1989. The abundance in 2011-2012 are the highest of the time series of this survey. Figure 9 shows 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). Grey and black bubbles indicate values above and below average, respectively, with larger sized bubbles corresponding to larger magnitudes. The plot 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 recruitment failures from 1996 to 2004, leading to very weak cohorts. Cohorts recruited from 2005 onwards appear to be above average. In the last three years a good recruitment can be seen.

Mean weight-at-age

Mean weight-at-age in the stock for Canadian survey is not available, so mean weight-at-age in the stock is only available from the EU survey from 1988 to 2012. For the previous years, as the stock change rapidly, it was decided to apply the weight-at-age for catch. As catch has no weight-at-age for the youngest ages (1 and 2), the mean of the EU survey weight-at-age between years 1988-1995 for those ages was taken. The reason for taking those years is that the stock seems to change suddenly its weights-at-age in 1996. The results are showed in Table 6.

Mean weight-at-age in the stock shows a strong increasing trend since the late 1990's, although in 2008 all the ages decreased their mean weight-at-age, but still remain much higher than at the beginning of the series. In 2009 youngest and oldest ages increased theirs mean weight-at-age with respect to 2008, while the ages 3-4 decreased them (see Table 6 and Figure 10). In 2011 all ages except 4 and 8+ decreased their mean weight-at-age with regards to 2009-2010. In 2012 the weight-at-age for ages 1-3 increased with regards 2011, but decreased significantly for ages 4-8+.

Maturity at age

Maturity ogives from the Canadian survey are available for all the years (1978-1985) and from the EU survey for years 1990-1998, 2001-2006 and 2008-2012. For those years logistic regression models for proportion mature at age have been fitted independently for each year. For years 1983-1985 the fit was no consistent, so those years were omitted for the fit. For 1972 to 1977, the 1978 maturity ogive was applied. The 1982 maturity ogive was taken for 1983 to 1987. For 1988 and 1989 the 1990 maturity ogive was applied. For 1999 and 2000 maturity ogive was computed as a mixture of 1998 and 2001 data, and for 2007 as a mixed of 2006 and 2008 maturity ogive. Maturity data for 1991 were of poor quality and did not allow a good fit, so a mixture of the ogives for 1990 and 1992 was used. The median of the maturity ogives for the whole period are presented in the Table 7. It can be seen that the percentage of matures in all ages has decreased since 2006. This fact, together with the decreasing mean weight at age, is consistent with a stock in a recovery process, whit a slower growth and maturing.

Figure 11 displays the evolution of the a50 (age at which 50% of fish are mature) through the years (estimate and 90% uncertainty limits). The figure shows a continuous decline of the a50 through time, from above 5 years old in the late 1980's to below 3 years old in 2002. Since 2005 the a50 has increased slowly, especially in 2011, reaching a value slightly above 4 years old. In 2012 the age decreased with regards to 2011, but the trend is still increasing.

Assessment methodology

The Bayesian model used last years was updated with 2012 data. For years with catch-at-age data, it works starting from cohort survivors and reconstructing cohorts backwards in time using catch-at-age and the assumed mortality rate. When catch-at-age is not available for a year but an estimate of total catch in 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 combining years with catch-at-age and years where only total catch is available. Years with no information on commercial catch are also allowed. A detailed description of the model is in Fernandez *et al.*, 2008. The priors were chosen this year as last approved assessment.

The two lasts years (2011 and 2012) there is a lack of information because estimated catches by the Scientific Council are not available and the available figures (from the STATLANT 21A) are no consistent with 2010 catch. For this reason, Scientific Council decided to incorporate a new prior for the total catch in 2011 and 2012. In 2011, the effort in the major fleets has increased 40% approximately regarding 2010 effort and the 2010 catch was 9 192 tons, so it was decided to fit a prior to 2011 catch with a median value of approximately 12 800 tons and a standard deviation that allows the catch to move between 9 905 and 16 630 tons (95% confidence interval). The chosen prior was a lognormal. In 2012 the TAC was slightly below the 2011 TAC and the effort was virtually the same, so no evidences of change in the catch of 2012 with regards to the catch of 2011 exists, therefore the same prior was taken. The priors for 2011 catch and 2012 catch are independent.

The inputs of the assessment of this year are as follow:

Catch data for 39 years, from 1972 to 2010

For 2011: $TotalCatch(2011) \sim LN(median = 9.46, sd = 0.1313)$

For 2012: $TotalCatch(2012) \sim LN(median = 9.46, sd = 0.1313)$

Years with catch-at-age: 1972-2001, 2006-2012

Tuning with Canadian survey for 1978 to 1985

EU survey for 1988 to 2012

Ages from 1 to 8+ in all cases

Catchability analysis

Catchability dependent on stock size for ages 1 and 2

Priors over parameters:

Priors over the survivors:

For (2012, a), a=1,…,7 and (y, 7), y=1972,…, 2011

$$surv(y,a) \sim LN\left(median = medrec \times e^{-medM - \sum_{age=1}^{a} medFsurv(age)}, cv = cvsurv \right),$$

where medrec=15000

medFsurv(1,…,7)={0.0001, 0.1, 0.5, 0.7, 0.7, 0.7, 0.7}

cvsurv=1

Prior over F for years with no catch-at-age:

For a=1,…,7 and y=2002,…,2005

$$F(y,a) \sim LN\left(median = medF(a),\ cv = cvF\right)$$

where medF=c(0.0001, 0.005, 0.01, 0.01, 0.01, 0.005, 0.005)

cvsurv=0.7

Prior over the total catch in the years with no catch-at-age data:

For y=2002,…,2005

$$CW(y) \sim LN\left(median = CW_{\mathrm{mod}}(y),\ cv = cvCW\right)$$

where CW_{mod} is arised from the Baranov equation

cvCW=0.05

Prior over the survey abundance at age indices:

For a=1,…,8 and y=1978,...,1985 (Canadian survey) and y=1988,…,2012 (EU survey)

$$I(y) \sim LN\left(median = \mu(y,a),\ cv = \sqrt{e^{\frac{1}{\psi(a)}} - 1}\right)$$

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

$$\gamma(a)\begin{cases} \sim N(\text{mean} = 1, \text{variance} = 0.25),\ if\ a = 1,2 \\ = 1,\ if\ a \geq 3 \end{cases}$$

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

$$\psi(a) \sim gamma(shape = 2, rate = 0.07)$$

where I is the survey abundance index

q is the survey catchability at age

N is the commercial abundance index

$\alpha = 0.5$, $\beta = 0.58$ (survey made in July)

Z is the total mortality

Prior over natural mortality, M:

$$M \sim LN(\text{median} = 0.218, cv = 0.3)$$

In 2008 STACFIS recommended *that retrospective analysis be performed as a standard diagnostic of the assessment with the Bayesian model*. So, six year retrospective plot was made.

Three years projections were made with four different scenarios, as later described, in order to see the possible evolution of the stock. The settings and the results are explained above.

Results

Assessment results regarding to total biomass, SSB, recruitment and F_{bar} (ages 3-5) are presented in Table 8 and Figure 12. The SSB graph also includes the expected value at the beginning of the year 2013. To calculate it, weight-at-age and maturity-at-age random draws from the three last years with data were used (assuming always that maturity at age 1 is equal to 0, as there is no estimate of recruitment in 2013). The results indicate that there has been a substantial increase in SSB in the last few years, with the largest increase occurring from 2007 onwards. SSB in 2009 (and even its confidence intervals) are well above B_{lim}, and in 2011 is the second highest value of the time series, only below the 1972 value. In 2012 the value decreased below the 2010 value, but it is still between the highest of the entire series. The SSB at the beginning of 2013 is expected to be the highest of the series, although the uncertainty associated with this value is very high and year by year the projection value is always larger than the actual one. It must be taking into account that to calculate this value the mean of the last three years maturity was used, but as the age of first maturation is decreasing it is expected that next year this value will remain at similar levels of 2010-2012 range.

Recruitment has an increasing trend since 2005, being the 2010 and 2012 values at the level of the mean recruitment of the period and the 2011 value above it, although the actual recruitment levels for these years can not yet be precisely estimated (wide uncertainty limits in Figure 12 and Table 8).

F_{bar} (mean for ages 3-5) has been at very low levels in the period 2001-2009 (Figure 12), although an unusual high value has been estimated for 2006. In 2010, when the fishery was reopen, the F_{bar} has increased up to 0.28, although the 5 500 tons TAC corresponded to a target F_{bar} around 0.14 was established. In 2011, with a TAC of 10 000 tons corresponding to a target F_{bar} around 0.13, a F_{bar} of 0.33 was estimated. In 2012 F_{bar} is around 0.36, while the TAC of 9 280 was established under a F_{bar} of 0.13. Table 9 and Figure 14 provide more detailed information on the estimated F-at-age values, indicating that the increase in F_{bar} in 2006 is mostly due to fishing mortality at age 3. In 2010 the highest fishing mortalities are in ages 4 and 6; in 2011 in 5-8+ and in 2012 in 5-6, mainly 5. To illustrate these changes, in Figure 15 a plot of the PR along the years is provided, being the PR the F divided by F_{bar}.

Figure 13 shows total biomass and abundance by year. Except in the first years of the assessment and the period 1985-1989, there is a good concordance between numbers and weight, although in last years biomass has increased more than abundance. It must be noted that, although SSB is in 2010 at the level of the beginning of the time series (Figure 12), total biomass and abundance have not reached yet the highest analysed level.

Estimates of stock abundance at age for 1972-2012 are presented in Table 10 and Figure 16. Abundance at age in 2013 are the survivors of the same cohort in 2012, the last assessment year, so only abundances of ages older than age 1 can be estimated. It can be seen a general increase trend in all the age numbers since 2005 and in the total number of matures, although since the reopening of the fishery ages 6 and 7 have suffered a slight decrease.

Figure 17 depicts the prior and posterior distributions of survivors at age at the end of the final assessment year, where by survivors(2012, a) it is meant individuals of age a + 1 at the beginning of 2013 (in other words, survivors(2012, a) = N(2013, a + 1)). The plotting range for the horizontal axis is the 95% prior credible interval in all cases, to facilitate comparison between prior and posterior distributions; the same procedure will be followed in all subsequent prior-posterior plots. There has been substantial updating of the prior distribution for survivors.

Figure 18 displays prior and posterior distributions 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 in 1996, between 2002 and 2005 and in years 2008 and 2010.

In Figure 19 the priors and posteriors for the total catch in 2011and 2012 are shown. In both cases, although there is a small update of the total catch, with a posterior value a little greater than the prior value, the update is no important. While the median of the priors is 12 836 tons (exp(9.46)), the posterior medians are 13 640 tons for 2011 and 13 670 tons for 2012.

Figure 20 shows the prior and the posterior of the natural morality, M. In this case the posterior indicates that an M of value 0.2 is overestimated, as the posterior median is 0.1462.

Bubble plot of standardised residuals (observed minus fitted values divided by estimated standard deviations and in logarithmic scale) for the survey abundance at age indices is displayed in Figure 21 for the Canadian survey and in Figure 22 for the EU survey. 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. This graph should highlight year effects, identified as years in which most of the residuals are above or below zero.

For the Canadian survey, a value near -2 is the age 7 of year 1985, so it could be seen that there are a few of values higher than 2 in absolute value. For years 1978-1981 all the ages higher than 3 have positive values while year 1982 has all its residuals except for age 1 negative or near 0, suggesting year effects (i.e. survey catchabilities that are below average in 1982 and above average in 1978-1981).

For the EU survey a value near to -2 is age 3 of year 2004. In the case of this survey almost all residuals are below 2 in absolute value, and all of them happened before 2005. In 1988 all residuals are negative except for the one for age 7, whereas the opposite happens in 1996, 1997 and 2011, suggesting year effects (i.e. survey catchabilities that are below average in 1988 and above average in 1996, 1997 and 2011). All residuals were positive in 2008-2010 except for ages 1 in 2008, 1 and 2 in 2009 and 5 and 7 (this last value is almost 0) in 2010. In 2012 all the standardized residuals except age 3 are positive.

Biological Referent Points

Figure 24 shows a SSB-Recruitment plot and Figure 25 a SSB-F_{bar} plot, both with the 14 000 value of B_{lim} indicated with a vertical red line. The value of B_{lim} appears as a reasonable choice for B_{lim}: only low recruitments have been observed with SSB below this level whereas both high and low recruitments have been seen at higher SSB values. SSB is well above B_{lim} in 2012. Figure 25 shows the Bayesian Yield per Recruit with respect to F_{bar}, in which the estimated values for $F_{0.1}$ (0.085), F_{max} (0.14) and F_{2010} (0.363) are indicated.

Retrospective pattern

A retrospective analysis of six years was made (Figure 26). Retrospective analysis show an underestimation in the last two years after several years of underestimation. SSB has shown a large revision with no systematic patterns. Fishing mortality presents an overestimation in the last two years.

The results of the retrospective analysis are quite different from what we saw in last year assesment. Further studies can be necessary.

Recruits per Spawner

Figure 27 displays the Recruits per Spawner. The variability over the years of the assessment is very high.

Projections

Stochastic projections over a three years period (2013-2015) have been performed. Variability of input data was taken from the results of the Bayesian assessment. Input data were as follows:

Numbers aged 2 to 8+ in 2013: estimates from the assessment

Recruitments for 2013-2015: Recruits per spawner were estimated for each year (Figure 20). As the variability over the years of the assessment is very high, using just the last 3 years was not considered realistic. Hence, in the projections, recruits per spawner were drawn randomly from the last eight years of the assessment (2005-2012), as these are the years in which recruitment has started to recover.

Maturity ogive: 2012 maturity ogive

Weight-at-age in stock and weight-at-age in catch: 2012 weight-at-age in catch and in stock (Tables 3 and 6).

PR at age for 2013-2015: Mean of 2011 and 2012 PRs (Figure 15).

F_{bar}(ages 3-5): Four options were considered. All Scenarios assumed that the 2013 catch is the TAC (14 113 tons):

1. $F_{0.1}$ (median value at 0.085).
2. F_{max} (median value at 0.14).
3. $F_{statusquo}$ (median value at 0.363).
4. Additionally, a projection based in a constant catch equal to the TAC of 2013 (14 113 t) was performed.

Results for the six options are presented in Tables 11-18 and Figure 28. They indicate that fishing at any of the considered values of F_{bar}, total biomass and SSB during the next 3 years have high probability of reaching levels equal or higher than all of the 1972-2012 estimates. Depending of the projection, the number of matures has a variable probability of being above the level of the previous year, that indicates that the SSB increased more that the number of matures. The removals associated with these F_{bar} levels are lower than those in the period before 1995 except in the case of F_{bar}=F_{2012}, for which the catches reach the level seen until 1979 and before the collapse of the stock.

Results indicate that fishing at the F_{bar} level currently estimated for 2012 should allow SSB to increase, although abundance will increase at a less degree. Under all scenarios there is a very low probability (<5%) of SSB being below B_{lim}.

The projected values for the period 2013-2015 are heavily reliant on the relatively abundant eight most recent cohorts, namely those recruited in 2005-2012, especially the 2010 cohort, which is estimated to be extremely large, but with high uncertainty.

