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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. As there are inconsistencies with total catch of the last three years, a prior was added for 2011 and 2012 catch and the Daily Catch Report data were used in 2013. Results indicate a general increase in SSB since 2005, reaching a value well above B_{lim} since 2009.

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 2010-2012 values over the highest of the studied series, only below the recruitments of years 1991 and 1992 (González-Troncoso *et al.*, 2013).

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 2006-2009 were between 339 and 1 161 tons (Table 1 and Figure 1), 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, 14 113 tons in 2013 and 14521 tons in 2014 were established. The estimated catch by the Scientific Council for 2010 was 9 291 tons, which almost double the TAC. Since 2011 there have not been available estimated catches by the Scientific Council. The STATLANT 21A catch was 9 794 for 2011, 9 003 for 2012 and 13544 for 2013.

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 2013 there were catches of 3M cod from Estonia, Faroe Islands (Denmark), Norway, Portugal, Russia, Spain and United Kingdom with a total amount of 13 985 tons from the Daily Catch Report (DCR) data (Table 1, Figure 1). To 2010 scientific catches were used; in 2011 and 2012, a prior over the total catch was applied. In 2013 the DCR data was used (see Assessment Methodology).

Length distributions

In 2013 length sampling of catch was conducted by Estonia (SCS 14/16), Portugal (SCS 14/10), Russia (SCS 14/13) and Spain (SCS 14/06). Length frequency distributions from the commercial catch and from the EU survey (Mandado, 2014) are shown in Figure 2.

It must be noted that countries with a high proportion of TAC and catch, as Denmark (22.3% of the TAC) and Norway (9.25% of the TAC), have not reported length frequencies for the catch in 2013.

Estonia has measured 1357 individuals in a range of 23-95 cm and a mode in 47 cm. Portugal has measured 6117 individuals between 21 and 102 cm with a mode in 42 cm. Russia has a 2966 individuals sample in a range of 34-124. The modal length is 42 cm. The number of sampled individuals for Spain was 5123. The mode of this length distribution is at 40 cm. For UK the number of measured individuals was 14226, the highest sample, in a range of 26-128 cm. The mode was in 62 cm, quite highest than for the rest of the fleets. In general, fish in the length distribution of UK are bigger than those in the rest. The EU survey has a well-defined mode around 25 cm, followed with another mode in 37-46. The range is from 9 to 128 cm.

It was an update of the UK length distribution in years 2011 and 2012, so the consequence indices (catch-at-age and mean weight-at-age in catch) have slightly changed since last year assessment.

Catch-at-age

Catch-at-age is presented in Table 2. 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 only from the Portuguese commercial data and was applied to the total commercial length distribution. In 2012 otholits were no collected by the Portuguese fleet, and although a commercial ALK from the Spanish fleet was available, it was not used because it was no validated, so the commercial 2011 ALK was applied to the total commercial length distribution. In 2013 there are two available ALKs for commercial length distribution, one from Portugal and the other from Spain, but as they have not been validated yet, the 2013 survey ALK was used. 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 2013 catch) is comprised of 3-5 years age cod. In years 2006 and 2009 catches containing mostly age 4 individuals. In 2007 the greatest presence was at ages 2 to 4 and at ages 2 and 3 in 2008 and 2013.

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 (2006-2013). 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. But the corresponding cohort was weak. It is remarkable the catch over the recruitment in some of the last years. In 2013, all the values are negative except age 3, with a quite large positive value.

Mean weight-at-age

There are available data of mean weight-at-age in catch for years 1972-1987 from the 1999 assessment (Vázquez *et. al*, 1999). For 1988-2012, the same data as last year assessment were taken.

For 2013, 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 three length-weight relationships available in 2013: Estonian, Portuguese and Spanish. All of them are presenting in Figure 6 with the survey one. There are no significant differences between them, although the Portuguese one gives highest weight to the same lengths. 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 and Figure 7. Since 2005 there are a general decrease in the trend of the mean-weight for the ages between 2 and 6 years old, especially since 2010. 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, especially for the oldest ages. In 2013 the mean weight of all the ages decreased.

The SOP (sum over ages of the product of catch weight-at-age and numbers at age) for the commercial catch differs in 4.8% from the estimated total catch.

Survey data

Canadian survey

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 8 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 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 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 1988-2013 are presented in Mandado, 2014.

Survey indices of abundance at age are presented in Table 5. Figure 8 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 and 2013 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. In 2013 a new decrease in abundance and biomass occurred, both reaching the level of 2009-2010. Figure 10 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 2010-2012 a good recruitment can be seen, especially in 2011. 2013 recruitment is not as good as in the last three years, but it is still at the level of the beginning of the recovery of the stock.

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 2013. 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 their mean weight-at-age with respect to 2008, while the ages 3-4 decreased them (Table 6 and Figure 11). 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+. In 2013 the weight of all ages slightly decreased.

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 2008-2013. 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 decreased since 2006 to 2011, especially in 2011. 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.

In 2012 the percentage in ages 4 and 5 increased, as in all ages in 2013 (especially for ages 3 to 5). This is not consistent with the decrease in the mean weight for all ages.

Figure 12 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 and 2013 the age decreased, in particular in 2013, due to the increase in the percentage of maturation on all the ages.

Assessment methodology

The Bayesian model used last years was updated with 2013 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.

In years 2011 to 2013 there were 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.

In 2013 some flag states significant in the Div. 3M cod fishery did not submit their 2013 STATLANT 21A data before the start of the meeting, so STATLANT 21A could not be compared to other catch estimates for 2013. Scientific Council analyzed the CPUEs resulting from Daily Catch Reports (DCR) of 3M cod for the period 2011-2013. These CPUEs were compared with the available scientific data. The results of this comparison show significant differences in 2011 and 2012 and a decrease of such differences in 2013. Based on these results, Scientific Council decided to use total catches from the DCR in 2013 (13 985 t), maintaining the model catch estimation for 2011 and 2012.

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

Catch data for 42 years, from 1972 to 2013

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, 2006-2013

Tuning with Canadian survey for 1978 to 1985

EU survey for 1988 to 2013

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 (2013, a), a=1,…,7 and (y, 7), y=1972,…, 2012

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

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

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

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,…,2013 (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

α = 0.5, β = 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 eight 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 13.

Total biomass has had an increased trend since 2006, reaching the same level as before the collapse of the stock in the mid 1990´s.

The SSB graph also includes the expected value at the beginning of the year 2014. To calculate it, weight-at-age and maturity-at-age from the last year were used (assuming always that maturity at age 1 is equal to 0, as there is no estimate of recruitment in 2014). 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 since 2010 has been around the highest values of the time series, only below the 1972 and 1989 values. This increase is probably due to the increase in the percentage of maturity in all ages, that compensates the decrease in the mean weight in all ages, and to the incorporation of the strong 2010 year class. The SSB at the beginning of 2014 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.

Recruitment has had an increasing trend since 2005 to 2011, being the 2009 and 2010 values at the level of the mean recruitment of the period and the 2011 and 2012 values above it. In 2013 the recruitment has decreased and is around the level at the beginning of the recovery of the stock. Take into account that the actual recruitment levels for last years can not yet be precisely estimated (wide uncertainty limits in Figure 13 and Table 8).

F_{bar} (mean for ages 3-5) has been at very low levels in the period 2001-2009 (Figure 13), although an unusual high value has been estimated for 2006. In 2010, when the fishery was reopen, the F_{bar} has increased up to 0.27, 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 0.3 was estimated. In 2012 F_{bar} is 0.32, while the TAC of 9 280 was established under a F_{bar} of 0.13. In 2013 the TAC was increased almost 50% with regards to 2012 TAC, and the F_{bar} (0.35) is 2.5 times the F_{bar} approved in 2012. Table 9 and Figure 15 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 6-8+ and in 2012 in 5-8+. In 2013 the highest fishing mortality is in age 6. So, since the reopening of the fishery F_{bar} is highly unsteady. To illustrate these changes, Figure 16 shows the PR along the years, being the PR the F divided by F_{bar}. Figure 17 shows the PR for the years in which the fishery was reopened (2010-2013) and Figure 18 the mean of the three last years (2011-2013) PR *versus* the 2013 PR. They are no significant differences between them except in age 7.

Figure 14 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 13), total biomass and abundance have not reached yet the highest analysed level.

Estimates of stock abundance at age for 1972-2013 are presented in Table 10 and Figure 19. Abundance at age in 2014 are the survivors of the same cohort in 2013, 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, especially in 2013, due probably to the decreasing in the age of maturity. Since the reopening of the fishery ages 6 and 7 have suffered a slight decrease. From 2013 to 2014 a big decrease in number at age 2 and a big increase in age 4 have occurred.

Figure 20 depicts the prior and posterior distributions of survivors at age at the end of the final assessment year, where by survivors(2013, a) it is meant individuals of age a + 1 at the beginning of 2014 (in other words, survivors(2013, a) = N(2014, 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 in almost all ages.

Figure 21 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 22 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 13 650 tons for 2011 and 13 570 tons for 2012.

Figure 23 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 0.156.

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 24 for the Canadian survey and 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 2005. 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.

Figure 25 shows another plot of the standardized residuals for the EU surveys for better understanding the patterns. It seems to be a positive pattern in the last years.

Biological Referent Points

Figure 26 shows a SSB-Recruitment plot and Figure 27 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 2013. Figure 28 shows the Bayesian Yield per Recruit.

Retrospective pattern

A retrospective analysis of six years was made (Figure 29). Retrospective analysis shows revisions in the recruitment, but no evident patterns can be seen. SSB and F show stability over the years.

Recruits per Spawner

Figure 30 displays the Recruits per Spawner. The variability over the years of the assessment is very high. Since 2007 a decreasing trend can be seen, reaching in 2013 a low value.

Projections

Stochastic projections over a three years period (2014-2016) 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 2014: estimates from the assessment

Recruitments for 2014-2016: Recruits per spawner were estimated for each year (Figure 30). 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 nine years of the assessment (2005-2013), as these are the years in which recruitment has started to recover.

Maturity ogive for 2014-2016: 2013 maturity ogive

Natural mortality for 2014-2016: 2013 natural mortality from the assessment results.

Weight-at-age in stock and weight-at-age in catch for 2014-2016: 2013 weight-at-age in catch and in stock (Tables 3 and 6).

PR at age for 2014-2016: 2013 PR (Figures 16, 17 and 18).

F_{bar}(ages 3-5): Eight options were considered. All Scenarios assumed that the 2014 catch is the TAC (14 521 tons):

1. $F_{0.1}$ (median value at 0.090).
2. F_{max} (median value at 0.145).
3. 2/3Fmax (median value at 0.097).
4. 3/4Fmax (median value at 0.109).
5. 0.85Fmax (median value at 0.123).
6. 0.75$F_{statusquo}$ (median value at 0.259).
7. $F_{statusquo}$ (median value at 0.346).
8. 1.25$F_{statusquo}$ (median value at 0.432).

Results for the eight options are presented in Tables 11-26 and Figure 32. They indicate that fishing at any of the considered values of F_{bar}, total biomass and SSB during the next 2 years have high probability of reaching levels equal or higher than all of the 1972-2013 estimates. The number of matures increases in less proportion than the SSB. The removals associated with these F_{bar} levels are lower than those in the period before 1995 except in the cases of F_{bar}=F_{2013} and any of its probabilities, for which the catches reach the level found before the collapse of the stock.

Rapid changes in the biological parameters of this stock in recent years and the sudden decrease in the 2013 EU-survey index has led to substantial revision in estimate numbers for 2014 in the current assessment, compared to projected numbers for 2014 in the previous assessment. If next year the same pattern happens, this year projections would be unrealistic. The update from one year to the next of the numbers at age is very important in some cases. Figure 31 shows these differences for the abundance at age (2-8) estimating for the year 2014, comparing the abundances estimated by the model in last assessment and the abundances estimated in this assessment. It can be seen a large update in ages 2 and 4, with less individuals in the current assessment.

The 2014 yield projection was derived from an F_{bar} of 0.14 in the 2013 assessment. Given the revision to estimated numbers and significant changes in biological parameters since the last assessment, the same level of catch in 2014 can now only be generated with an F_{bar} of 0.28 in the current assessment.

The projected values for the period 2014-2016 are heavily reliant on the relatively abundant most recent cohorts, 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 from 1988 to 2010 in tons.

Year	Estimated	Portugal	Russia	Spain	France	Faroes	UK	Poland	Norway	Germany	Cuba	Others	Total[1]
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
2013	n.a.	4709	899	2323		2819	1485		1296			455	13985[2]

[1] Recalculated from NAFO Statistical data base using the NAFO 21A Extraction Tool
[2] Daily Catch Report from the NAFO Secretariat

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
2013	31	894	5624	1236	1158	640	382	252

[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	0.939	1.523	2.224	3.558	5.979	8.677
2012	0.086	0.374	0.99	1.491	2.135	3.585	6.198	9.041
2013	0.067	0.284	0.758	1.289	2.027	2.868	4.476	8.243

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
2013	5525	67521	32339	4776	4185	2782	1807	963	278	40	29	32	5	0

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
2013	0.07	0.17	0.69	1.16	2.00	2.75	4.21	7.61

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

	1	2	3	4	5	6	7	8+	a50
1972	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1973	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1974	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1975	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1976	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1977	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1978	0.000	0.000	0.000	0.002	0.507	0.998	1.000	1.000	5.00
1979	0.000	0.000	0.000	0.008	0.154	0.813	0.991	1.000	5.54
1980	0.000	0.000	0.002	0.029	0.302	0.862	0.989	1.000	5.31
1981	0.000	0.000	0.005	0.104	0.716	0.982	0.999	1.000	4.70
1982	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000	4.55
1983	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000	4.55
1984	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000	4.55
1985	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000	4.55
1986	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000	4.55
1987	0.000	0.000	0.007	0.146	0.809	0.991	1.000	1.000	4.55
1988	0.054	0.099	0.175	0.291	0.441	0.603	0.745	0.879	5.36
1989	0.054	0.099	0.175	0.291	0.441	0.603	0.745	0.879	5.36
1990	0.054	0.099	0.175	0.291	0.441	0.603	0.745	0.879	5.36
1991	0.018	0.045	0.111	0.247	0.463	0.687	0.849	0.951	5.16
1992	0.002	0.011	0.048	0.184	0.503	0.819	0.953	0.993	4.99
1993	0.001	0.007	0.049	0.282	0.751	0.959	0.994	1.000	4.46
1994	0.000	0.001	0.050	0.657	0.986	1.000	1.000	1.000	3.82
1995	0.000	0.000	0.006	0.803	1.000	1.000	1.000	1.000	3.79
1996	0.000	0.000	0.029	0.666	0.993	1.000	1.000	1.000	3.84
1997	0.000	0.008	0.111	0.670	0.971	0.998	1.000	1.000	3.75
1998	0.000	0.002	0.096	0.874	0.998	1.000	1.000	1.000	3.54
1999	0.000	0.001	0.130	0.902	0.999	1.000	1.000	1.000	3.46
2000	0.000	0.001	0.160	0.971	1.000	1.000	1.000	1.000	3.34
2001	0.000	0.001	0.315	0.998	1.000	1.000	1.000	1.000	3.12
2002	0.000	0.010	0.636	0.997	1.000	1.000	1.000	1.000	2.89
2003	0.001	0.024	0.513	0.978	0.999	1.000	1.000	1.000	2.99
2004	0.000	0.000	0.100	0.967	1.000	1.000	1.000	1.000	3.40
2005	0.041	0.171	0.502	0.830	0.959	0.991	0.998	1.000	3.00
2006	0.000	0.014	0.365	0.959	0.999	1.000	1.000	1.000	3.15
2007	0.000	0.012	0.261	0.920	0.997	1.000	1.000	1.000	3.31
2008	0.000	0.012	0.231	0.882	0.995	1.000	1.000	1.000	3.37
2009	0.000	0.010	0.181	0.830	0.991	1.000	1.000	1.000	3.49
2010	0.000	0.009	0.167	0.812	0.989	1.000	1.000	1.000	3.52
2011	0.001	0.008	0.072	0.428	0.878	0.986	0.999	1.000	4.13
2012	0.000	0.000	0.018	0.578	0.990	1.000	1.000	1.000	3.93
2013	0.004	0.037	0.285	0.804	0.977	0.998	1.000	1.000	3.39

