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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 SCAA (statistical catch-at-age) model was used for the first time to perform the analysis. The STACFIS estimations have been used as catch estimations. Using the results of the new assessment model, B_{lim} was set as 20 000 t. Results indicate a general increase in SSB since 2005 to the highest value in 2017 and 2018, reaching a value above B_{lim} since 2008. After 2012 recruitment has decreased substantially and in 2016 is among the lowest of the series; as a consequence, 3-year projections indicate that total biomass and SSB will decrease sharply during the projection years.

Introduction

The 3M cod stock was on fishing moratorium from 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 after the collapse of the stock confirmed the poor situation, with SSB at very low levels, well below B_{lim} (Vázquez and Cerviño, 2005). Nevertheless, recruitment was estimated above the historical average in 2005 and 2006, which in turn caused an increase of SSB that allowed the reopening of the fishery in 2009. Recruitment estimates from 2010 to 2012 (2009-2011 year-classes) have been the highest since 1992 (González-Troncoso, 2017) and have resulted in a very high stock biomass level at present; however, they have been followed by low recruitments and, as a consequence, a strong decrease in stock biomass is expected in the near future.

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 below 1 000 tons and from 2000 to 2005 they were lower than 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 2010-2015 assessments TACs for 2011-2017 of 10 000, 9 280, 14 113, 14 521, 13 795, 13 931 and 13 931 tons were established. The STACFIS estimated catches for 2010 was 9 291 tons, which almost doubled the TAC. The STACFIS estimated catches for 2011-2017 were 12 836, 12 836, 13 985, 14 290, 13 785, 14 023 and 13 928 tons, respectively.

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), being used between 2008 and 2017 in the assessment of this stock.

In April 2018 a benchmark on the 3M cod was carried out by the NAFO Scientific Council. During that meeting it was decided to replace the Bayesian XSA used to assess this stock between 2008 and 2017 with a Bayesian SCAA (statistical catch-at-age). Another important change introduced at the benchmark is the value of the natural mortality, which the benchmark agreed to base on biological and multi-species considerations; this has resulted in considerably higher values of M than estimated in previous assessments. The results of the model agreed at the benchmark are presented here, including the updated data until 2017.

Material and Methods

Data used

The last approved assessment, performed in June 2017, had a period of time from 1972 to 2016. The NAFO Scientific Council, during a meeting in March 2018, decided to shorten the time period to start in 1988 because of the lack of confidence in some of the data before 1988 (NAFO, 2018a). So, the data used in the present assessment is between 1988 and 2017.

A deep review of the data was carried out for the SC March meeting. Some errors encountered were corrected. The new data series is presented and was used in this work. To know more details about the review of the data, see González-Costas *et al.* (2018).

Commercial data

Total Catch

In 2017 there were catches of 3M cod from EU-Estonia, EU-Portugal, EU-Spain, EU-UK, Faroe Islands (Denmark), Japan, Norway, Russia and United States with a total amount of 13 928 tons from the Secretariat estimates (Table 1, Figure 1).

In 2010 the fishery on this stock was reopened. Since then, STACFIS estimated catches were used for the stock assessment. To know more details, see González-Costas *et. al* (2018) and NAFO (2018b).

Length distributions

In 2017 length sampling of catch was conducted by EU-Estonia (SCS 18/05), EU-Portugal (SCS 18/08), EU-Spain (SCS 18/07), Faroe Islands (SCS 18/09) and Russia (SCS 18/13). Length frequency distributions from the commercial catch and from the EU survey (González-Troncoso *et al.*, 2018) are shown in Figure 2A.

EU-Estonia has measured 1097 individuals in a range of 22-95 cm, with mean and mode in 60 cm. The sample of EU-Portugal contains 9292 individuals measured within 36-105 cm, mean 64 cm and mode in the range 63-65 cm. EU-Spain has a 1557 individuals sample in a range of 31-127 with two different modes, one around 60 cm and another one, lower, between 36-44 cm. Faroe Islands has catch only with longliners, measuring 1546 individuals with lengths between 38 and 136 cm. The modal length is 70 cm and the mean length 76 cm. This values are quite highest than for the rest of the fleets. The number of sampled individuals for Russia was 1331 between 41 and 107 cm. The mode of this length distribution is between 61-66 cm and the mean is 67 cm. The mean length of the total commercial catch is at 64 cm and the mode at 63. The EU survey has two modes, one at 44 cm and another one at 61 cm. Although the recruitment is not high, there is a good presence of individuals around 15-20 cm, the best signal since 2014. The range is from 14 to 127 cm and the mean is at 53 cm.

It is remarkable the difference in the 2017 length distribution with regards to last years (Figure 2B). While since the reopening of the fishery the bulk of the commercial length distribution was between 40 and 60 cm, in 2017 most of the catches are between 55 and 75 cm. In fact, the mean length in 2010-2016 was between 47 and 59 cm, whereas in 2017 was 64 cm. While during the period 2010-2012 the mode of the commercial length distribution was around 54 cm, in 2013 that mode was decreased substantially, being around 42 cm. In 2014 and 2015 the first mode is about 51 and 54 cm respectively, but in both years there is a second mode around 39-42 cm. In 2016 the mode is at 39 cm, whereas in 2017 is at 63 cm, which is a big change from one year to the other.

In order to see if this behaviour of the fleets is because the fish is bigger or if it is due to commercial reasons, the survey length distribution is plot in Figure 2C. It can be seen that the percentage of individuals of more than 60 cm (which come probably from the good cohorts of 2010-2011) is slightly higher than in past years, although in less extent than in the commercial length distribution.

Indices by age

As no age-length keys (ALK) were available for commercial catch from 1988 to 2008, each year the corresponding ALKs from the EU survey (read by the IIM in Vigo) 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 otoliths were not 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 2013-2016 there were two available ALKs for commercial length distribution, one from Portugal and the other from Spain, but as they have not been validated yet, the 2013-2016 survey ALKs were used respectively. Much progress in understanding where the differences between the commercial and survey ALKs come from were made but still need more research to completely know the problem.

In 2017, due to administrative problems, the survey ALK is not available. An ALK from the Spanish commercial fleet is available, but it has not been validated. For this reason, the SC decided to apply the 2016 survey ALK to the 2017 commercial data.

Catch-at-age

Catch-at-age is presented in Table 2. 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 3A shows a bubble plot of catch proportions at age over time (with larger bubbles corresponding to larger values), indicating that the bulk of the catch is comprised of 3-5 years age cod, although in the last three years a shift to the oldest ages can be seen. Between years 2006 and 2014, in general the catches contain mostly age 3 and 4 individuals. In 2015 age 6 was the most fished, in 2016 age 5 and in 2017 ages 6-7. These ages corresponds to the strong cohorts of 2009-2011.

Figure 3B 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. Some strong and weak cohorts can be followed, although the pattern is not too evident. It is remarkable the catch over the recruitment in 2010-2012. In 2013, all the values for ages younger than 7 are negative except age 3, with a quite large positive value. In 2014 the biggest value is at age 4, being the values at ages 1-3 large and negative and at ages 5-8 very small. In 2015 ages 2-4 are negative and 6-8+ values quite large. In 2016, the first positive value is at age 5, and the values increase by age, being 8+ the largest in that year. In 2017 the first positive is at age 6, being 6-8+ values quite large.

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

For 2017, mean weight-at-age has been computed using length-weight relationships from the commercial sampling. For this year, for the commercial case, there are four length-weight relationships available: EU-Estonia, EU-Portugal, EU-Spain and Faroes. All of them are presenting in Figure 4 besides the 2017 EU survey one. The Spanish relationship gives the highest weight while Estonian one gives the smallest weight to the same length. The EU survey and the Faroese longliner weights are very similar in the highest lengths. As Portugal has the biggest proportion of the total catches, so the total commercial length distribution is similar to the Portuguese one, the length-weight relationship from this country was applied to the trawl commercial data to calculate the mean weight-at-age in the catch. The Faroese longliner is considered separated in order to get the total length distribution, but age distribution were obtained by applying the trawl EU survey ALK to the total length distribution.

Updated mean weight-at-age for 1988-2017 is showed in Table 3 and Figure 5. Since 2007 there is a general decrease in the trend of the mean-weight for the ages older than 2, especially since 2010. Age 1 presents a quite stable trend over these years. In 2017 the mean weight in catch for all ages but 3 is lower than in 2014, and they are among the lowest in the entire series.

There are some gaps in the series of mean weights in catch due to the lack of individuals to calculate a mean weight. This affects directly the calculation of the total catch. Those gaps were filled using the mean of the previous year and the following year and were incorporated to Table 3 in red.

The SOP (sum over ages of the product of catch weight-at-age and numbers at age) for the commercial catch differs 5% from the estimated total catch in the last year.

<u>EU survey data</u>

The EU bottom trawl survey on Flemish Cap has been carried out since 1988 using a *Lofoten* type gear, 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 1988-2017 are presented in González-Troncoso *et al.* (2018).

During the review made for the March SC meeting, an error in the survey indices of abundance was encountered: the calibrated figures for years 1988-2003 were not the correct ones. The corrected ones are presented in Table 4 and were used in the updated assessment. Figure 6 displays the estimated biomass and abundance indices over time. 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. From 2009 biomass is higher than the level of the first years of the assessment (is approximately twice the mean of the EU series), but it must be noted that abundance in these years is roughly the same as the years pre-collapse (it is below the mean abundance of the EU entire series). In 2010 the biomass has suffered a slight decrease, probably due to the opening of the fishery, but a new huge increase can be seen in 2011 and 2012. The abundances in 2011-2012 are, by far, 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. In 2014 the biomass increased again reaching the maximum of the time series by a long way. The abundance increased too but much less, being well below the maximum observed during years 2011-2012. The increase in biomass is due to a big increase in the number of individuals of 3 and 4 years old, those from the 2010-2011 cohorts, and the decrease in abundance to a less presence of individuals of ages 1 and 2 (González-Troncoso *et al.*, 2018). From 2013 a slight increase can be seen in biomass and a general decrease in abundance, due mainly to the fail of the recruitment, break in 2017 with an increase.

Figure 7 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 to 2014 appear to be above average. In 2010-2012 a good recruitment can be seen, especially in 2011, lead to two reasonably good cohorts. 2013 and 2014 recruitment were not as good as in those years, but it is still at the level of the beginning of the recovery of the stock. 2015-2017, especially 2016 recruitments, have failed. Age 8+ in 2014-2017 presented a high value, which indicates the strength of the 2006-2009 cohorts.

Mean weight-at-age

Results are showed in Table 5 and Figure 8. There are two gaps in the series of mean weights in stock due to the lack of individuals to calculate a mean weight. This affects directly the calculation of the biomass. Those gaps were filled using the mean of the previous year and the following year and were incorporated to Table 5 in red. For 2017, length-weight relationship from the EU survey (Figure 4) was used to calculate the mean weight-at-age in stock

Mean weight-at-age in the stock showed a strong increasing trend from the late 1990's until 2007, being much higher than at the beginning of the series. Since 2008 to 2017 a deceasing trend was observed for all age groups, being very steep in some cases. In those years the mean weights in stock for ages 1-7 decreased among 38% and 75% and all of them are among the minimum of the entire series. The biggest difference is from 2011 to 2012, when the weight-at-age for ages 1-2 increased, but decreased substantially for ages 3-8+. It is remarkable the low value of weight at age 3 (0.35 kg) in 2014, which is the lowest since 1990. Although it increased slightly since then, it is still very low.

Maturity at age

Maturity ogives are available from the EU survey for years 1990-1998, 2001-2006 and 2008-2016. For those years a Bayesian logistic regression models for proportion mature at age with 1000 iterations have been fitted independently for each year. 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. In 2017, due to different problems, no maturity ogive is available. The 2016 maturity ogive was applied to the 2017 data.

The median of the maturity ogives for the whole period are presented in Table 6 and Figure 9A. It can be seen that the percentage of matures in all ages decreased since 2006 to 2011, especially in 2011. This fact, along with the decreasing mean weight at age, is consistent with a stock in a recovery process, with 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 and 4). This is not consistent with the decrease in the mean weight for all ages. Maturity for all age groups declined sharply from 2013 to 2016.

Figure 9B displays the evolution of the a50 (age at which 50% of fish are mature) through the years (estimate and 90% uncertainty limits) and the median value is presented in Table 6. 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 and 2003. An upward trend is present in a50 since 2005. From 2005 to 2011 a50 increased monotonously from 3 to 4.13 years respectively and it declined in 2012 and again in 2013 to 3.39 years due to the increase in the percentage of maturation on all the ages. In 2014-2016 it increased substantially to 5.17 years old in 2016, around the maximum in the time series.

Assessment methodology

A Bayesian SCAA model was applied to the data. Ages are from 1 to A+=8+ and years are from 1988 to 2017. The cohorts are modelled forwards in time, starting from the recruits (age 1) in each year and abundance of each age 2-8+ in the first assessment year, taking into account the natural and fishing mortality. The model equations are listed in Annex I. The model run were made in Jags called from R via the package rjags.

The input data, configuration and settings of this model were chosen during the 2018 benchmark on 3M cod (NAFO, 2018b). The natural mortality, M, is estimated by the model via a prior to be constant by year but variable through the ages.

Given the very low catch numbers observed at age 1 (Table 2), the catch at age 1 data was set equal to zero in all years and it was assumed in the model that F at age 1 is equal to zero. The benchmark also decided to treat as NAs the zeros observed in the survey abundance indices at age and those observed in the catch at age matrix for ages > 1.

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

Catch data for 30 years, from 1988 to 2017

Catch in tonnes in all years; Years with catch-at-age: 1972-2001, 2006-2017

Tuning with EU survey for 1988 to 2017

Ages from 1 to 8+ in all cases (catch-at-age and survey indices at age)

Catchability analysis

Survey catchability dependent on stock size for age 1

Priors over parameters: See Annex I to know the details. The values used in the priors are:

Recruitment: *medrec* = 45000, *cvrev* = 10

N in the first assessment year: *medF*[a] = c(0.0001,0.1,0.5,0.7,0.7,0.7,0.7,0.7), cvyear1 = 10

f: *medf* = 0.2, *cvf* = 4

rC: *aref* = 5, *medrC*[a] = c(0.001,0.3,0.6,0.9,1,1,1), *cvrC*[a] = c(4,4,4,4,4,4,4), *cvrCcond*=0.2

Catch in tonnes: *cvCW* = 0.077 (95% probability of no more than 15% deviation)

Catch numbers-at-age: *psi.C* corresponds to CV=0.2 on catch numbers-at-age (in original, not log-scale)

Survey index: *psi.EU* corresponds to CV=0.3 on abundance index at age (in original, not log-scale)

Survey catchability: *medlogphi* = 0, *taulogphi* = 1/5

Survey catchability exponent at age 1: *medgama* = 1, *taugama* = 1/0.25

M: *medM*[a]= c(1.26,0.65,0.44,0.35,0.30,0.27,0.24,0.24), *cvM* = 0.15

A five year retrospective plot was made. Three years projections were made with three 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 total biomass, SSB, recruitment and F_{bar} (ages 3-5) are presented in Table 7 and Figure 10. SSB in 2018 was calculated using the numbers estimated by the assessment at the beginning of 2018, applying the maturity ogive and mean weight at age in stock from 2017.