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Table 1.- Total commercial cod catch in Division 3M. Reported nominal catches since 1960 and estimated total catch since 1988 in tons

Year	Estimated[1]	Portugal	Russia	Spain	France	Faroes	UK	Poland	Norway	Germany	Cuba	Others	Total
1960		9	11595	607					46	86		10	12353
1961		2155	12379	851	2626		600	336		1394		0	20341
1962		2032	11282	1234			93	888	25	4		349	15907
1963		7028	8528	4005	9501		2476	1875				0	33413
1964		3668	26643	862	3966		2185	718	660	83		12	38797
1965		1480	37047	1530	2039		6104	5073	11	313		458	54055
1966		7336	5138	4268	4603		7259	93		259		0	28956
1967		10728	5886	3012	6757		5732	4152		756		46	37069
1968		10917	3872	4045	13321		1466	71				458	34150
1969		7276	283	2681	11831					20		52	22143
1970		9847	494	1324	6239		3	53				35	17995
1971		7272	5536	1063	9006			19		1628		25	24549
1972		32052	5030	5020	2693	6902	4126	35	261	506		187	56812
1973		11129	1145	620	132	7754	1183	481	417	21		18	22900
1974		10015	5998	2619		1872	3093	700	383	195		63	24938
1975		10430	5446	2022		3288	265	677	111	28		108	22375
1976		10120	4831	2502	229	2139		898	1188	225		134	22266
1977		6652	2982	1315	5827	5664	1269	843	867	45	1002	553	27019
1978		10157	3779	2510	5096	7922	207	615	1584	410	562	289	33131
1979		9636	4743	4907	1525	7484		5	1310		24	76	29710
1980		3615	1056	706	301	3248		33	1080	355	1	62	10457
1981		3727	927	4100	79	3874			1154			12	13873
1982		3316	1262	4513	119	3121	33		375			14	12753
1983		2930	1264	4407		1489			111	3		1	10205
1984		3474	910	4745		3058			47	454	5	9	12702
1985		4376	1271	4914		2266			405	429	9	5	13675
1986		6350	1231	4384		2192				345	3	13	14518
1987		2802	706	3639	2300	916						269	10632
1988	28899	421	39	141		1100					3	14	1718
1989	48373	170	10	378								359	917
1990	40827	551	22	87		1262						840	2762
1991	16229	2838	1	1416		2472	26		897		5	1334	8989
1992	25089	2201	1	4215		747	5				6	51	7226
1993	15958	3132	0	2249		2931						4	8316
1994	29916	2590	0	1952		2249			1			93	6885
1995	10372	1641	0	564		1016						0	3221
1996	2601	1284	0	176		700	129			16		0	2305
1997	2933	1433	0	1			23					0	1457
1998	705	456	0									0	456
1999	353	2	0									0	2
2000	55	30	6									0	36
2001	37	56	0									0	56
2002	33	32	1									0	33
2003	16	7	0									9	16
2004	5	18	2									3	23
2005	19	16	0			7						3	26
2006	339	51	1	16								55	123
2007	345	58	6	33								28	125
2008	889	219	74	42		0						66	401
2009	1161	856	87	85		22						122	1172
2010	9192	1482	374			1183	761		519			85	4404
2011	n.a.	2412	655	1609	200	2211	1063		1117		185	342	9794
2012	n.a.	2663	745	1597		2045	868		826		172	87	9003

[1] Recalculated from NAFO Statistical data base using the NAFO 21A Extraction Tool

Table 2.- Catch-at-age (thousands)

	1	2	3	4	5	6	7	8+
1972	0	0	278	19303	12372	6555	3083	3177
1973	0	0	2035	116	11709	3470	853	1085
1974	0	0	5999	11130	2232	1894	271	257
1975	0	0	7090	2436	1241	238	281	258
1976	0	0	17564	10653	386	100	63	5
1977	0	0	119	17581	8502	436	267	318
1978	0	0	428	3092	18077	3615	329	270
1979	0	0	167	2616	5599	5882	316	137
1980	0	0	551	500	1423	1051	1318	96
1981	0	0	1732	6768	161	326	189	539
1982	0	0	21	3040	1926	310	97	357
1983	0	0	2818	713	765	657	94	131
1984	0	0	9	2229	966	59	90	146
1985	0	0	19	5499	3549	1232	931	218
1986	0	2549	2266	4251	2943	1061	169	162
1987	814	1848	3102	1915	1259	846	313	112
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
2008	1	89	136	133	3	40	1	3
2009	0	23	51	210	108	0	32	7
2010	34	452	1145	1498	808	388	4	103
2011[1]	0.003	0.098	0.293	0.126	0.198	0.161	0.063	0.056
2012[1]	0.008	0.080	0.297	0.171	0.199	0.136	0.061	0.048

[1] As there is no total catch available, the proportion of number per age is given

Table 3.- Weight-at-age (kg) in catch

	1	2	3	4	5	6	7	8+
1972			0.811	0.722	0.981	1.500	1.930	2.296
1973			0.633	0.314	1.300	0.994	0.828	3.430
1974			0.657	0.805	1.769	2.829	3.983	7.701
1975			0.697	1.636	1.798	2.658	3.766	6.497
1976			0.671	1.293	4.192	5.085	5.923	6.298
1977			0.314	0.845	1.400	3.433	5.156	7.722
1978			0.374	0.600	1.102	1.582	2.658	6.351
1979			0.790	1.070	1.480	2.450	4.350	7.079
1980			0.859	1.137	1.747	2.466	3.167	4.676
1981			0.620	1.250	1.880	2.680	3.190	4.747
1982			0.760	1.340	2.450	2.870	4.680	6.146
1983			1.330	1.140	2.240	3.530	4.760	9.163
1984			0.460	1.866	3.695	3.660	6.588	6.655
1985			0.283	0.851	1.605	2.816	4.522	7.978
1986		0.165	0.411	0.784	1.631	2.836	4.317	7.389
1987	0.091	0.133	0.327	1.040	1.890	2.993	4.440	7.630
1988	0.058	0.198	0.442	0.821	2.190	3.386	5.274	7.969
1989		0.209	0.576	0.918	1.434	2.293	4.721	7.648
1990	0.080	0.153	0.500	0.890	1.606	2.518	3.554	7.166
1991	0.118	0.229	0.496	0.785	1.738	2.622	3.474	6.818
1992		0.298	0.414	0.592	1.093	1.704	2.619	3.865
1993		0.210	0.509	0.894	1.829	2.233	3.367	4.841
1994		0.289	0.497	0.792	1.916	2.719	2.158	4.239
1995			0.415	0.790	1.447	2.266	3.960	5.500
1996		0.286	0.789	1.051	1.543	2.429		
1997			0.402	0.640	0.869	1.197	1.339	
1998			0.719	1.024	1.468	1.800	2.252	3.862
1999			0.920	1.298	1.848	2.436	3.513	4.893
2000		0.583	0.672	1.749	2.054	2.836	3.618	
2001		0.481		1.696	2.560		3.905	5.217
2002		0.588	1.323	1.388	2.572	3.770	5.158	5.603
2003		0.462	1.063	1.455	2.978	3.696	5.859	6.120
2004		0.839	1.677	2.009	3.353	5.576	6.241	8.273
2005		0.895	1.618	2.368	3.259	4.767	6.177	6.553
2006		1.081	1.462	2.283	3.966	5.035	6.332	
2007		0.974	1.858	3.388	4.062	6.128	6.809	9.440
2008	0.088	0.448	1.364	3.037	3.498	5.248	6.643	8.251
2009	0.172	0.507	1.026	2.087	3.727		5.900	9.534
2010	0.162	0.700	1.279	1.829	2.764	4.372	4.199	8.575
2011	0.086	0.396	0.938	1.517	2.211	3.551	6.062	9.086
2012	0.086	0.374	0.990	1.487	2.114	3.533	6.128	8.678

Table 4- Canadian bottom trawl survey abundance at age (thousands)

	1	2	3	4	5	6	7	8+
1978	0	95	4757	15531	45688	12135	476	570
1979	0	4675	1067	5619	5465	6676	1706	405
1980	0	1030	19475	2377	2990	2737	3912	224
1981	32	0	5172	15479	975	2108	1041	2211
1982	627	1781	21	1663	978	32	150	377
1983	293	71000	7817	319	2357	958	45	401
1984	43	1527	15834	1897	74	646	427	221
1985	39	520	6212	19955	774	50	105	196

Table 5.- EU bottom trawl survey abundance at age (thousands)

	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		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
2008	6090	16670	12440	4530	70	940	60	230	80	0	10	0	0	0
2009	5139	7479	16150	14310	4154	26	1091	0	335	0	0	14	0	0
2010	66370	27689	8654	7633	4911	1780	8	442	46	251	26	0	0	0
2011	347674	142999	16993	6309	7739	3089	1191	0	215	0	89	0	0	0
2012	103494	128087	10942	11721	4967	4781	1630	832	24	93	30	101	0	17

Table 6.- Weight-at-age (kg) in stock

	1	2	3	4	5	6	7	8+
1972	0.05	0.20	0.81	0.72	0.98	1.50	1.93	2.30
1973	0.05	0.20	0.63	0.31	1.30	0.99	0.83	3.43
1974	0.05	0.20	0.66	0.81	1.77	2.83	3.98	7.70
1975	0.05	0.20	0.70	1.64	1.80	2.66	3.77	6.50
1976	0.05	0.20	0.67	1.29	4.19	5.09	5.92	6.30
1977	0.05	0.20	0.31	0.85	1.40	3.43	5.16	7.72
1978	0.05	0.20	0.37	0.60	1.10	1.58	2.66	6.35
1979	0.05	0.20	0.79	1.07	1.48	2.45	4.35	7.08
1980	0.05	0.20	0.86	1.14	1.75	2.47	3.17	4.68
1981	0.05	0.20	0.62	1.25	1.88	2.68	3.19	4.75
1982	0.05	0.20	0.76	1.34	2.45	2.87	4.68	6.15
1983	0.05	0.20	1.33	1.14	2.24	3.53	4.76	9.16
1984	0.05	0.20	0.46	1.87	3.70	3.66	6.59	6.66
1985	0.05	0.20	0.28	0.85	1.61	2.82	4.52	7.98
1986	0.05	0.20	0.41	0.78	1.63	2.84	4.32	7.39
1987	0.05	0.20	0.33	1.04	1.89	2.99	4.44	7.63
1988	0.03	0.10	0.31	0.68	1.97	3.59	5.77	6.93
1989	0.04	0.24	0.54	1.04	1.60	2.51	4.27	6.93
1990	0.04	0.17	0.34	0.85	1.50	2.43	4.08	5.64
1991	0.05	0.17	0.50	0.86	1.61	2.61	4.26	7.69
1992	0.05	0.25	0.49	1.38	1.70	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	0.80	1.32	2.27	4.00	5.03
1997	0.08	0.32	0.64	1.00	1.31	2.10	2.00	9.57
1998	0.07	0.36	0.75	1.19	1.66	1.99	3.10	7.40
1999	0.10	0.37	0.92	1.30	1.85	2.44	3.51	4.89
2000	0.10	0.58	0.96	1.61	1.91	2.83	3.47	5.28
2001	0.08	0.48	1.25	1.70	2.56	3.42	3.91	5.22
2002	0.00	0.42	1.12	1.43	2.47	3.59	4.86	5.31
2003	0.05	0.33	0.90	1.50	2.86	3.52	5.52	5.80
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		6.21
2006	0.09	0.7	1.06	2.49	3.57	4.69	5.76	9.55
2007	0.05	0.59	1.60	3.40	4.01	5.69	6.27	8.76
2008	0.07	0.38	1.34	2.69	3.19	5.02	6.32	7.94
2009	0.08	0.41	0.98	2.07	3.88	6.96	6.58	9.46
2010	0.06	0.38	1.09	1.68	2.96	5.38	7.62	9.14
2011	0.04	0.23	0.97	1.70	2.45	3.74	6.26	9.67
2012	0.07	0.37	0.73	1.35	1.99	2.66	4.93	7.81

Table 7.- Maturity at age (median values of ogives)

	1	2	3	4	5	6	7	8+
1972	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000
1973	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000
1974	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000
1975	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000
1976	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000
1977	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000
1978	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000
1979	0.000	0.000	0.000	0.008	0.154	0.813	0.991	1.000
1980	0.000	0.000	0.002	0.029	0.302	0.862	0.989	1.000
1981	0.000	0.000	0.005	0.104	0.716	0.982	0.999	1.000
1982	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000
1983	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000
1984	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000
1985	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000
1986	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000
1987	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000
1988	0.054	0.099	0.175	0.291	0.441	0.603	0.745	0.879
1989	0.054	0.099	0.175	0.291	0.441	0.603	0.745	0.879
1990	0.054	0.099	0.175	0.291	0.441	0.603	0.745	0.879
1991	0.018	0.045	0.111	0.247	0.463	0.687	0.849	0.951
1992	0.002	0.011	0.048	0.184	0.503	0.819	0.953	0.993
1993	0.001	0.007	0.049	0.282	0.751	0.959	0.994	1.000
1994	0.000	0.001	0.050	0.657	0.986	1.000	1.000	1.000
1995	0.000	0.000	0.006	0.803	1.000	1.000	1.000	1.000
1996	0.000	0.000	0.029	0.666	0.993	1.000	1.000	1.000
1997	0.000	0.008	0.111	0.670	0.971	0.998	1.000	1.000
1998	0.000	0.002	0.096	0.874	0.998	1.000	1.000	1.000
1999	0.000	0.001	0.130	0.902	0.999	1.000	1.000	1.000
2000	0.000	0.001	0.160	0.971	1.000	1.000	1.000	1.000
2001	0.000	0.001	0.315	0.998	1.000	1.000	1.000	1.000
2002	0.000	0.010	0.636	0.997	1.000	1.000	1.000	1.000
2003	0.001	0.024	0.513	0.978	0.999	1.000	1.000	1.000
2004	0.000	0.000	0.100	0.967	1.000	1.000	1.000	1.000
2005	0.041	0.171	0.502	0.830	0.959	0.991	0.998	1.000
2006	0.000	0.014	0.365	0.959	0.999	1.000	1.000	1.000
2007	0.000	0.012	0.261	0.920	0.997	1.000	1.000	1.000
2008	0.000	0.012	0.231	0.882	0.995	1.000	1.000	1.000
2009	0.000	0.010	0.181	0.830	0.991	1.000	1.000	1.000
2010	0.000	0.009	0.167	0.812	0.989	1.000	1.000	1.000
2011	0.001	0.008	0.072	0.428	0.878	0.986	0.999	1.000
2012	0.000	0.000	0.018	0.578	0.990	1.000	1.000	1.000

Table 8.- Posterior results: total biomass, SSB, recruitment (tons) and F_{bar}.

	B quantiles			SSB quantiles			R quantiles			F_{bar} quantiles		
Year	**50%**	**5%**	**95%**	**50%**	**5%**	**95%**	**50%**	**5%**	**95%**	**50%**	**5%**	**95%**
1972	81869	77954	87248	36391	33426	39783	15740	13460	19321	0.714	0.677	0.743
1973	48275	45408	52355	20050	16934	23389	54135	45019	68520	0.606	0.561	0.631
1974	51301	47101	57706	14862	13113	19350	107400	89418	135600	1.411	1.237	1.522
1975	64896	58466	74229	7613	6147	11532	19850	16070	25860	0.710	0.599	0.790
1976	106227	97549	118469	8451	6495	12151	8820	7324	11210	0.357	0.324	0.385
1977	81657	75916	89806	20662	16848	26589	2592	2062	3450	0.480	0.448	0.505
1978	55394	52039	60057	28139	23197	33378	17680	14780	22220	0.488	0.451	0.515
1979	48707	45029	54477	23838	21044	28364	11810	9756	15050	0.743	0.681	0.797
1980	30183	27316	34896	11425	9665	15318	6535	5197	8780	0.582	0.532	0.620
1981	33191	28872	39331	13055	9259	18706	18210	15040	23211	0.524	0.489	0.554
1982	29094	26646	32746	13004	11553	15511	17975	14750	22960	0.630	0.582	0.668
1983	38683	35056	43782	11895	10309	14187	11320	9382	14450	0.295	0.265	0.321
1984	44399	40941	49244	19076	16846	22060	12785	10530	16391	0.247	0.226	0.262
1985	37662	35356	40889	20521	18952	22385	51070	42640	64322	0.600	0.549	0.634
1986	39350	35947	44396	15301	13718	17908	105700	90270	129500	0.779	0.717	0.825
1987	51802	47035	58484	12374	11052	14949	66980	57460	81442	0.458	0.409	0.495
1988	63728	59351	69748	18924	15232	23828	13800	11570	17280	0.520	0.479	0.554
1989	103430	97922	111045	33285	27199	40569	18600	16010	22540	0.877	0.825	0.918
1990	63588	60200	68123	25188	21602	29230	23560	20560	28020	0.915	0.862	0.958
1991	43553	40602	47659	17541	14866	20998	59850	53160	69812	0.504	0.473	0.529
1992	57327	54467	61254	20769	18316	23664	54180	47620	63781	1.563	1.490	1.619
1993	45298	42571	49147	10410	8813	12870	2924	2582	3453	1.044	0.980	1.097
1994	49101	46096	54070	21322	18493	26113	3996	3107	5541	0.963	0.919	0.997
1995	22330	21169	24071	19144	18004	20692	2109	1766	2655	1.417	1.278	1.518
1996	5685	5074	6607	3461	3072	4093	126	84	199	0.669	0.557	0.764
1997	4815	4110	5926	3259	2684	4178	121	80	193	0.749	0.610	0.897
1998	3520	2592	5059	3318	2403	4842	187	136	272	0.307	0.229	0.417
1999	2514	1712	3839	2375	1584	3681	32	23	47	0.290	0.218	0.381
2000	2322	1443	3847	2170	1297	3684	305	192	501	0.195	0.135	0.276
2001	1963	1367	2794	1776	1189	2593	541	343	852	0.035	0.025	0.052
2002	2312	1692	3139	2015	1415	2828	65	42	104	0.014	0.007	0.030
2003	2593	1993	3399	2325	1741	3098	1160	768	1796	0.011	0.006	0.018
2004	4178	3364	5199	3464	2719	4451	76	57	107	0.003	0.002	0.005
2005	4566	3781	5518	3786	3094	4649	3464	2403	5350	0.006	0.004	0.011
2006	6955	5662	8685	4089	3232	5105	7094	5046	10751	0.217	0.169	0.274
2007	12837	10400	16092	5787	4456	7558	9299	6813	13651	0.029	0.023	0.039
2008	19854	16285	25002	10059	8033	12779	7517	5572	11110	0.075	0.058	0.097
2009	30157	25200	37044	19205	15638	23980	12300	8102	19950	0.043	0.034	0.053
2010	44773	38194	53630	32152	26925	39152	19385	10520	36237	0.283	0.229	0.340
2011	52991	42770	66105	33436	26184	43515	48170	22210	103905	0.302	0.211	0.417
2012	62600	45499	86546	29060	20805	42129	28025	10279	73387	0.363	0.220	0.604
2013				53063	35646	78071						