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	82679	78598	88552	36598	33621	40121	16300	13770	20211	0.709	0.668	0.739
1973	48894	45855	53369	20162	17152	23664	56310	46389	72540	0.601	0.555	0.628
1974	52114	47664	59268	14971	13202	19390	111600	92069	143305	1.4	1.221	1.512
1975	66298	59300	76188	7678	6213	11490	20720	16670	27530	0.701	0.581	0.782
1976	108071	98744	121236	8539	6535	12369	9190	7556	11840	0.352	0.319	0.382
1977	82730	76675	91647	20865	16895	27066	2706	2125	3664	0.476	0.444	0.502
1978	55917	52450	60789	28306	23464	33683	18380	15200	23491	0.484	0.446	0.512
1979	49217	45362	55092	23977	21167	28605	12290	10080	15981	0.737	0.674	0.79
1980	30652	27658	35354	11438	9733	15465	6866	5373	9388	0.577	0.524	0.616
1981	33530	29191	39822	13081	9298	18870	18920	15530	24620	0.519	0.483	0.551
1982	29550	26958	33496	13131	11630	15521	18680	15210	24440	0.623	0.573	0.663
1983	39372	35536	44755	11992	10430	14398	11790	9622	15290	0.29	0.258	0.317
1984	45151	41386	50586	19317	16962	22380	13330	10860	17360	0.244	0.222	0.26
1985	38122	35708	41783	20681	19076	22565	53050	43870	68131	0.595	0.54	0.63
1986	40030	36341	45533	15417	13838	18053	109400	92599	136000	0.771	0.708	0.821
1987	52733	47718	60215	12492	11110	15118	69180	58850	85270	0.454	0.406	0.491
1988	64499	59890	70969	19125	15310	23974	14345	11900	18250	0.515	0.473	0.549
1989	104523	98640	112845	33537	27409	41015	19200	16390	23590	0.871	0.816	0.912
1990	64181	60679	68948	25320	21710	29433	24260	21000	29261	0.908	0.852	0.951
1991	43930	40994	48294	17615	14974	21190	61430	54120	72492	0.499	0.467	0.526
1992	57821	54850	62023	20835	18400	23621	55660	48590	66351	1.554	1.481	1.613
1993	45782	42885	49780	10452	8803	12727	2999	2629	3595	1.035	0.968	1.089
1994	49403	46278	54116	21335	18587	25926	4141	3182	5904	0.956	0.911	0.993
1995	22452	21275	24254	19211	18063	20828	2175	1817	2773	1.413	1.271	1.515
1996	5715	5111	6680	3470	3083	4087	130	87	206	0.668	0.561	0.763
1997	4822	4121	5954	3250	2693	4163	126	83	205	0.748	0.6	0.893
1998	3488	2577	4960	3279	2379	4730	194	140	288	0.308	0.227	0.416
1999	2479	1706	3870	2337	1573	3702	32	24	48	0.289	0.218	0.378
2000	2286	1433	3821	2128	1279	3644	313	193	521	0.191	0.132	0.272
2001	1938	1397	2792	1748	1207	2589	554	351	894	0.035	0.025	0.051
2002	2264	1709	3103	1970	1424	2795	66	42	108	0.014	0.007	0.031
2003	2530	1983	3327	2262	1727	3040	1188	772	1853	0.011	0.006	0.018
2004	4076	3326	5119	3357	2666	4348	80	59	115	0.003	0.002	0.005
2005	4459	3689	5412	3677	3011	4528	3622	2500	5646	0.007	0.004	0.011
2006	6960	5655	8795	4000	3158	5037	7484	5339	11180	0.214	0.164	0.272
2007	12976	10530	16582	5687	4334	7434	10030	7537	14370	0.03	0.023	0.04
2008	20339	16611	25599	10054	8118	12798	8382	6402	11851	0.073	0.056	0.095
2009	30775	25789	37517	19240	15848	24013	11010	7935	16990	0.043	0.034	0.052
2010	44888	38625	53171	32699	27570	39375	12885	8151	22190	0.268	0.222	0.317
2011	49289	41110	60239	32506	26240	41465	35000	20700	64374	0.308	0.228	0.405
2012	52339	40864	69256	28681	21364	41061	28950	13070	61601	0.322	0.227	0.439
2013	52533	39458	72319	32719	24409	45110	9619	3592	27245	0.346	0.229	0.543
2014				46878	33352	67375						

Table 9.- F at age (posterior median)

	F at age							
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**
1972	0.000	0.000	0.068	0.759	1.302	1.907	3.305	3.305
1973	0.000	0.000	0.122	0.035	1.649	2.154	2.091	2.091
1974	0.000	0.000	0.787	1.792	1.654	1.614	1.196	1.196
1975	0.000	0.000	0.206	0.842	1.070	0.751	1.208	1.208
1976	0.000	0.000	0.264	0.513	0.282	0.200	0.425	0.425
1977	0.000	0.000	0.009	0.437	0.983	0.567	1.191	1.191
1978	0.000	0.000	0.071	0.301	1.082	1.794	1.121	1.121
1979	0.000	0.000	0.096	0.752	1.365	1.378	0.720	0.720
1980	0.000	0.000	0.045	0.435	1.253	1.026	1.512	1.512
1981	0.000	0.000	0.234	1.096	0.230	1.122	0.473	0.473
1982	0.000	0.000	0.005	0.776	1.090	0.876	1.277	1.277
1983	0.000	0.000	0.248	0.199	0.424	1.568	0.691	0.691
1984	0.000	0.000	0.001	0.302	0.430	0.049	0.943	0.943
1985	0.000	0.000	0.002	0.711	1.076	1.644	2.704	2.704
1986	0.000	0.063	0.290	0.982	1.050	1.142	1.116	1.116
1987	0.013	0.022	0.096	0.405	0.867	0.989	1.335	1.335
1988	0.000	0.067	0.435	0.556	0.558	0.762	1.343	1.343
1989	0.000	0.005	0.440	0.865	1.311	0.898	1.249	1.249
1990	0.000	0.017	0.256	1.083	1.385	1.505	1.156	1.156
1991	0.000	0.030	0.522	0.366	0.612	0.793	1.087	1.087
1992	0.000	0.384	1.018	1.387	2.264	1.528	2.685	2.685
1993	0.000	0.062	0.720	1.273	1.118	1.869	1.296	1.296
1994	0.000	0.722	1.265	1.209	0.396	0.656	0.382	0.382
1995	0.000	0.000	0.313	1.461	2.479	3.279	1.580	1.580
1996	0.000	0.048	0.297	0.709	1.014	0.529	0.000	0.000
1997	0.000	0.000	0.864	0.565	0.813	0.798	0.589	0.589
1998	0.000	0.000	0.096	0.412	0.407	0.369	0.100	0.100
1999	0.000	0.000	0.194	0.249	0.411	0.132	0.054	0.054
2000	0.000	0.495	0.532	0.017	0.022	0.025	0.003	0.003
2001	0.000	0.037	0.000	0.063	0.041	0.000	0.015	0.015
2002	0.000	0.006	0.015	0.010	0.011	0.005	0.015	0.015
2003	0.000	0.005	0.010	0.010	0.010	0.005	0.005	0.005
2004	0.000	0.001	0.005	0.002	0.002	0.004	0.001	0.001
2005	0.000	0.005	0.005	0.009	0.005	0.004	0.003	0.003
2006	0.000	0.008	0.442	0.127	0.068	0.047	0.017	0.017
2007	0.000	0.000	0.012	0.022	0.054	0.050	0.079	0.079
2008	0.000	0.011	0.027	0.068	0.124	0.102	0.063	0.063
2009	0.000	0.003	0.008	0.052	0.069	0.000	0.105	0.105
2010	0.003	0.054	0.227	0.307	0.275	0.358	0.277	0.277
2011	0.001	0.058	0.279	0.218	0.426	0.642	0.690	0.690
2012	0.002	0.015	0.205	0.217	0.532	0.510	0.507	0.507
2013	0.003	0.040	0.278	0.246	0.471	0.673	0.480	0.480

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	16300	22360	4585	39245	18390	8355	3473	3437	116145	24928
1973	56310	13930	19130	3652	15700	4262	1054	1304	115342	14741
1974	111600	48160	11910	14470	2996	2567	420	392	192515	5096
1975	20720	95515	41200	4634	2051	488	434	392	165434	2506
1976	9190	17735	81755	28690	1701	598	196	15	139880	1899
1977	2706	7862	15170	53670	14700	1092	416	487	96103	9892
1978	18380	2312	6721	12860	29630	4694	527	426	75550	20838
1979	12290	15720	1979	5353	8136	8542	666	286	52972	9262
1980	6866	10510	13440	1536	2157	1774	1828	130	38241	4269
1981	18920	5872	8992	10990	849	524	542	1533	48222	4457
1982	18680	16190	5024	6087	3142	576	145	526	50370	4774
1983	11790	15980	13860	4273	2395	900	204	281	49683	4089
1984	13330	10090	13670	9244	2992	1336	160	255	51077	5665
1985	53050	11400	8627	11690	5838	1657	1082	245	93589	9524
1986	109400	45370	9741	7356	4906	1692	272	256	178993	7433
1987	69180	93610	36450	6230	2352	1461	460	162	209905	5281
1988	14345	58425	78370	28320	3545	842	463	234	184544	31366
1989	19200	12270	46735	43380	13890	1725	334	306	137840	30964
1990	24260	16425	10440	25740	15620	3187	598	182	96452	21774
1991	61430	20750	13820	6916	7451	3339	601	122	114429	11858
1992	55660	52560	17230	7014	4104	3441	1286	531	141826	9578
1993	2999	47605	30610	5328	1498	364	636	312	89352	5810
1994	4141	2564	38270	12750	1276	417	48	616	60082	12756
1995	2175	3533	1063	9237	3252	733	184	310	20487	11942
1996	130	1858	3013	663	1825	232	24	1	7746	2636
1997	126	111	1513	1911	278	563	116	1	4619	2454
1998	194	108	95	545	927	105	216	23	2213	1810
1999	32	166	92	74	308	527	62	21	1282	1028
2000	313	28	142	65	49	174	394	1	1166	734
2001	554	267	14	71	55	41	146	145	1293	468
2002	66	474	220	12	57	45	35	246	1155	552
2003	1188	57	403	184	10	48	38	238	2166	738
2004	80	1012	48	340	155	9	41	235	1920	789
2005	3622	68	867	41	289	132	7	236	5262	1322
2006	7484	3092	58	736	35	245	112	21	11783	1204
2007	10030	6387	2611	32	554	28	200	66	19908	1737
2008	8382	8570	5450	2200	27	446	22	61	25158	3924
2009	11010	7151	7237	4504	1756	20	344	78	32100	7434
2010	12885	9396	6084	6136	3648	1397	17	461	40024	11816
2011	35000	10990	7600	4145	3838	2360	831	618	65382	9862
2012	28950	29890	8843	4872	2838	2128	1052	963	79536	10344
2013	9619	24780	25130	6128	3339	1412	1084	710	72202	20456
2014[1]		8193	20292	16155	4103	1778	616	949	52086	28206

[1] Results without recruitment data

Table 11.- N-at-age in prediction years (medians) with $F_{bar}=F_{0.1}=0.090$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2014	73478	8193	20292	16155	4103	1778	616	949	125564	28349
2015	103538	62610	6740	13871	11298	2352	882	967	202258	33294
2016	117190	88135	52790	5310	11004	8391	1647	1466	285933	48990

Table 12.- Projections results with $F_{bar}=F_{0.1}=0.090$.

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2014	45089	66953	100551	29651	44869	67628	0.0000		14521	
2015	51148	85726	141169	33526	58334	96126	0.0000	3717	7091	13216
2016	80488	140565	242288	50201	84280	140612	0.0000			

Table 13.- N-at-age in prediction years (medians) with $F_{bar}=F_{max}=0.145$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2014	73478	8193	20292	16155	4103	1778	616	949	125564	28349
2015	100065	62610	6740	13871	11298	2352	882	967	198785	33380
2016	117889	85312	52366	5080	10560	7760	1462	1357	281786	47038

Table 14.- Projections results with $F_{bar}=F_{max}=0.145$.

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2014	45089	66953	100551	29651	44869	67628	0.0000		14521	
2015	51007	85528	141921	33538	58341	96142	0.0000	5804	10838	19894
2016	75911	134970	233068	47116	79646	133162	0.0000			

Table 15.- N-at-age in prediction years (medians) with $F_{bar}=2/3F_{max}=0.097$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2014	73478	8193	20292	16155	4103	1778	616	949	125564	28349
2015	103011	62610	6740	13871	11298	2352	882	967	201731	33348
2016	115496	87444	52767	5286	10967	8331	1626	1454	283371	48808

Table 16.- Projections results with $F_{bar}=2/3F_{max}=0.097$.

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2014	45089	66953	100551	29651	44869	67628	0.0000		14521	
2015	51600	85659	140511	33564	58355	96133	0.0000	3984	7463	13901
2016	79919	139414	241557	49720	83828	140158	0.0000			

Table 17.- N-at-age in prediction years (medians) with $F_{bar}=3/4F_{max}=0.109$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2014	73478	8193	20292	16155	4103	1778	616	949	125564	28349
2015	100438	62610	6740	13871	11298	2352	882	967	199158	33352
2016	113155	86181	52610	5227	10846	8171	1583	1430	279203	48381

Table 18.- Projections results with $F_{bar}=3/4F_{max}=0.109$.

	Total Biomass quantiles			**SSB quantiles**			**$P(SSB<B_{lim})$**	**F quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2014	45089	66953	100551	29651	44869	67628	0.0000		14521	
2015	51451	85707	141013	33554	58302	96130	0.0000	4449	8327	15461
2016	79064	138195	238799	49331	82737	138519	0.0000			

Table 19.- N-at-age in prediction years (medians) with $F_{bar}=0.85F_{max}=0.123$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2014	73478	8193	20292	16155	4103	1778	616	949	125564	28349
2015	100812	62610	6740	13871	11298	2352	882	967	199532	33360
2016	119828	85805	52505	5171	10735	8007	1534	1400	284985	47900

Table 20.- Projections results with $F_{bar}=0.85F_{max}=0.123$.

	Total Biomass quantiles			**SSB quantiles**			**$P(SSB<B_{lim})$**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2014	45089	66953	100551	29651	44869	67628	0.0000		14521	
2015	50976	85605	140451	33567	58341	96114	0.0000	4999	9351	17275
2016	77772	136555	239130	48233	81562	136327	0.0000			

Table 21.- N-at-age in prediction years (medians) with $F_{bar}=0.75F_{statusquo}=0.259$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2014	73478	8193	20292	16155	4103	1778	616	949	125564	28349
2015	102372	62610	6740	13871	11298	2352	882	967	201092	33374
2016	116421	86878	51581	4598	9634	6554	1152	1143	277961	43790

Table 22.- Projections results with $F_{bar}=0.75F_{statusquo}=0.259$.

	Total Biomass quantiles			**SSB quantiles**			**$P(SSB<B_{lim})$**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2014	45089	66953	100551	29651	44869	67628	0.0000		14521	
2015	50963	85988	141194	33526	58346	96068	0.0000	12494	17926	27715
2016	68617	125904	226920	39178	70884	121773	0.0000			

Table 23.- N-at-age in prediction years (medians) with $F_{bar}=F_{statusquo}=0.346$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2014	73478	8193	20292	16155	4103	1778	616	949	125564	28349
2015	99671	62610	6740	13871	11298	2352	882	967	198391	33310
2016	120276	84747	50952	4280	9061	5823	966	1010	277115	41612

Table 24.- Projections results with $F_{bar}=F_{statusquo}=0.346$.

	Total Biomass quantiles			**SSB quantiles**			**$P(SSB<B_{lim})$**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2014	45089	66953	100551	29651	44869	67628	0.0000		14521	
2015	51451	85545	140120	33538	58375	96144	0.0000	15768	22605	34554
2016	64236	119001	216119	35038	65093	113266	0.0004			

Table 25.- N-at-age in prediction years (medians) with F_{bar}=1.25$F_{statusquo}$=0.432 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2014	73478	8193	20292	16155	4103	1778	616	949	125564	28349
2015	100257	62610	6740	13871	11298	2352	882	967	198977	33382
2016	117361	85062	50484	3974	8501	5153	808	892	272235	39474

Table 26.- Projections results with F_{bar}=1.25$F_{statusquo}$=0.432.

	Total Biomass quantiles			SSB quantiles			P(SSB<B_{lim})	F quantiles		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2014	45089	66953	100551	29651	44869	67628	0.0000		14521	
2015	51073	85533	139749	33525	58327	96233	0.0000	18611	26799	40670
2016	59161	113669	207151	31681	60010	106017	0.0006			

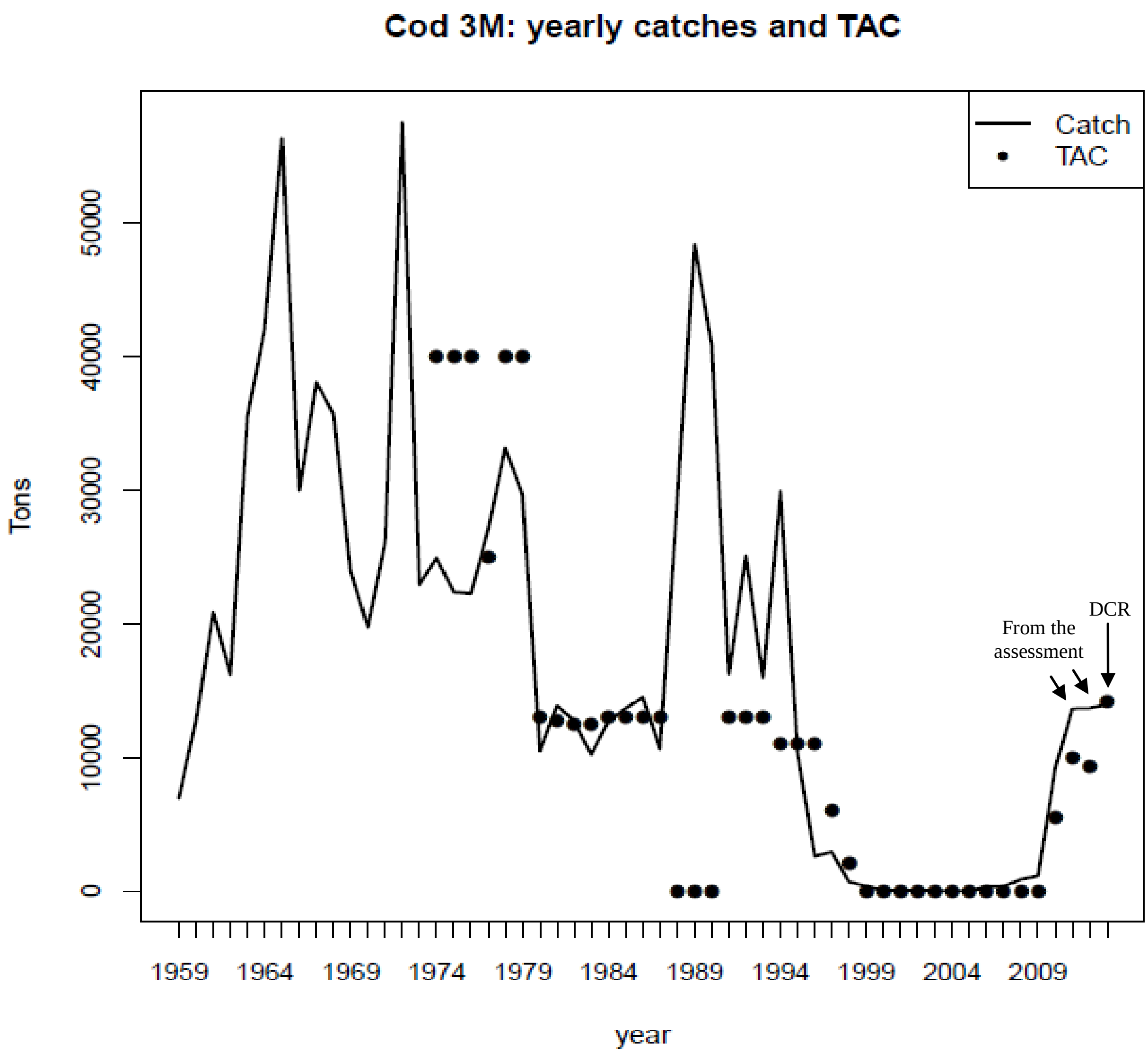


Figure 1.- Catch and TAC of the 3M cod for the period 1959-2013.