Total biomass had a sharp increasing trend during 2006-2012, reaching a higher level than before the collapse of the stock in the mid 1990´s. After 2012, a decreasing trend can be observed, but the biomass is still above the level at the beginning of the series.

The results for SSB indicate that there has been a substantial increase in SSB in the last few years, with the largest increase occurring from 2007 onwards. After a small decrease in 2011 and 2012, the SSB since 2013 has increased slightly. Nowadays the SSB is at the highest level of the historical series (starting in 1988). The high values of SSB in the last years are probably due to the incorporation of the strong 2009-2011 year classes which leads in a higher number of individuals.

Recruitment had an increasing trend from 2005 to 2012, being above the mean recruitment of the period between 2007 and 2012. The 2010-2012 values are the highest of the series. Since 2012 the recruitment has been decreased substantially and in 2016 is among the lowest of the series. Recruitment increased in 2017 but is still low.

F_{bar} (mean for ages 3-5) was estimated at very low levels in the period 2001-2009. In 2010, when the fishery was reopened, the F_{bar} increased although it did not reach the level of the pre-collapse years. Since then fishing mortalities has decreased and they are well below the values of the pre-collapse period. Table 8 and Figure 11 provide more detailed information on the estimated F-at-age values. Since 2010 the F-at-age increases with the age. Figure 12 shows the PR along the years, calculated as the ratio of fishing mortalities to F_{bar}. Figure 13A shows the PR for the years since the reopening of the fishery (2010-2017) and Figure 13B the mean of the three last years (2015-2017) PR *versus* the 2017 PR. In general, except 2010 and 2017 PRs, all the years have a similar and increasing PR. In the case of the 2017 PR, age 4 value is lower than age 3 value, and age 5 value is higher than in the rest of the years. The mean PRs of the last three years is quite similar to the 2017 one.

The results for the two components of F, the year effect (*f*) and the selectivity by year and age (*rC*), are presented in Figure 14. It can be seen a clear different level of *f* before and after year 2000. In the case of *rC*, for age 1 was set as 0, the age of reference is 5 and for age 8+ is the same as for age 7. During the period on which the fishery was closed (1999-2009) *rC* of ages 2 and 3 increased to high levels probably because the catches came from by catches of other fisheries. Age 4 shows a decreasing trend in the whole period while for ages 6 and 7 an increasing trend can be observed (with a decrease in the last two years).

Figure 15 shows total biomass and abundance by year. In general there is a good concordance between biomass and abundance, although in last years abundance has decreased more than biomass. It must be noted that, although SSB in last years has been increased (Figure 10), total biomass and abundance have been decreased since 2011-2012. Total biomass is at the highest levels of the total period biomass, but abundance is below the mean.

Estimates of stock abundance at age for 1988-2017 are presented in Table 9 and Figure 16. It can be seen a general increasing trend in the total number of matures, especially in 2013, due probably to the decreasing in the age of maturity. Since then it has decreased slightly. The maximum numbers-at-age since 2005 in all the ages correspond to the 2010 cohort (reaching 7 years old in 2017), followed by the 2011 cohort (reaching 6 years old in 2017). Since those cohorts, all the numbers at age have decreased (ages 1 to 5). It is remarkable the big value of ages 6+ in the last years, which is the driver to the huge increase in the SSB in those years. But as no new good recruitment is entering in the stock, it is feasible that the SSB starts to decrease in the next years.

Figure 17 depicts the prior and posterior distributions of the recruitment in all the years. Although in some years there has been substantial updating on the prior distribution for recruitment, in general the posterior is among the prior distribution.

Figure 18 displays prior and posterior distributions for the numbers in the first year (1988) for ages 2 to 8+. Whereas the prior distribution is the same every year, posterior distributions vary depending on the year. For all the ages, the update posterior numbers is to higher values than the prior median.

In Figure 19 observed versus estimated total catches by year are presented. Before 2001 the discrepancies seems to be more variable than after that year. No clear patterns can be observed in the whole period.

Figure 20 shows the prior and the posterior distributions of the natural mortality, M, by age. The prior and posterior medians can be seen in Table 10. For ages 1 and 6+, the posterior median of M is higher than the prior median. Overall, the priors on M are not much updated by the posteriors for any of the ages; this is as intended by the Benchmark, who considered the stock assessment has little ability to estimate M and decided to use a relatively tight prior distribution (CV=15%) around median values of M derived from biological considerations, including multi-species interactions. This has resulted in much higher values of M than estimated in previous assessments (where the posterior median of M did not exceed 0.2). A higher M can be expected to result in the stock abundance changing more rapidly from year to year, because it generally results in higher estimates of recruitment but, at the same time, the fish disappear more quickly from the population ("killed by M") than with a lower M.

Bubble plot of standardised residuals (observed minus fitted values divided by estimated standard deviations and in logarithmic scale) for the catch number-at-age and the EU survey abundance at age indices are displayed in Figure 21. This graph should highlight year effects, identified as years in which most of the residuals are above or below zero. No clear trends can be seen in the graphs. In general, the residuals are quite high both in the catch numbers at age and in the EU survey indices. In the case of the EU survey indices, in year 2004 all the residuals are negative, i.e. survey catchabilities are below average.

Figure 22 illustrates the distribution of the catchabilities for the EU survey by group of ages (1, 2, 3, 4+). The catchability at age 1 is very low. Age 2 catchability is lower than age 3 catchability, which is quite similar to the catchabilities of ages 4+.

Biological Referent Points

The new assessment results were used to re-estimate the limit reference points. The stock-recruit scatterplot was examined to find an SSB below which no good recruitments have been observed (Figure 23). This SSB (20 000 t) was set as B_{lim} and is displayed in the graphs. SSB is well above B_{lim} in recent years.

Figure 24 shows the SSB-F_{bar} scatterplot. F_{lim} for this stock was estimated based on $F_{30\%SPR}$ calculated with the 2015-2017 data as 0.153. This period was chosen due to the rapid change in biological parameters in the stock.

Figure 26 shows the Yield per Recruit versus F_{bar} curve calculated with the data of years 2015-2017 as well as the value of F_{lim} and $F_{statusquo}$ (defining the latter as the mean fishing mortality over 2015-2017).

Retrospective pattern

A retrospective analysis of five years was made (Figure 25). The analysis shows revisions in the recruitment, mainly regarding the highest values of recruitment in years 2011 and 2012, but no patterns are evident in recent years. The downwards revision of these two recruitment estimates results in a tendency to over-estimate total biomass and SSB in recent years. No retrospective pattern is evident in the F estimates.

Recruits per Spawner

Figure 27 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 since 2013 a very low value.

Projections

The same method as last year was used to calculate the projections and the risk. To know more details about the projection method, see Fernández *et al.* (2017). Stochastic projections of the stock dynamics from 2018 to

2020 were conducted. The variability in the input data is taken from the results of the Bayesian assessment. Input data for the projections are as follows:

Numbers aged 2 to 8+ in 2018: estimated from the assessment.

Recruitments for 2018-2020: Recruits per spawner were drawn randomly from 2014-2016. The 2017 value of recruits per spawner was omitted due to uncertainty in estimating the recruitment.

Maturity ogive for 2018-2020: 2017 maturity ogive.

Natural mortality for 2018-2020: Natural mortality from the 2017 assessment results.

Weight-at-age in stock and weight-at-age in catch for 2018-2020: 2017 weight-at-age.

PR at age for 2018-2020: Mean of the last three years (2015-2017) PRs.

F_{bar}(ages 3-5): Four scenarios were considered:

(*Scenario 1*) $F_{bar}=F_{lim}$ (median value = 0.153).

(*Scenario 2*) $F_{bar}=3/4F_{lim}$ (median value = 0.115).

(*Scenario 3*) $F_{bar}=F_{statusquo}$ (median value = 0.073).

All scenarios assumed that the Yield for 2018 is the established TAC (11 145 t). $F_{statusquo}$ was established as the mean fishing mortality over 2015-2017.

Results for the four options are presented in Tables 11-16 and Figure 28. They indicate that under all scenarios total biomass and SSB during the projected years will decrease sharply. The probability of SSB being below B_{lim} in 2020 is very low (<1%) in all cases. For both $F_{2015-2017}$ and ¾F_{lim}, the probability of SSB being below B_{lim} in 2021 is very low (≤1%). However, the probability of being below B_{lim} is 13% if F = F_{lim}. The probability of SSB in 2021 being above that in 2018 is <1%.

Under ¾F_{lim} and $F_{statuquo}$, the probability of F exceeding F_{lim} is less than or equal to 5%.

Under all scenarios, the projected Yield increases in 2019 relative to the Yield in 2018, but decreases again in 2020.

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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 2017 in tons.

Year	Estimated[2]	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	3	0						63	401
2009	1161	856	87	85		22						122	1172
2010	9291	1345	374	921		1183	761		514			147	5245
2011	12836	2412	655	1610	200	2211	1063		1301		185	340	9977
2012	12836	2593	745	1597	131	2045	868		809		172	108	9068
2013	13985	4427	896	2380		2723	1328		1322			445	13521
2014	14290	5345	950	2099		3370		393	1344			855	14356
2015	13785	4680	893	1999		3319			1296			641	12828
2016	14023	5484	893			3124	1198		1336			72	12107
2017	13928	5245	900	900		3165	1148		1240			1322	13920

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

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

	1	2	3	4	5	6	7	8+
1988	1	3500	25593	11161	1399	414	315	162
1989	0	52	15399	23233	9373	943	220	205
1990	7	254	2180	15740	10824	2286	378	117
1991	1	561	5196	1960	3151	1688	368	76
1992	0	15517	10180	4865	3399	2483	1106	472
1993	0	2657	14530	3547	931	284	426	213
1994	0	1358	28303	9218	430	206	16	203
1995	0	0	192	4773	2003	474	98	169
1996	0	81	714	311	1072	88	0	0
1997	0	0	1016	956	179	359	60	0
1998	0	0	8	170	286	30	19	2
1999	0	0	15	15	96	60	3	1
2000	0	0	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	18	537	1608	701	1144	961	354	275
2012	39	389	1443	834	1013	739	357	344
2013	22	646	4169	962	1124	755	521	388
2014	7	13	730	4131	1464	871	556	405
2015	0	94	402	1548	1457	2596	602	480
2016	0	40	883	731	1822	1167	939	757
2017	0	2	130	122	771	1940	1594	649

Table 3.- Weight-at-age (kg) in catch. In red, the filled zero values.

	1	2	3	4	5	6	7	8+
1988	0.058	0.198	0.442	0.821	2.190	3.386	5.274	7.969
1989	0.069	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	0.115	0.298	0.414	0.592	1.093	1.704	2.619	3.865
1993	0.115	0.210	0.509	0.894	1.829	2.233	3.367	4.841
1994	0.112	0.248	0.649	0.973	1.686	2.331	3.008	4.898
1995	0.112	0.248	0.649	0.973	1.686	2.331	3.008	4.898
1996	0.110	0.286	0.789	1.051	1.543	2.429	2.730	4.653
1997	0.107	0.360	0.754	1.038	1.506	2.115	2.451	4.408
1998	0.098	0.472	0.719	1.024	1.468	1.800	2.252	3.862
1999	0.098	0.472	0.920	1.298	1.848	2.436	3.513	4.893
2000	0.098	0.583	0.672	1.749	2.054	2.836	3.618	5.055
2001	0.098	0.481	0.998	1.696	2.560	3.303	3.905	5.217
2002	0.098	0.588	1.323	1.388	2.572	3.770	5.158	5.603
2003	0.098	0.462	1.063	1.455	2.978	3.696	5.859	6.120
2004	0.098	0.839	1.677	2.009	3.353	5.576	6.241	8.273
2005	0.098	0.895	1.618	2.368	3.259	4.767	6.177	6.553
2006	0.098	1.081	1.462	2.283	3.966	5.035	6.332	7.997
2007	0.098	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	4.810	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	1.522	2.228	3.560	5.980	8.753
2012	0.086	0.374	0.990	1.491	2.136	3.583	6.183	9.183
2013	0.007	0.284	0.762	1.305	2.112	2.990	4.530	8.564
2014	0.108	0.203	0.538	1.108	1.809	2.874	4.087	7.671
2015	0.085	0.261	0.531	0.857	1.370	1.938	3.570	6.252
2016	0.085	0.191	0.550	0.787	1.237	2.157	3.439	6.719
2017	0.085	0.106	0.441	0.715	1.239	2.090	3.002	5.821

Table 4.- EU bottom trawl survey abundance at age and total (thousands) and total biomass (tons).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total Abundance	Total Biomass
1988	4868	79905	49496	13448	1457	211	225	72	0	0	0	0	0	0	0	0	149683	40839
1989	19604	10800	91303	54613	20424	1336	143	126	6	7	0	0	0	0	0	0	198363	114050
1990	2303	12348	5121	16952	15834	4492	340	146	77	25	0	0	0	0	0	0	57637	59362
1991	129032	26220	16903	2125	6757	1731	299	68	32	4	10	0	0	0	0	0	183181	40248
1992	71533	41923	5578	2385	385	1398	244	14	0	0	8	0	0	0	0	0	123468	26719
1993	4075	138357	31096	1099	1317	173	489	87	0	0	0	0	0	0	0	0	176693	60963
1994	3017	4130	27756	5097	130	67	7	111	0	5	0	0	0	0	0	0	40319	26463
1995	1425	11901	1338	3892	928	33	23	0	21	5	0	0	0	0	0	0	19567	9695
1996	36	3121	6659	892	2407	192	8	5	0	0	0	0	0	0	0	0	13320	9013
1997	37	150	3478	4803	391	952	21	0	0	0	0	4	0	0	0	0	9837	9966
1998	23	83	95	1256	1572	78	146	0	6	0	0	0	0	0	0	0	3259	4986
1999	5	84	116	117	717	444	19	5	0	0	0	0	0	0	0	0	1507	2854
2000	178	16	327	198	96	446	172	11	17	0	0	5	0	5	0	0	1470	3062
2001	473	1990	13	122	79	15	142	99	6	6	6	0	0	0	0	0	2951	2695
2002	0	1330	641	29	70	33	26	96	30	0	5	0	0	0	0	0	2261	2496
2003	684	54	628	134	22	42	7	8	39	24	0	0	0	0	0	0	1642	1593
2004	14	3380	25	600	168	5	10	3	5	15	0	0	0	0	0	0	4226	4071
2005	8069	16	1118	78	709	136		17	16	8	0	0	0	0	0	0	10166	5242
2006	19709	3886	62	1481	85	592	115	7	0	7	14	0	7	0	0	0	25965	12505
2007	3917	11620	5022	21	1138	58	425	74	13	20	0	0	0	0	0	0	22308	23886
2008	6096	16671	12433	4530	72	946	56	231	76	0	14	0	0	0	0	0	41124	43676
2009	5139	7479	16150	14310	4154	26	1091	0	335	0	0	14	0	0	0	0	48697	75228
2010	66370	27689	8654	7633	4911	1780	8	442	46	251	26	0	0	0	0	0	117810	69295
2011	347674	142999	16993	6309	7739	3089	1191	0	215	0	89	0	0	0	0	0	526300	106151
2012	103494	128087	10942	11721	4967	4781	1630	832	24	93	30	101	0	17	0	0	266720	113227
2013	5525	67521	32339	4776	4185	2782	1807	963	278	40	29	32	5	0	0	0	120280	72289
2014	7282	2372	48564	43168	17861	6842	3447	1931	1551	600	79	54	8	0	0	0	133760	159939
2015	1141	12952	7250	25614	14107	21854	3434	1426	762	366	194	14	21	21	0	7	89164	114807
2016	56	4485	14356	2230	14540	12375	4814	1157	522	303	145	28	20	0	0	0	55032	80583
2017	1714	484	9895	7051	12486	14741	8019	1784	554	318	146	26	7	0	0	14	57241	89414

Table 5.- Weight-at-age (kg) in stock. In red, the filled cero values.