Table 9.- F at age (posterior median)

Year	F at age							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8+**
1972	0.000	0.000	0.069	0.766	1.311	1.920	3.287	3.287
1973	0.000	0.000	0.124	0.035	1.661	2.162	2.133	2.133
1974	0.000	0.000	0.798	1.807	1.666	1.625	1.198	1.198
1975	0.000	0.000	0.209	0.855	1.083	0.758	1.208	1.208
1976	0.000	0.000	0.269	0.519	0.286	0.202	0.427	0.427
1977	0.000	0.000	0.009	0.442	0.990	0.568	1.187	1.187
1978	0.000	0.000	0.072	0.304	1.090	1.796	1.109	1.109
1979	0.000	0.000	0.098	0.759	1.374	1.383	0.710	0.710
1980	0.000	0.000	0.046	0.441	1.264	1.032	1.492	1.492
1981	0.000	0.000	0.238	1.106	0.232	1.132	0.473	0.473
1982	0.000	0.000	0.005	0.789	1.099	0.875	1.294	1.294
1983	0.000	0.000	0.253	0.202	0.431	1.579	0.675	0.675
1984	0.000	0.000	0.001	0.306	0.434	0.050	0.949	0.949
1985	0.000	0.000	0.002	0.718	1.085	1.650	2.706	2.706
1986	0.000	0.064	0.295	0.990	1.057	1.151	1.104	1.104
1987	0.013	0.022	0.098	0.410	0.871	0.986	1.346	1.346
1988	0.000	0.068	0.441	0.560	0.563	0.757	1.298	1.298
1989	0.000	0.005	0.446	0.873	1.317	0.899	1.201	1.201
1990	0.000	0.017	0.260	1.093	1.394	1.497	1.135	1.135
1991	0.000	0.030	0.527	0.369	0.618	0.795	1.043	1.043
1992	0.000	0.390	1.027	1.397	2.271	1.528	2.618	2.618
1993	0.000	0.063	0.726	1.285	1.126	1.854	1.279	1.279
1994	0.000	0.733	1.273	1.216	0.399	0.656	0.371	0.371
1995	0.000	0.000	0.317	1.468	2.483	3.280	1.539	1.539
1996	0.000	0.049	0.300	0.711	1.008	0.523	0.000	0.000
1997	0.000	0.000	0.872	0.568	0.806	0.771	0.572	0.572
1998	0.000	0.000	0.096	0.413	0.403	0.359	0.094	0.094
1999	0.000	0.000	0.197	0.248	0.408	0.129	0.051	0.051
2000	0.000	0.503	0.544	0.017	0.022	0.025	0.003	0.003
2001	0.000	0.037	0.000	0.064	0.040	0.000	0.015	0.015
2002	0.000	0.006	0.014	0.010	0.012	0.005	0.015	0.015
2003	0.000	0.005	0.010	0.010	0.010	0.005	0.004	0.004
2004	0.000	0.001	0.005	0.002	0.002	0.004	0.001	0.001
2005	0.000	0.005	0.004	0.009	0.005	0.004	0.003	0.003
2006	0.000	0.008	0.454	0.125	0.066	0.045	0.016	0.016
2007	0.000	0.000	0.013	0.022	0.053	0.048	0.075	0.075
2008	0.000	0.012	0.028	0.068	0.126	0.098	0.060	0.060
2009	0.000	0.004	0.008	0.053	0.069	0.000	0.100	0.100
2010	0.002	0.047	0.251	0.323	0.276	0.354	0.275	0.275
2011	0.000	0.037	0.237	0.238	0.421	0.563	0.633	0.633
2012	0.002	0.012	0.146	0.201	0.703	0.549	0.407	0.407

Table 10.- N at age (posterior median), with the total number and number of matures (posterior median) by year.

	N at age									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**	**Total**	**Matures**
1972	15740	21780	4469	38820	18250	8293	3455	3432	114239	24762
1973	54135	13600	18820	3588	15580	4232	1044	1293	112292	14632
1974	107400	46765	11750	14360	2974	2545	418	391	186603	5052
1975	19850	92760	40400	4564	2026	483	431	390	160904	2480
1976	8820	17140	80160	28330	1672	589	195	15	136921	1876
1977	2592	7623	14810	52930	14570	1083	414	485	94507	9790
1978	17680	2235	6586	12680	29350	4665	530	428	74154	20658
1979	11810	15270	1931	5292	8072	8475	668	287	51805	9207
1980	6535	10200	13200	1512	2137	1759	1829	131	37303	4256
1981	18210	5643	8804	10890	838	519	541	1534	46979	4425
1982	17975	15725	4878	5996	3110	572	144	521	48921	4713
1983	11320	15530	13580	4188	2352	892	206	284	48352	4038
1984	12785	9788	13400	9102	2955	1317	158	254	49759	5601
1985	51070	11040	8450	11560	5780	1645	1076	244	90865	9445
1986	105700	44125	9534	7282	4865	1675	272	257	173710	7384
1987	66980	91330	35770	6131	2334	1454	456	160	204615	5247
1988	13800	57115	77225	28000	3504	841	467	236	181188	30912
1989	18600	11930	46080	42930	13790	1714	339	311	135694	30522
1990	23560	16070	10260	25470	15490	3176	600	183	94809	21564
1991	59850	20350	13650	6834	7371	3319	612	125	112111	11866
1992	54180	51720	17060	6957	4083	3420	1286	532	139238	9522
1993	2924	46790	30260	5277	1485	363	637	313	88049	5780
1994	3996	2526	37950	12650	1261	415	49	632	59479	12680
1995	2109	3434	1047	9171	3235	729	185	312	20222	11866
1996	126	1821	2963	658	1819	233	24	1	7645	2624
1997	121	109	1498	1894	278	572	119	1	4592	2454
1998	187	104	94	541	928	107	228	24	2213	1814
1999	32	161	90	73	309	534	65	22	1286	1040
2000	305	27	139	64	49	177	405	1	1167	746
2001	541	264	14	69	54	42	149	149	1282	473
2002	65	466	219	12	56	45	36	253	1152	559
2003	1160	56	399	186	10	48	38	247	2144	746
2004	76	1002	48	342	159	9	41	245	1922	802
2005	3464	66	864	41	295	137	8	248	5123	1333
2006	7094	2988	56	743	35	252	117	22	11307	1225
2007	9299	6110	2558	31	566	28	208	69	18869	1733
2008	7517	8039	5262	2169	26	462	23	64	23562	3876
2009	12300	6480	6828	4426	1744	20	360	81	32239	7296
2010	19385	10615	5556	5848	3616	1405	17	460	46902	11463
2011	48170	16700	8774	3717	3650	2364	851	756	84982	9860
2012	28025	41585	13845	5959	2515	2052	1148	902	96031	10842
2013[1]		24101	35596	10322	4196	1066	1017	1174	77472[1]	17638

[1] Results without recruitment data

Table 11.- N-at-age in prediction years (medians) with $F_{bar}=F_{0.1}=0.085$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2013	45364	24101	35596	10322	4196	1066	1017	1174	122836	15007
2014	63325	39108	20389	27098	7767	2602	638	1432	162359	29774
2015	124995	54478	33560	16637	21951	5798	1918	1590	260927	44304

Table 12.- Projections results with $F_{bar}=F_{0.1}=0.085$.

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2013	56681	84139	123214	23218	36274	53972	0.0002	14109	14113	14117
2014	73341	116604	180008	36290	61946	98400	0.0000	5253	9142	14787
2015	108560	171317	265541	60070	100614	165438	0.0000	9397	15640	25783

Table 13.- N-at-age in prediction years (medians) with $F_{max}=0.14$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2013	45431	24101	35596	10322	4196	1066	1017	1174	122903	15025
2014	62307	39058	20389	27098	7767	2602	638	1432	161291	29768
2015	124008	53778	33355	16061	21145	5291	1737	1446	256821	42154

Table 14.- Projections results with $F_{bar}=F_{max}=0.14$.

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2013	56319	84086	122757	23168	36277	54027	0.0000	14109	14113	14117
2014	73277	116617	178999	36528	62032	98464	0.0000	8536	14521	23305
2015	104107	164311	256187	56909	94836	157739	0.0000	14346	23494	38074

Table 15.- N-at-age in prediction years (medians) with $F_{bar}=F_{statusquo}=0.363$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2013	45454	24101	35596	10322	4196	1066	1017	1174	122926	15041
2014	63389	39335	20389	27098	7767	2602	638	1432	162650	29878
2015	122850	54505	32894	13918	17868	3576	1159	972	247742	34847

Table 16.- Projections results with $F_{bar}= F_{statusquo}=0.363$.

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2013	56621	84208	123004	23183	36460	54255	0.0004	14109	14113	14117
2014	73787	116640	179196	36862	61824	98655	0.0000	21512	32470	52390
2015	85144	142867	227577	40818	75177	131648	0.0000	27472	41778	66781

Table 17.- N-at-age in prediction years (medians) with $Catch_{2013\text{-}2015}=TAC_{2013}$=14 113 tons including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2013	45503	24101	35596	10322	4196	1066	1017	1174	122975	15062
2014	62739	39106	20389	27098	7767	2602	638	1432	161771	29932
2015	123902	54012	33403	16113	21221	5290	1735	1452	257128	42438

Table 18.- Projections results with $Catch_{2013\text{-}2015}=TAC_{2013}$=14 113 tons.

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**F quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2013	56613	84078	122899	23190	36230	54366	0.0004	0.1201	0.1913	0.3043
2014	73466	116513	178478	36807	62157	97733	0.0000	0.0830	0.1337	0.2285
2015	98745	165579	262320	51811	95533	164692	0.0000	0.0450	0.0787	0.1480

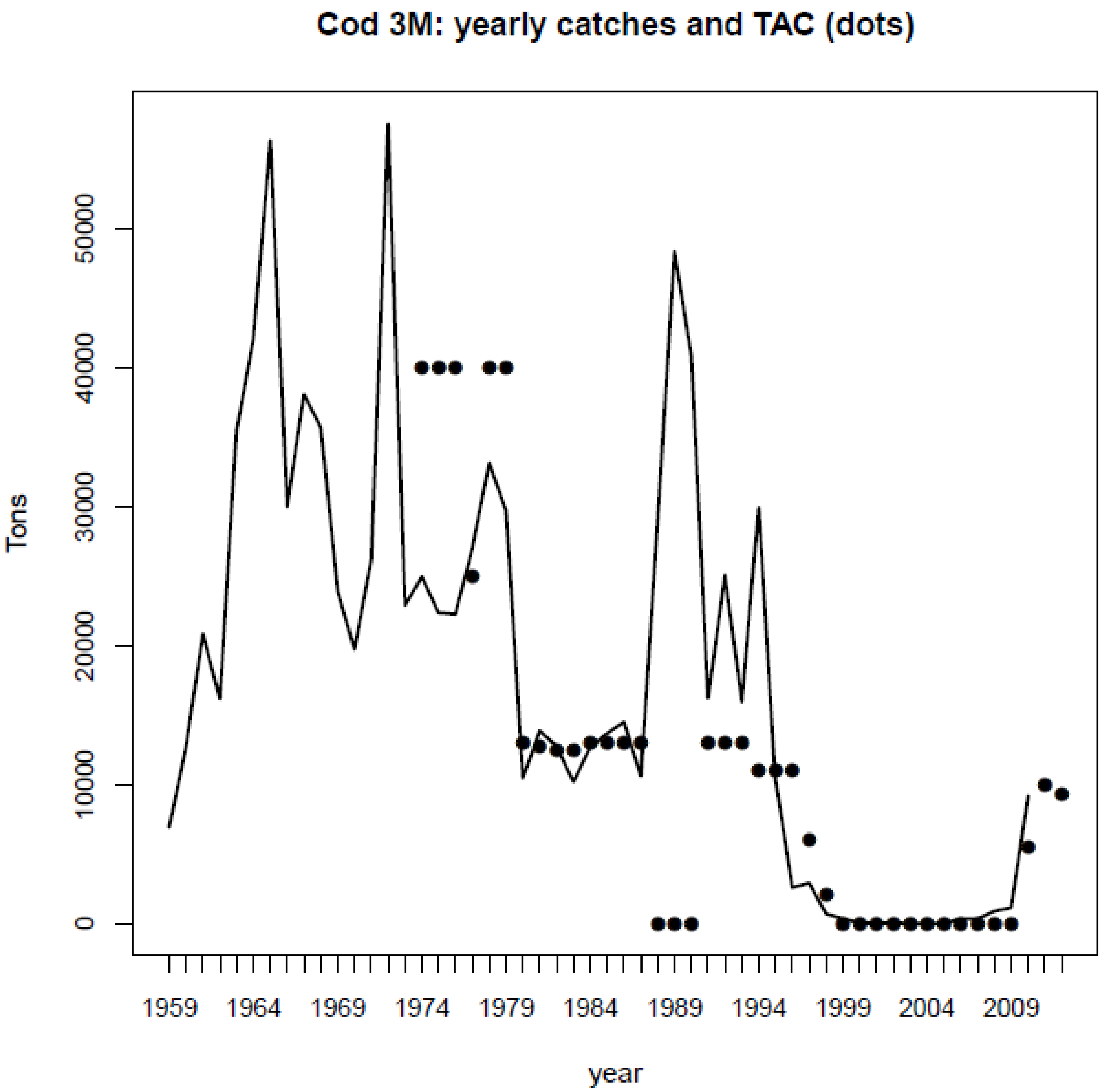

Figure 1.- Catch and TAC of the 3M cod for the period 1959-2012

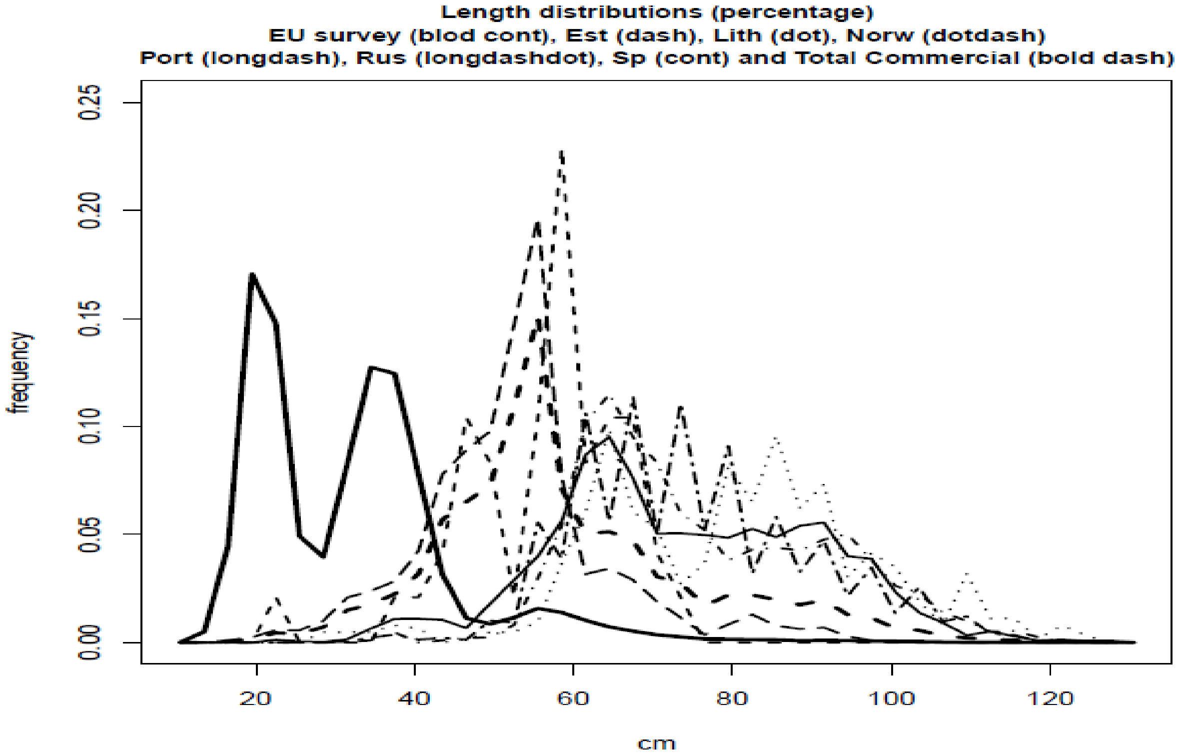

Figure 2.- Length frequencies in 2012. Lith: Lithuania; Est: Estonia; Norw: Norway; Port: Portugal; Rus: Russia; Sp: Spain