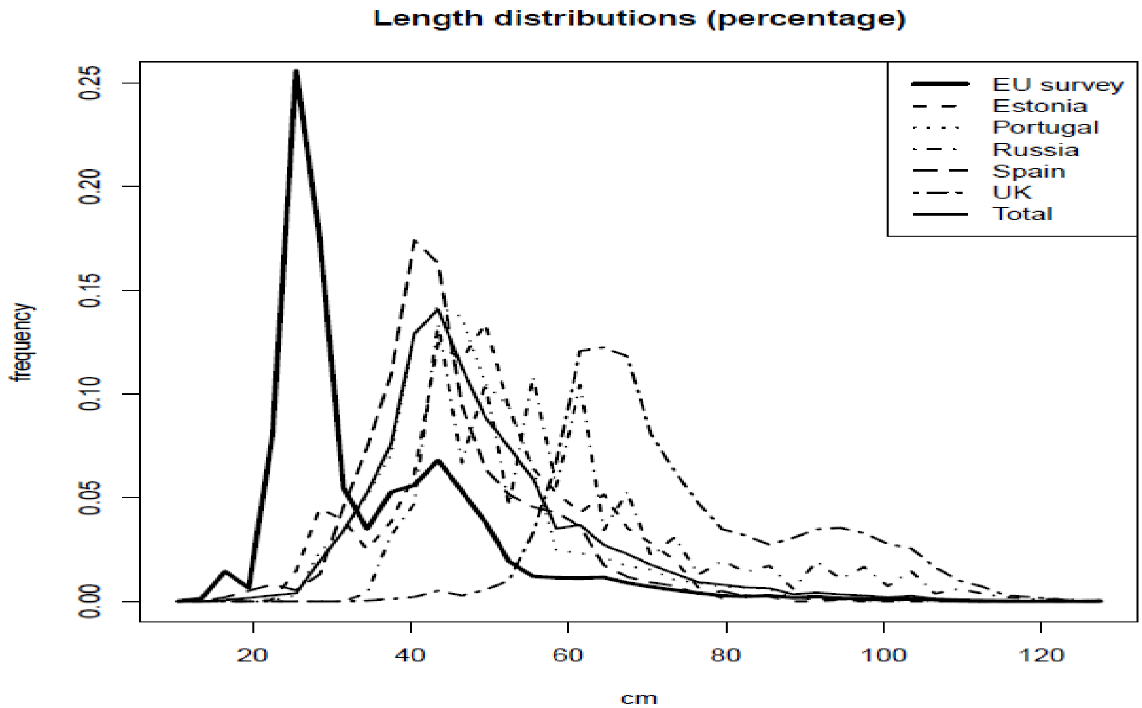


Figure 2.- Length frequencies in commercial catches and EU survey in 2013.

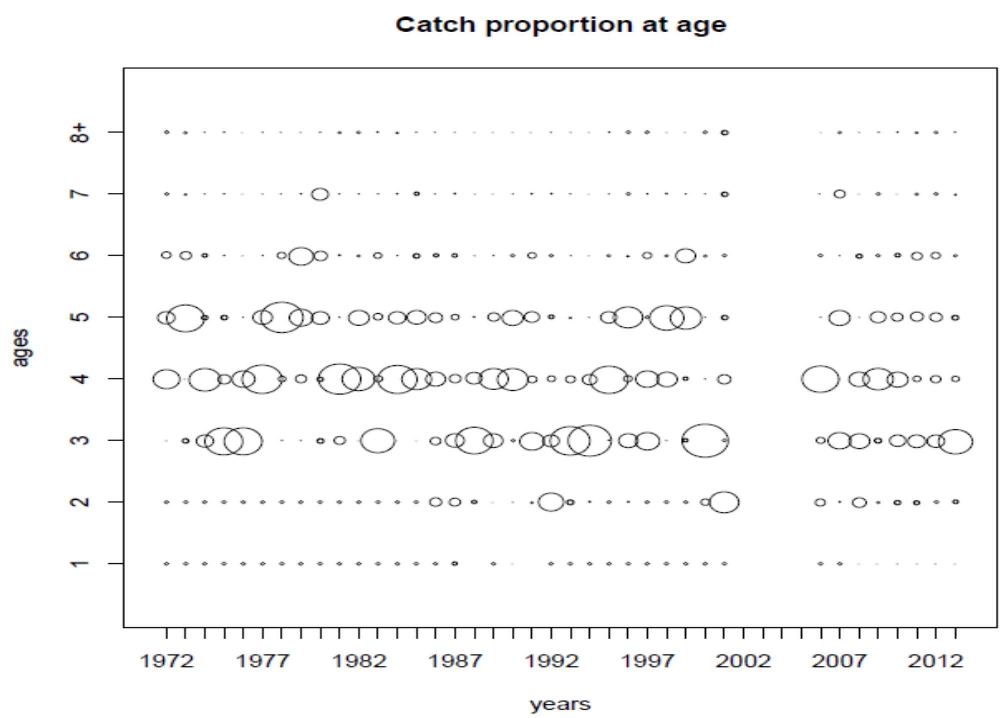


Figure 3.- Commercial catch proportions at age.

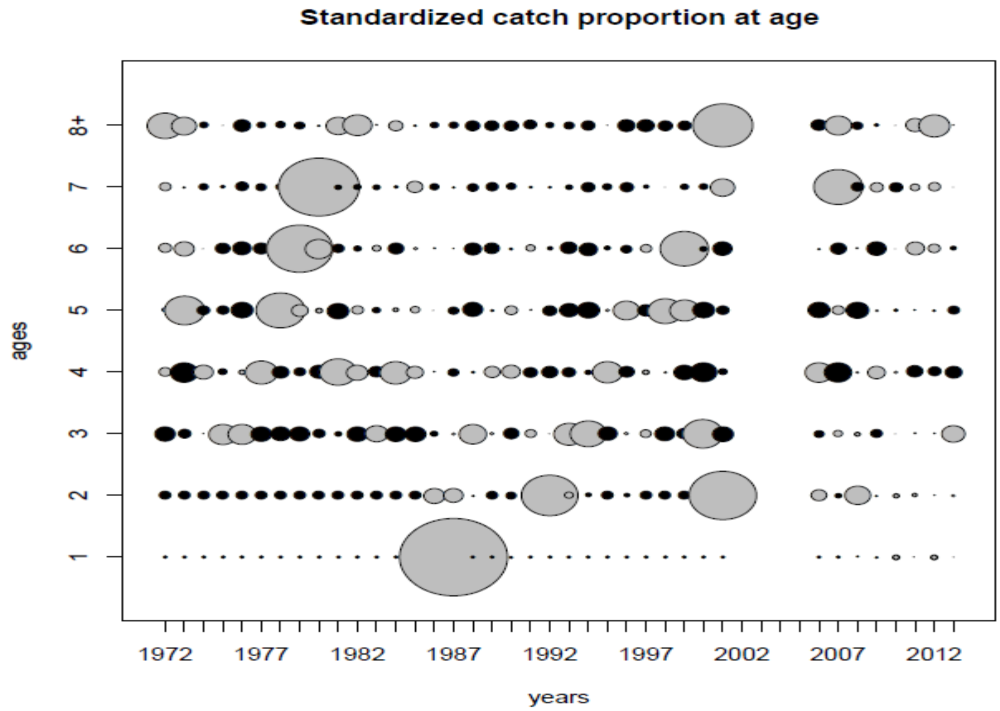


Figure 4.- Commercial catch standardised proportions at age. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

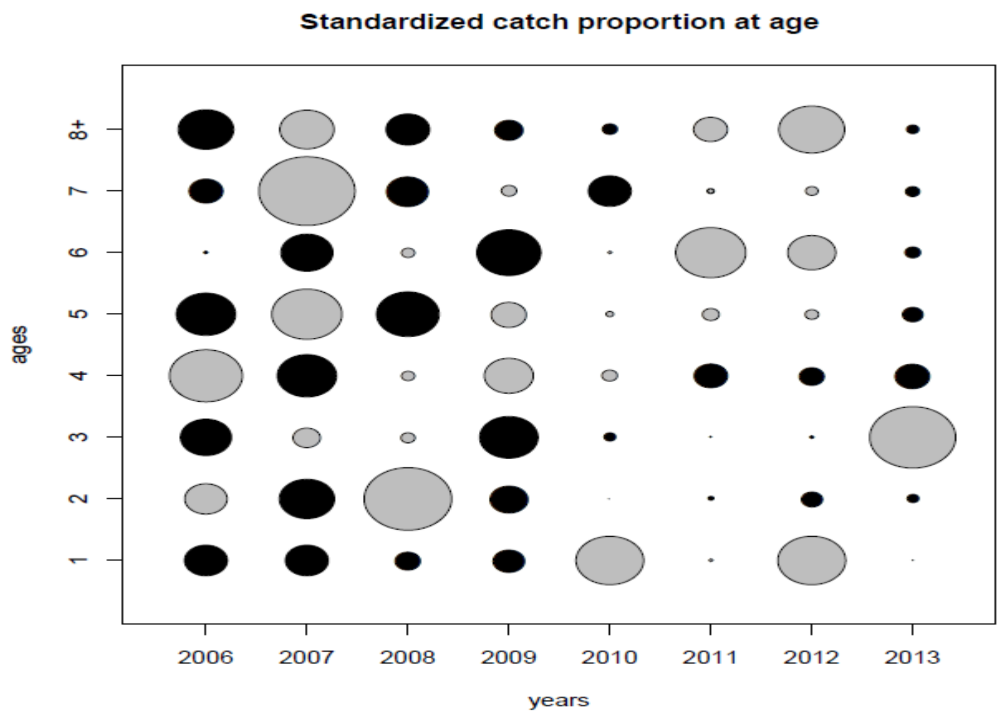


Figure 5.- Commercial catch standardised proportions at age for the last cohort (2006-2013). Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

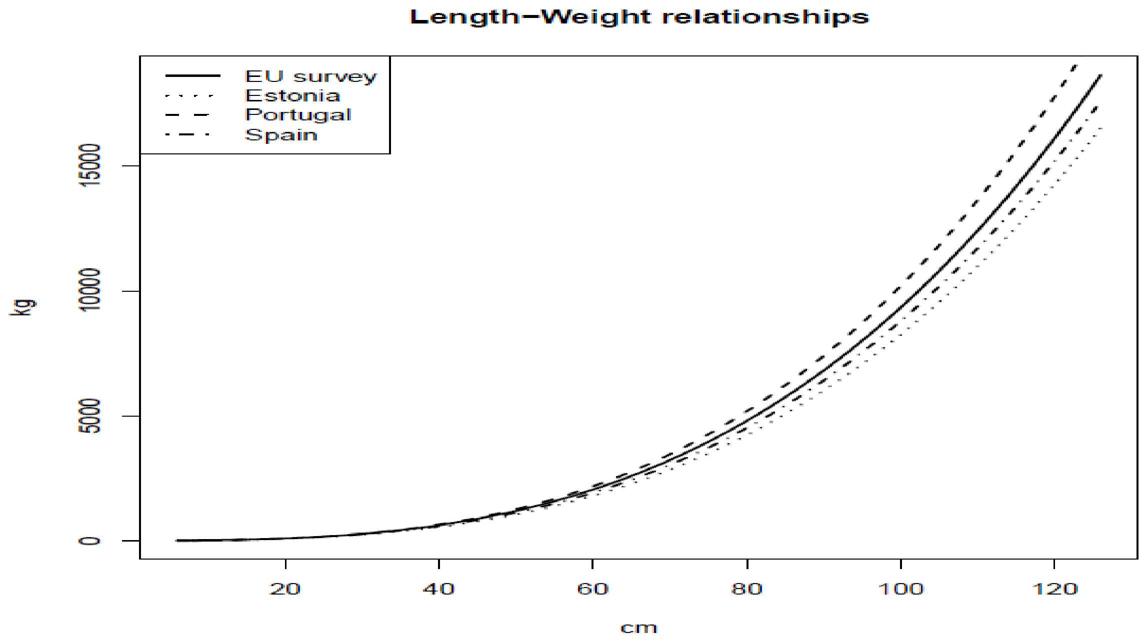


Figure 6.- Length-weight relationships for commercial catches and EU survey in 2013.

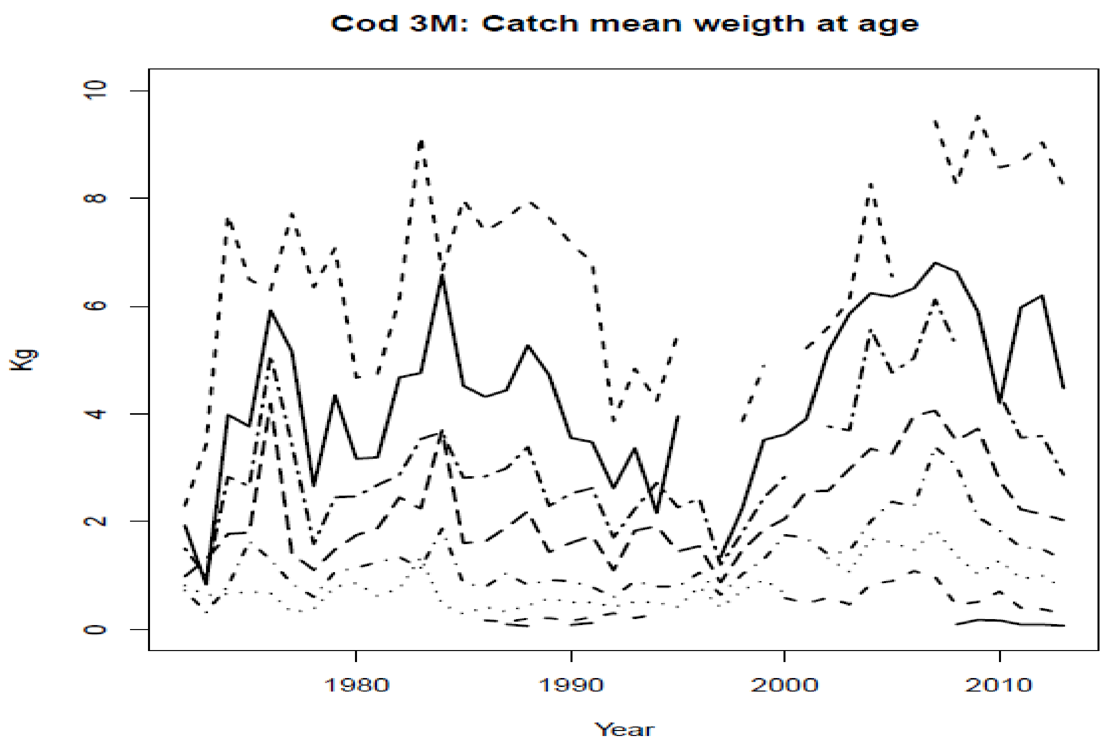


Figure 7.- Catch mean weight at age.