	1	2	3	4	5	6	7	8+
1988	0.032	0.106	0.308	0.664	1.970	3.500	5.742	6.954
1989	0.036	0.101	0.330	0.836	1.293	2.118	4.199	7.360
1990	0.043	0.181	0.354	0.868	1.566	2.507	4.132	6.572
1991	0.056	0.171	0.501	0.865	1.594	2.593	3.423	6.182
1992	0.056	0.247	0.485	1.394	1.723	2.578	3.068	9.406
1993	0.043	0.227	0.657	1.216	2.279	2.381	3.373	5.731
1994	0.063	0.214	0.599	1.321	2.132	4.054	4.119	6.555
1995	0.048	0.243	0.479	0.969	1.851	2.680	5.532	7.309
1996	0.044	0.260	0.544	0.813	1.331	2.252	4.079	5.118
1997	0.081	0.333	0.652	1.020	1.327	2.092	1.997	9.717
1998	0.073	0.371	0.773	1.206	1.684	2.015	3.070	7.525
1999	0.108	0.398	0.946	1.329	1.866	2.444	3.461	4.987
2000	0.106	0.606	0.971	1.638	1.940	2.860	3.461	7.985
2001	0.084	0.493	1.281	1.724	2.588	3.488	3.893	5.137
2002	0.071	0.440	1.191	1.540	2.661	3.916	5.302	5.672
2003	0.058	0.337	0.926	1.566	3.047	3.769	5.721	6.451
2004	0.004	0.620	1.488	2.098	3.332	4.808	6.207	7.886
2005	0.084	0.580	1.256	2.242	2.875	4.187	6.033	8.148
2006	0.096	0.720	1.096	2.549	3.644	4.777	5.858	9.691
2007	0.053	0.609	1.640	3.478	4.097	5.787	6.373	8.315
2008	0.068	0.382	1.344	2.695	3.191	5.015	6.324	7.938
2009	0.078	0.407	0.976	2.072	3.881	6.958	6.583	9.461
2010	0.061	0.384	1.089	1.677	2.956	5.379	7.616	9.144
2011	0.038	0.211	0.913	1.618	2.339	3.594	6.050	9.396
2012	0.074	0.369	0.726	1.349	1.988	2.656	4.933	7.812
2013	0.071	0.175	0.687	1.159	2.004	2.750	4.206	7.614
2014	0.048	0.169	0.354	1.059	1.623	2.536	3.846	8.444
2015	0.049	0.156	0.469	0.747	1.216	1.847	3.434	6.775
2016	0.044	0.169	0.412	0.783	1.304	2.024	2.883	6.905
2017	0.042	0.098	0.421	0.678	1.058	1.980	2.754	5.905

Table 6.- Maturity at age and age of first maturation (median values of ogives).

	1	2	3	4	5	6	7	8+	a50
1988	0.053	0.097	0.172	0.286	0.438	0.599	0.742	0.878	5.38
1989	0.053	0.097	0.172	0.286	0.438	0.599	0.742	0.878	5.38
1990	0.053	0.097	0.172	0.286	0.438	0.599	0.742	0.878	5.38
1991	0.017	0.042	0.107	0.241	0.459	0.685	0.851	0.957	5.16
1992	0.002	0.011	0.046	0.181	0.499	0.818	0.953	0.993	5.00
1993	0.001	0.006	0.047	0.280	0.750	0.959	0.995	1.000	4.47
1994	0.000	0.001	0.049	0.655	0.986	1.000	1.000	1.000	3.82
1995	0.000	0.000	0.005	0.801	1.000	1.000	1.000	1.000	3.79
1996	0.000	0.000	0.028	0.666	0.993	1.000	1.000	1.000	3.84
1997	0.000	0.007	0.109	0.670	0.972	0.998	1.000	1.000	3.75
1998	0.000	0.001	0.087	0.872	0.998	1.000	1.000	1.000	3.55
1999	0.000	0.001	0.119	0.898	0.999	1.000	1.000	1.000	3.46
2000	0.000	0.001	0.142	0.966	1.000	1.000	1.000	1.000	3.37
2001	0.000	0.000	0.271	0.997	1.000	1.000	1.000	1.000	3.15
2002	0.000	0.010	0.633	0.997	1.000	1.000	1.000	1.000	2.90
2003	0.000	0.022	0.515	0.979	1.000	1.000	1.000	1.000	2.99
2004	0.000	0.000	0.092	0.966	1.000	1.000	1.000	1.000	3.41
2005	0.038	0.165	0.500	0.830	0.959	0.991	0.998	1.000	3.00
2006	0.000	0.013	0.354	0.959	0.999	1.000	1.000	1.000	3.16
2007	0.000	0.012	0.264	0.919	0.997	1.000	1.000	1.000	3.30
2008	0.000	0.012	0.232	0.883	0.995	1.000	1.000	1.000	3.37
2009	0.000	0.010	0.181	0.829	0.991	1.000	1.000	1.000	3.49
2010	0.000	0.009	0.164	0.810	0.989	1.000	1.000	1.000	3.53
2011	0.001	0.008	0.071	0.424	0.877	0.986	0.999	1.000	4.14
2012	0.000	0.000	0.016	0.572	0.991	1.000	1.000	1.000	3.94
2013	0.003	0.035	0.283	0.802	0.977	0.998	1.000	1.000	3.40
2014	0.000	0.003	0.044	0.397	0.901	0.992	0.999	1.000	4.16
2015	0.000	0.000	0.004	0.113	0.790	0.991	1.000	1.000	4.60
2016	0.000	0.000	0.004	0.046	0.388	0.892	0.991	1.000	5.18
2017	0.000	0.000	0.004	0.046	0.388	0.892	0.991	1.000	5.18

Table 7.- 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%**
1988	86327	80652	92957	23272	18701	29203	62566	44890	92516	0.519	0.464	0.576
1989	96807	90779	103317	29436	23572	36097	123085	89468	187160	0.622	0.567	0.684
1990	88336	82746	94646	32601	27485	37976	109808	79469	166464	0.734	0.666	0.804
1991	74514	67416	85467	24798	21013	29117	378437	277237	563544	0.433	0.383	0.489
1992	88009	80072	98514	25485	22276	29162	305060	224962	450742	1.398	1.279	1.517
1993	62018	56926	68333	10348	8979	12206	20626	15027	30434	0.961	0.868	1.055
1994	54370	50150	58991	21209	18068	24683	37947	27545	57210	1.365	1.262	1.459
1995	19787	18330	21458	13530	12211	14901	15898	11676	23949	1.3	1.194	1.408
1996	7320	6800	7929	3606	3209	4035	985	719	1499	0.477	0.422	0.533
1997	6176	5731	6666	3977	3578	4390	862	625	1317	0.92	0.828	1.02
1998	3044	2746	3407	2631	2352	2953	1434	1039	2215	0.326	0.278	0.377
1999	2454	2145	2831	2189	1876	2552	217	153	344	0.21	0.175	0.253
2000	2761	2369	3240	2138	1786	2539	3987	2932	6040	0.065	0.052	0.079
2001	3498	3017	4108	2141	1817	2505	9480	6889	14322	0.075	0.057	0.101
2002	3823	3329	4339	2431	2116	2777	919	650	1420	0.021	0.017	0.025
2003	5013	4397	5859	2869	2518	3232	24862	18204	36879	0.006	0.005	0.008
2004	8505	7502	9822	4276	3817	4816	759	547	1127	0.002	0.001	0.002
2005	13344	11671	15913	6511	5685	7501	54653	40204	82061	0.002	0.002	0.003
2006	29599	25935	35474	10527	9455	11918	88734	64698	131654	0.054	0.045	0.064
2007	44414	39723	51140	14985	13149	18433	120800	89220	179475	0.015	0.012	0.017
2008	59847	54145	67273	26311	23646	29330	107008	78515	162901	0.028	0.024	0.032
2009	80731	73608	89939	40908	37239	45089	151489	110626	225812	0.021	0.018	0.024
2010	108112	99173	120556	59604	53677	66050	259836	189907	386047	0.13	0.113	0.15
2011	113019	103250	126378	51957	47357	57644	455238	332912	683227	0.14	0.121	0.162
2012	158845	141644	182168	54642	49560	60470	363180	261029	541769	0.095	0.082	0.111
2013	146820	133202	162416	88840	79725	99206	69224	49437	103896	0.094	0.081	0.11
2014	140686	128178	154563	87231	77732	97812	90916	64712	136019	0.068	0.058	0.081
2015	122445	110663	134515	82651	73204	93243	32879	21840	49538	0.076	0.065	0.089
2016	127326	114258	141224	92067	81040	104584	2357	1548	3747	0.083	0.069	0.101
2017	114530	101066	129343	99194	86937	113624	24865	15747	43523	0.059	0.049	0.072

Table 8.- F at age (posterior median).

	F at age							
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**
1988	0.000	0.018	0.333	0.578	0.637	0.650	0.781	0.781
1989	0.000	0.011	0.351	0.786	0.724	0.788	0.861	0.861
1990	0.000	0.018	0.377	0.905	0.910	1.244	1.033	1.033
1991	0.000	0.023	0.291	0.469	0.538	0.567	0.659	0.659
1992	0.000	0.140	0.971	1.454	1.763	1.438	1.979	1.979
1993	0.000	0.084	0.663	1.129	1.075	1.536	0.862	0.862
1994	0.000	0.189	0.970	1.739	1.372	1.352	0.989	0.989
1995	0.000	0.183	0.534	1.483	1.876	2.309	2.147	2.147
1996	0.000	0.047	0.240	0.491	0.697	0.916	0.820	0.820
1997	0.000	0.107	0.558	0.840	1.354	2.039	1.839	1.839
1998	0.000	0.042	0.194	0.320	0.460	0.542	0.391	0.391
1999	0.000	0.023	0.223	0.180	0.224	0.225	0.079	0.079
2000	0.000	0.005	0.125	0.026	0.042	0.032	0.010	0.010
2001	0.000	0.007	0.134	0.036	0.054	0.040	0.013	0.013
2002	0.000	0.002	0.035	0.011	0.016	0.011	0.004	0.004
2003	0.000	0.000	0.010	0.004	0.005	0.004	0.002	0.002
2004	0.000	0.000	0.003	0.001	0.002	0.001	0.001	0.001
2005	0.000	0.000	0.003	0.001	0.002	0.001	0.001	0.001
2006	0.000	0.002	0.075	0.039	0.046	0.032	0.028	0.028
2007	0.000	0.000	0.010	0.016	0.018	0.017	0.023	0.023
2008	0.000	0.002	0.014	0.030	0.040	0.036	0.029	0.029
2009	0.000	0.001	0.008	0.025	0.030	0.029	0.032	0.032
2010	0.000	0.011	0.069	0.131	0.188	0.194	0.206	0.206
2011	0.000	0.010	0.087	0.111	0.219	0.275	0.362	0.362
2012	0.000	0.006	0.059	0.076	0.150	0.203	0.283	0.283
2013	0.000	0.006	0.061	0.073	0.146	0.211	0.275	0.275
2014	0.000	0.002	0.031	0.076	0.097	0.164	0.222	0.222
2015	0.000	0.004	0.046	0.068	0.112	0.187	0.224	0.224
2016	0.000	0.005	0.060	0.069	0.119	0.126	0.209	0.209
2017	0.000	0.005	0.043	0.032	0.101	0.129	0.168	0.168

Table 9.- 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**
1988	62566	144780	98667	30629	4332	954	703	279	342910	46680
1989	123085	16183	76882	48621	13107	1755	346	322	280300	42626
1990	109808	31691	8559	37027	16915	4824	552	201	209577	31915
1991	378437	28476	16691	4038	11428	5210	975	193	445448	20278
1992	305060	97297	14939	8592	1929	5107	2067	435	435427	11552
1993	20626	78503	45538	3898	1531	252	846	250	151443	6233
1994	37947	5285	39005	16091	963	396	38	332	100058	14154
1995	15898	9787	2354	10158	2153	186	72	94	40702	10617
1996	985	4110	4370	946	1763	254	13	14	12455	2780
1997	862	254	2114	2363	442	672	70	8	6787	2999
1998	1434	222	123	829	781	87	61	9	3546	1669
1999	217	374	114	69	461	376	36	34	1682	983
2000	3987	56	195	63	44	280	209	46	4880	666
2001	9480	1036	30	119	47	33	191	183	11118	579
2002	919	2446	554	18	88	34	22	261	4341	795
2003	24862	237	1316	368	14	66	24	193	27080	1343
2004	759	6416	127	892	281	10	46	148	8681	1361
2005	54653	195	3447	88	684	216	7	135	59425	4971
2006	88734	14076	105	2373	67	525	150	97	106127	3348
2007	120800	22784	7572	67	1744	49	356	172	153544	4768
2008	107008	31010	12293	5185	50	1314	34	369	157263	9614
2009	151489	27358	16682	8362	3855	37	886	268	208936	15296
2010	259836	39036	14755	11413	6258	2861	25	806	334991	21869
2011	455238	67542	20860	9495	7649	3960	1657	461	566861	19083
2012	363180	116907	35815	13138	6468	4705	2102	1060	543375	22355
2013	69224	93687	62670	23225	9339	4268	2679	1699	266793	57635
2014	90916	17683	50110	40672	16520	6191	2422	2367	226879	44381
2015	32879	23289	9537	33492	28926	11515	3669	2715	146023	44515
2016	2357	8322	12471	6273	23903	19794	6665	3631	83416	37447
2017	24865	610	4434	8100	4493	16260	12195	5939	76896	34530

Table 10.- Prior and posterior median for M

	1	2	3	4	5	6	7	8+
Prior	1.26	0.65	0.44	0.35	0.30	0.27	0.24	0.24
Posterior	1.35	0.62	0.37	0.26	0.27	0.35	0.31	0.38

Table 11.- N-at-age in prediction years (medians) with F_{bar}=F_{lim}=0.153 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2018	20614	6420	322	2942	6011	3104	9999	10970	60381	26172
2019	14485	5409	3420	214	2183	4276	1970	12921	44876	19540
2020	11188	3853	2869	2119	147	1301	2163	6677	30315	10212
2021	5920	2986	2094	1779	1433	88	665	4013	18976	5465

Table 12.- Projections results (median and 90% CI) with F_{bar}=F_{lim}=0.153.