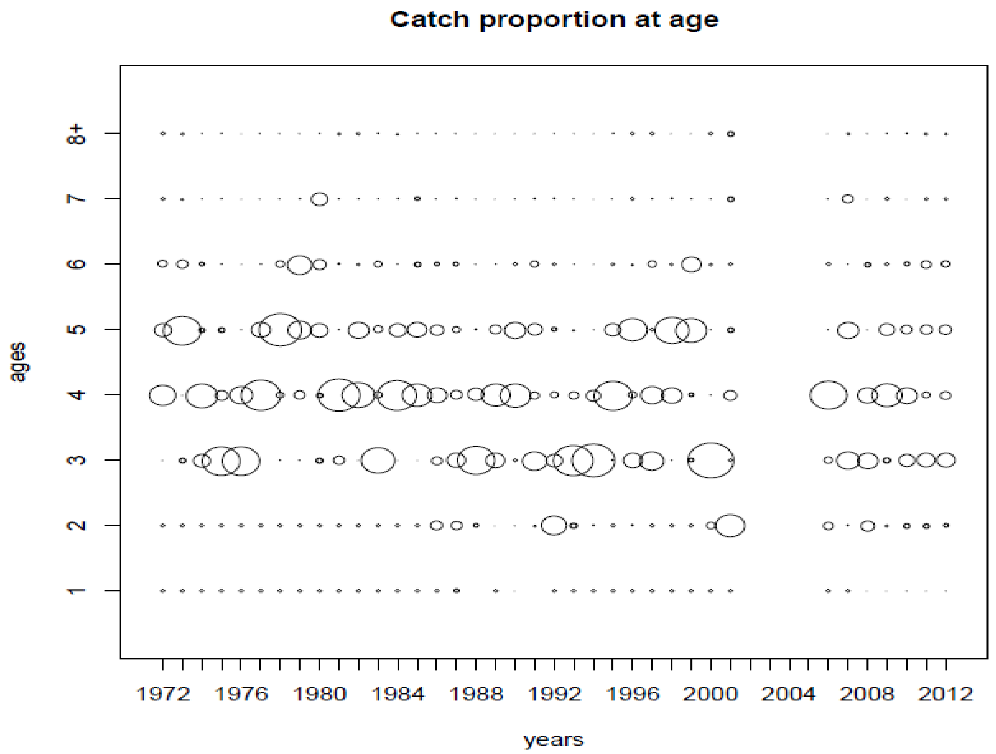

Figure 3.- Commercial catch proportions at age

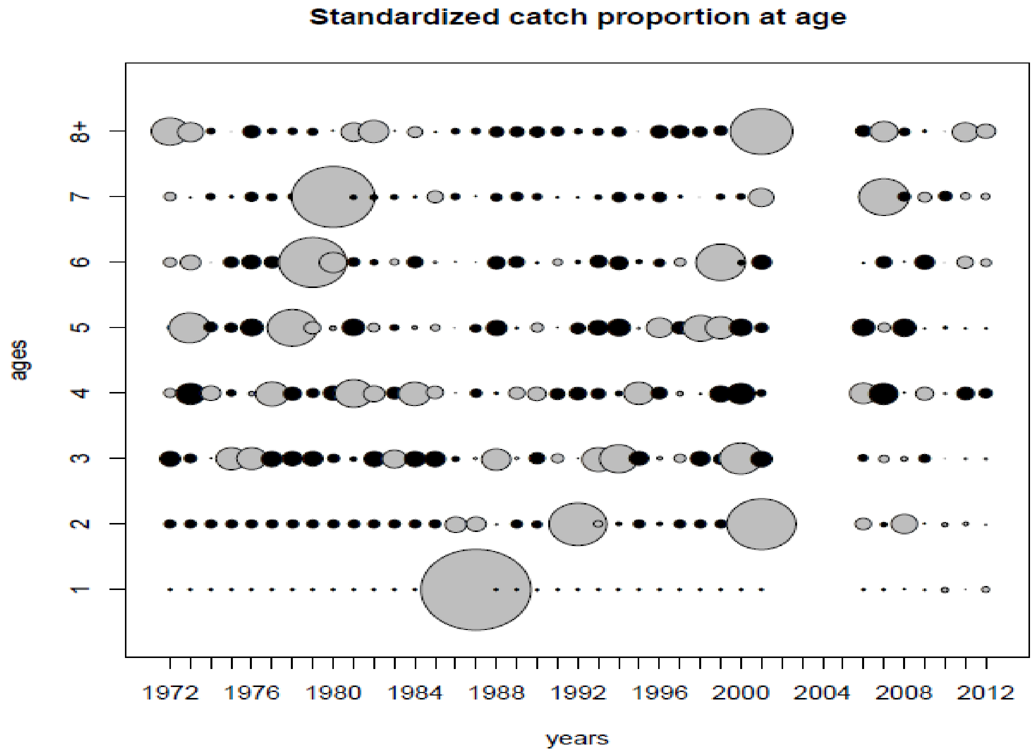

Figure 4.- Commercial catch standardised proportions at age. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

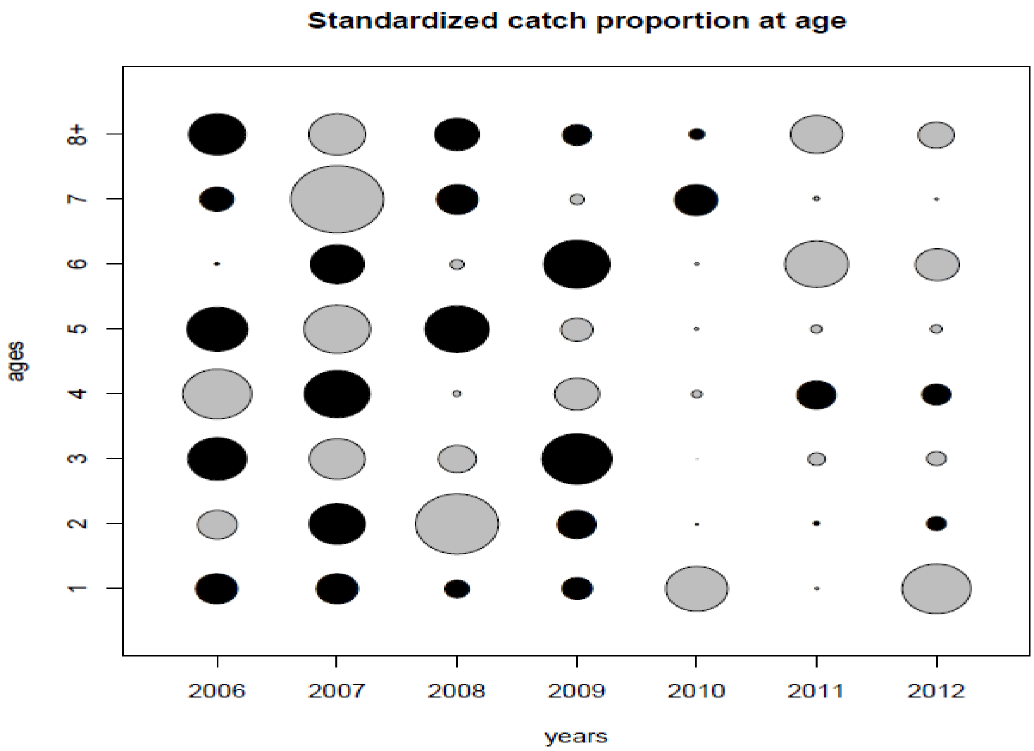

Figure 5.- Commercial catch standardised proportions at age for the last cohort. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

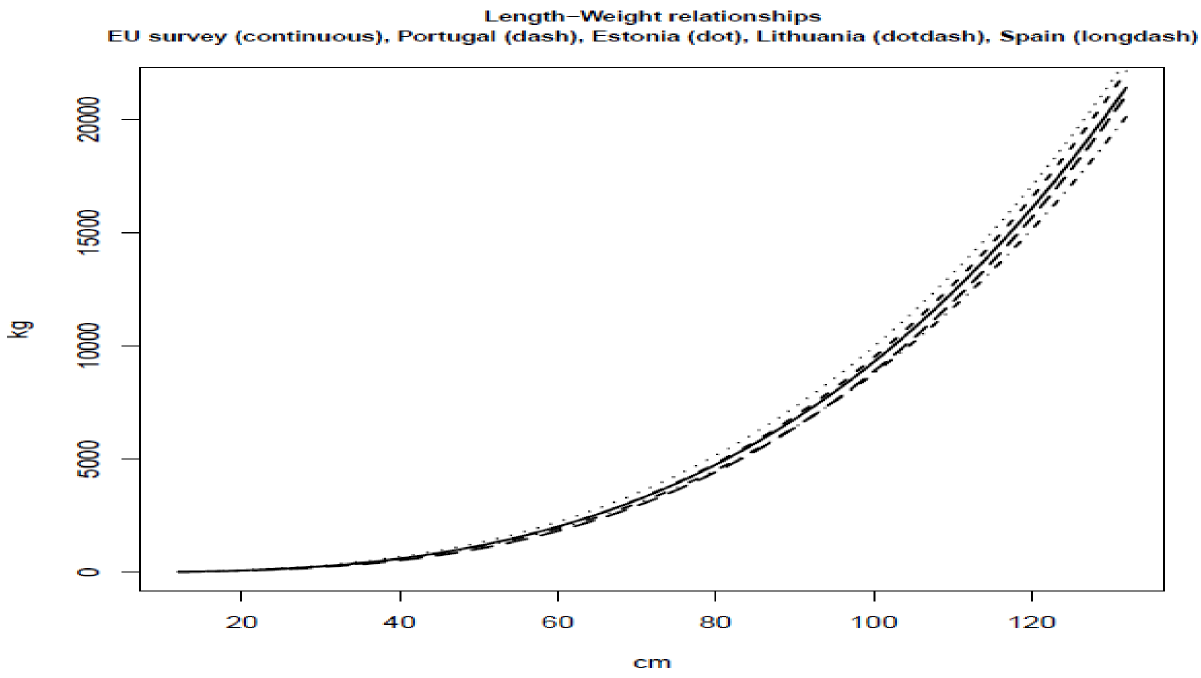

Figure 6.- Length-weight relationships for commercial and survey catches

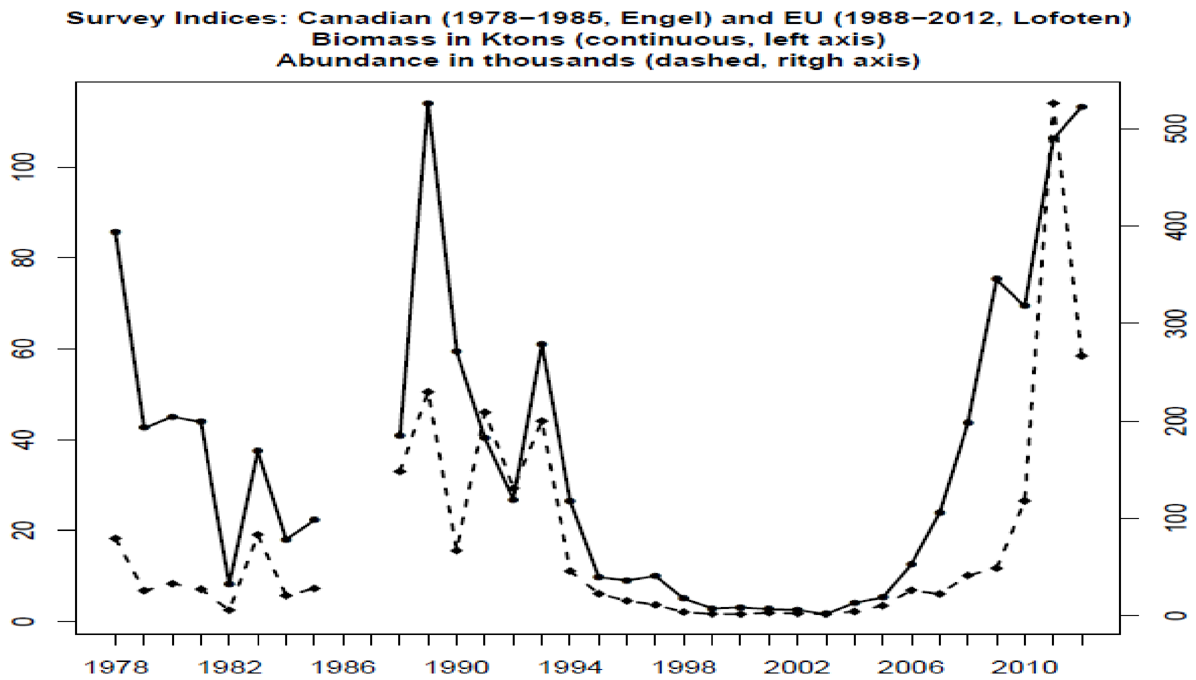

Figure 7.- Biomass and abundance from Canadian and EU surveys

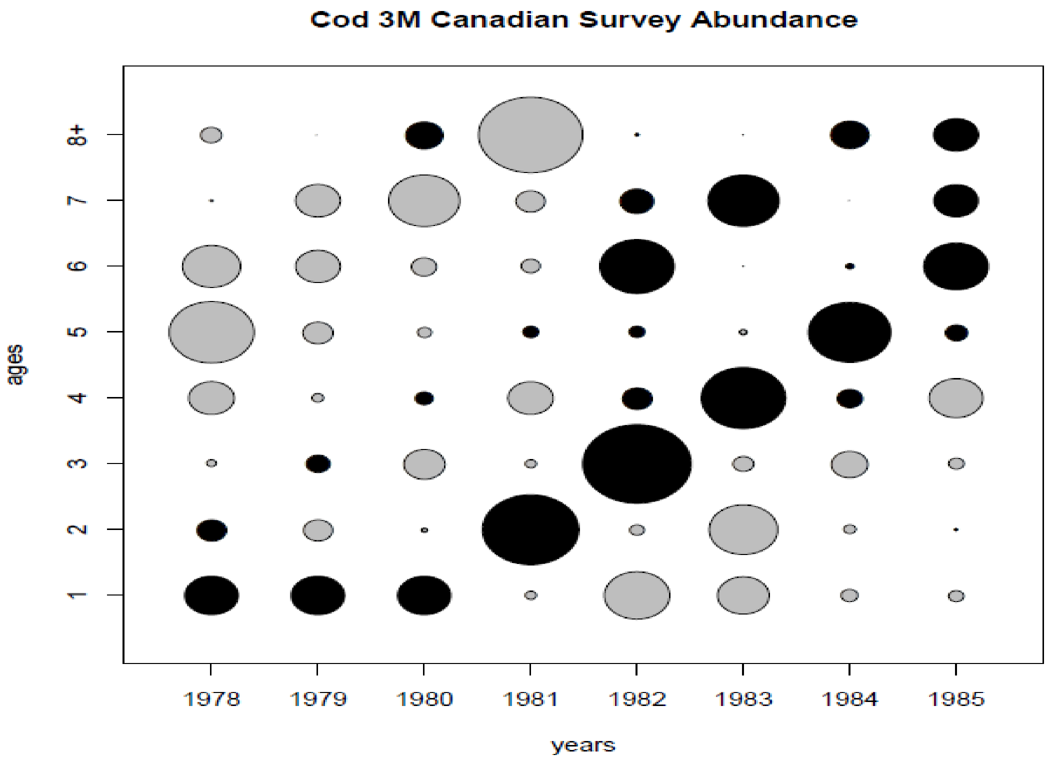

Figure 8.- Standardised log(1+Abundance at age) indices from Canadian survey. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