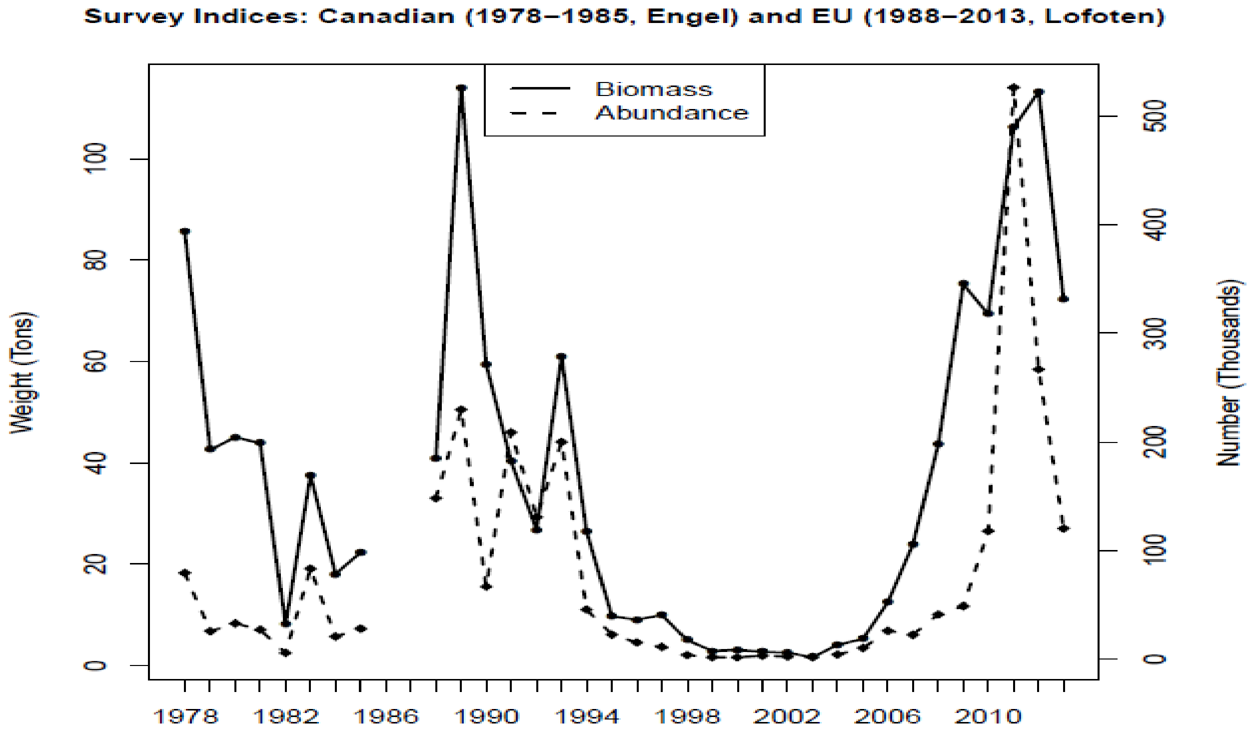


Figure 8.- Biomass and abundance from Canadian and EU surveys.

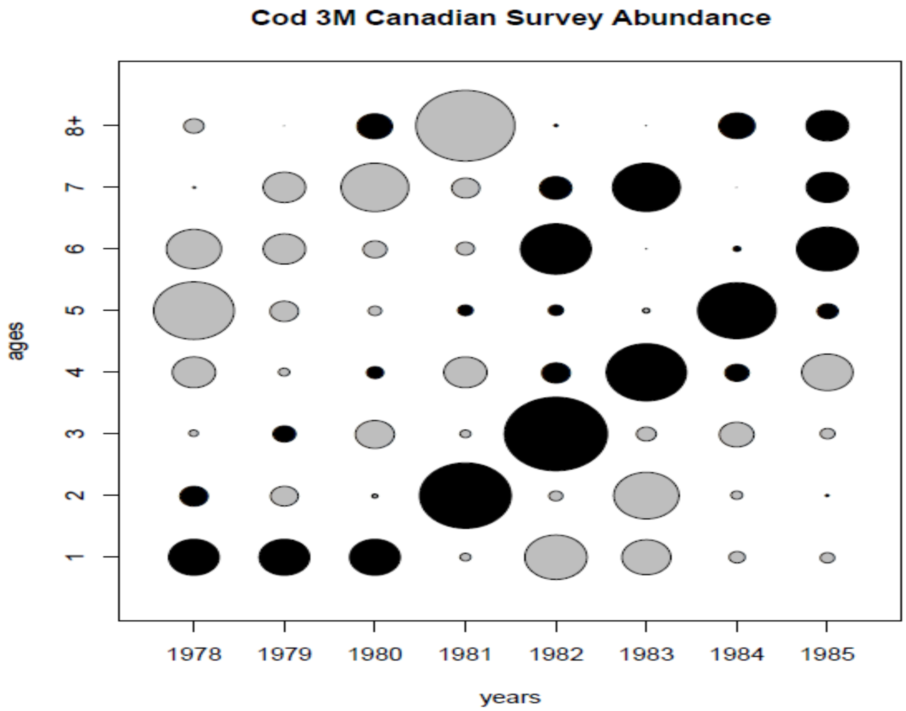


Figure 9.- Standardised log(1+Abundance at age) indices from Canadian survey. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

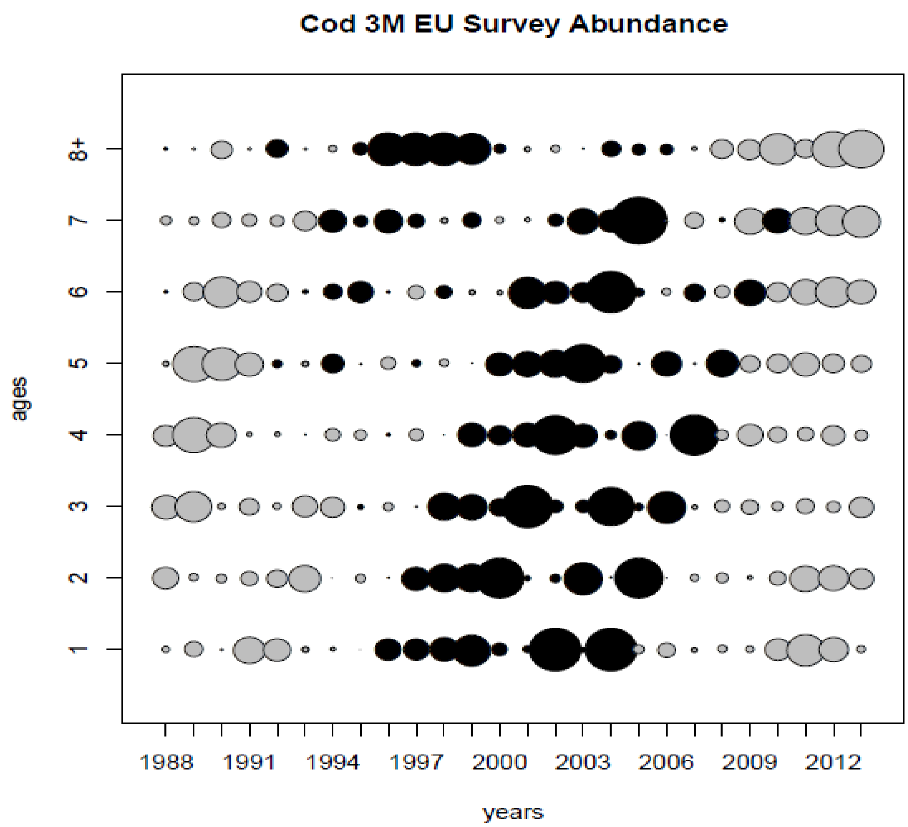


Figure 10.- Standardised log(1+Abundance at age) indices from EU survey. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

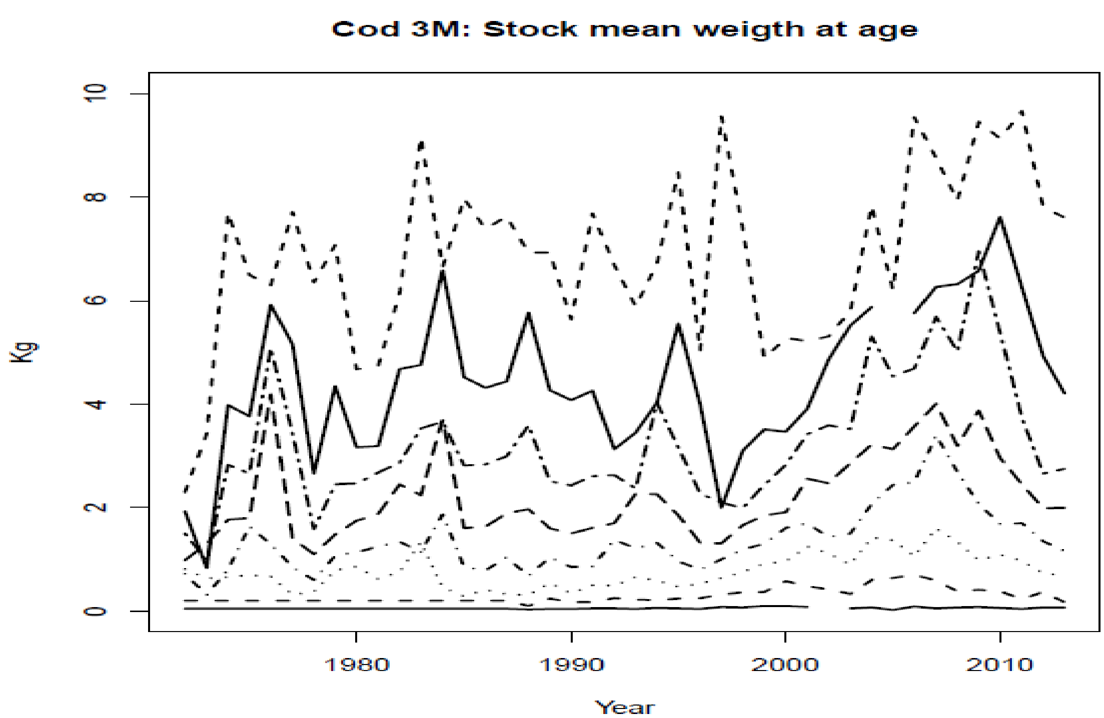


Figure 11.- Stock mean weight at age

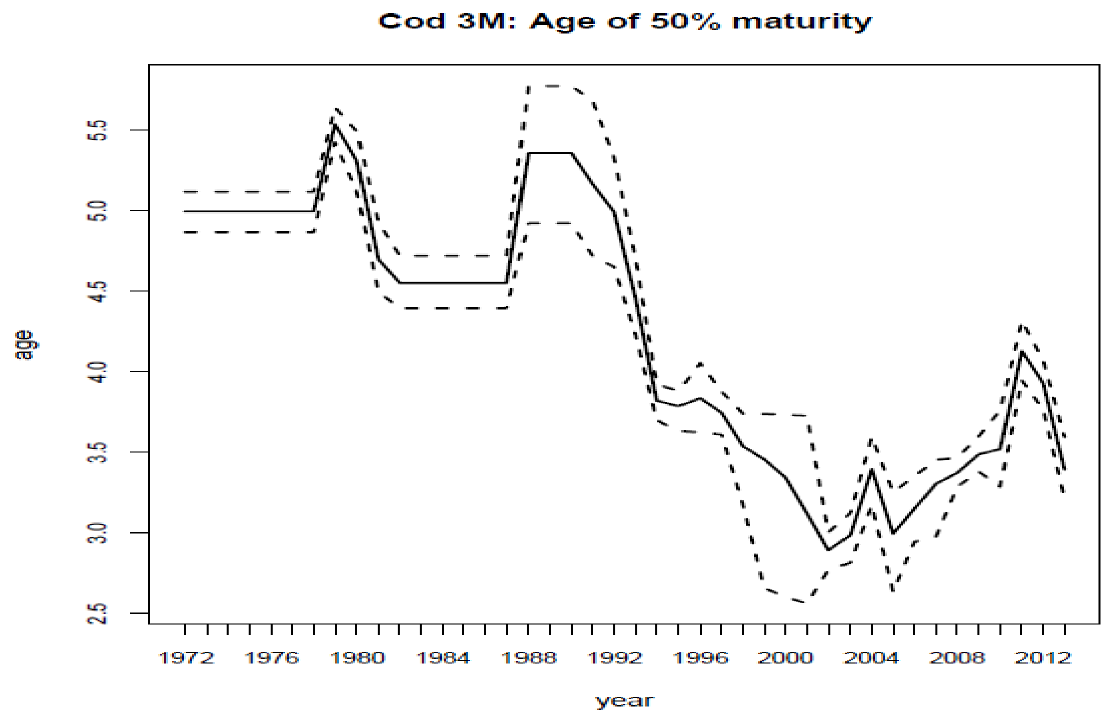


Figure 12.- Age at which 50% of fish are mature.

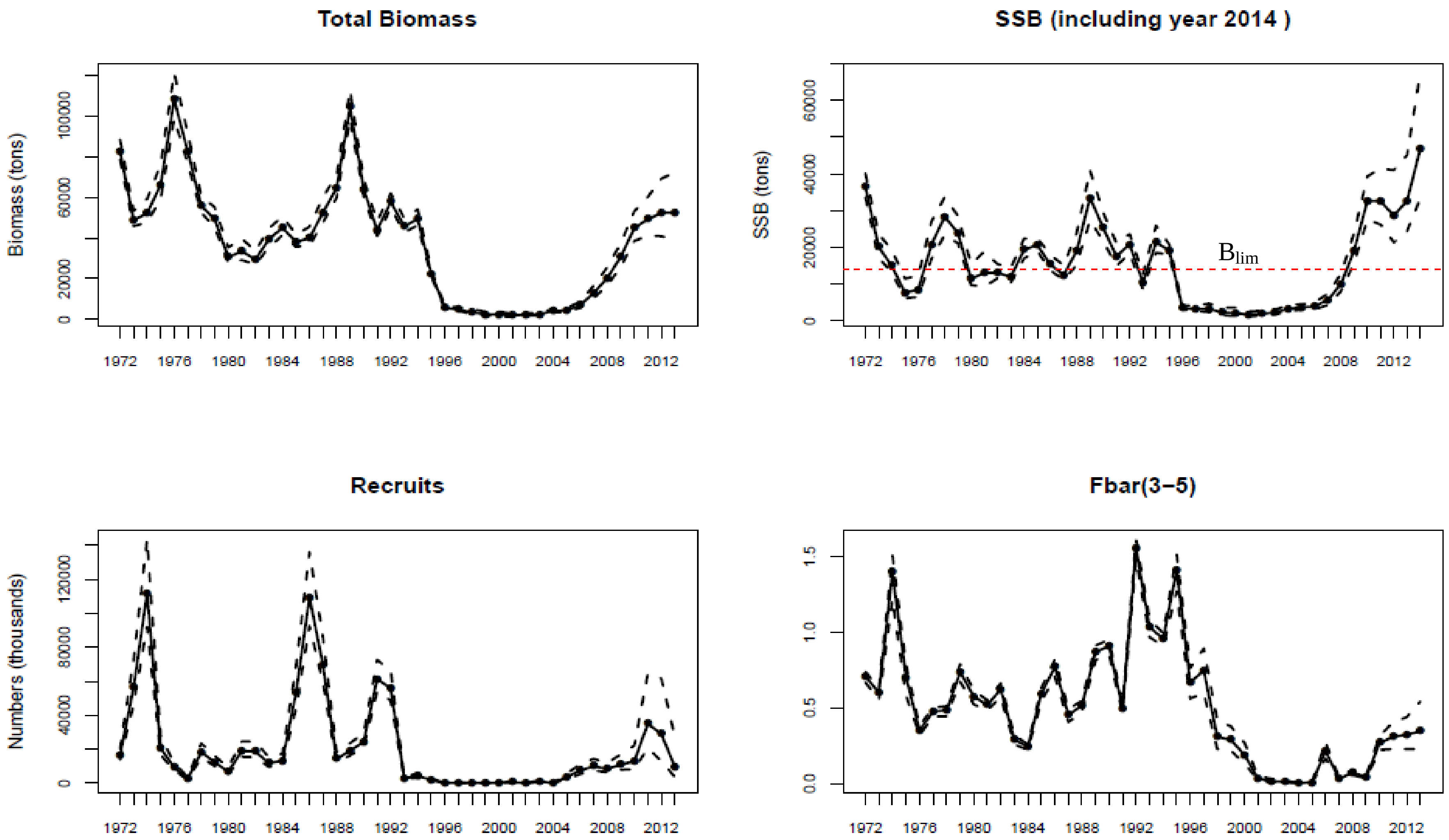


Figure 13.- Estimated trends in biomass, SSB, recruitment and F_{bar}. The solid lines are the posterior medians and the dashed lines show the limits of 90% posterior credible intervals. Red horizontal line in the SSB graph represents B_{lim} = 14 000 tons.