Year	Total Biomass		SSB		P(SSB<B_{lim})	Yield
2018	108705	(94014 - 125180)	100343	(86263- 116383)	0%	11145
2019	95351	(80800 - 111466)	90123	(76337 - 106201)	0%	26502
2020	51428	(40481 - 64418)	47805	(37198 - 60396)	0%	14260
2021	29467	(20160 - 40273)	26392	(17815 - 36684)	13%	

Table 13.-N-at-age in prediction years (medians) with F_{bar}=3/4F_{lim}=0.115 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2018	20614	6420	322	2942	6011	3104	9999	10970	60381	26172
2019	14485	5409	3420	214	2183	4276	1970	12921	44876	19540
2020	11188	3853	2879	2175	151	1383	2344	7416	31389	11219
2021	6541	2986	2100	1838	1525	96	764	4939	20787	6530

Table 14.- Projections results (median and 90% CI) with F_{bar}=3/4F_{lim}=0.115.

Year	Total Biomass		SSB		P(SSB<B_{lim})	Yield
2018	108705	(94014 - 125180)	100343	(86263- 116383)	0%	11145
2019	95351	(80800 - 111466)	90123	(76337 - 106201)	0%	20796
2020	56533	(45623 - 69596)	52867	(42341 - 65526)	0%	12359
2021	35407	(26166 - 46024)	32204	(23660 - 42420)	1%	

Table 15.- N-at-age in prediction years (medians) with F_{bar}=$F_{2014\text{-}2016}$=0.073 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2018	20614	6420	322	2942	6011	3104	9999	10970	60381	26172
2019	14485	5409	3420	214	2183	4276	1970	12921	44876	19540
2020	11188	3853	2890	2240	156	1482	2557	8350	32714	12456
2021	7278	2986	2107	1900	1631	106	892	6192	23090	7951

Table 16.- Projections results (median and 90% CI) with F_{bar}=$F_{2014\text{-}2016}$=0.073

Year	Total Biomass		SSB		P(SSB<B_{lim})	Yield
2018	108705	(94014 - 125180)	100343	(86263- 116383)	0%	11145
2019	95351	(80800 - 111466)	90123	(76337 - 106201)	0%	13863
2020	62796	(51855 - 75854)	59056	(48509 - 71796)	0%	9191
2021	43374	(34048 - 54034)	39963	(31485 - 50314)	0%	

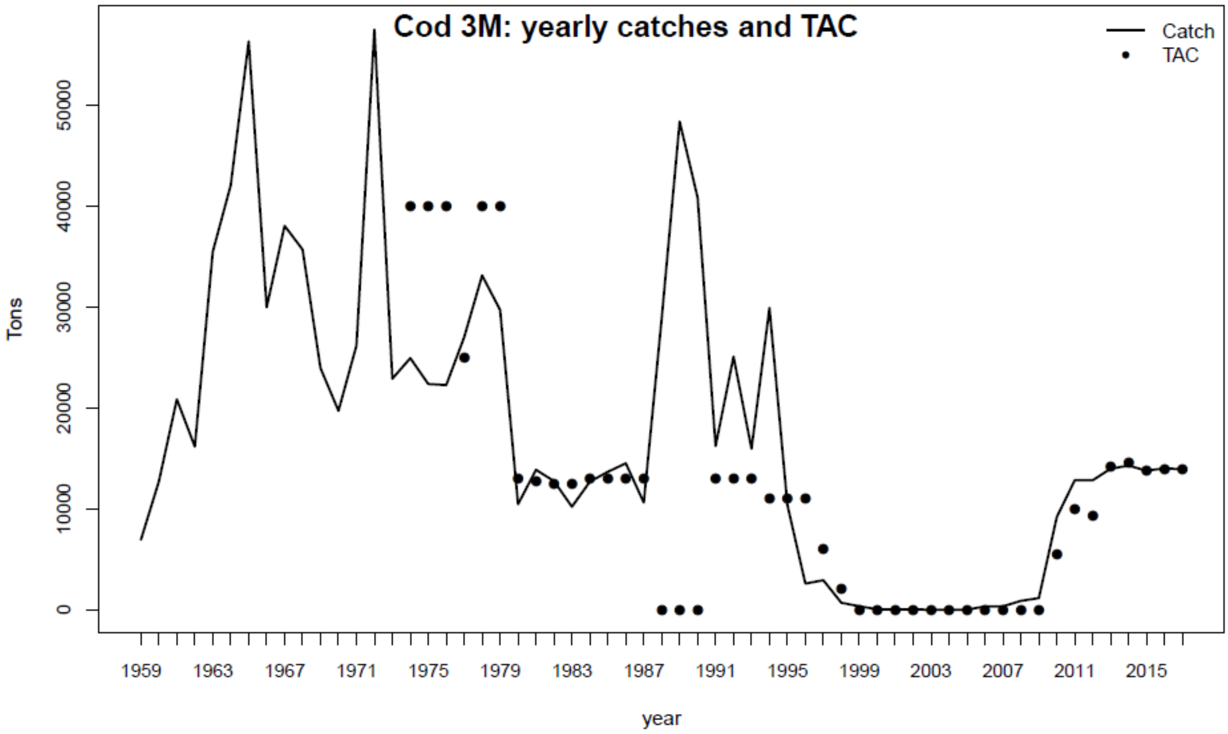

Fig. 1. Catch and TAC of the 3M cod for the period 1959-2017.

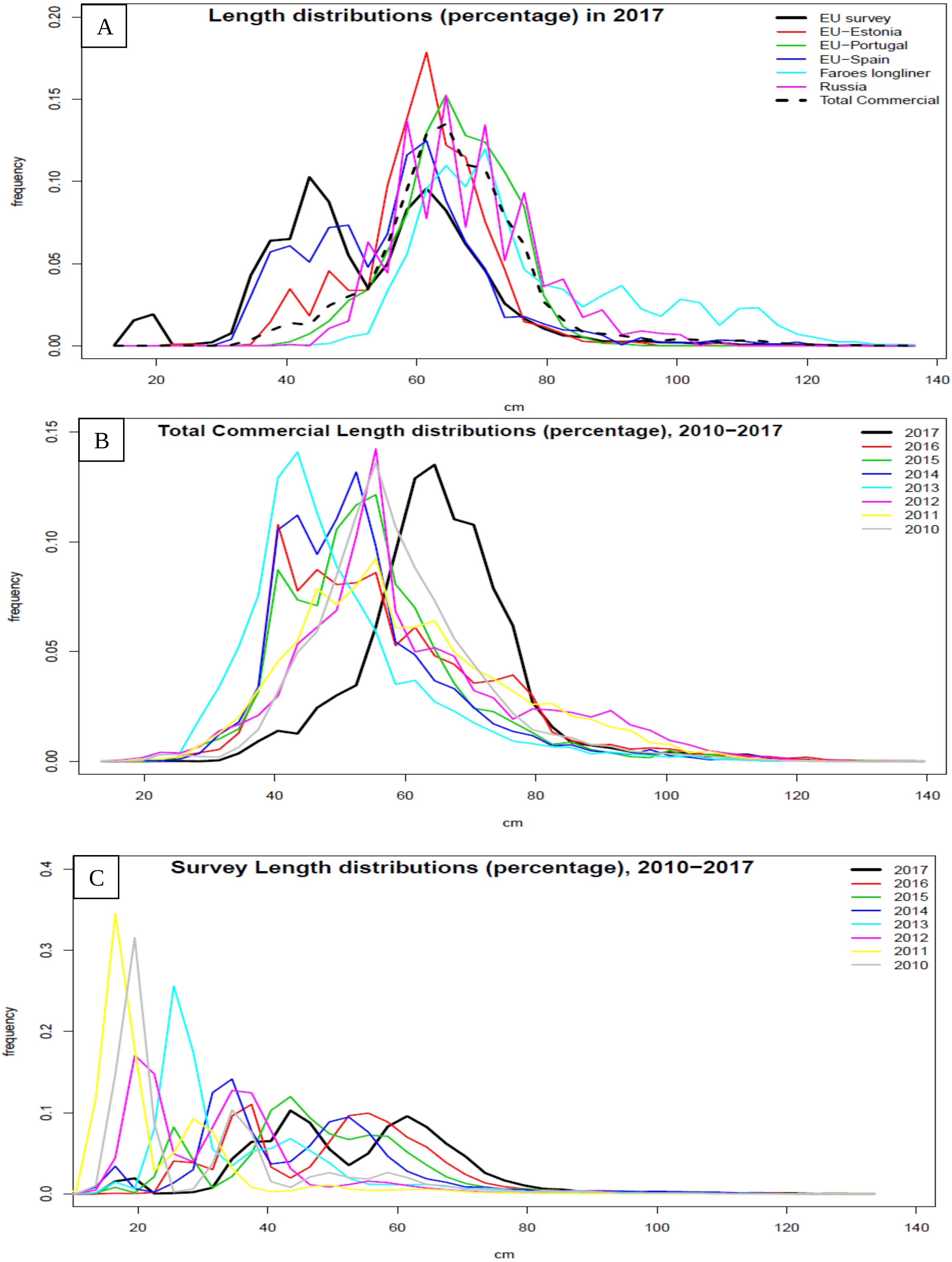

Fig. 2. Length frequencies in commercial catches and EU survey in 2017 (A), and for the last fishery period (2010-2017) the total commercial (B) and the survey (C).

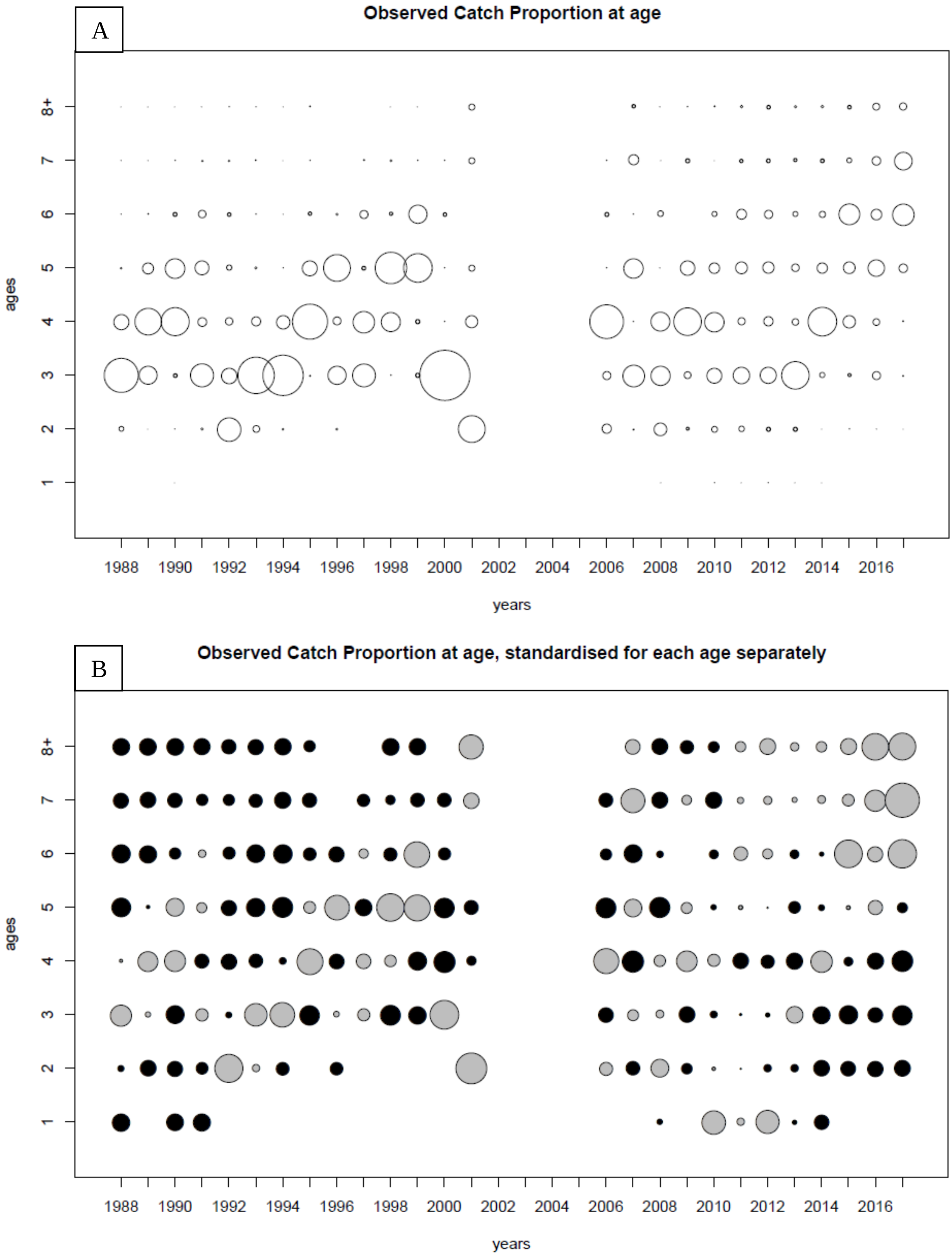

Fig. 3. Commercial catch proportions at age (A) and standardised proportions at age (B). In B, grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

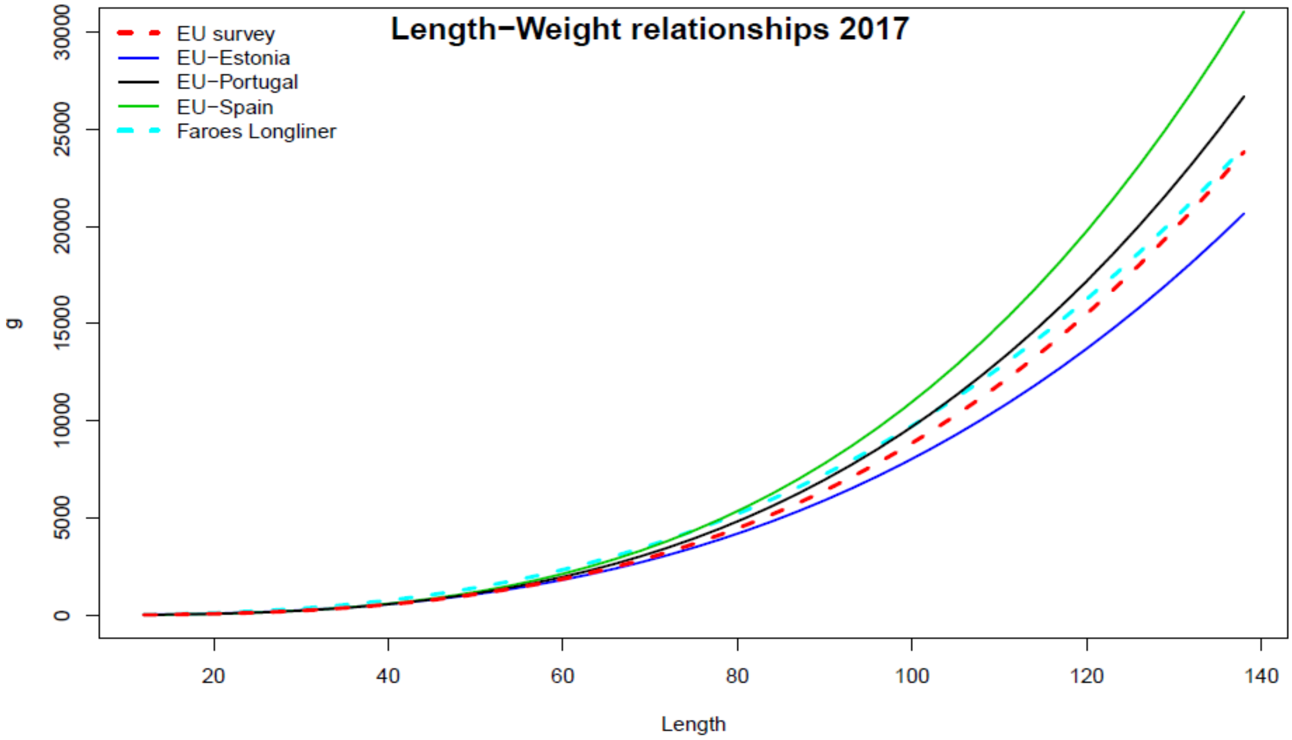

Fig. 4. Length-weight relationships for commercial catches and EU survey in 2017.