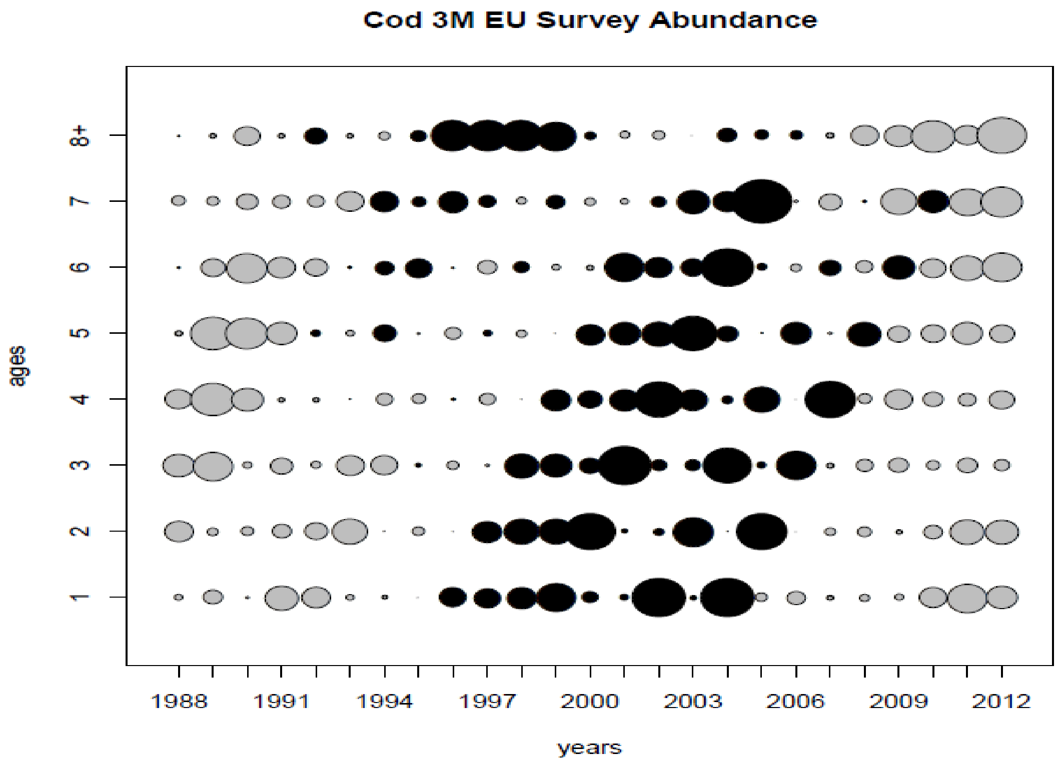

Figure 9.- Standardised log(1+Abundance at age) indices from EU survey. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

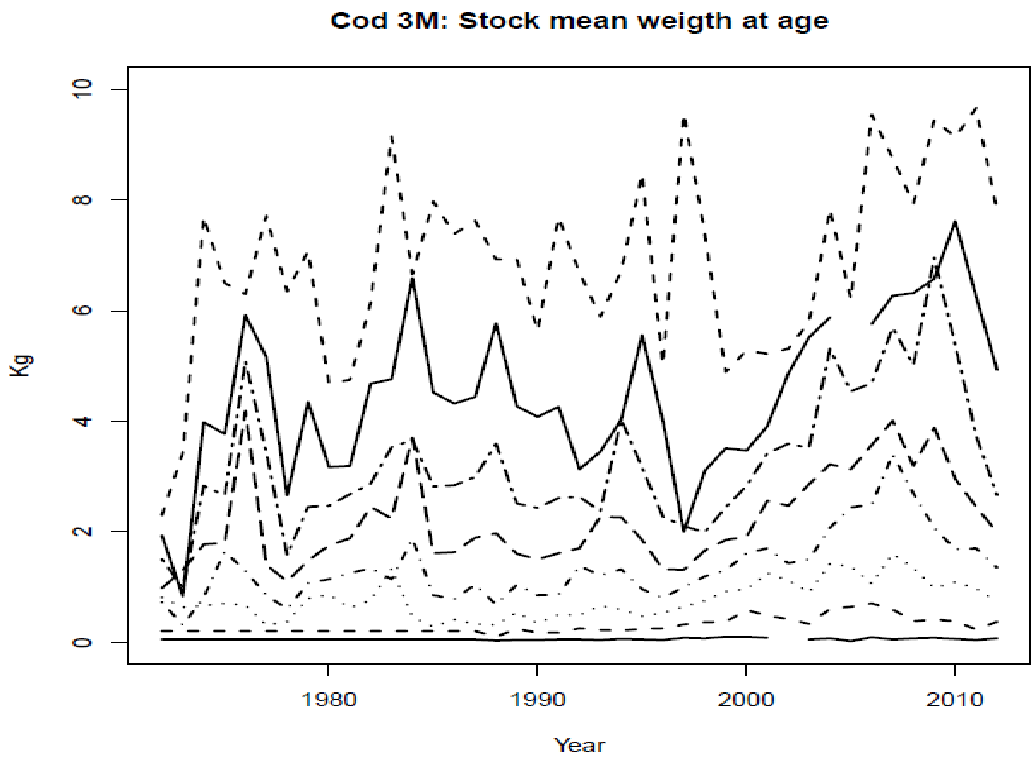

Figure 10.- Stock mean weight at age

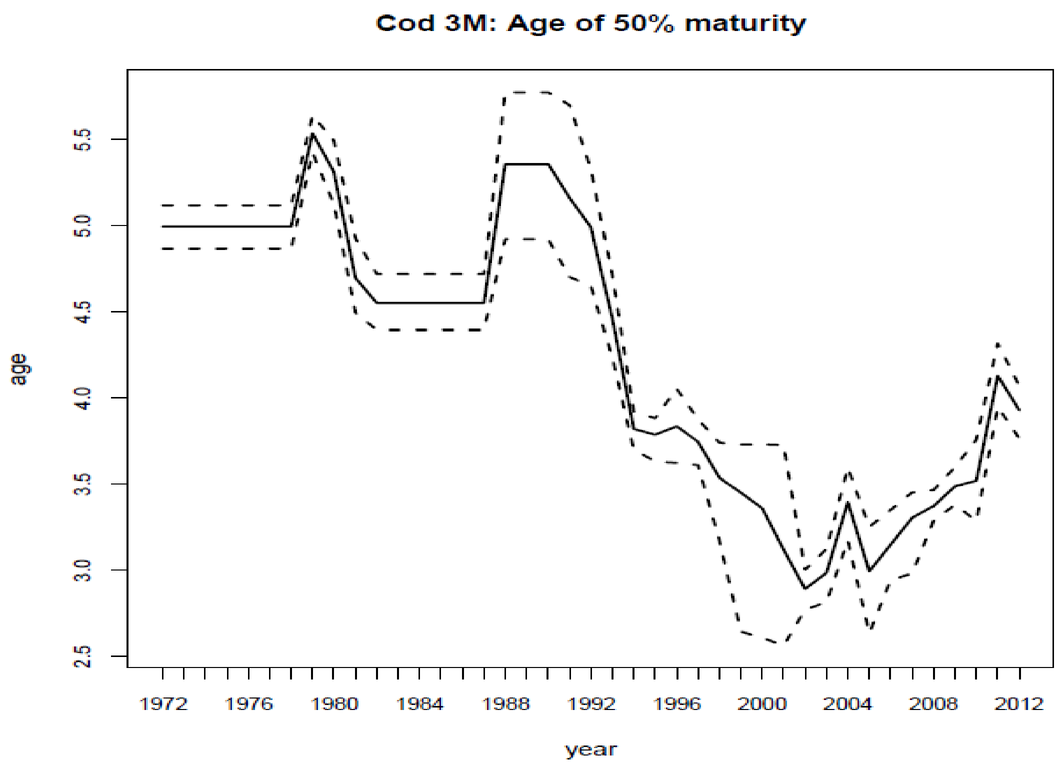

Figure 11.- Age at which 50% of fish are mature

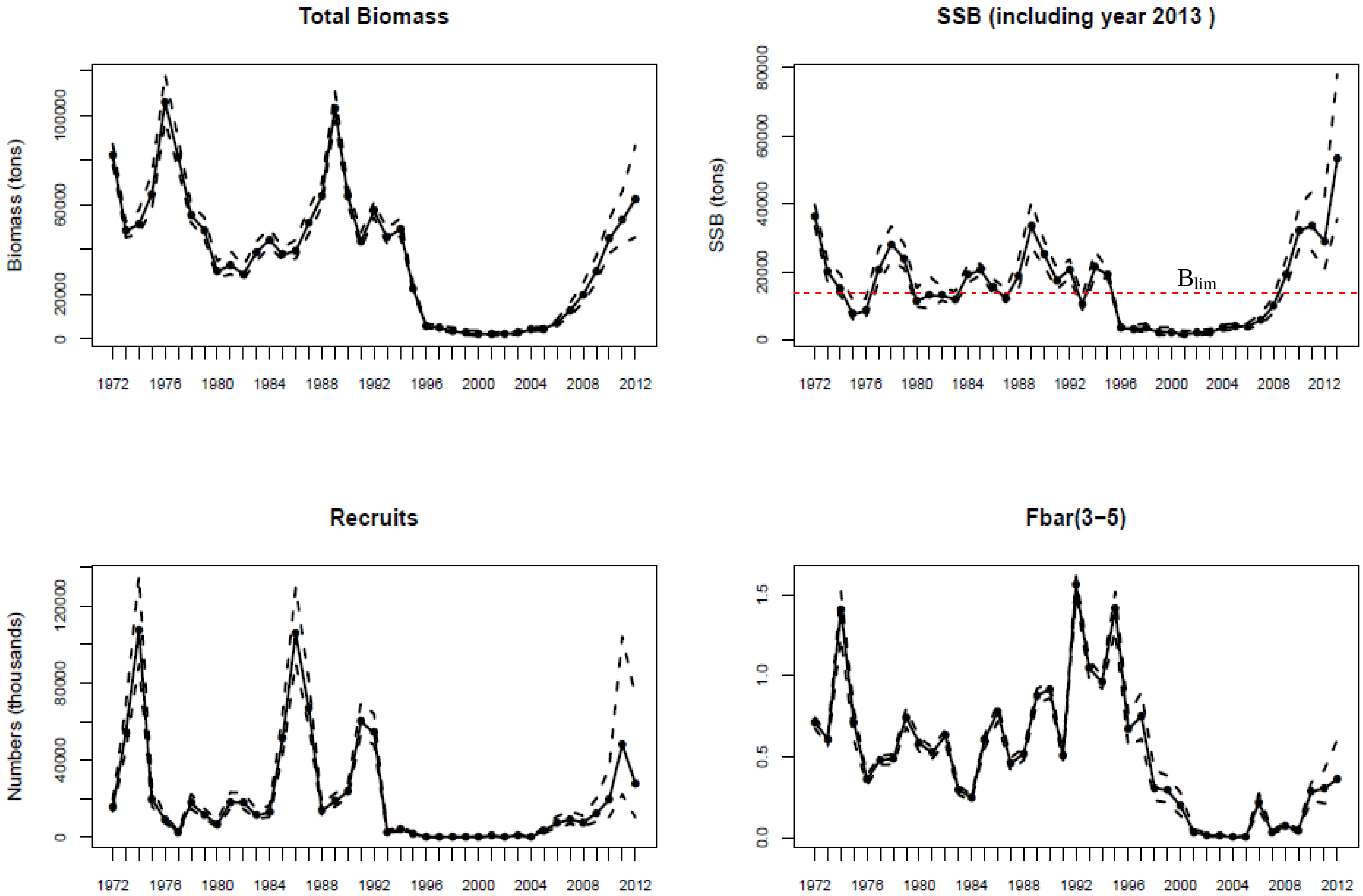

Figure 12.- Estimated trends in biomass, SSB, recruitment and Fbar. The solid lines are the posterior medians and the dashed lines show the limits of 90% posterior credible intervals. Red horizontal line in the SSB graph represents B_{lim} = 14 000 tons.

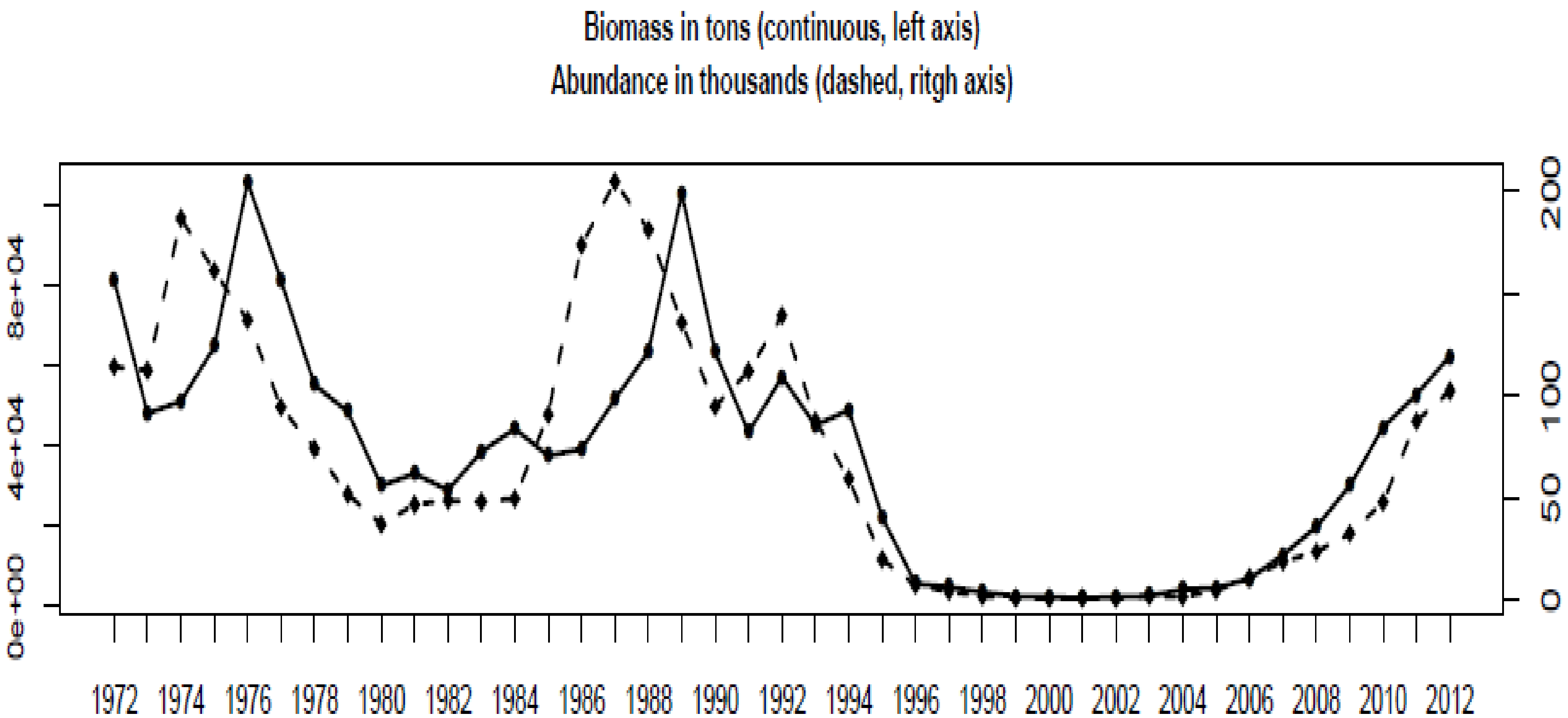

Figure 13.- Estimated trends in biomass and abundance.