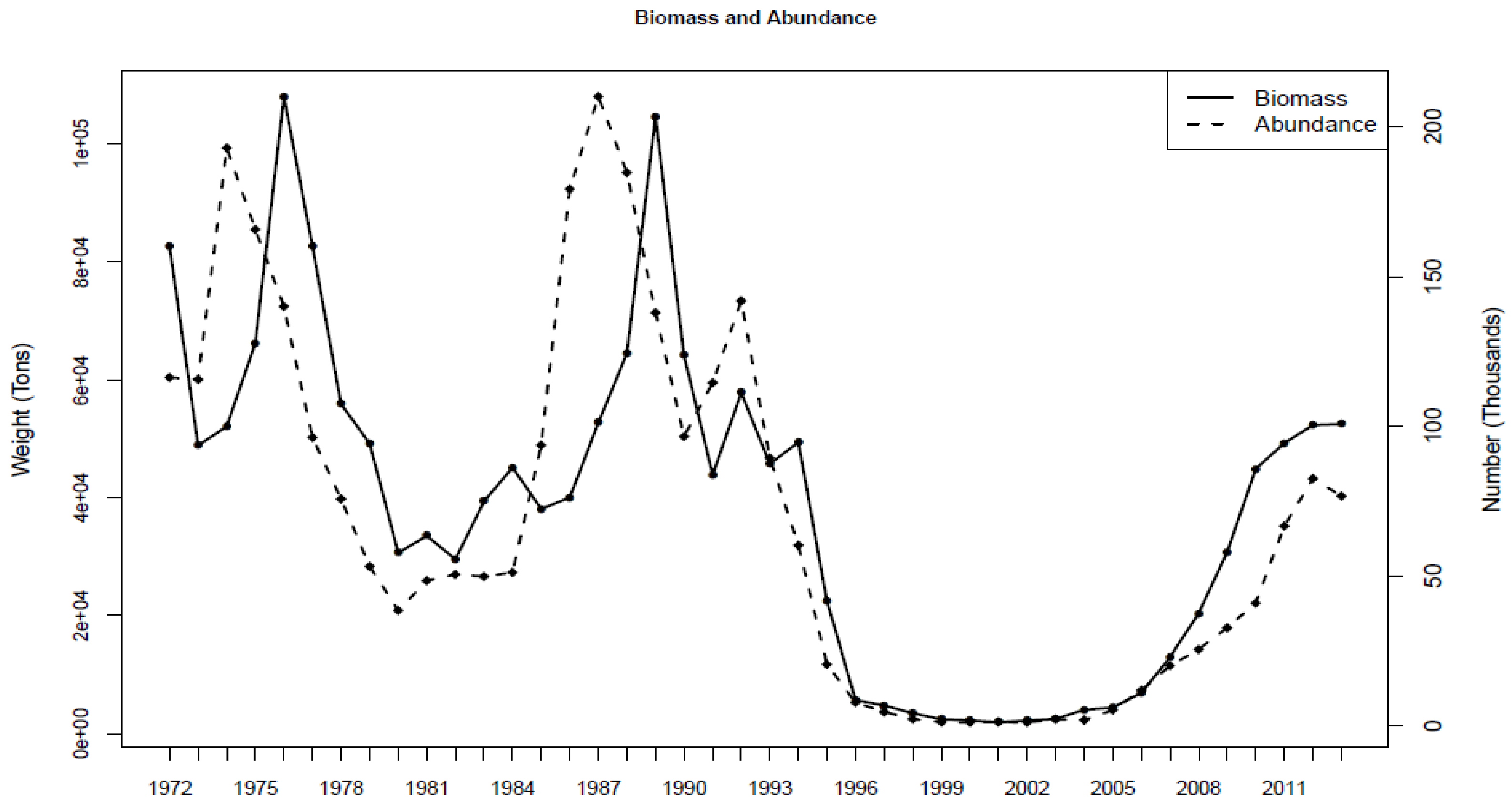


Figure 14.- Estimated trends in biomass and abundance.

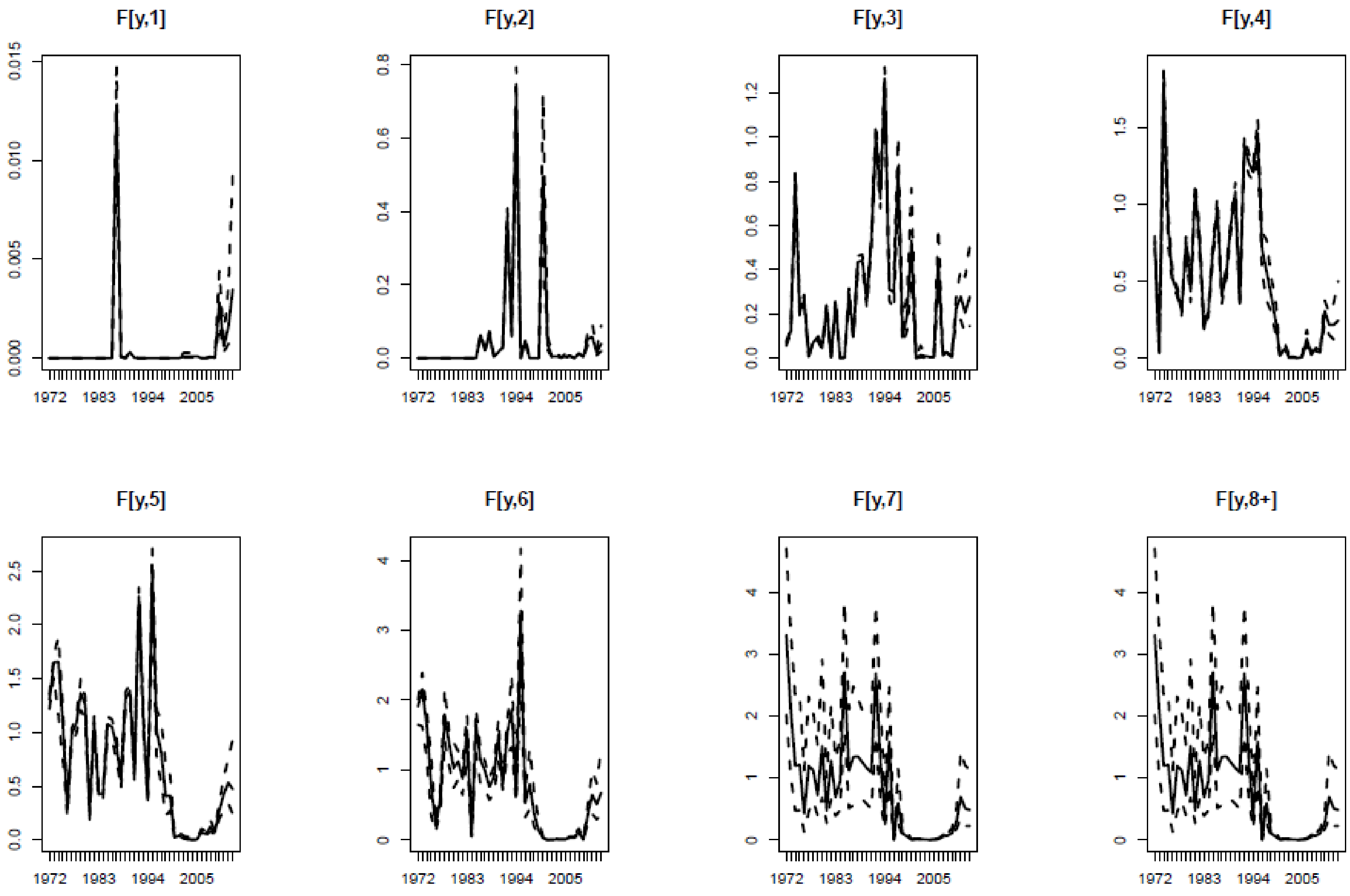


Figure 15.- Estimated fishing mortality at age. The y-axis scale is different in all the graphs.

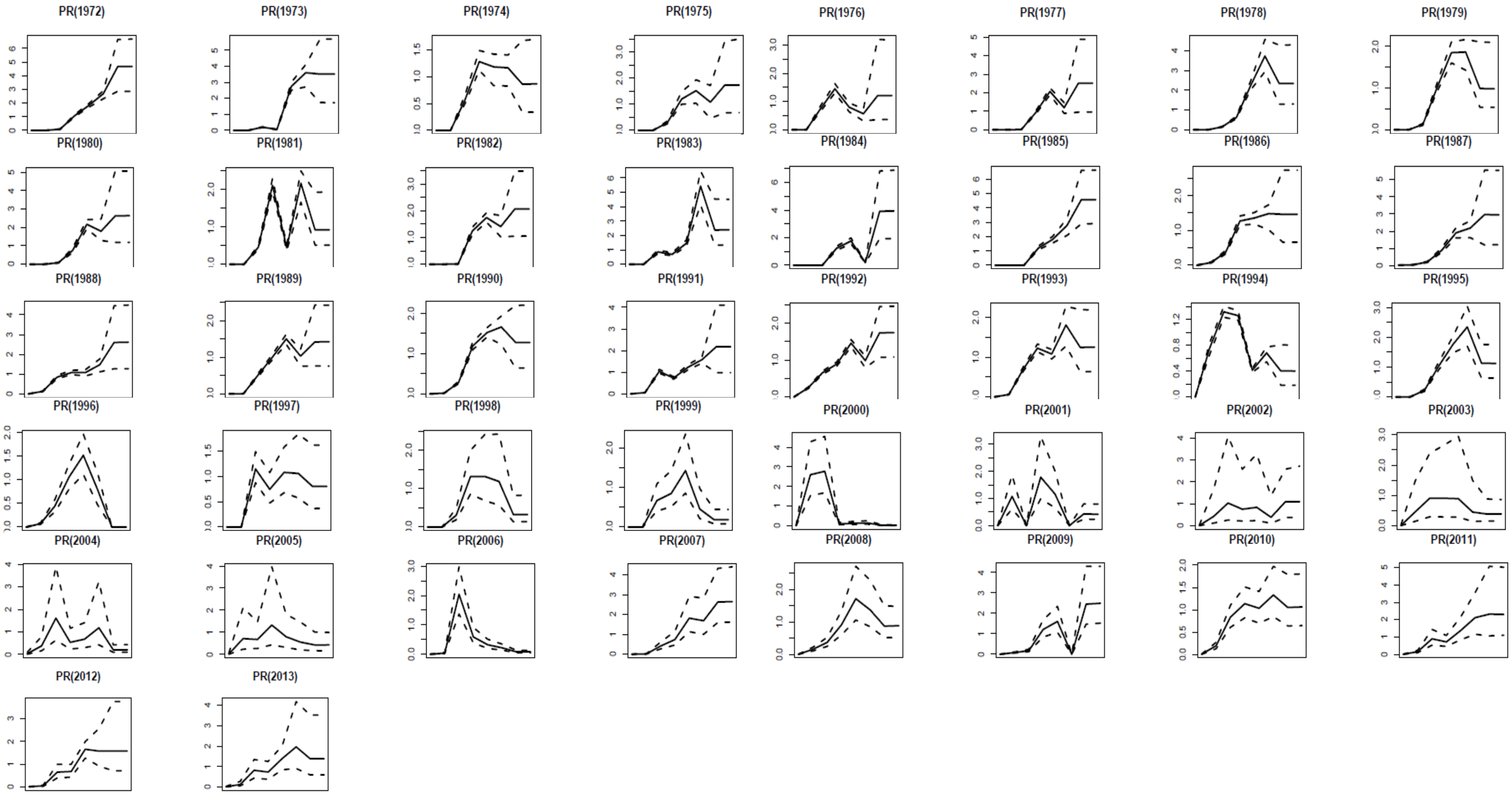


Figure 16.- Estimated PR (F/F_{bar}) per age and year.

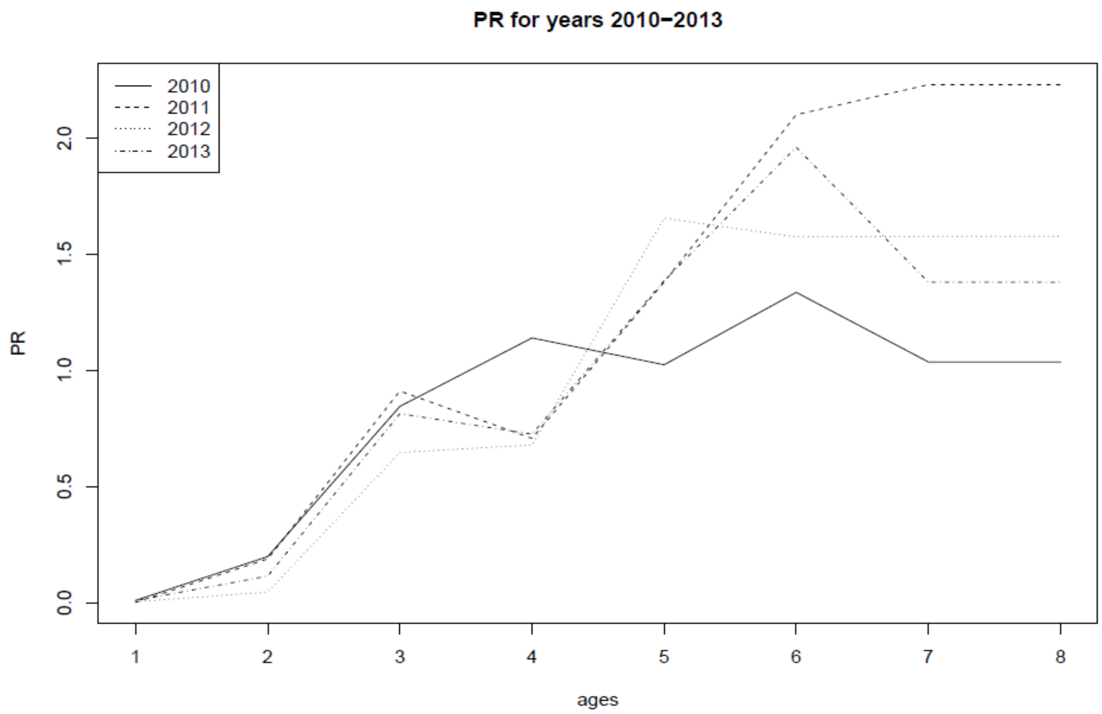


Figure 17.- Estimated PR (F/F_{bar}) per age for the last four years.

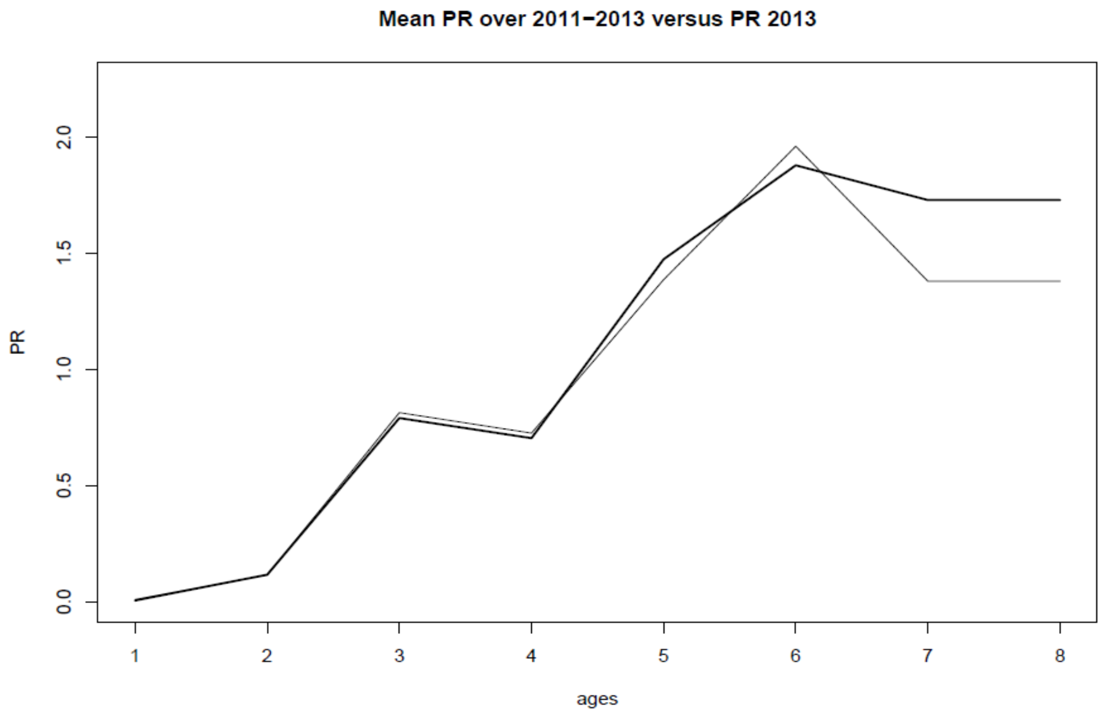


Figure 18.- Mean of 2011-2013 PR versus 2013 PR (posterior medians). Bold line is the mean of the last three years PR.