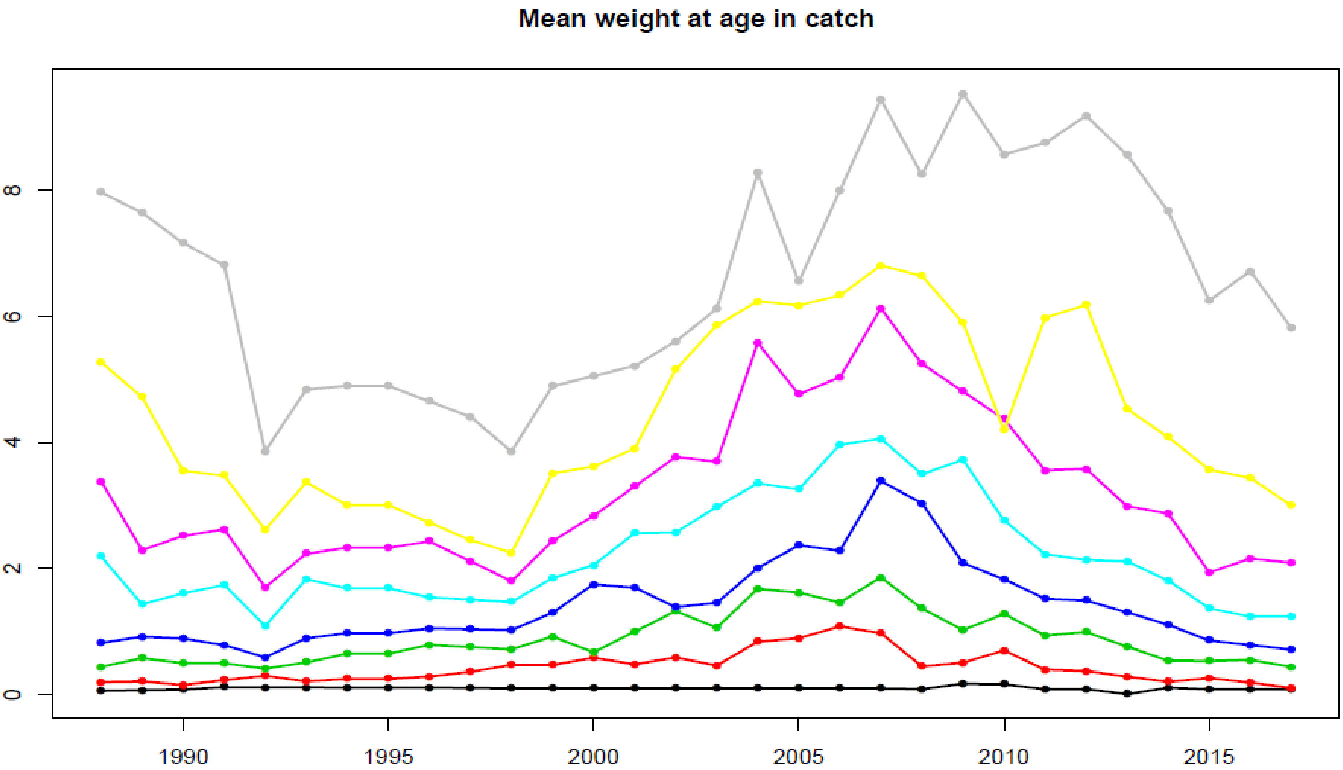

Fig. 5. Catch mean weight at age.

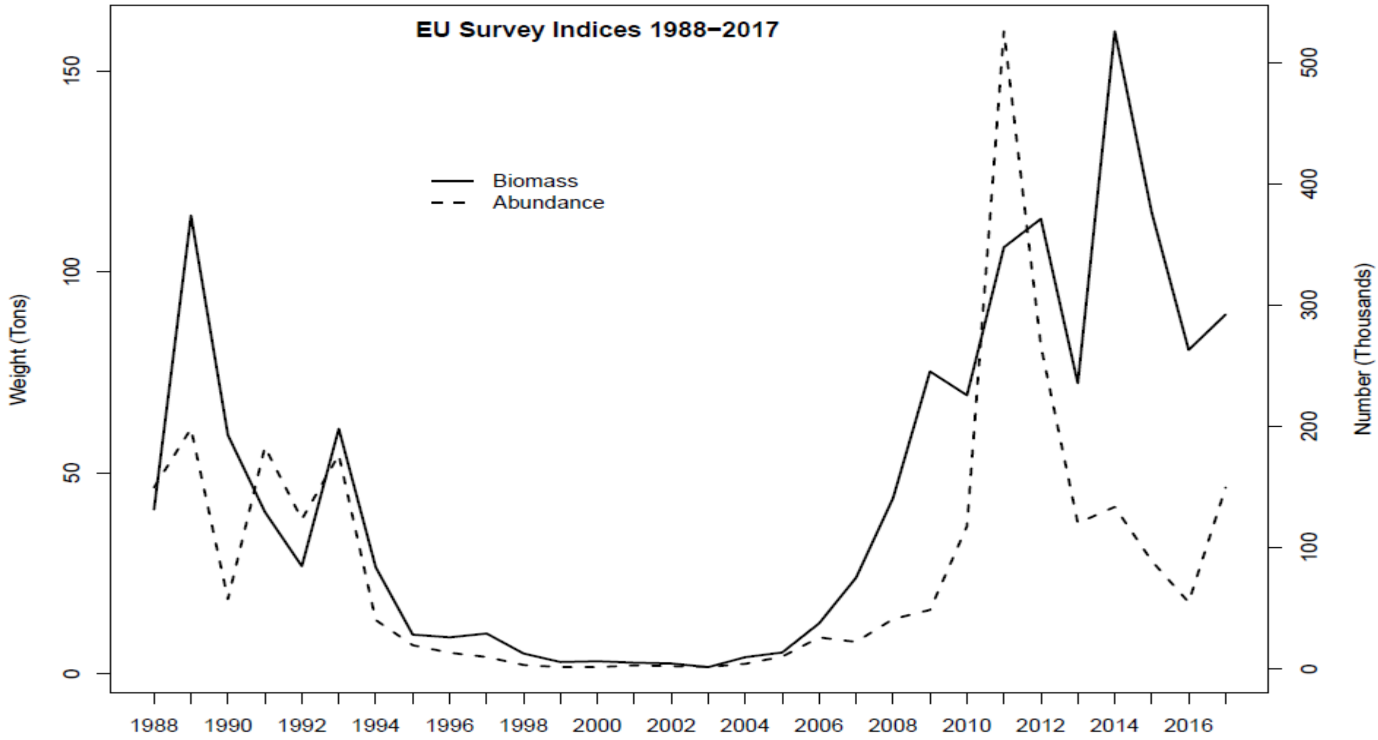

Fig. 6. Biomass and abundance from EU surveys.

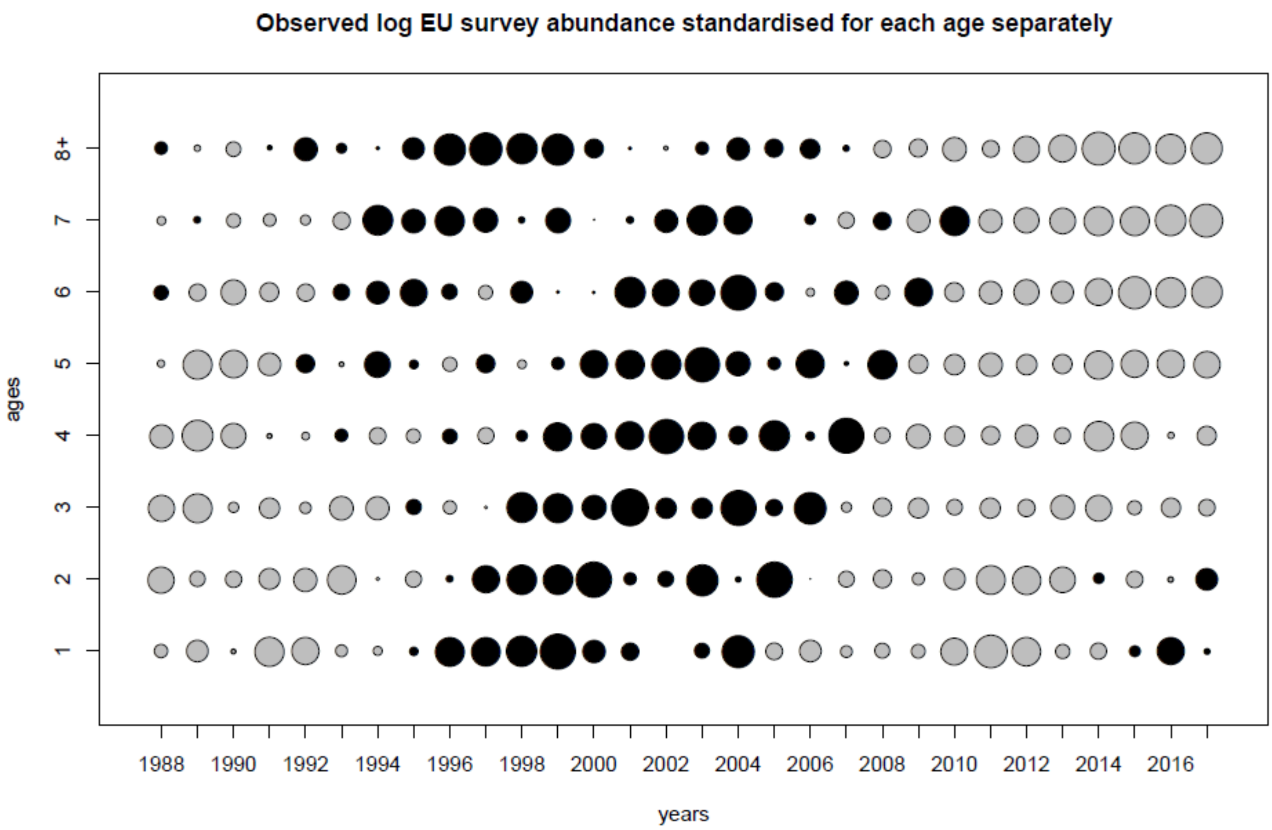

Fig. 7. Standardised log(Abundance at age) indices from EU survey. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

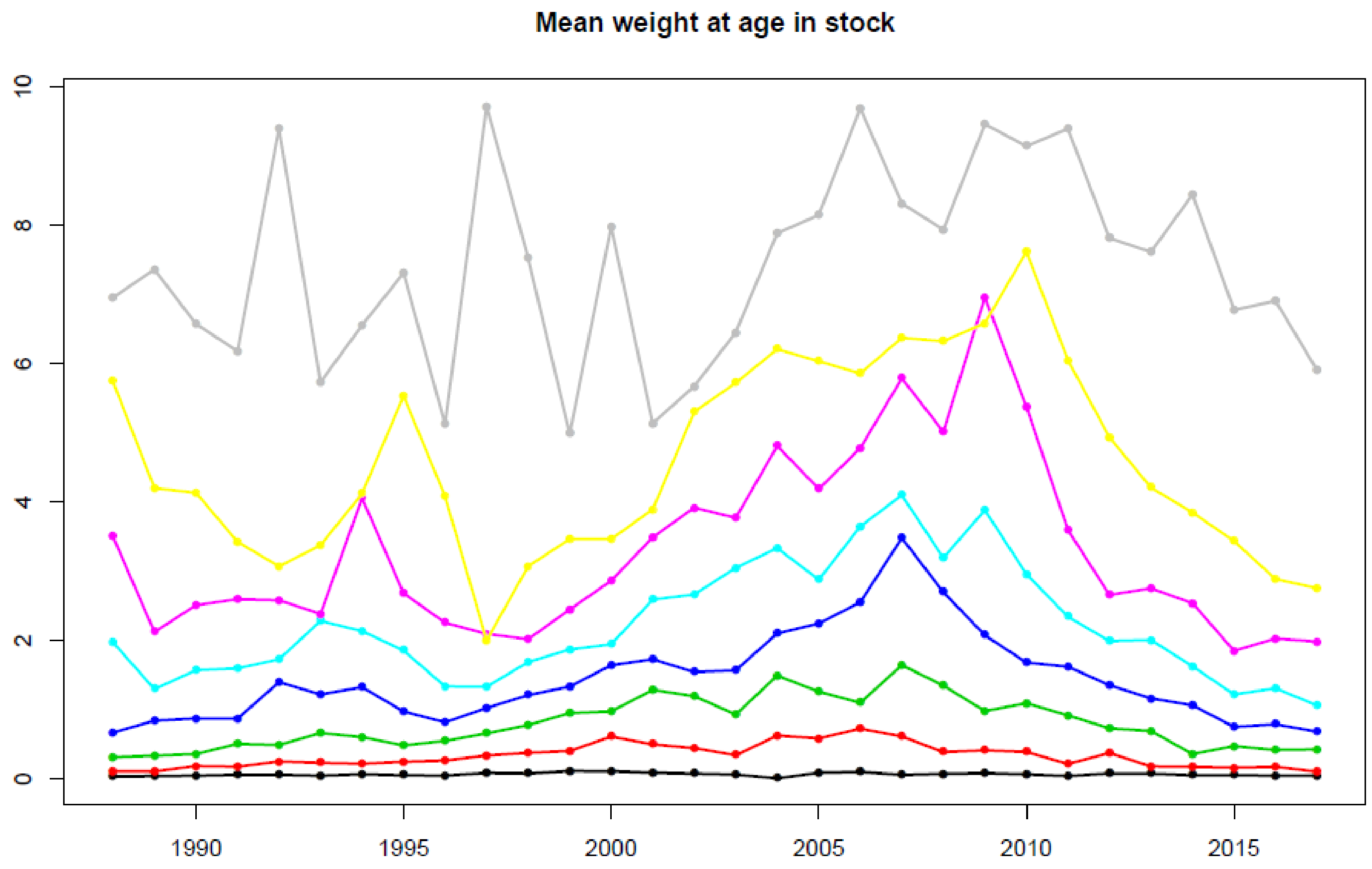

Fig. 8. Stock mean weight at age.