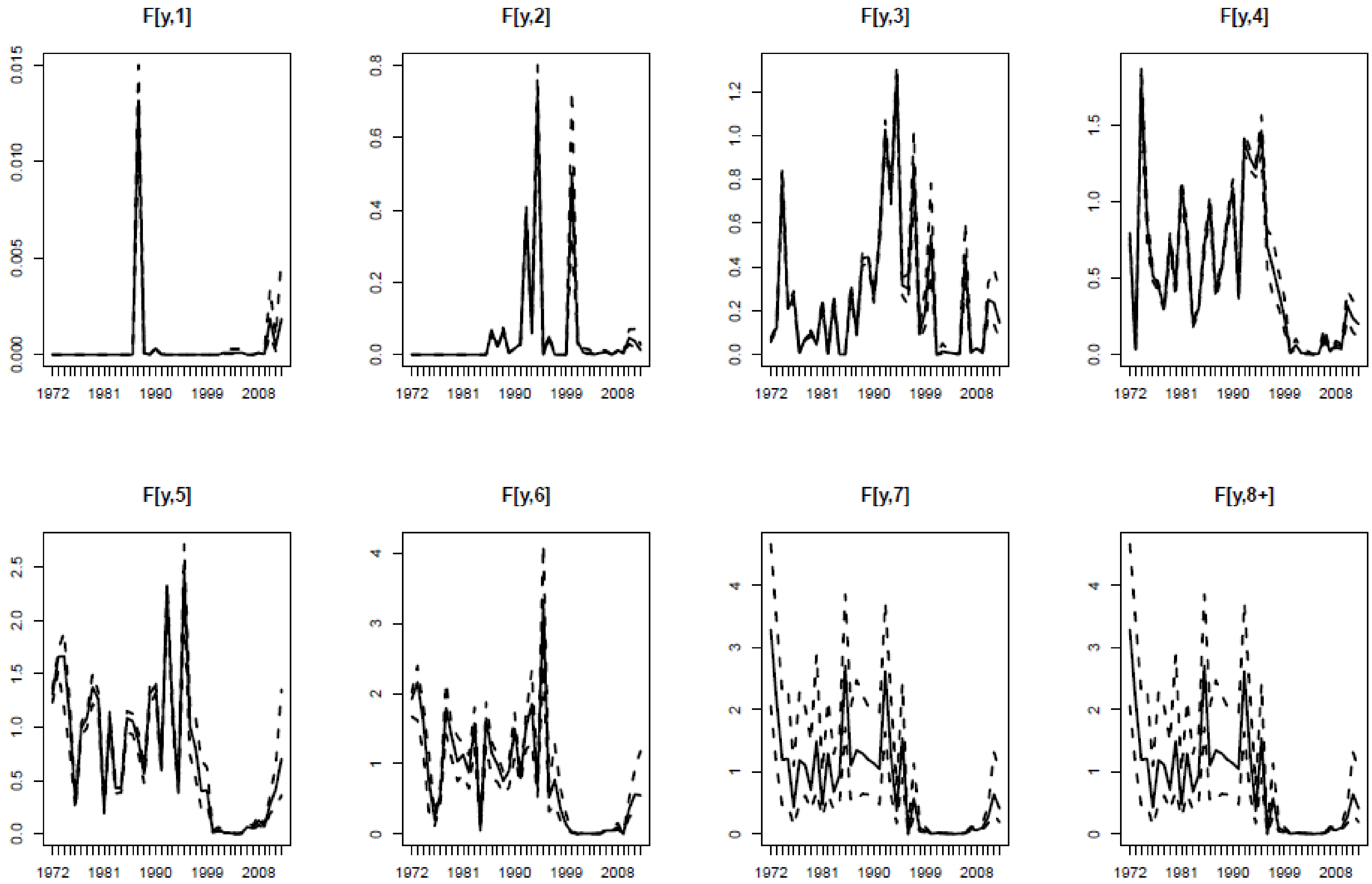

Figure 14.- Estimated fishing mortality at age.

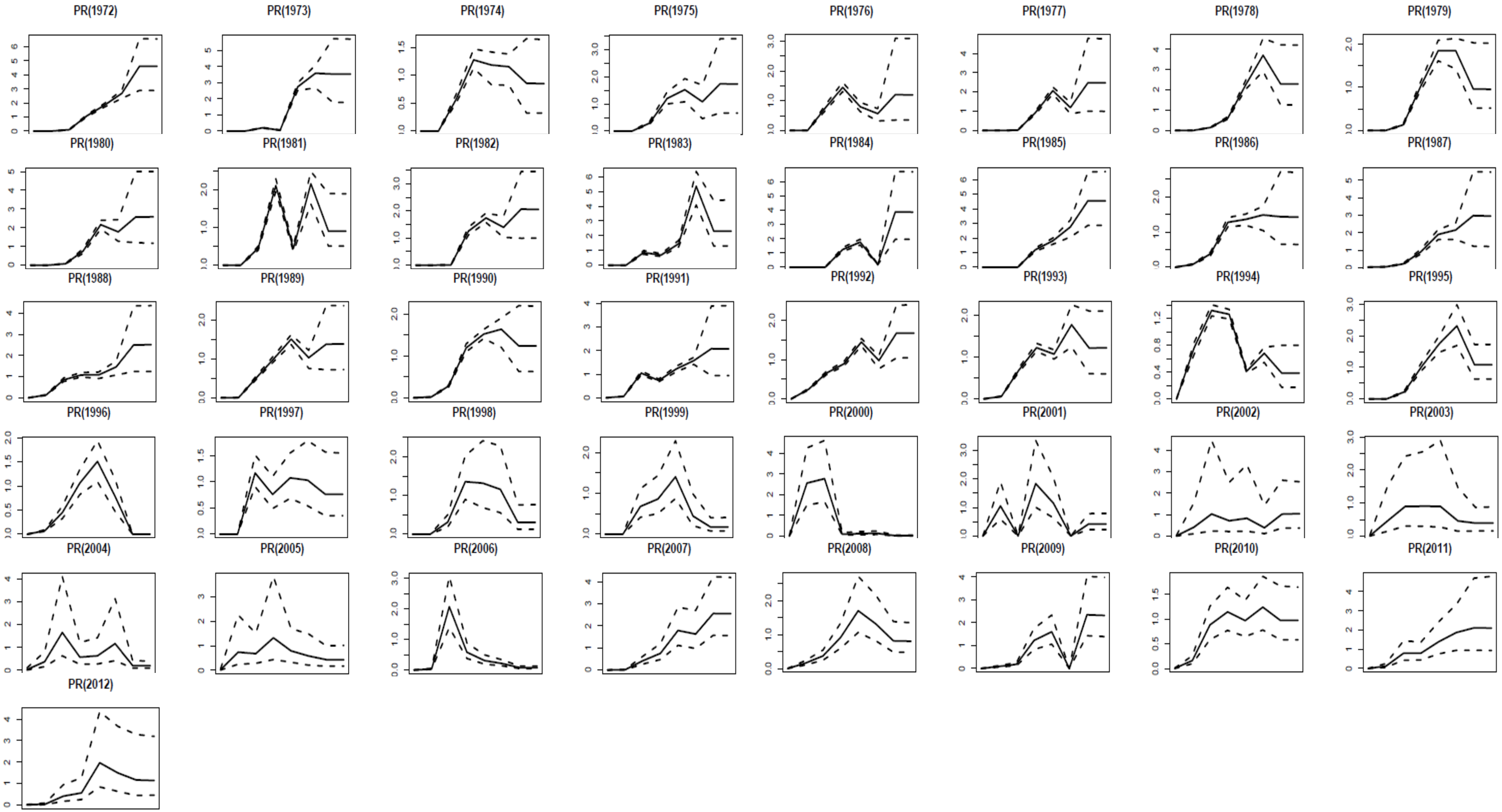

Figure 15.- Estimated PR (F/F_{bar}) per age and year.

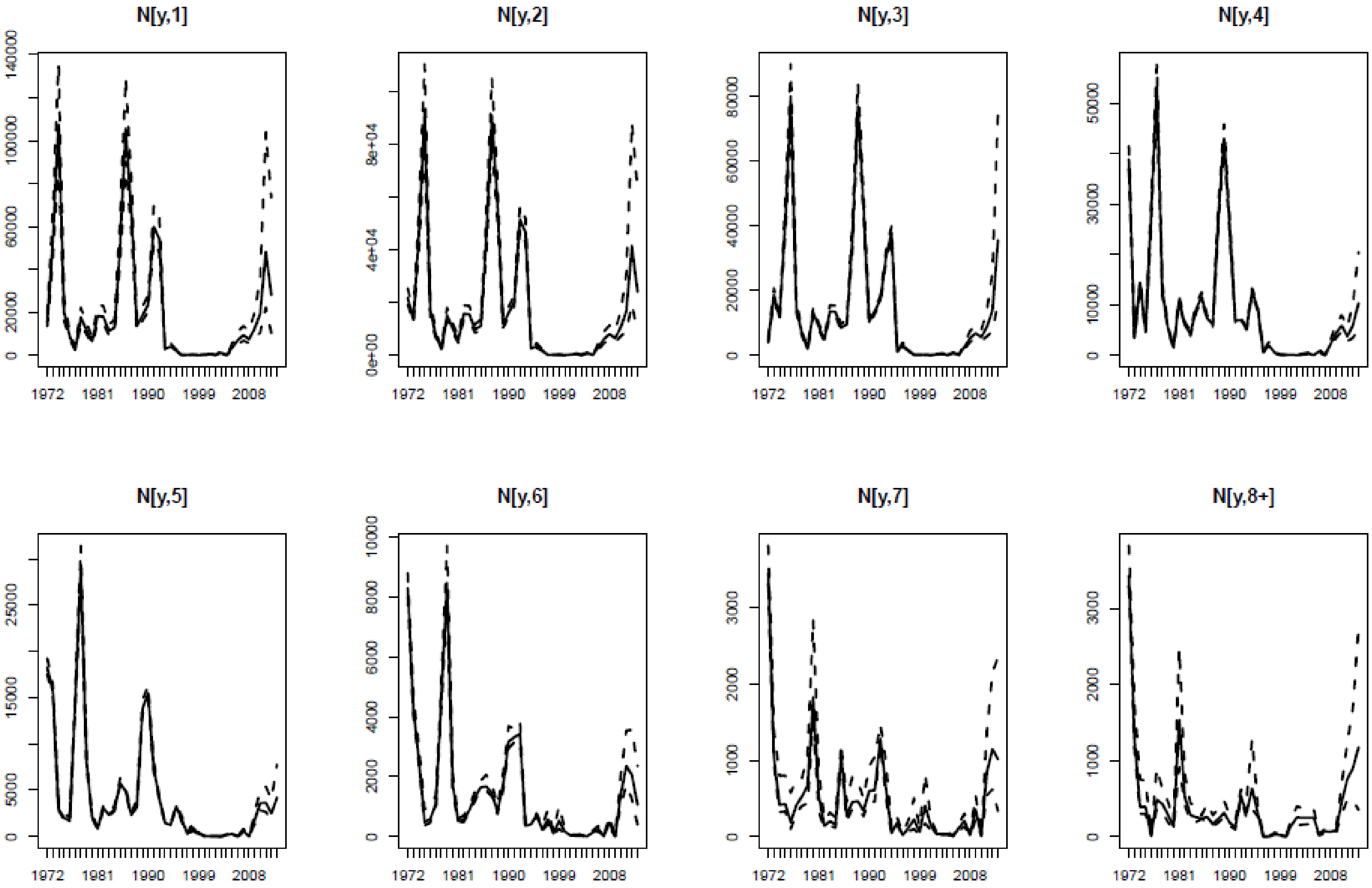

Figure 16.- Estimated numbers at age.

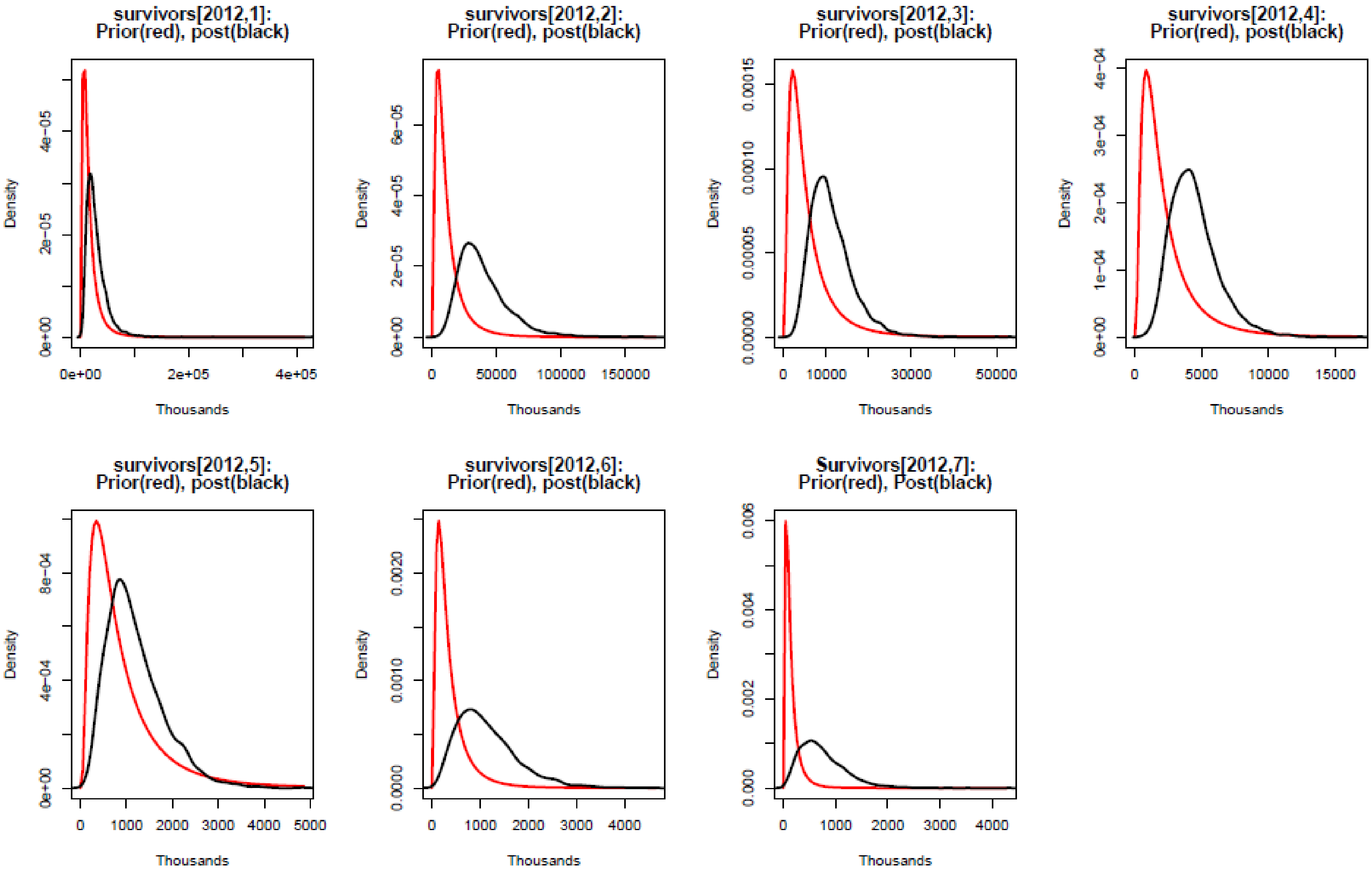

Figure 17.- Survivors at age at the end of 2012 (*survivors* (2012,a) are the number of individuals of age a+1 at the beginning of 2013).

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

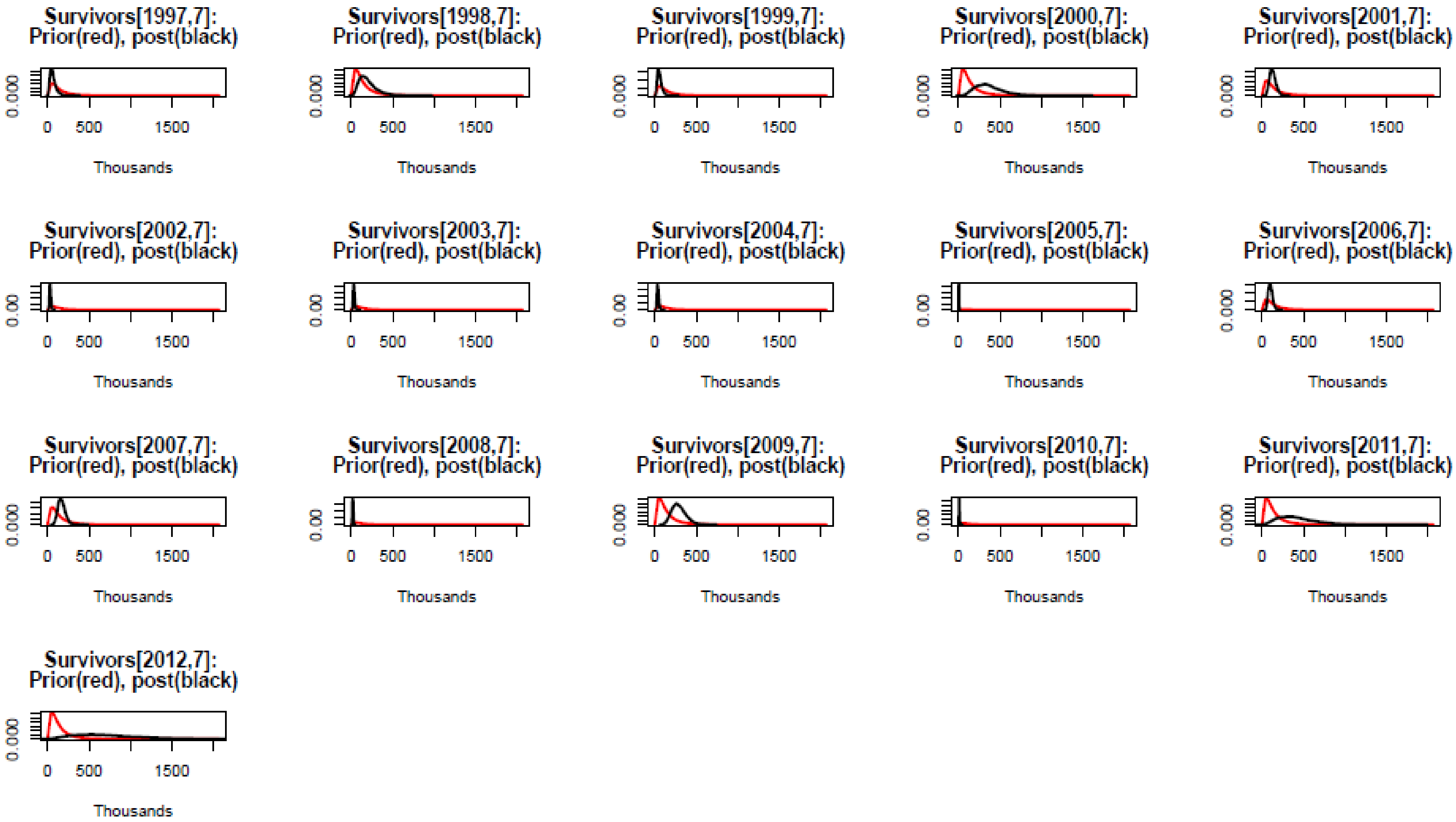

Figure 18 (cont.).- Survivors from age 7 in each year (*survivors* (y,7) are the individuals of age 8 at the beginning of year y+1).