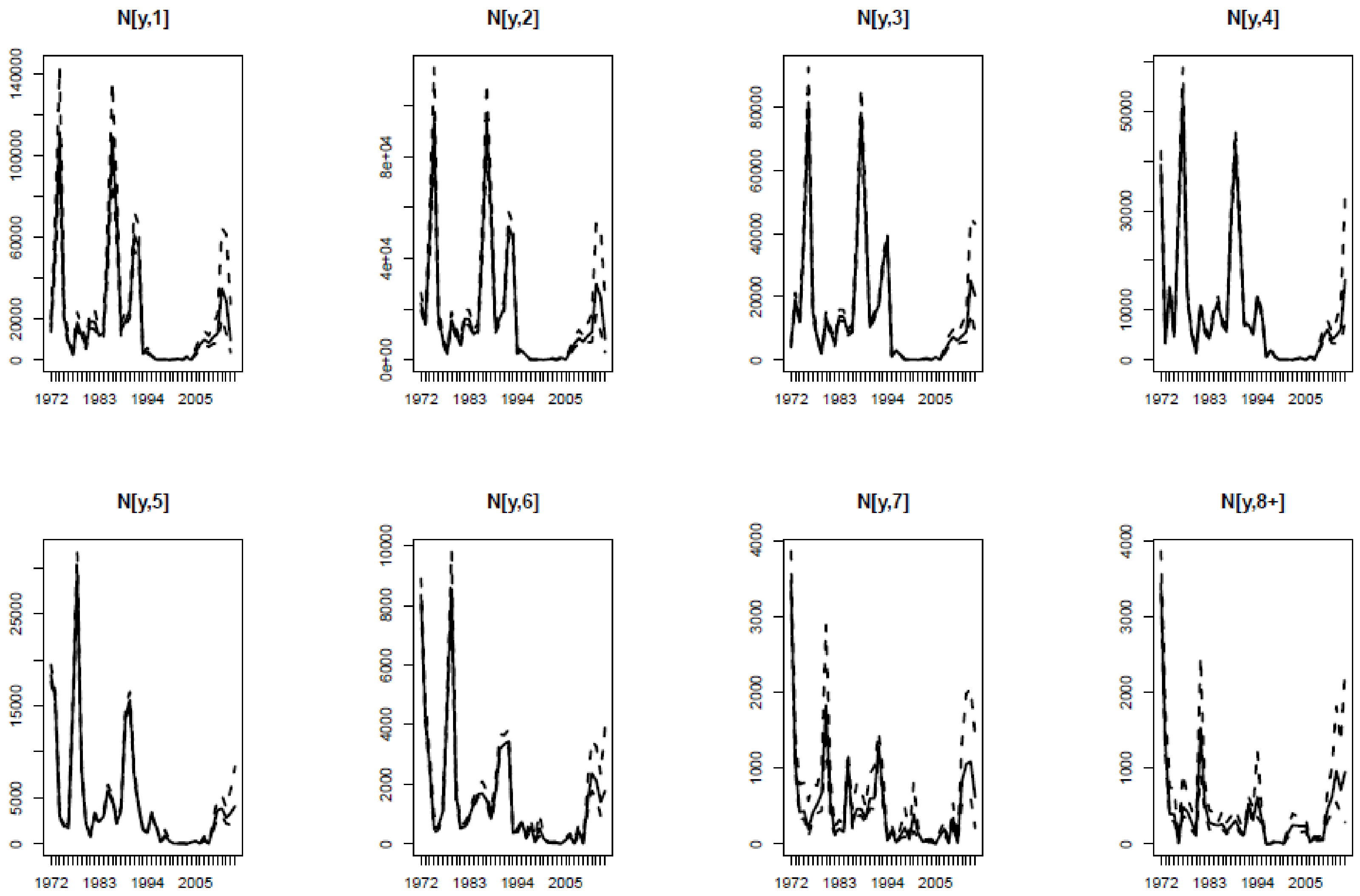


Figure 19.- Estimated numbers at age. The y-axis scale is different in all the graphs.

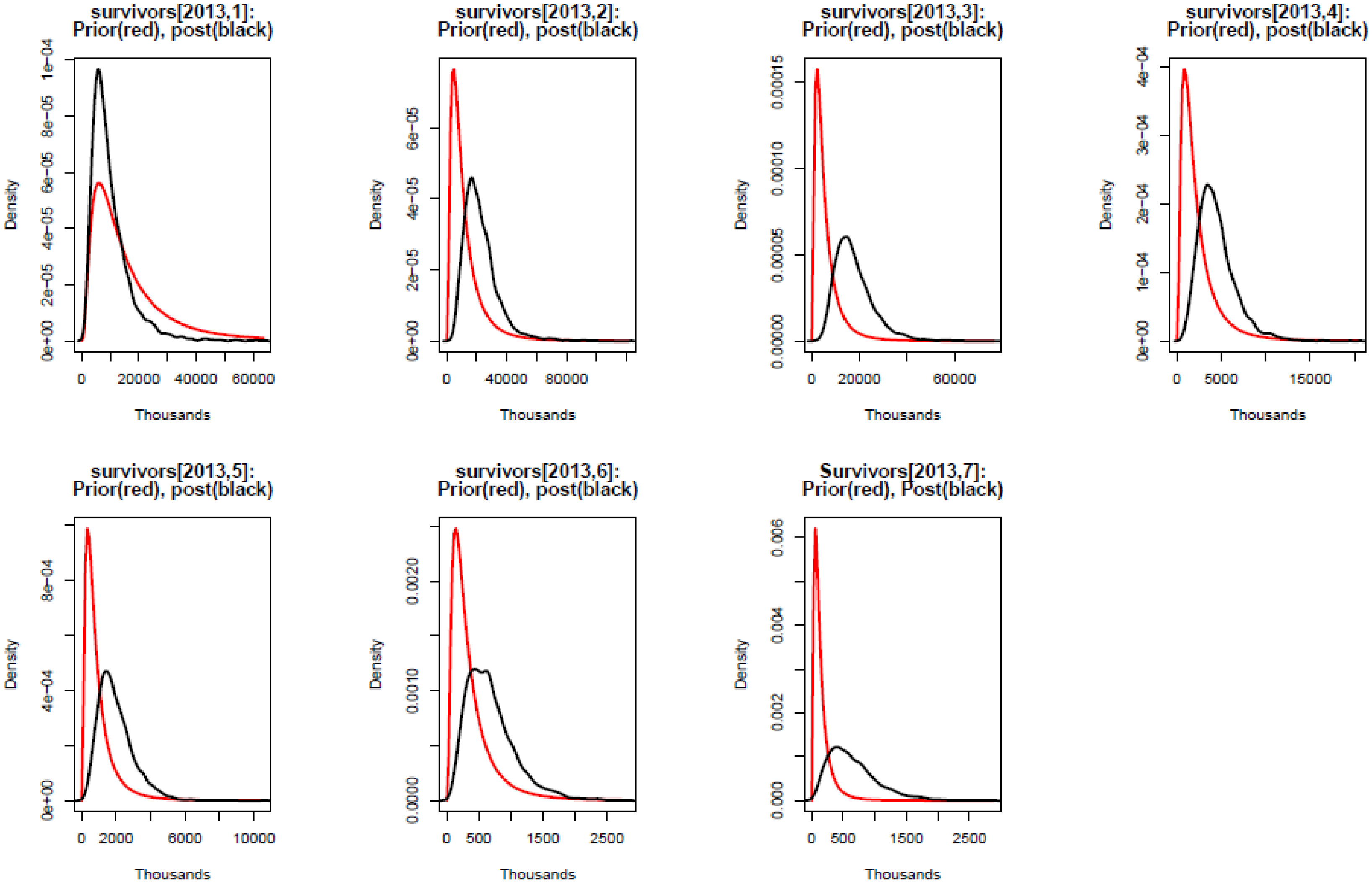


Figure 20.- Survivors at age at the end of 2012 (*survivors* (2012,a) are the number of individuals of age a+1 at the beginning of 2013). The y-axis scale is different in all the graphs.

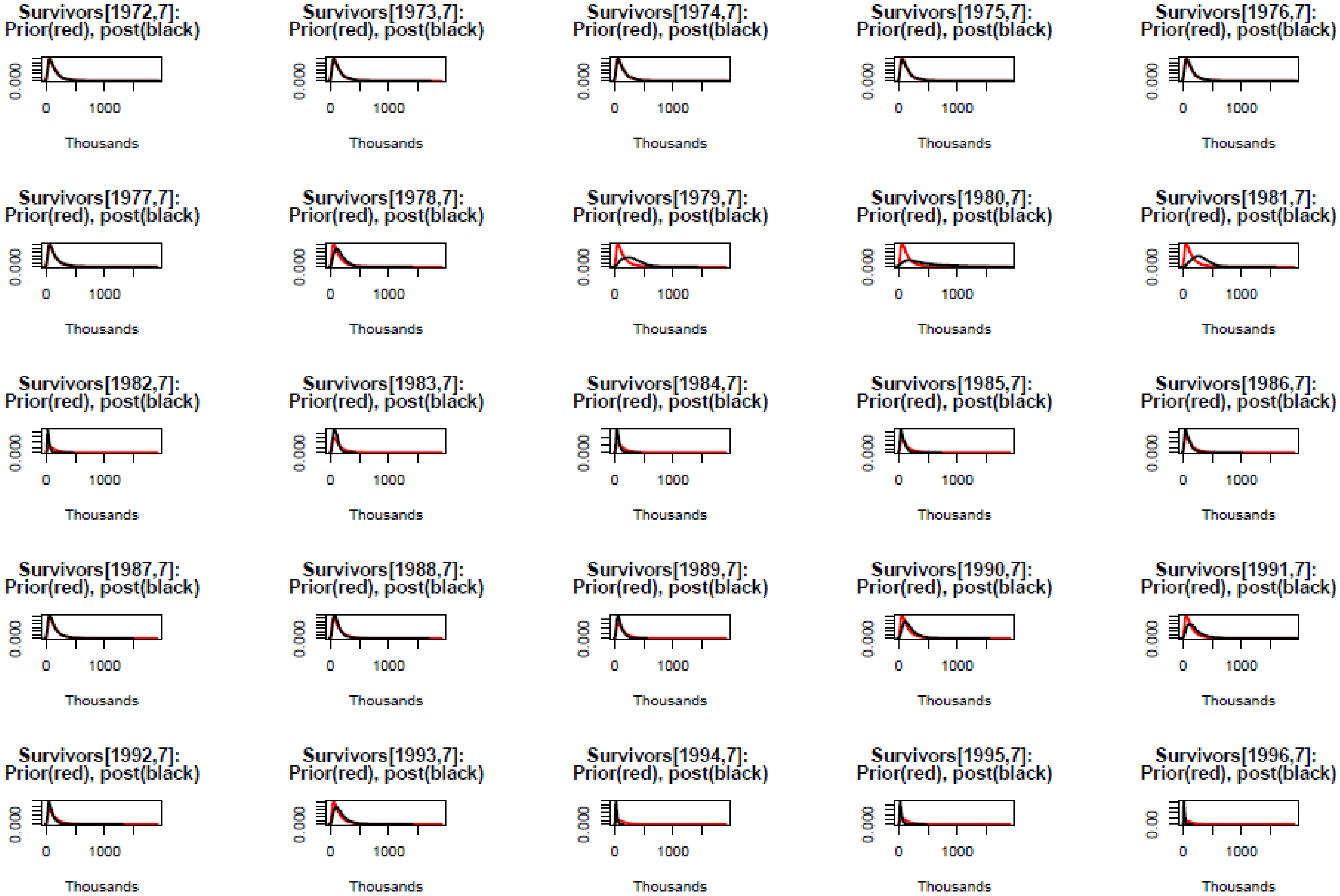


Figure 21.- Survivors from age 7 in each year (*survivors* (y,7) are the individuals of age 8 at the beginning of year y+1). The y-axis scale is different in all the graphs.

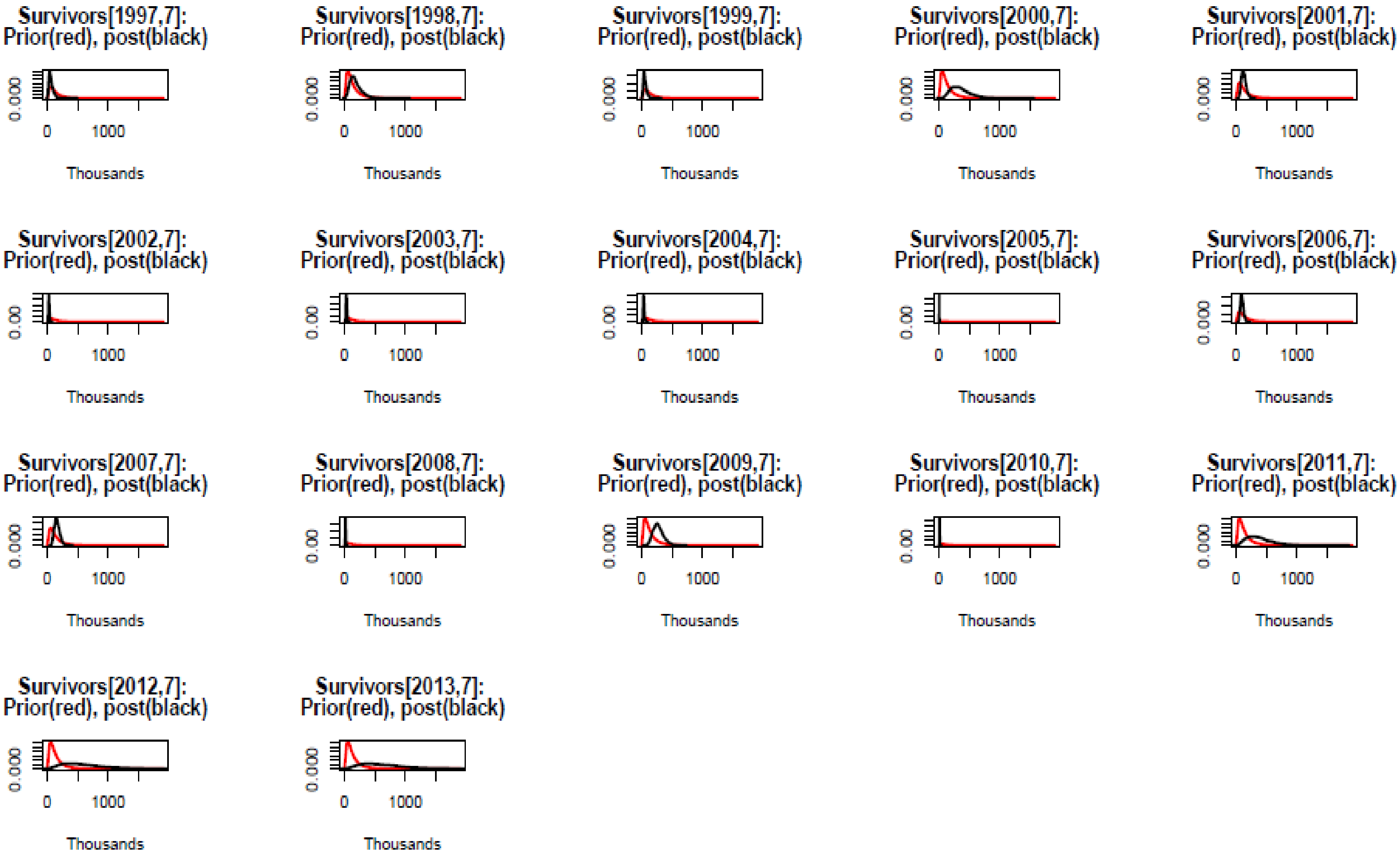


Figure 21 (cont.).- Survivors from age 7 in each year (*survivors* (y,7) are the individuals of age 8 at the beginning of year y+1). The y-axis scale is different in all the graphs.