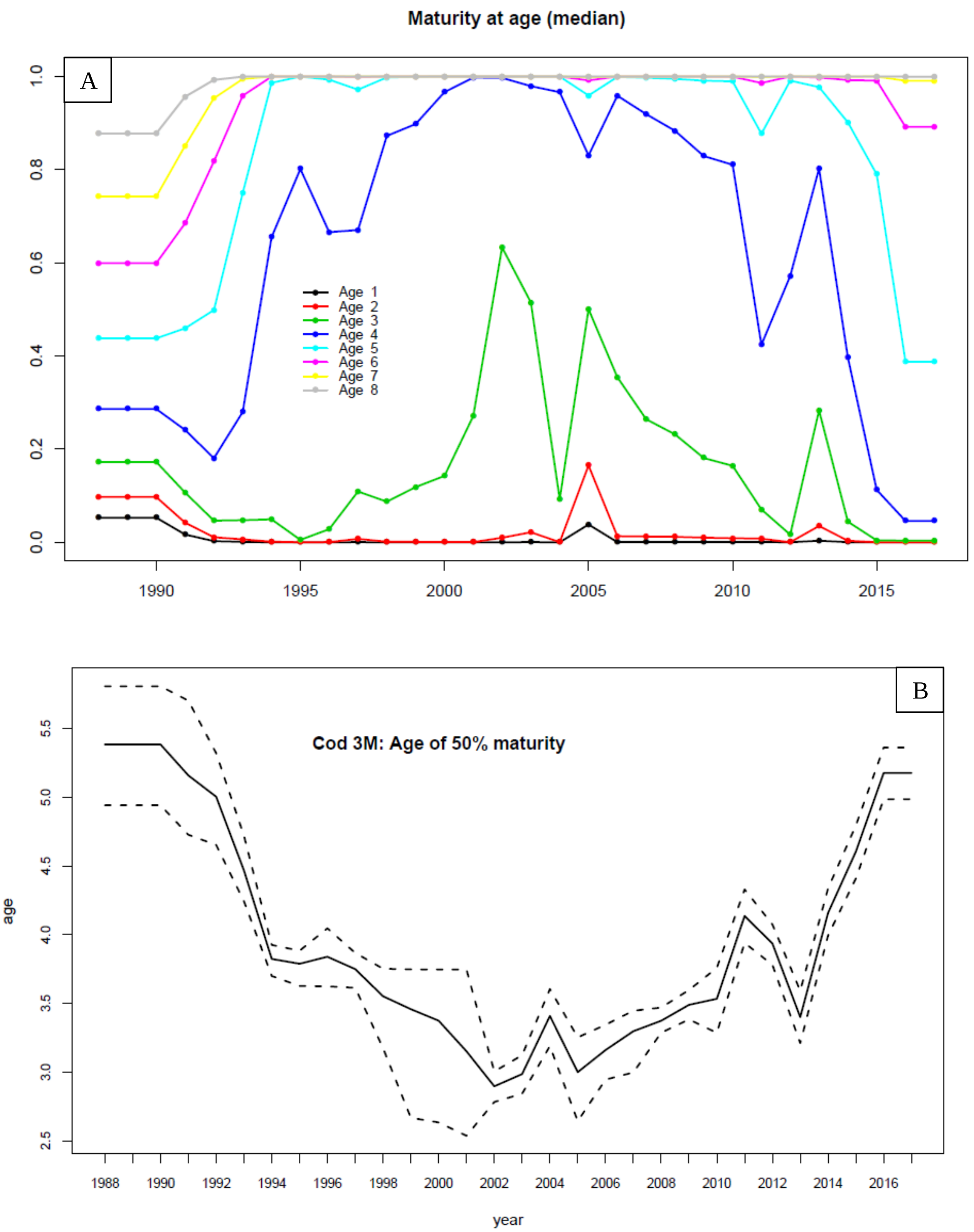

Fig. 9. Maturity ogive by age (A) and age at which 50% of fish are mature (B).

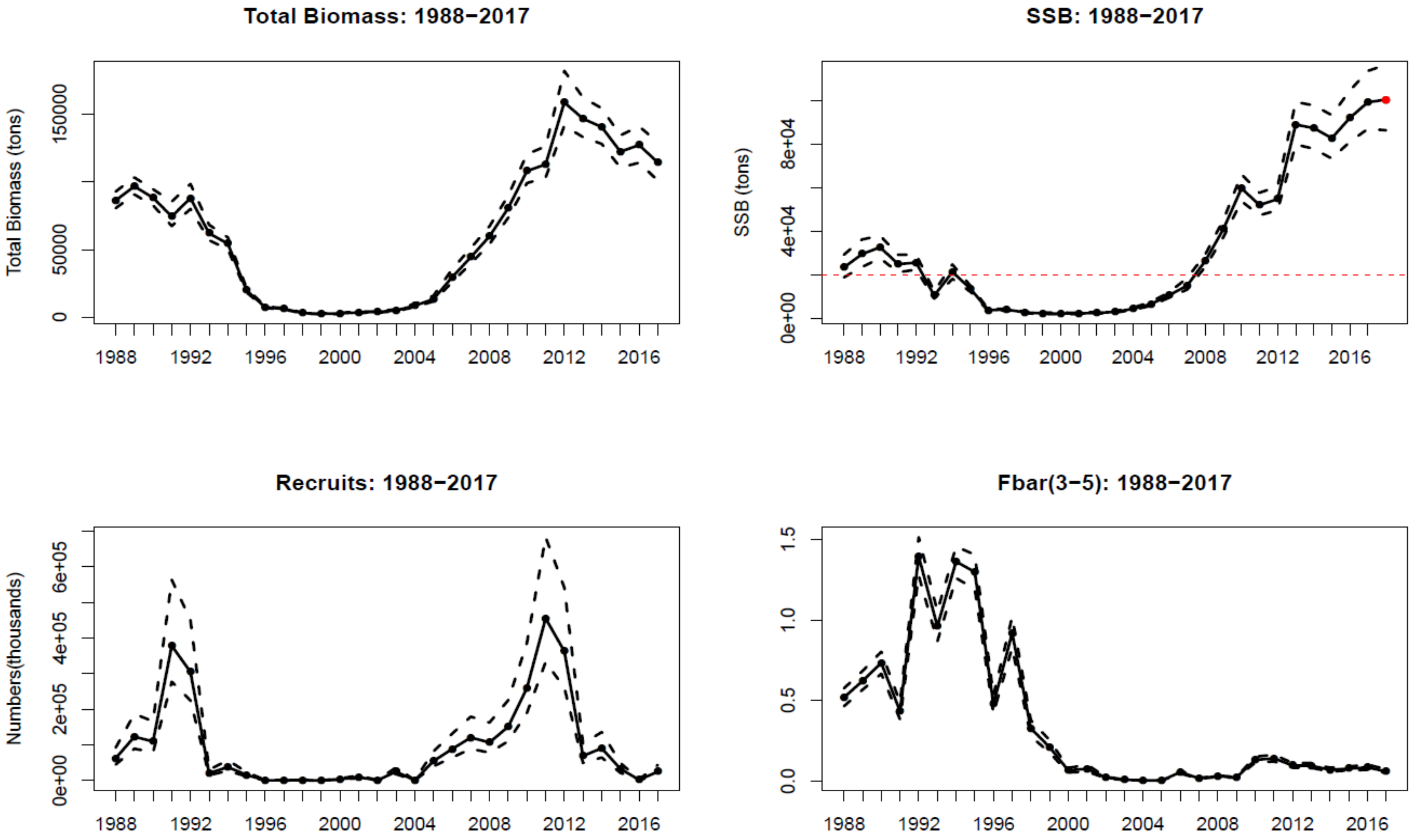

Fig. 10. Estimated trends in biomass, SSB, recruitment and F_{bar}. The solid lines are the posterior medians and the dashed lines show the limits of 90% posterior credible intervals. Red point in the SSB plot indicates the SSB in 2018. Red horizontal line in the SSB graph represents B_{lim} = 20 000 tons.

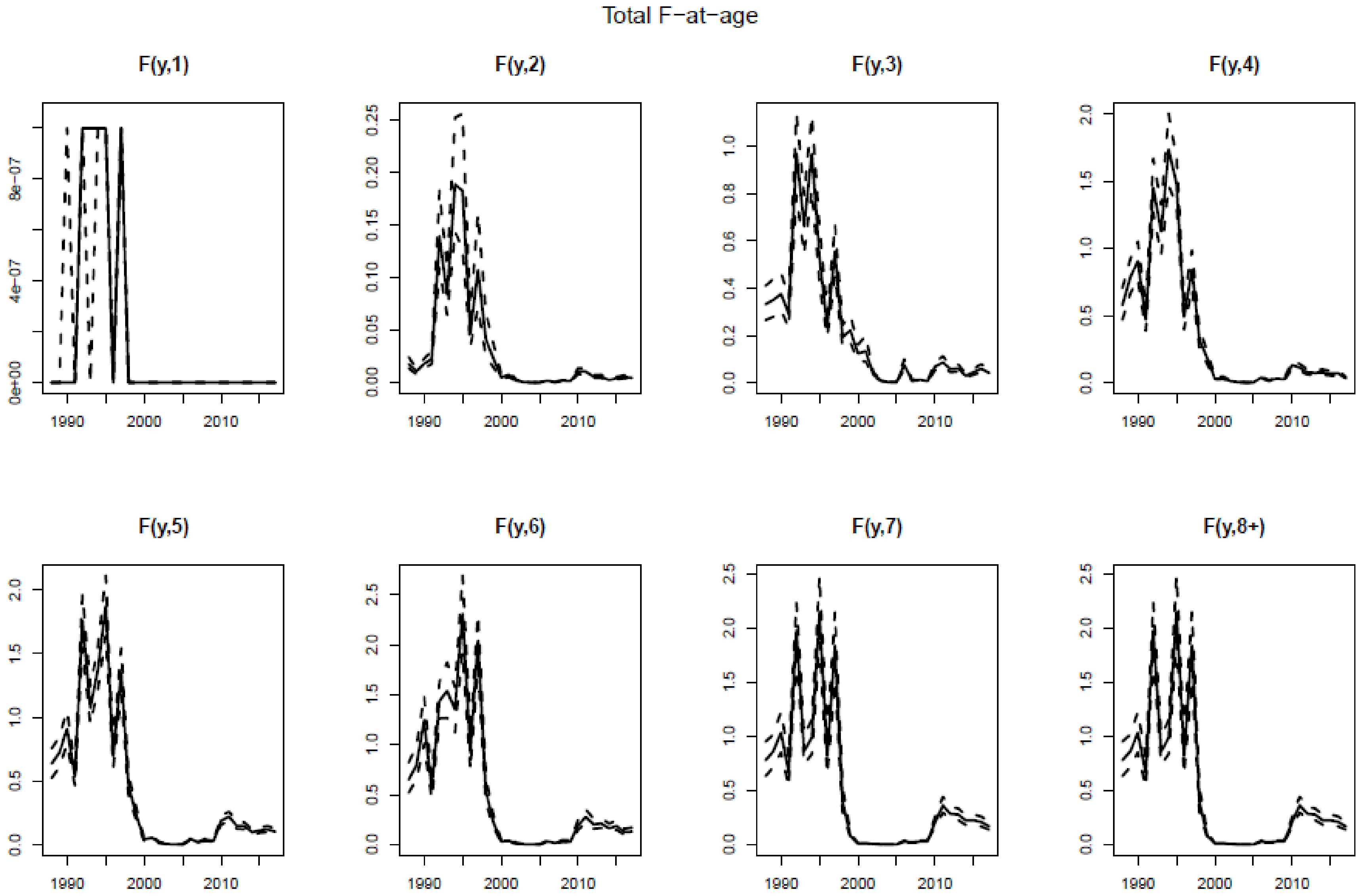

Fig. 11. Estimated fishing mortality at age. The y-axis scale is different in all the graphs.

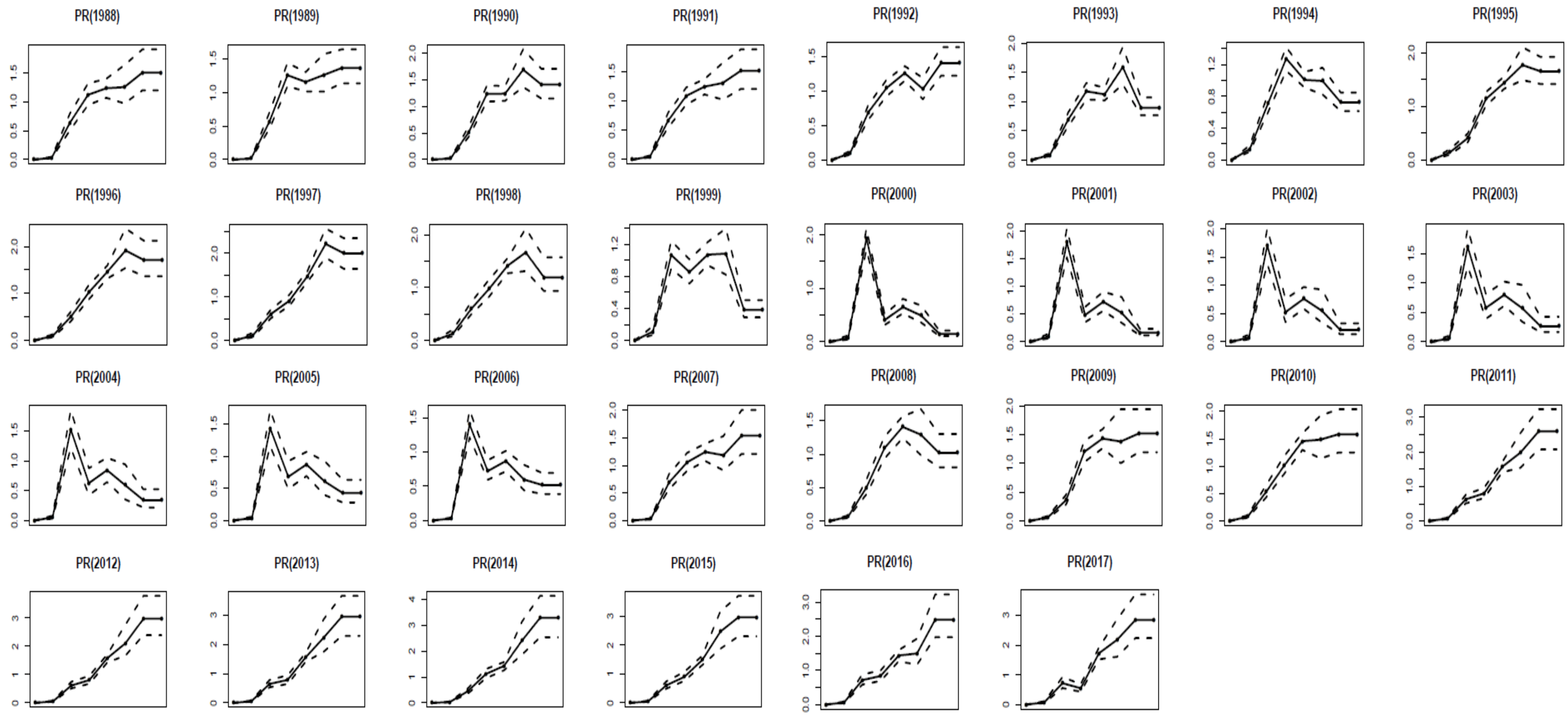

Fig. 12. Estimated PR (F/F_{bar}) per age and year. Take into account the different y-axis between figures.