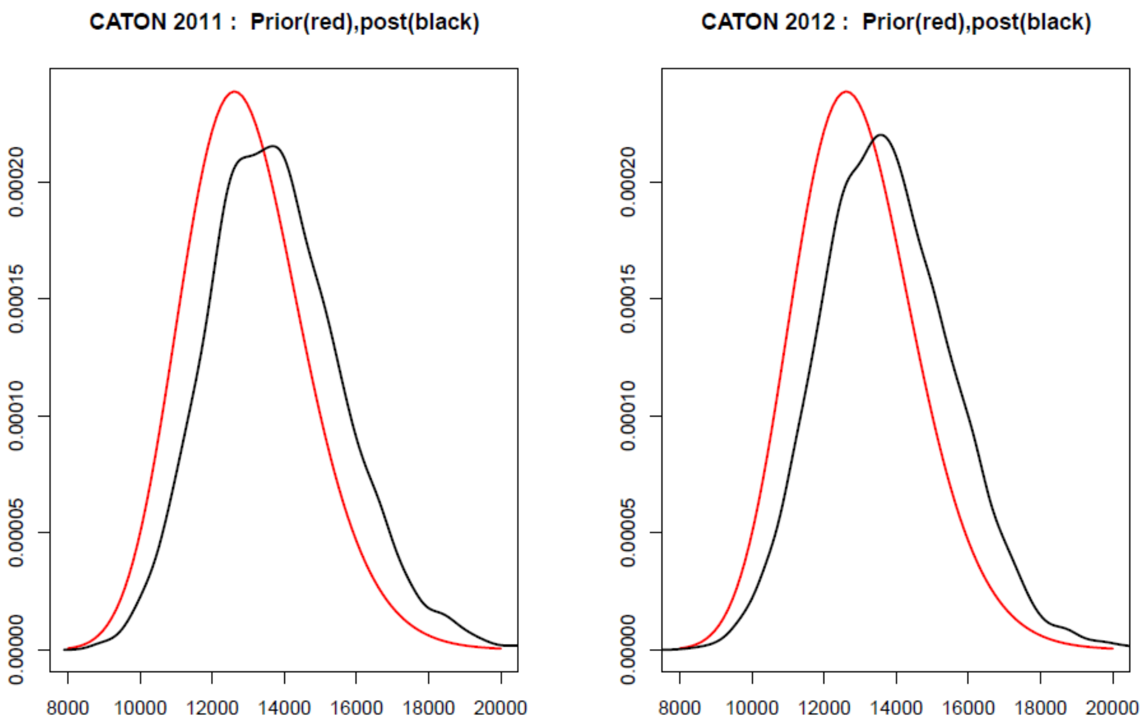

Figure 19.- Estimated total catch in 2012 and 2012

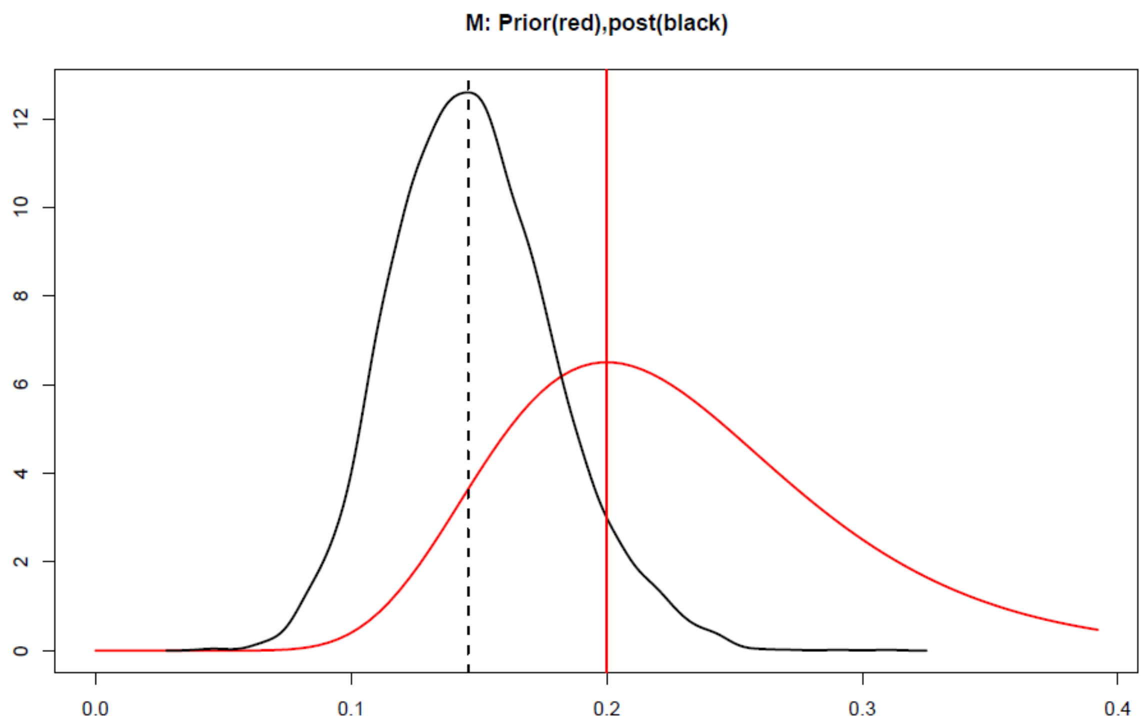

Figure 20.- Estimated natural mortality

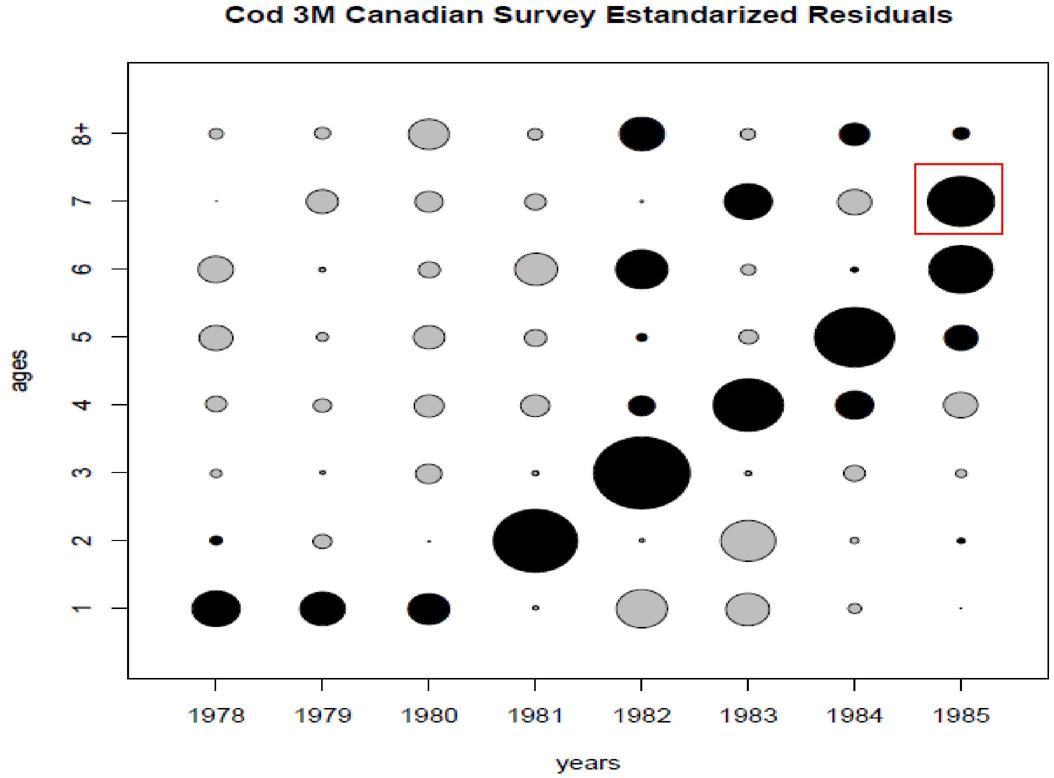

Figure 21.- Standardised residuals (observed minus fitted value) in logarithmic scale of Canadian survey abundance indices at age. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value. The red square indicates a bubble with a value near 2 (in absolute values).

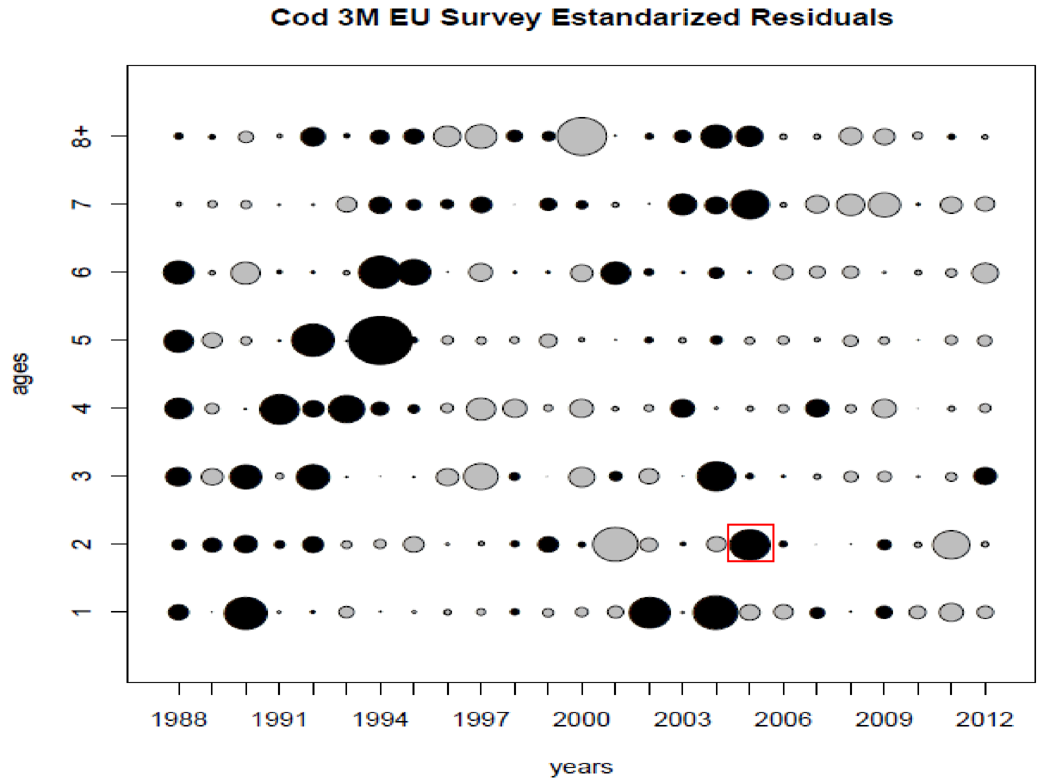

Figure 22.- Standardised residuals (observed minus fitted value) in logarithmic scale of EU survey abundance indices at age. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value. The red square indicates a bubble with a value near 2 (in absolute values).

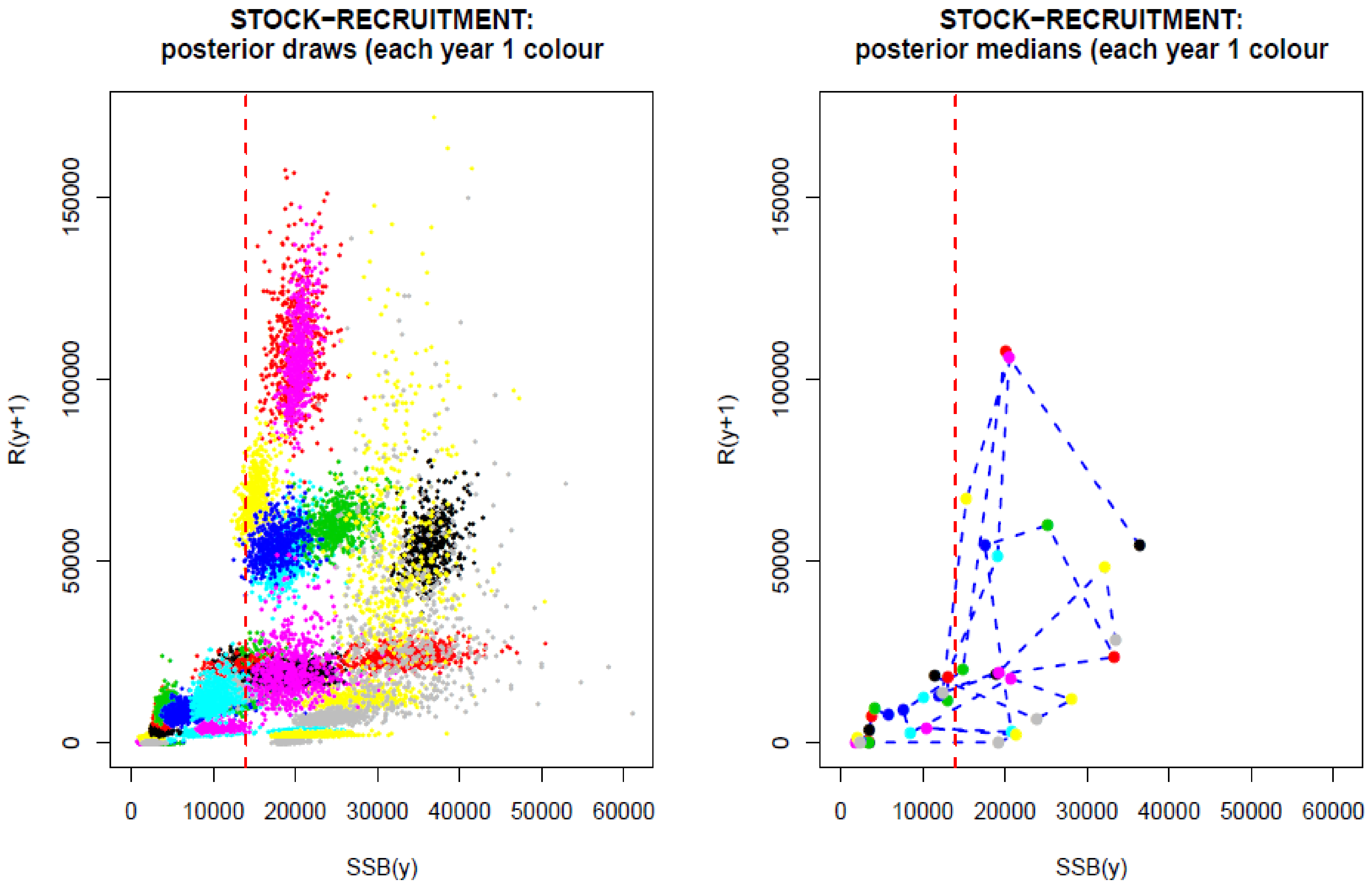

Figure 23.- Stock-Recruitment plots. B_{lim}=14000 is shown as the red vertical line.