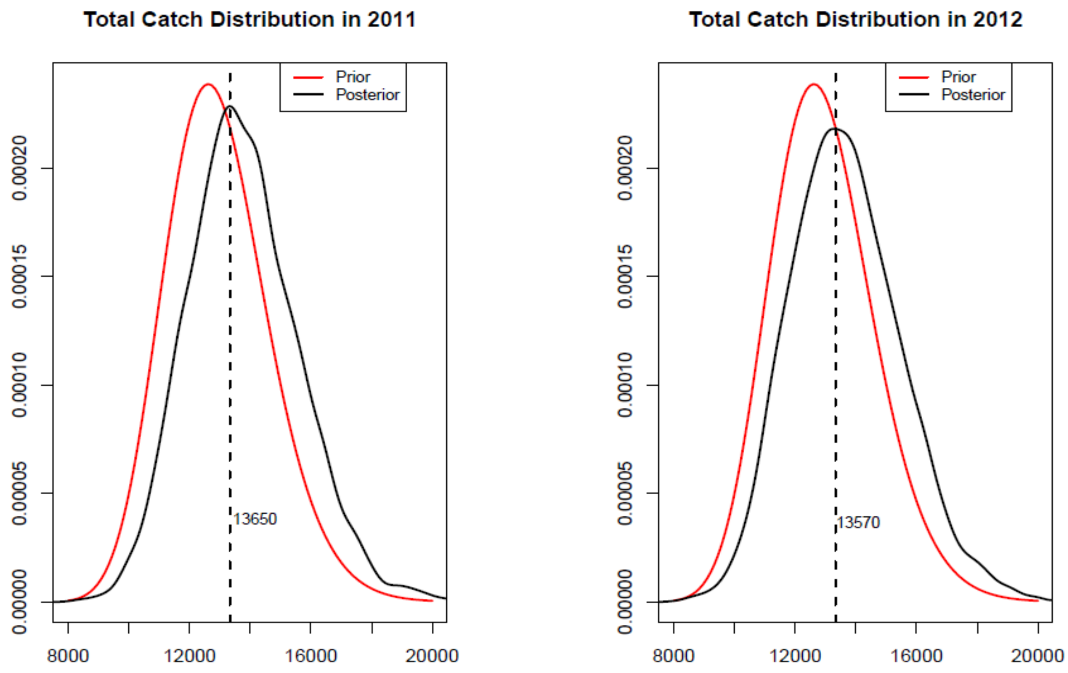


Figure 22.- Estimated total catch in 2011 and 2012

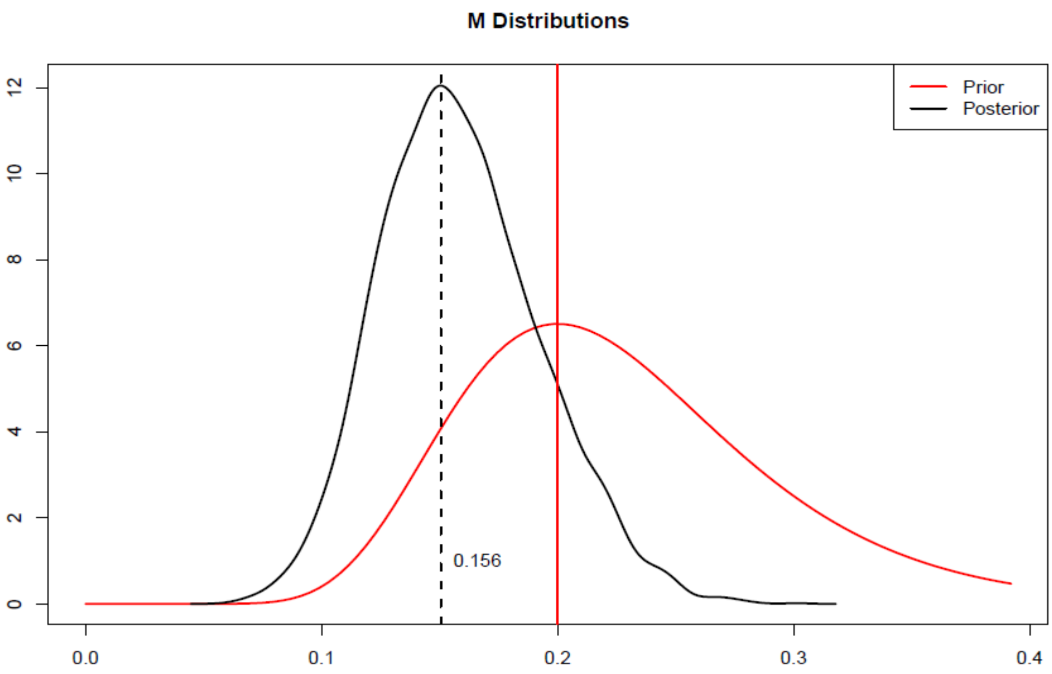
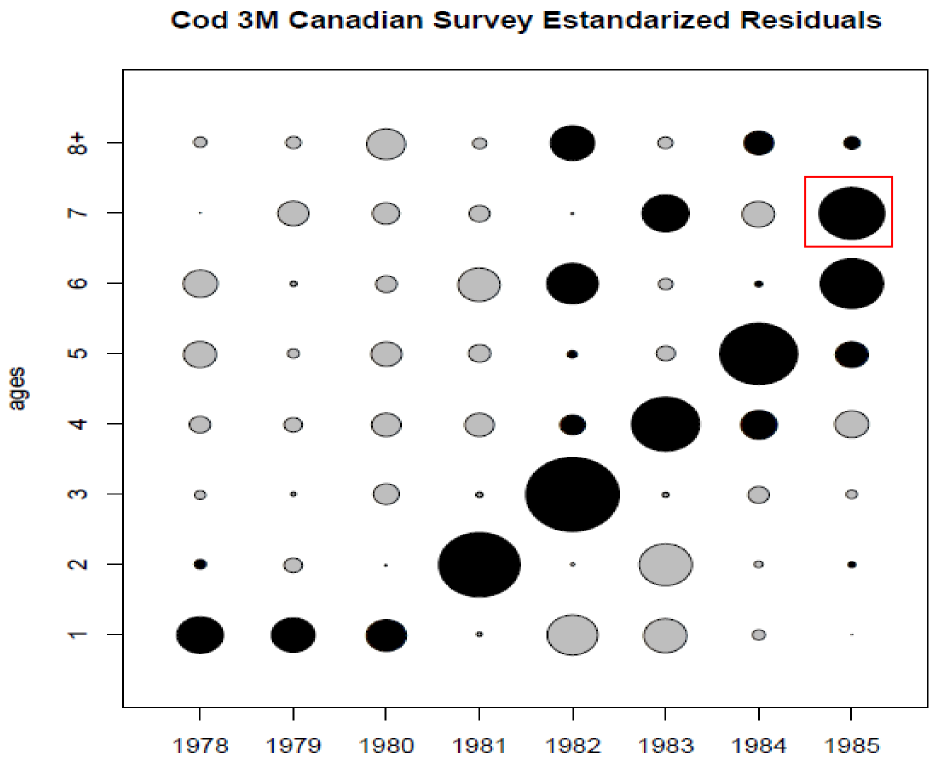


Figure 23.- Estimated natural mortality.



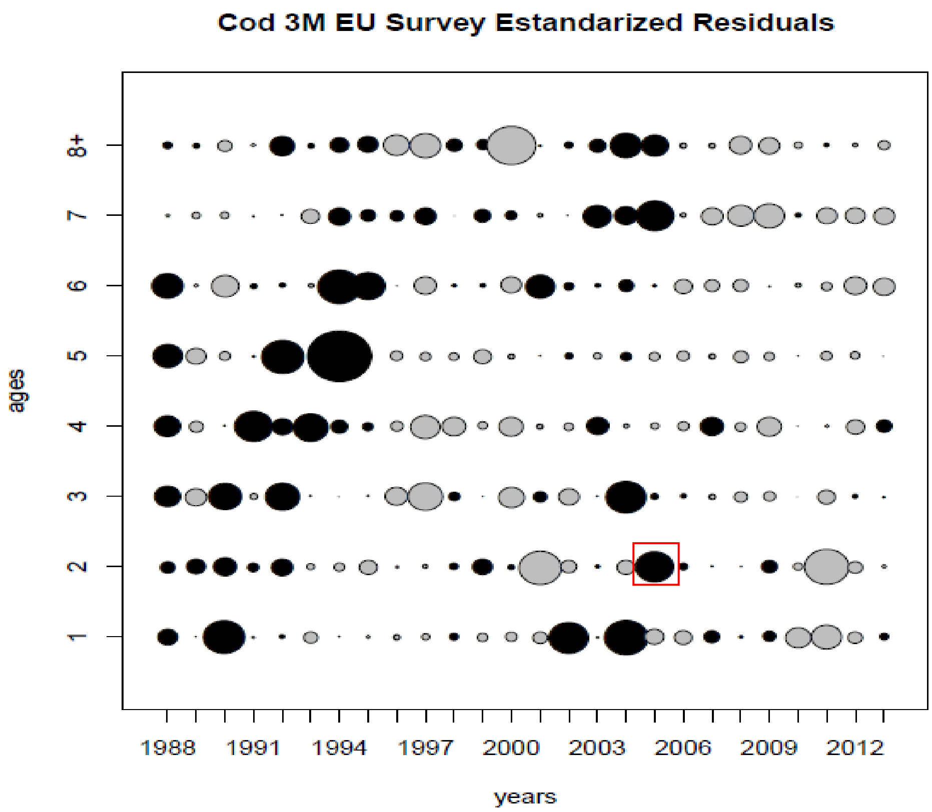


Figure 24.- Standardised residuals (observed minus fitted value) in logarithmic scale of survey abundance indices at age: Canadian and EU surveys. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value. The red square indicates a bubble with a value near 2 (in absolute values).

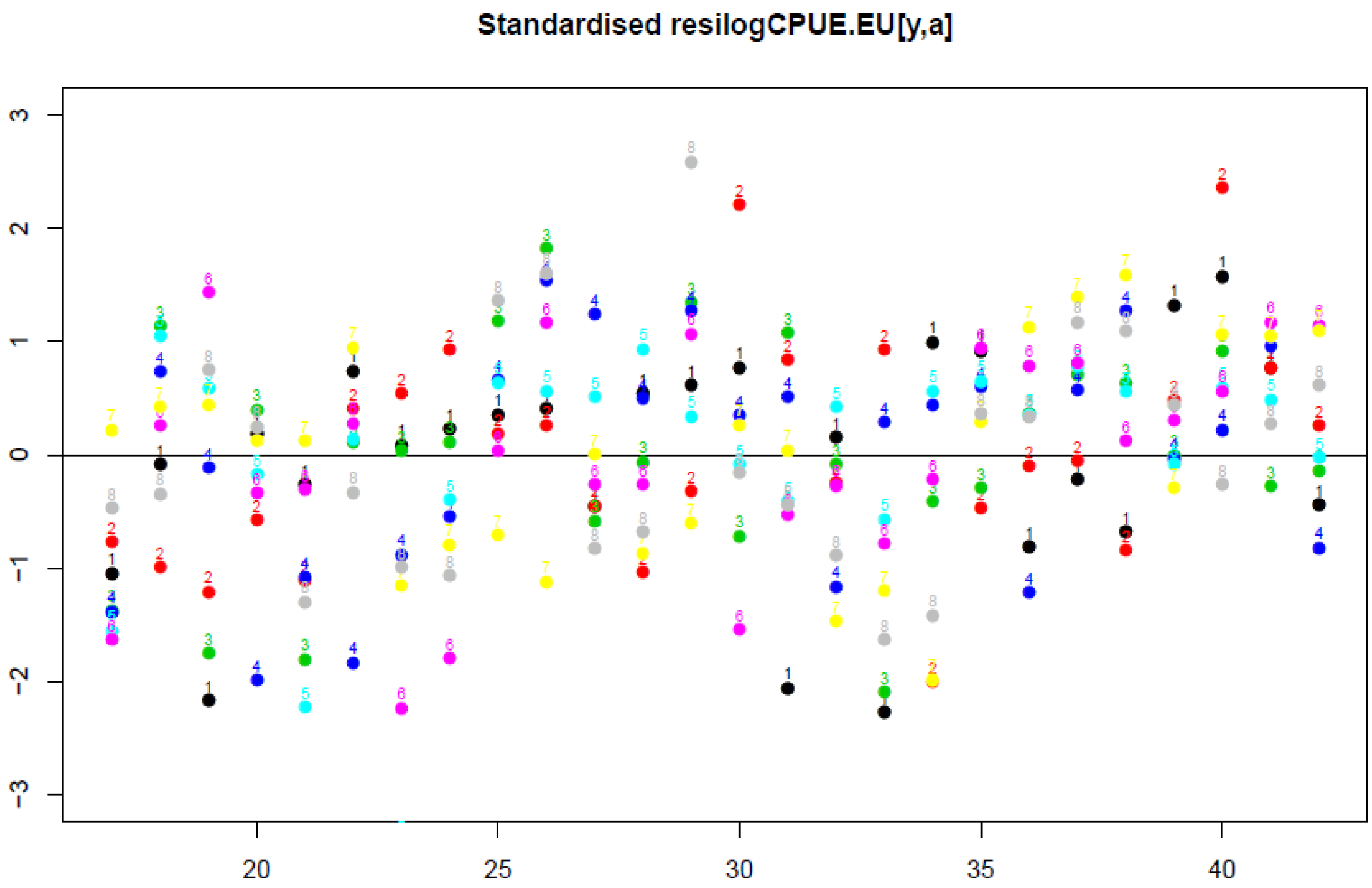


Figure 25.- Standardised residuals (observed minus fitted value) in logarithmic scale of survey abundance indices at age for EU survey by age.

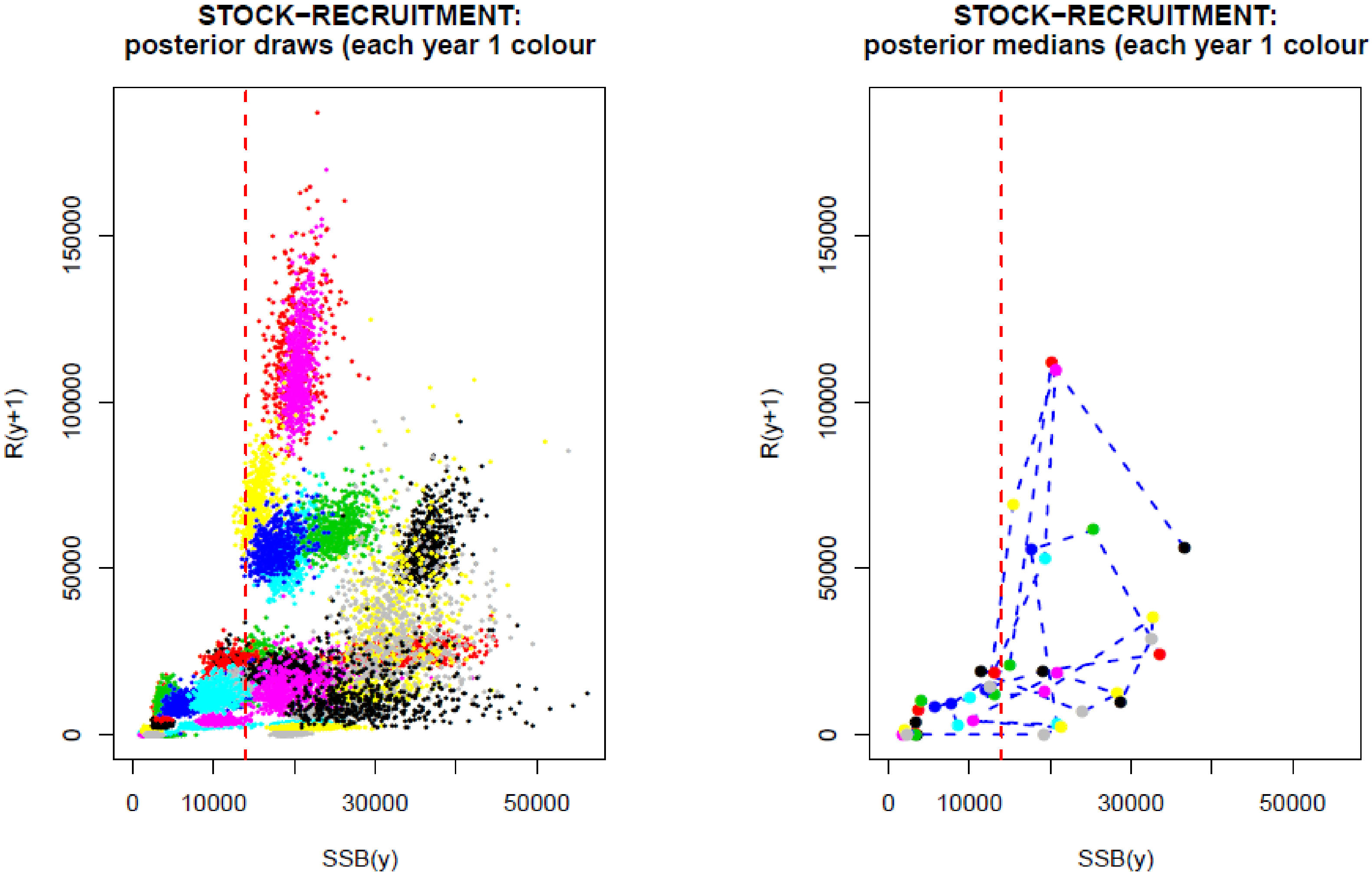


Figure 26.- Stock-Recruitment plots. B_{lim}=14000 is shown as the red vertical line.

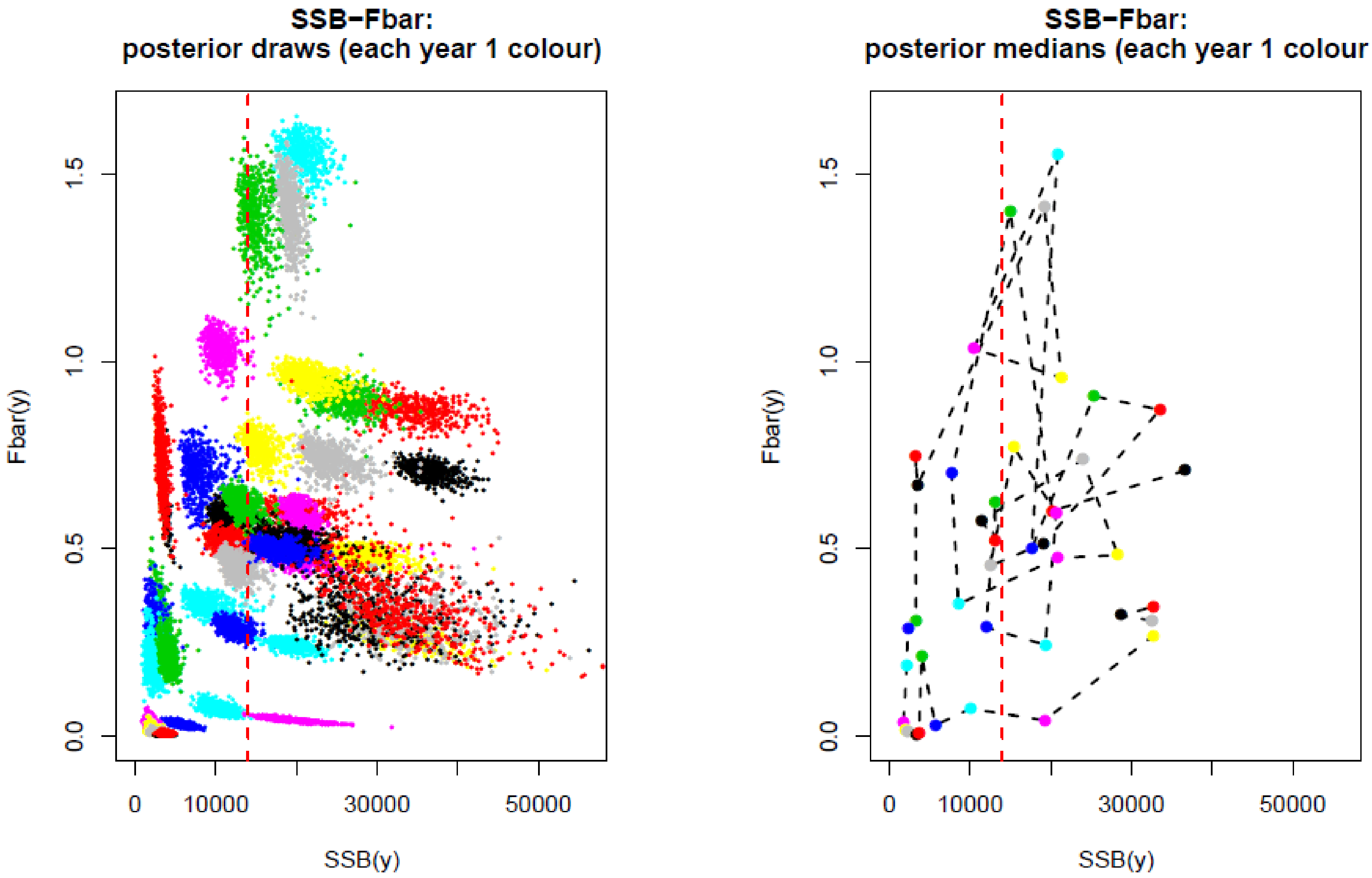


Figure 27.- F_{bar} versus SSB plots. B_{lim}=14000 is shown as the red vertical line.