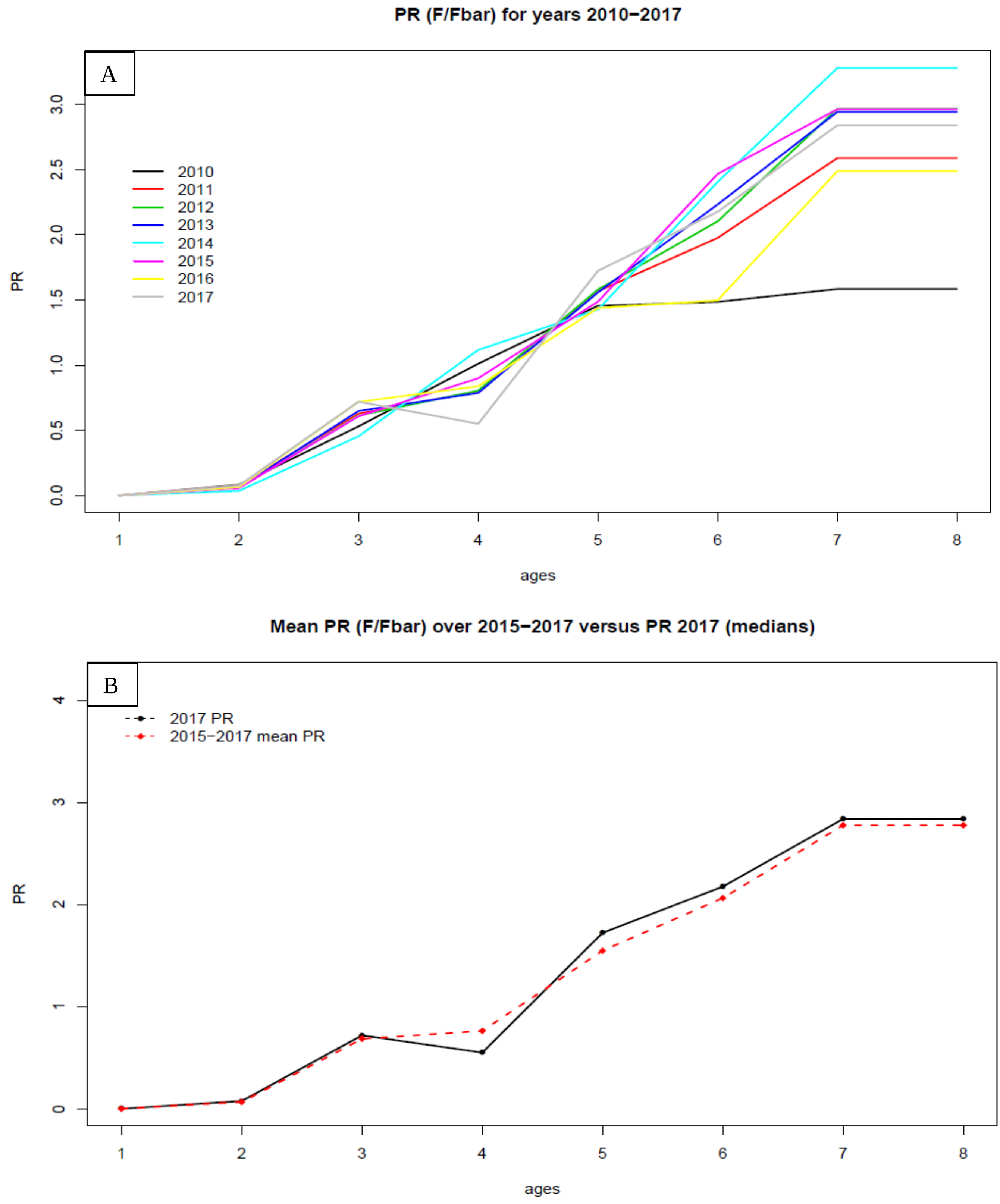

Fig. 13. (A) Estimated PR (F/F_{bar}) per age for the last six years and (B) mean of 2015-2017 PR versus 2017 PR (posterior medians). Bold line is the mean of the last three years PR.

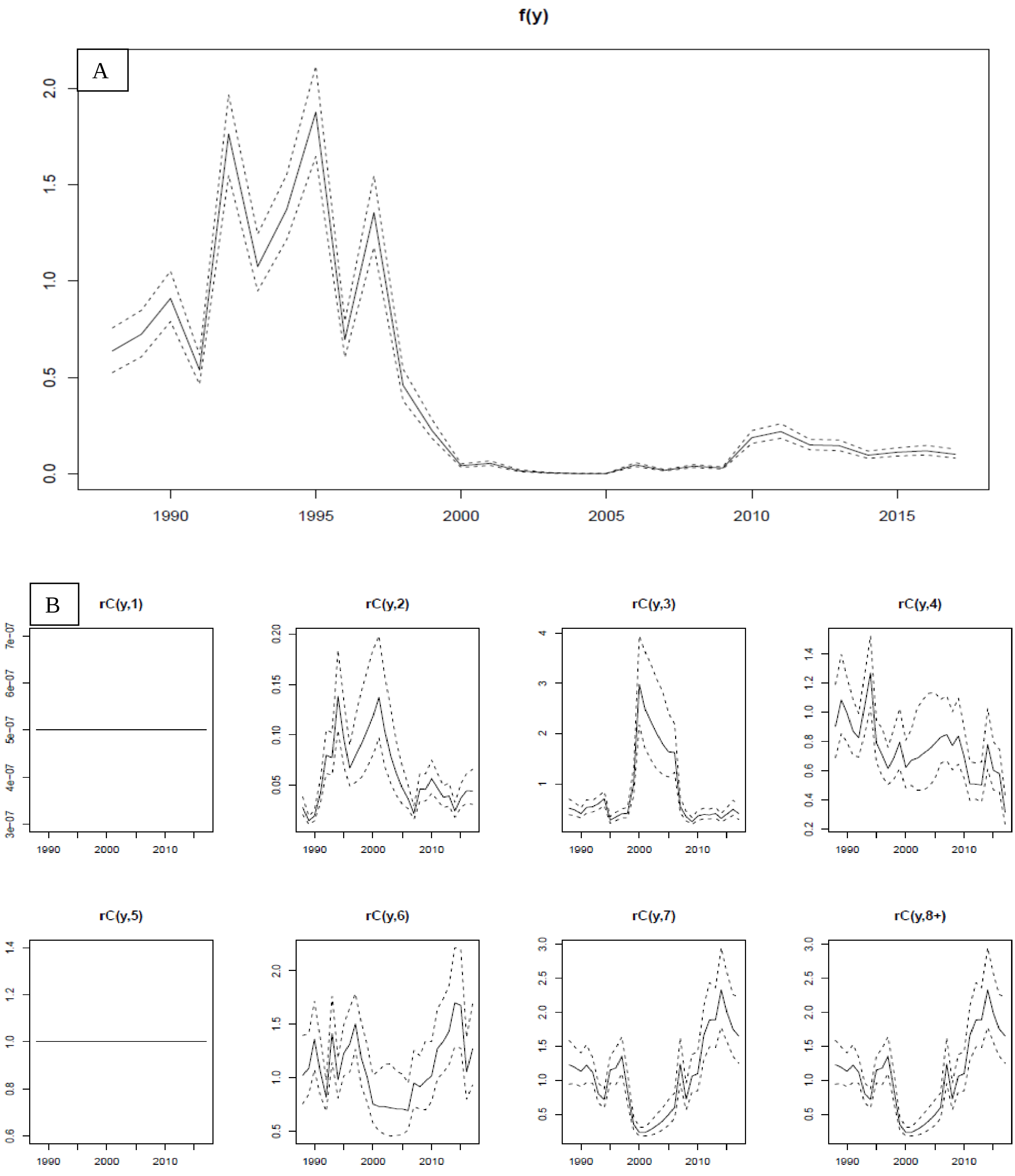

Fig. 14. Components of the semiseparable model for Fishing Mortality: F[y,a]=*f*[y]**rC*[y,a].

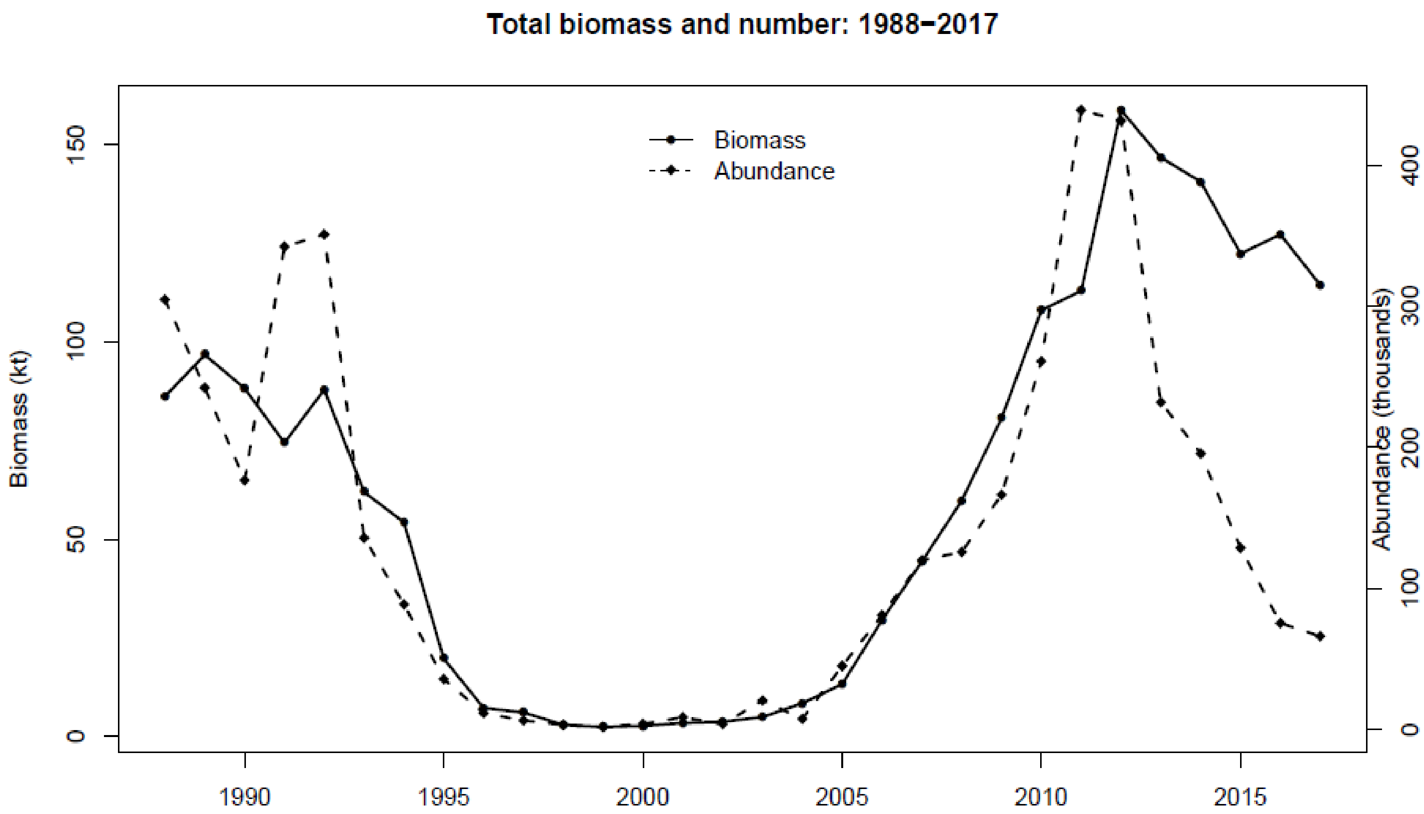

Fig. 15. Estimated trends in biomass and abundance.

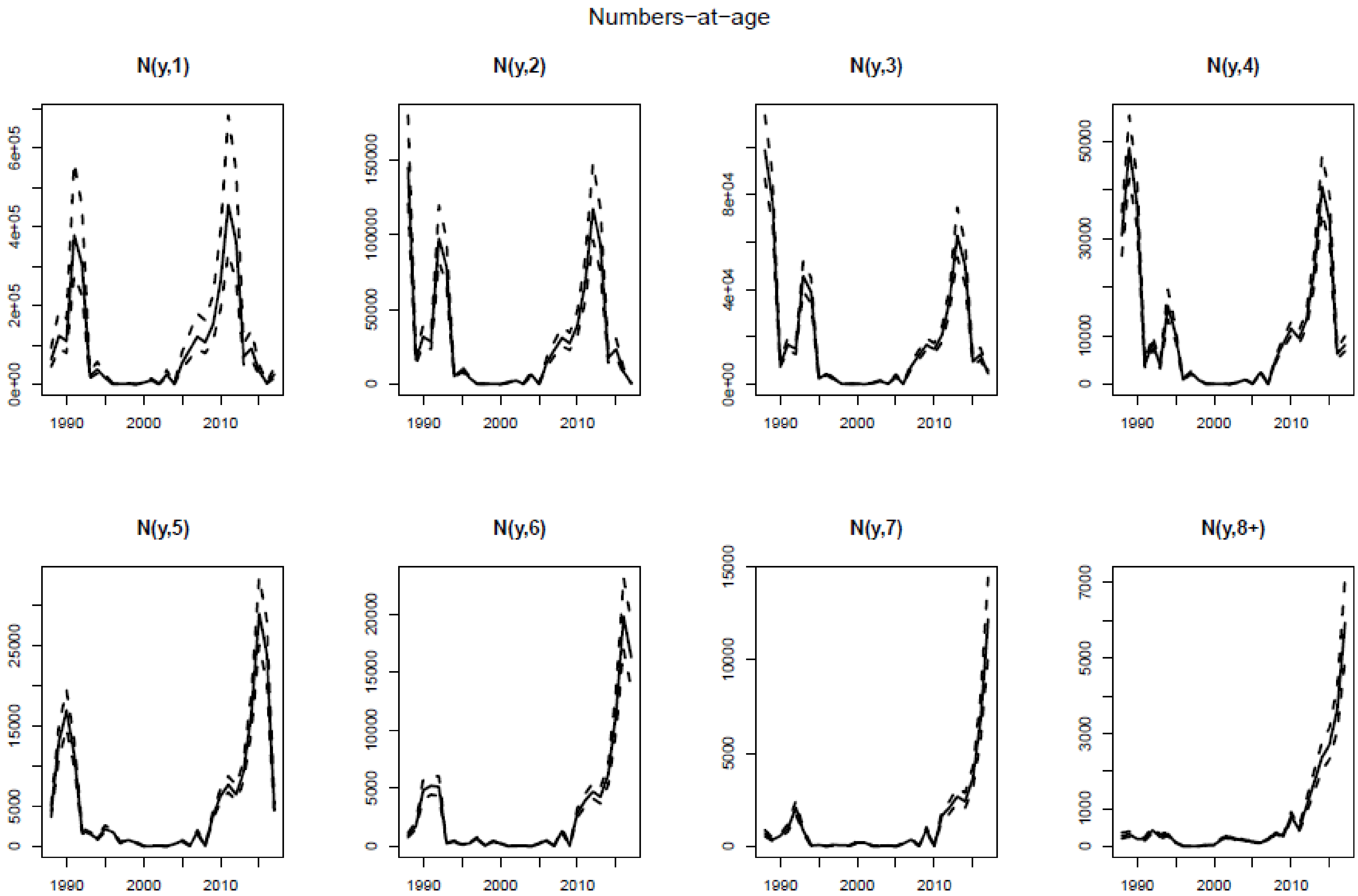

Fig. 16. Estimated numbers at age. The y-axis scale is different in all the graphs.