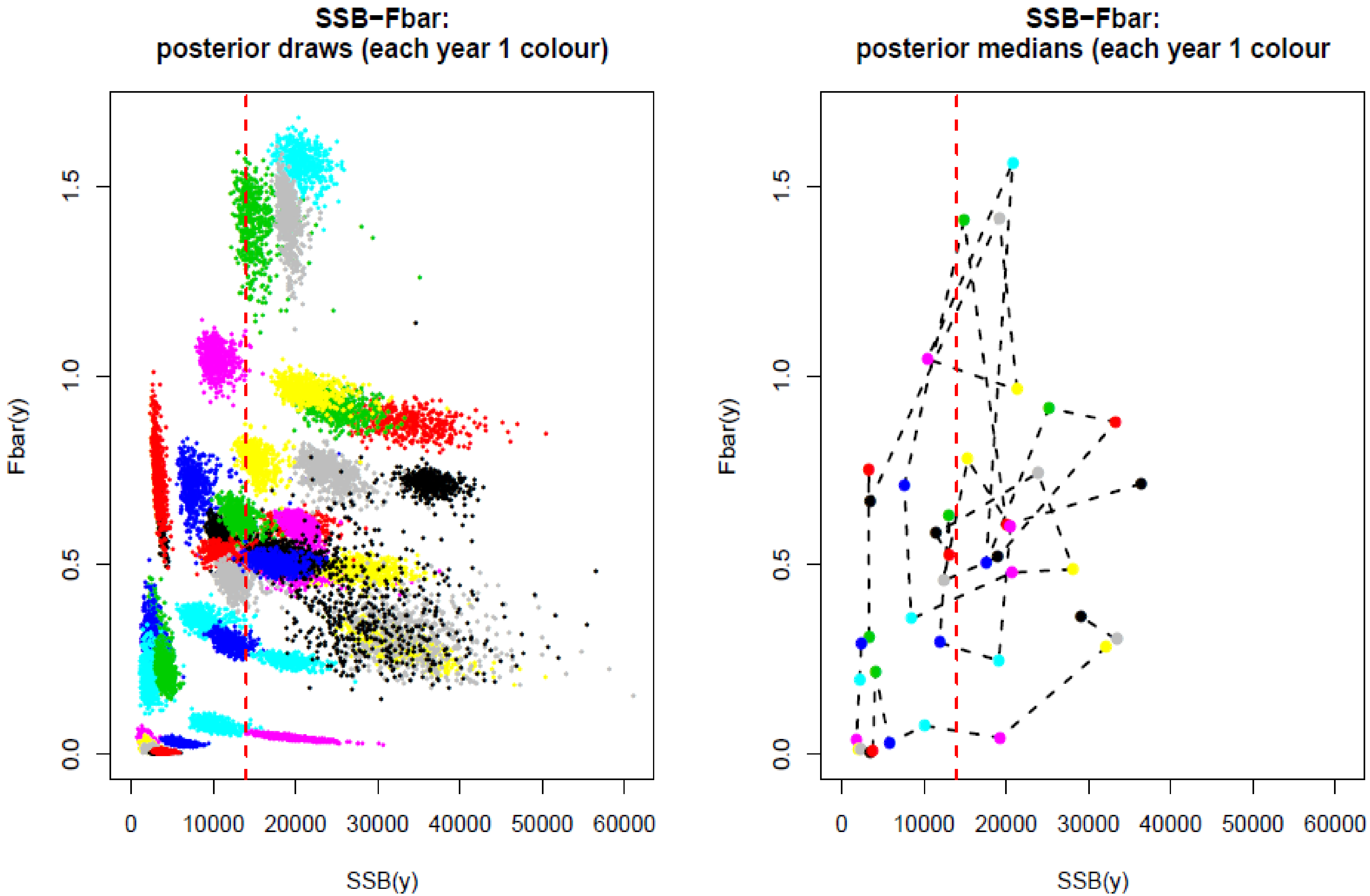

Figure 24.- F_{bar} versus SSB plots. B_{lim}=14000 is shown as the red vertical line.

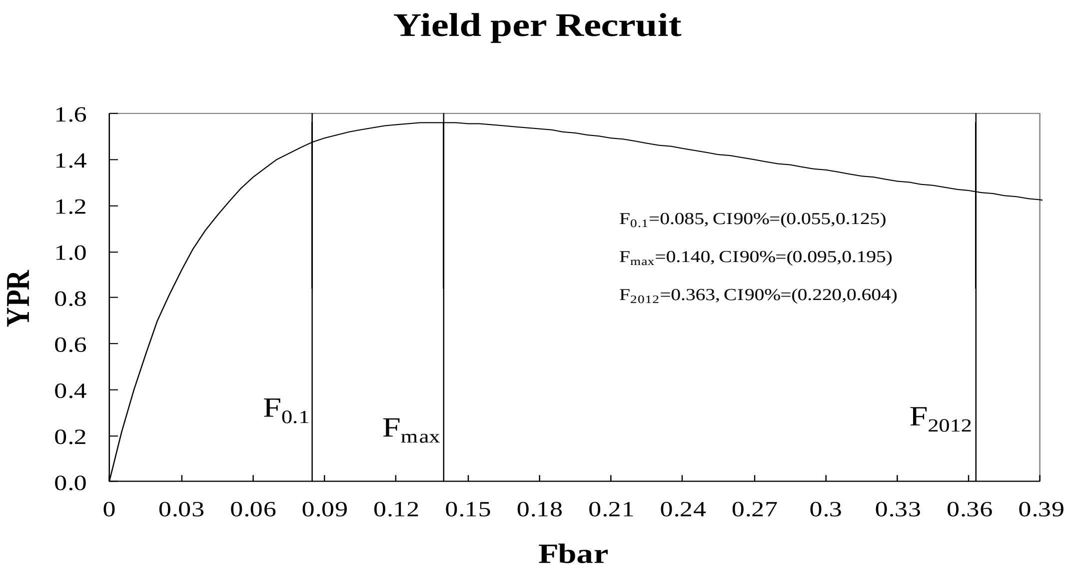

Figure 25.- Bayesian Yield per Recruit versus F_{bar}. The values of $F_{0.1}$, F_{max} and F_{2012} are indicated

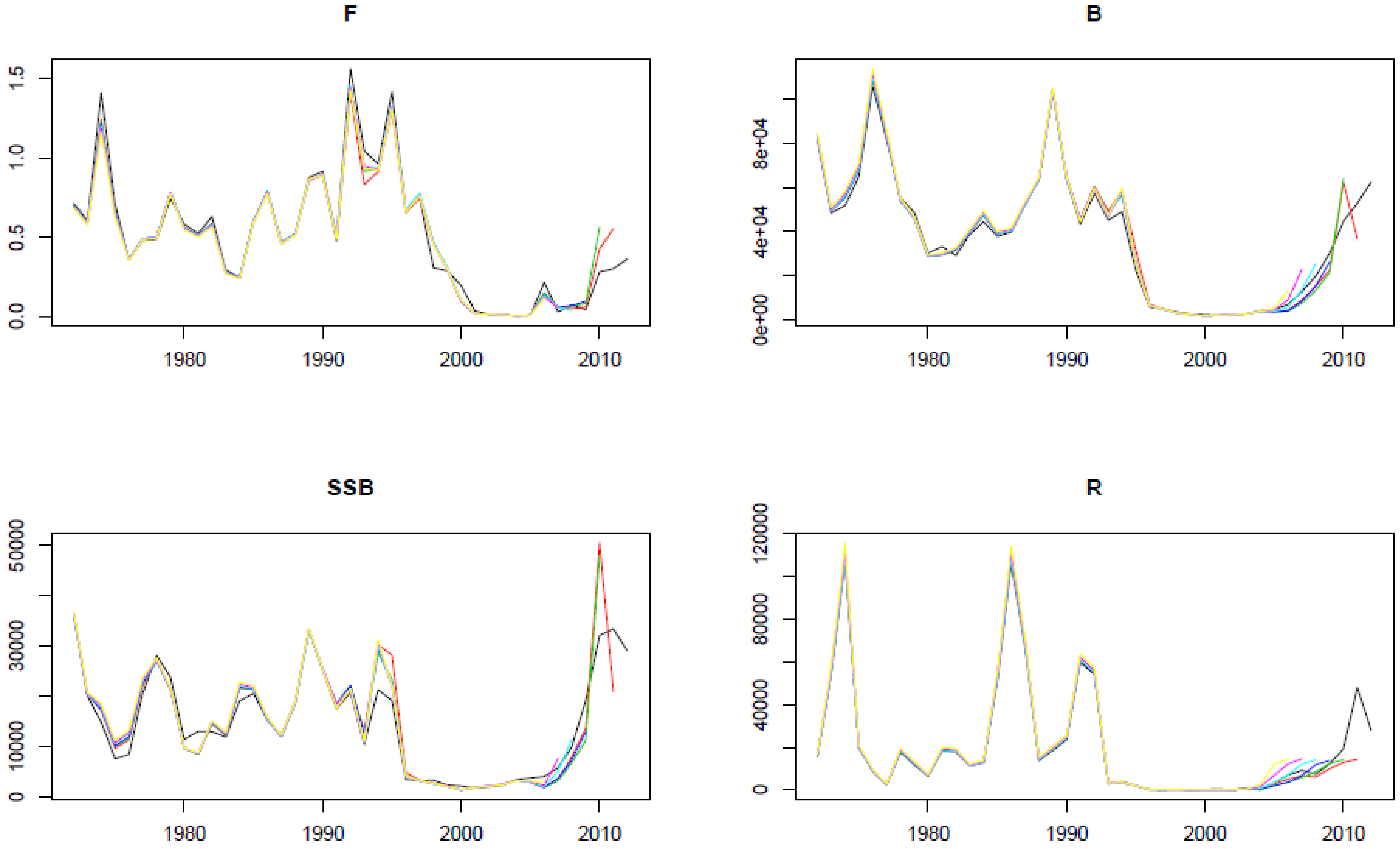

Figure 26.- Retrospective patterns.

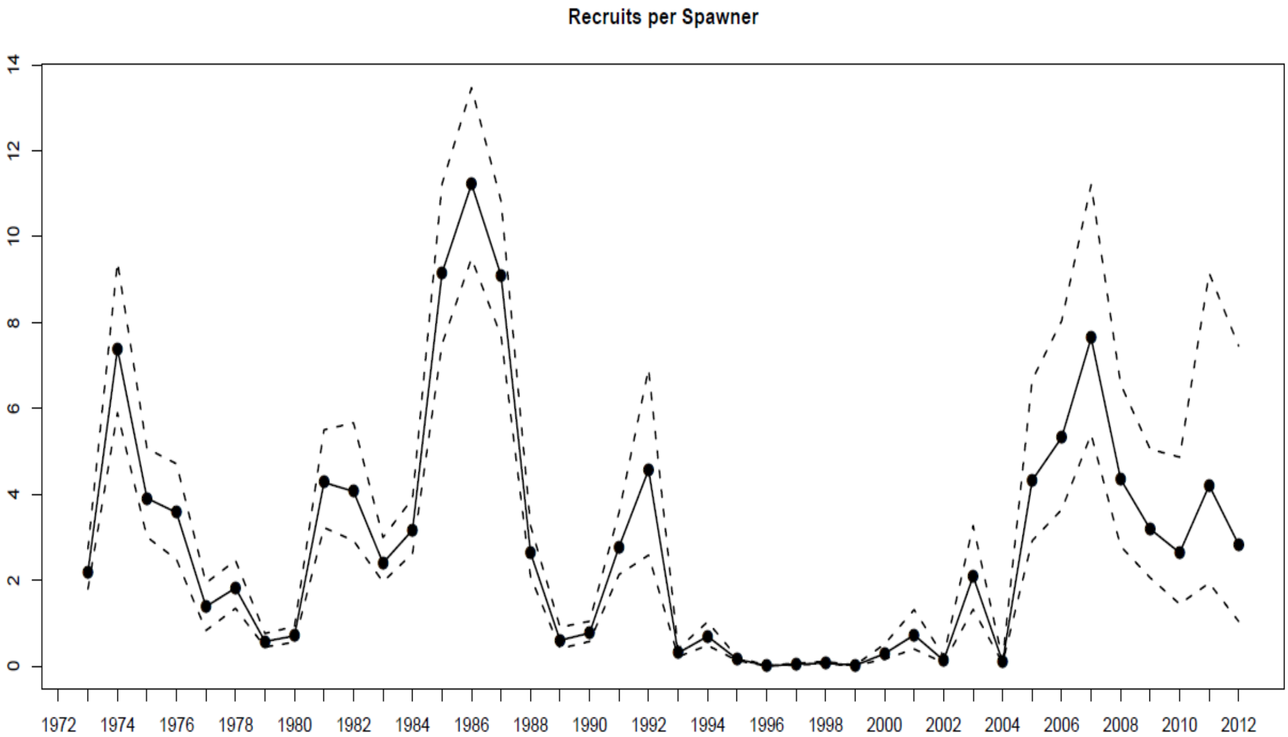

Figure 27.- Estimated recruits (age 1) per spawner.

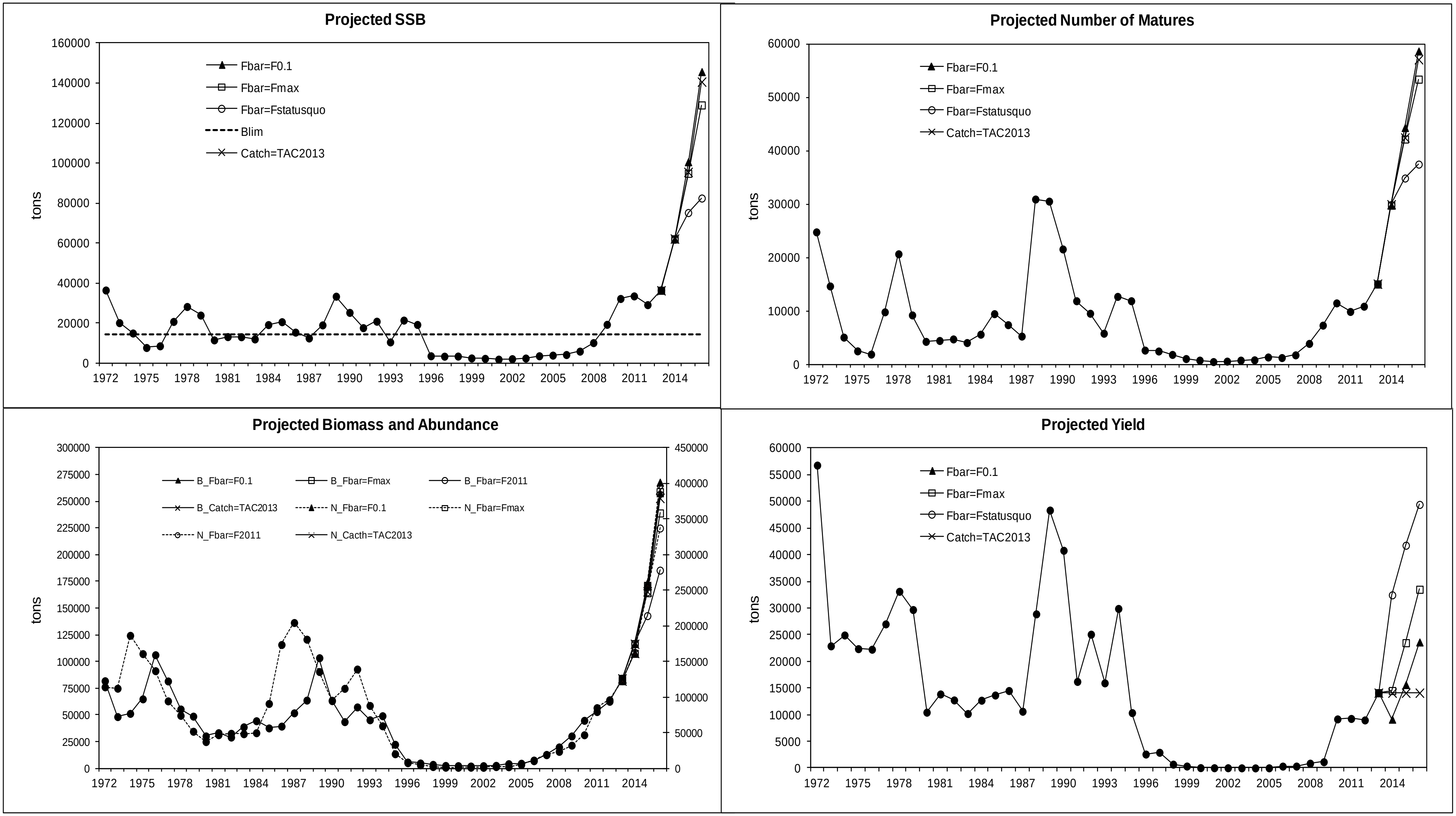

Figure 28.- Projections for SSB, number of matures, Total Biomass and Abundance and Yield with different scenarios.