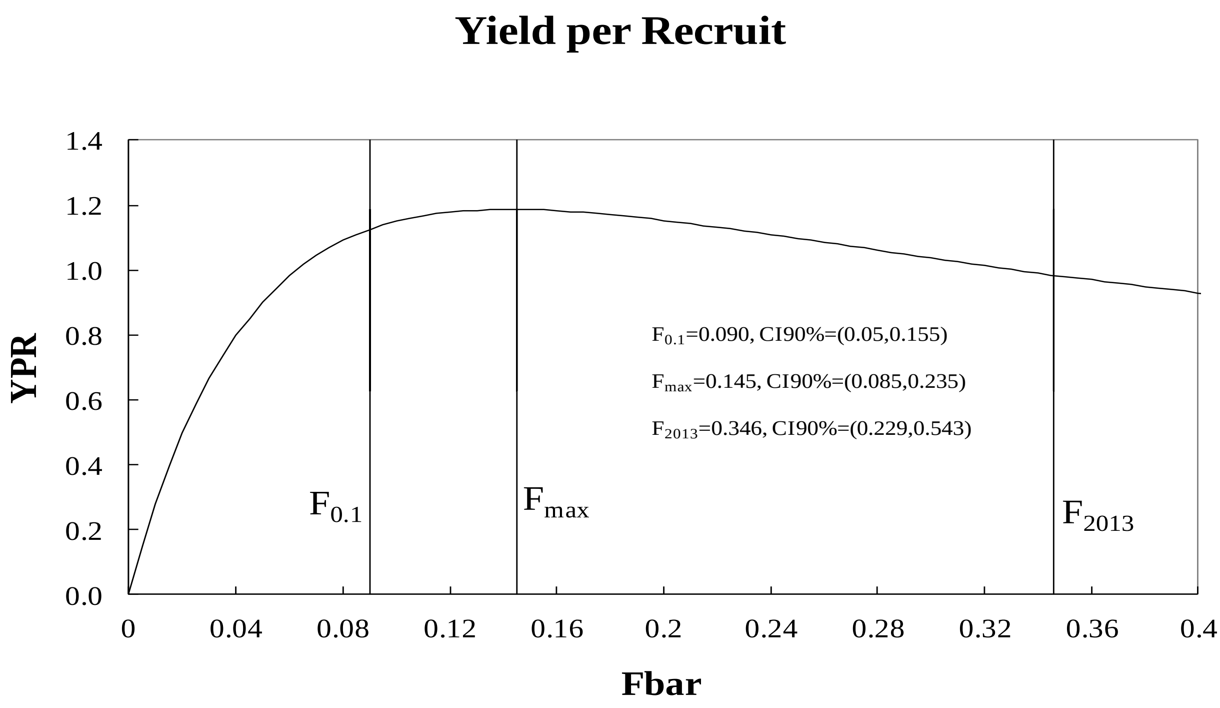


Figure 28.- Bayesian Yield per Recruit versus F_{bar}. The values of $F_{0.1}$, F_{max} and F_{2013} are indicated

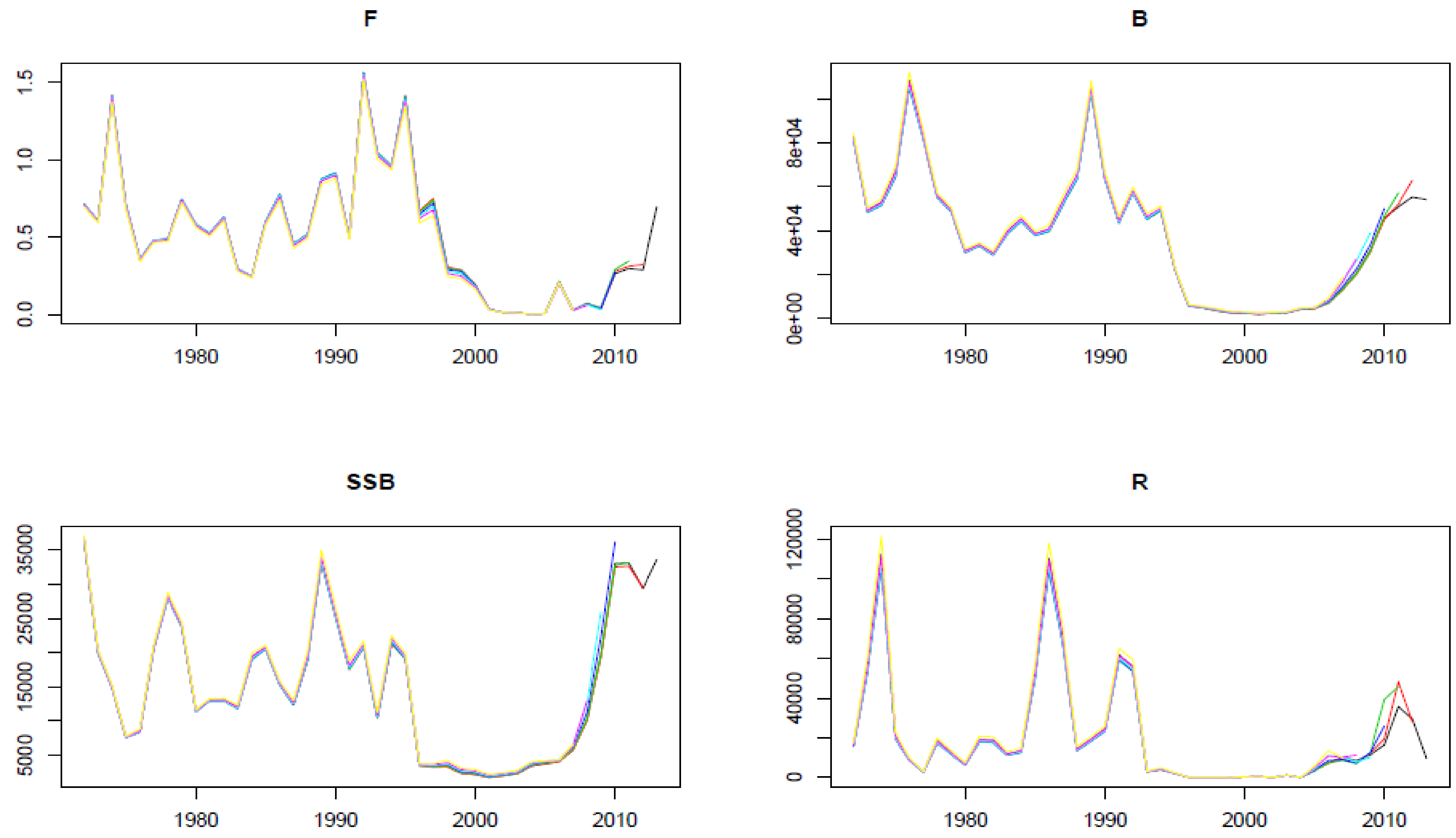


Figure 29.- Retrospective patterns.

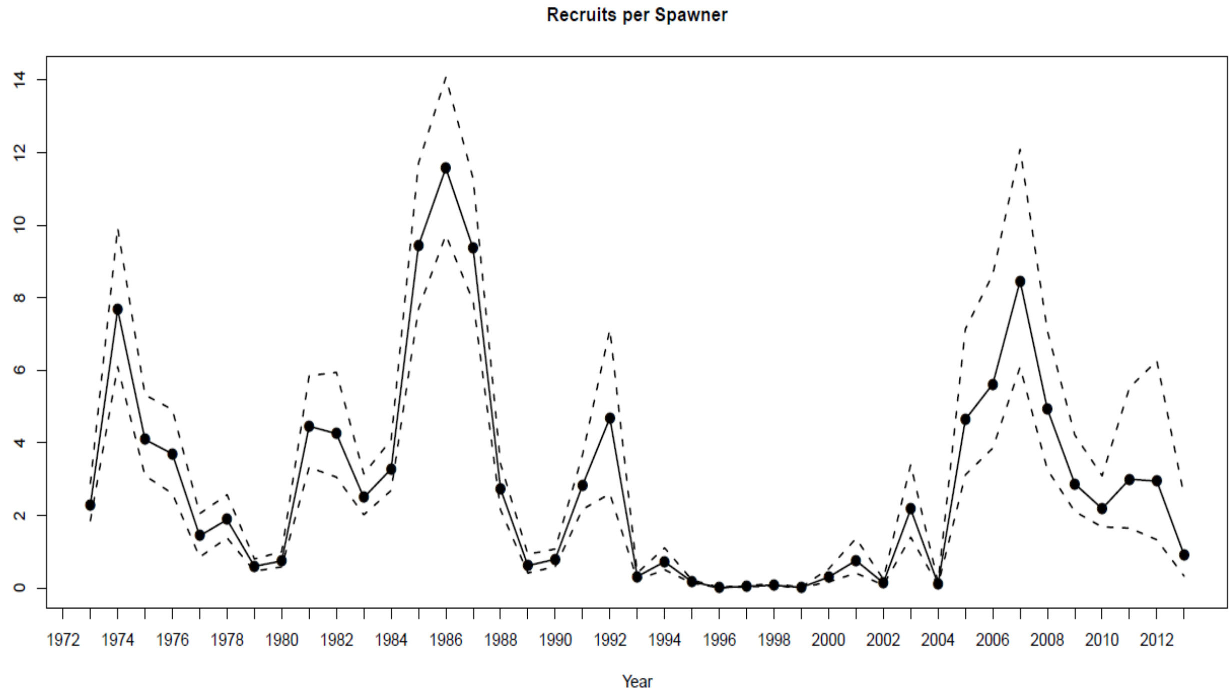


Figure 30.- Estimated recruits (age 1) per spawner.

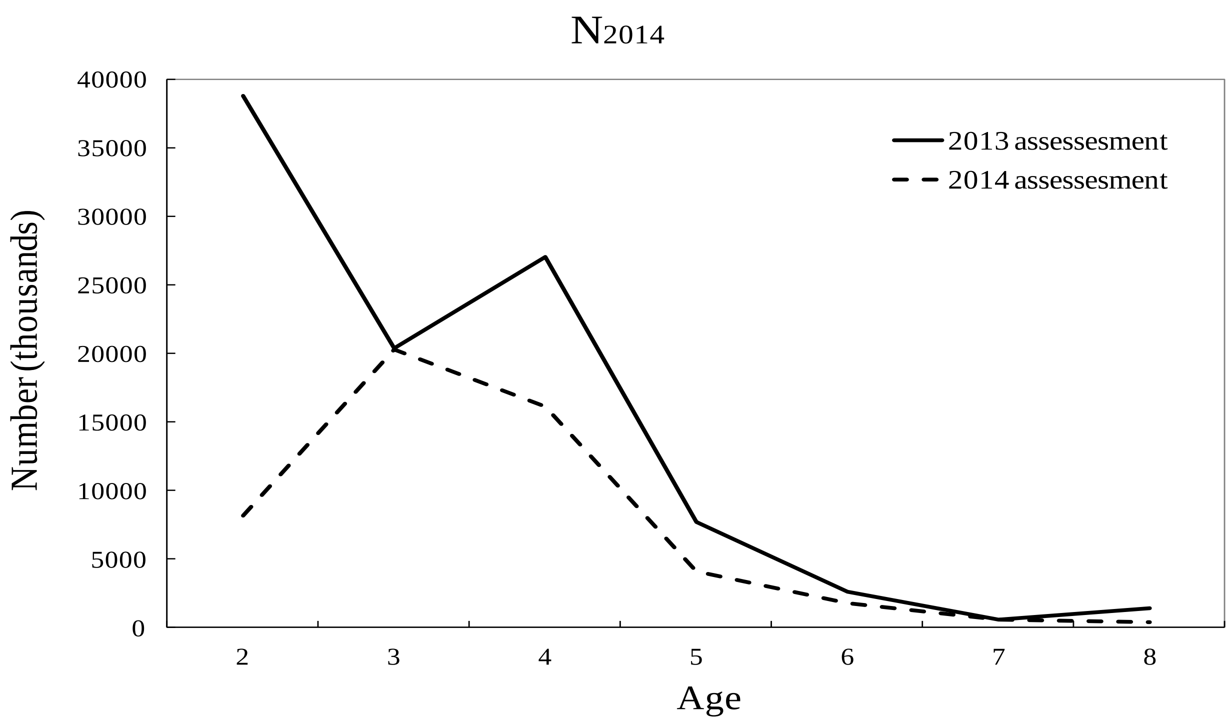


Figure 31.- Numbers at ages 2 to 8 in 2014 from the assessment of 2013 and 2014.

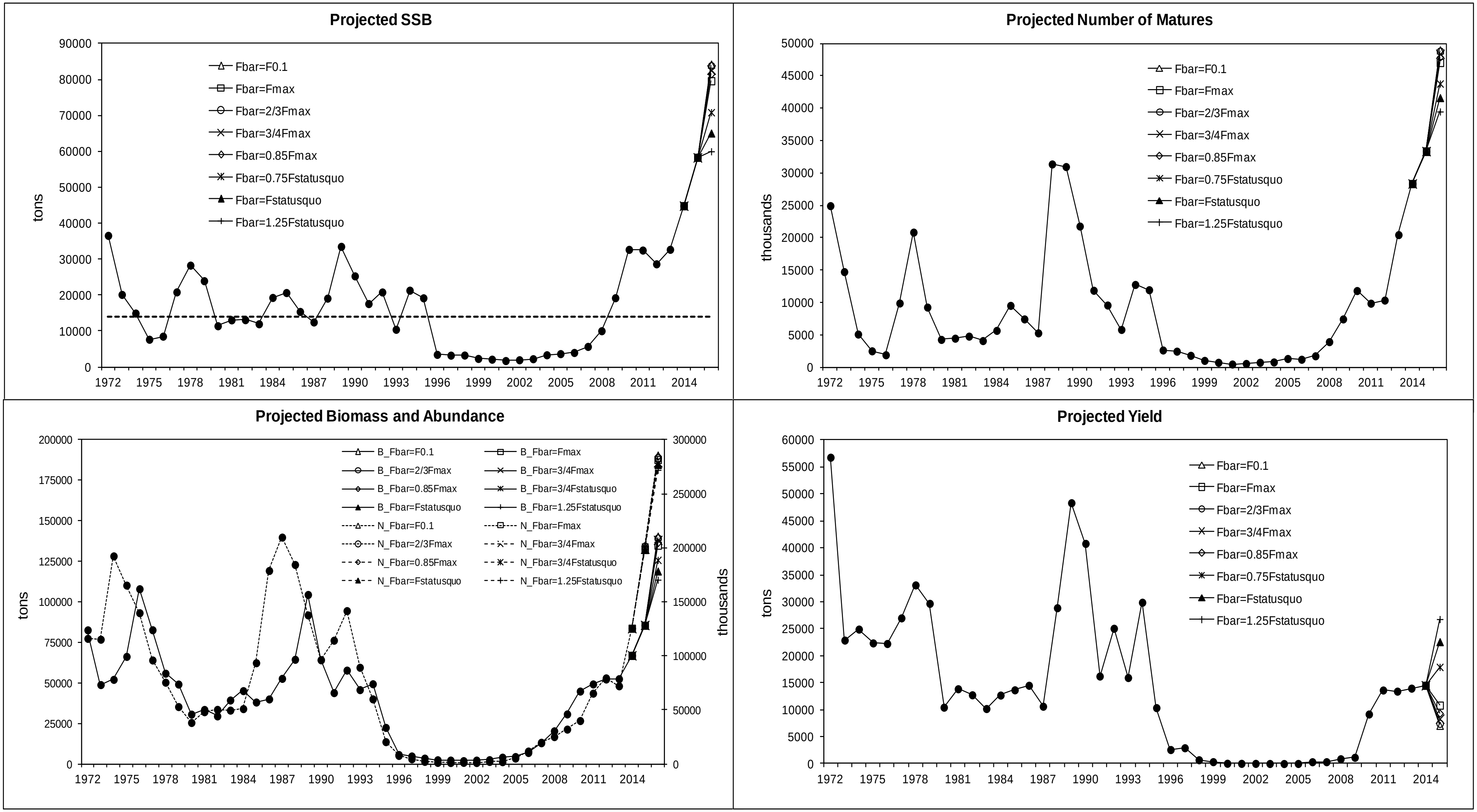


Figure 32.- Projections for SSB, number of matures, total Biomass and Yield with different scenarios.