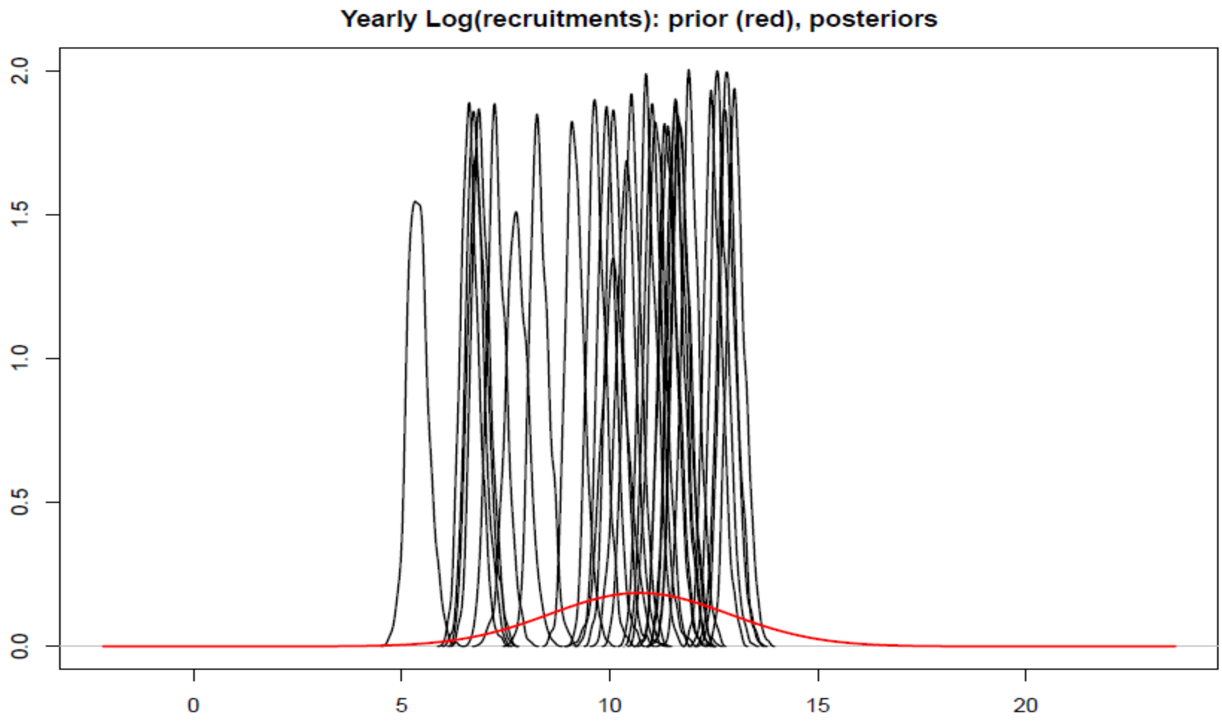

Fig. 17. Prior and posterior of recruitment by year.

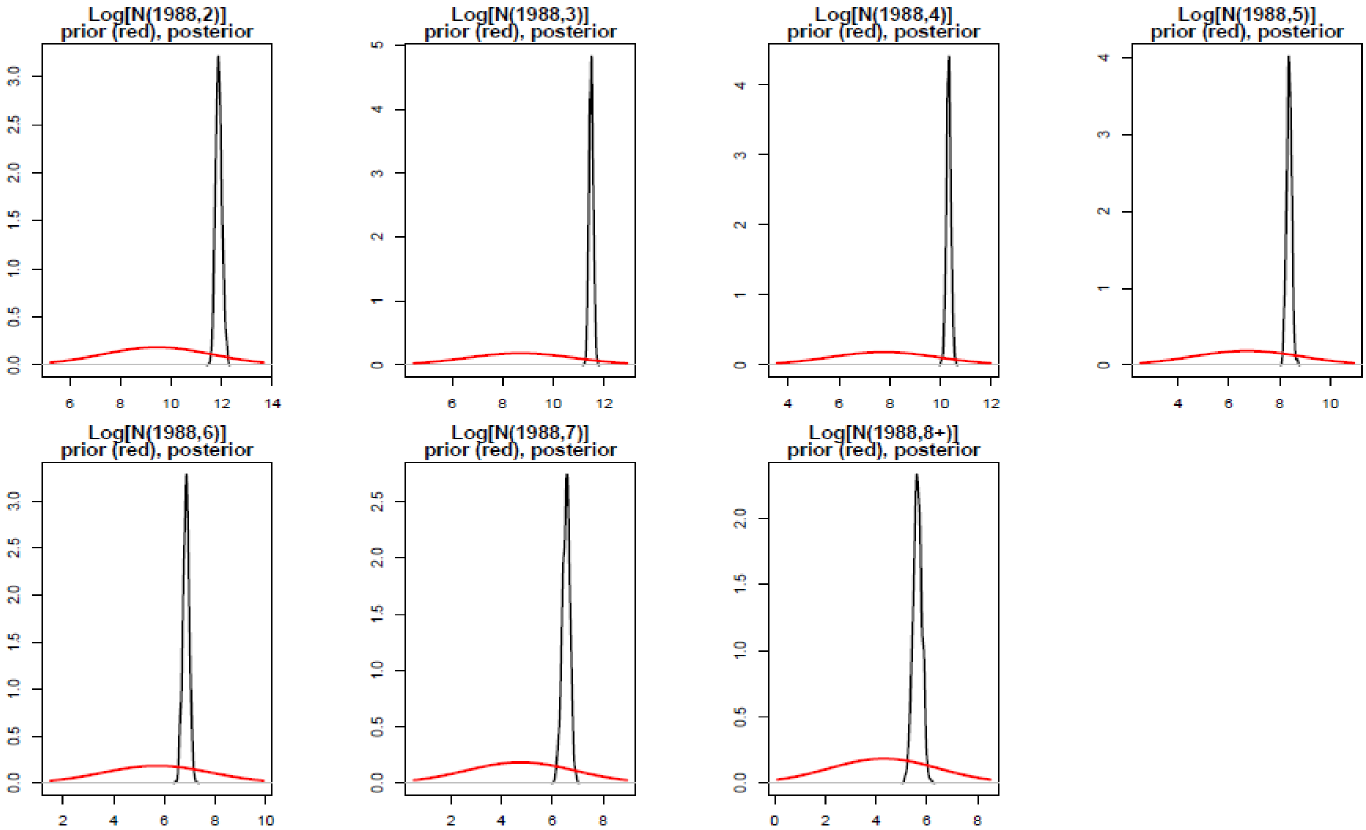

Fig. 18. Prior and posterior of the numbers in the first year (1988) from age 2 to 8+.The x- and y-axis scales are different in all the graphs.

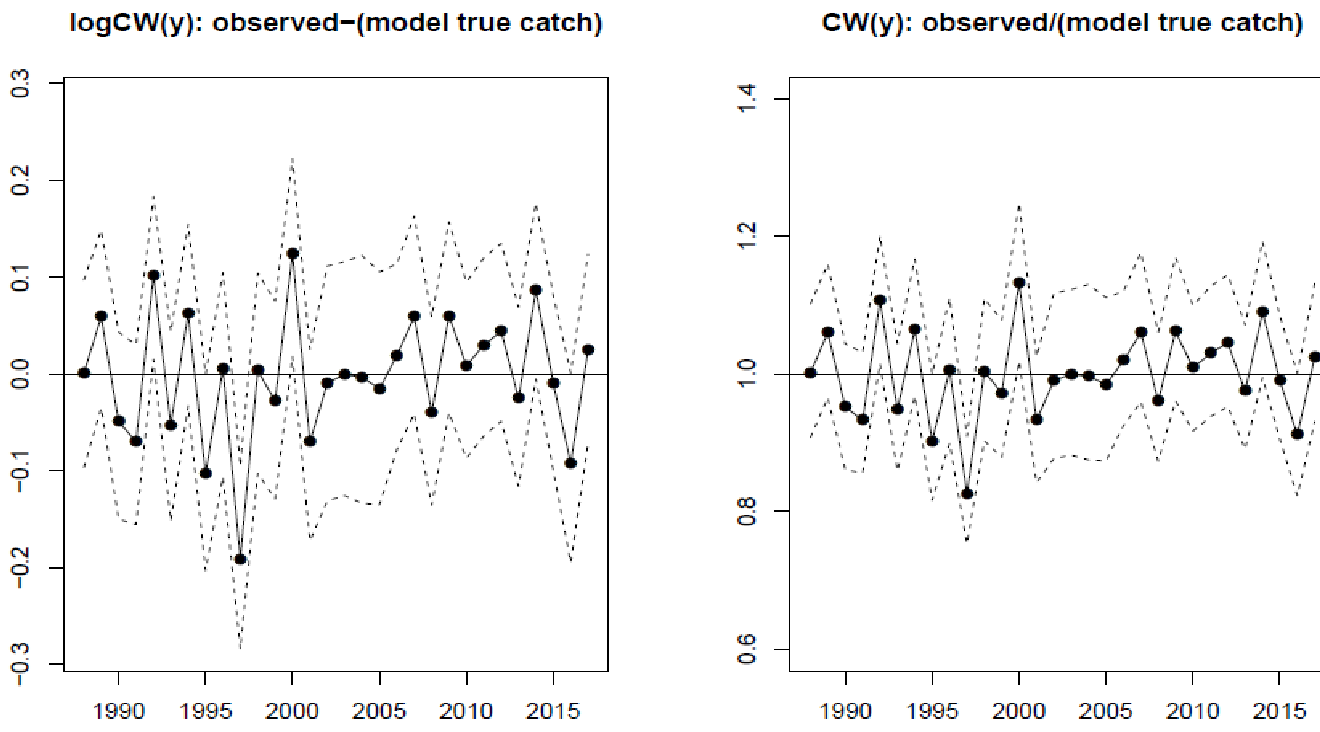

Fig. 19. Observed versus estimated total catches by year.

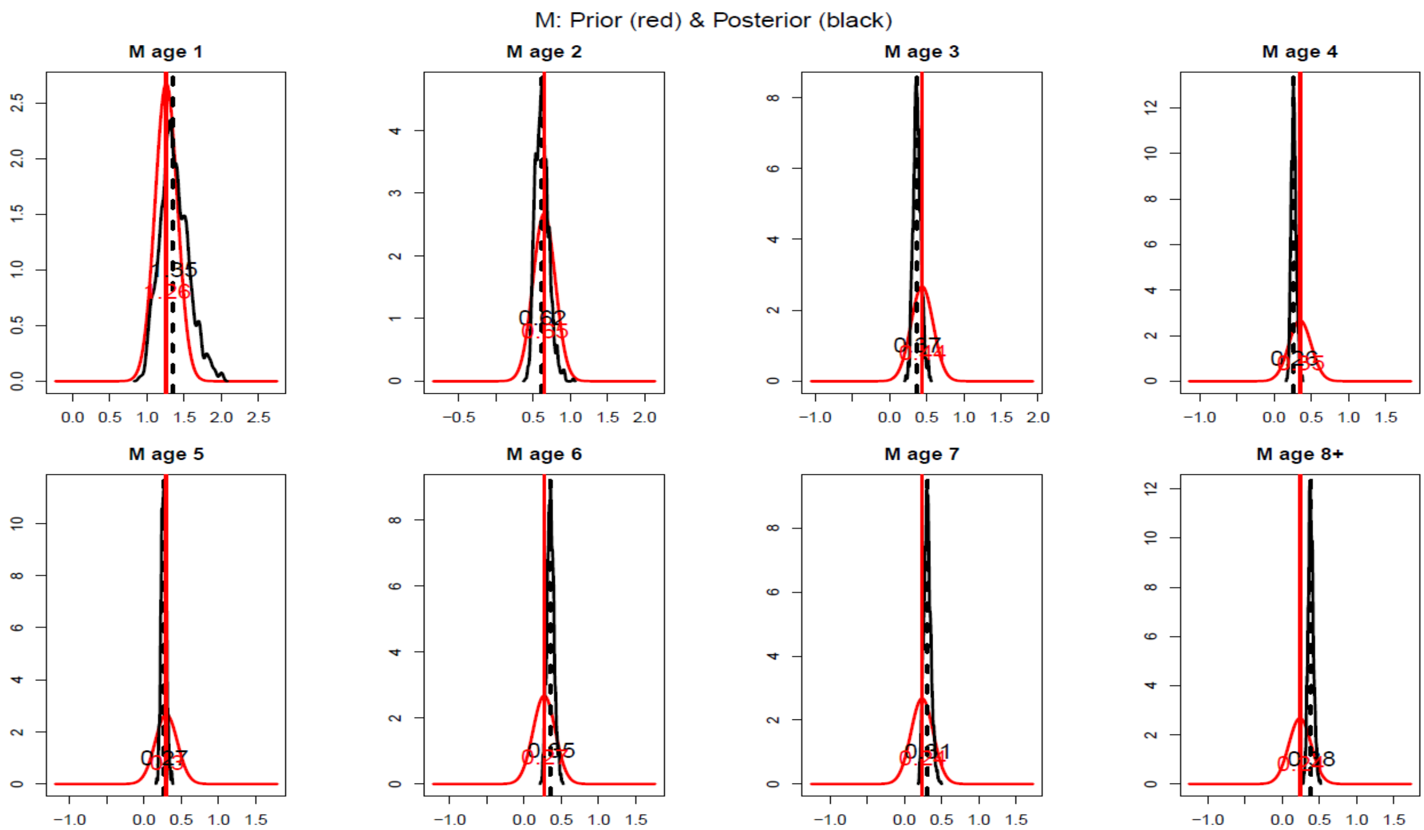

Fig. 20. Estimated natural mortality by age in 2017.

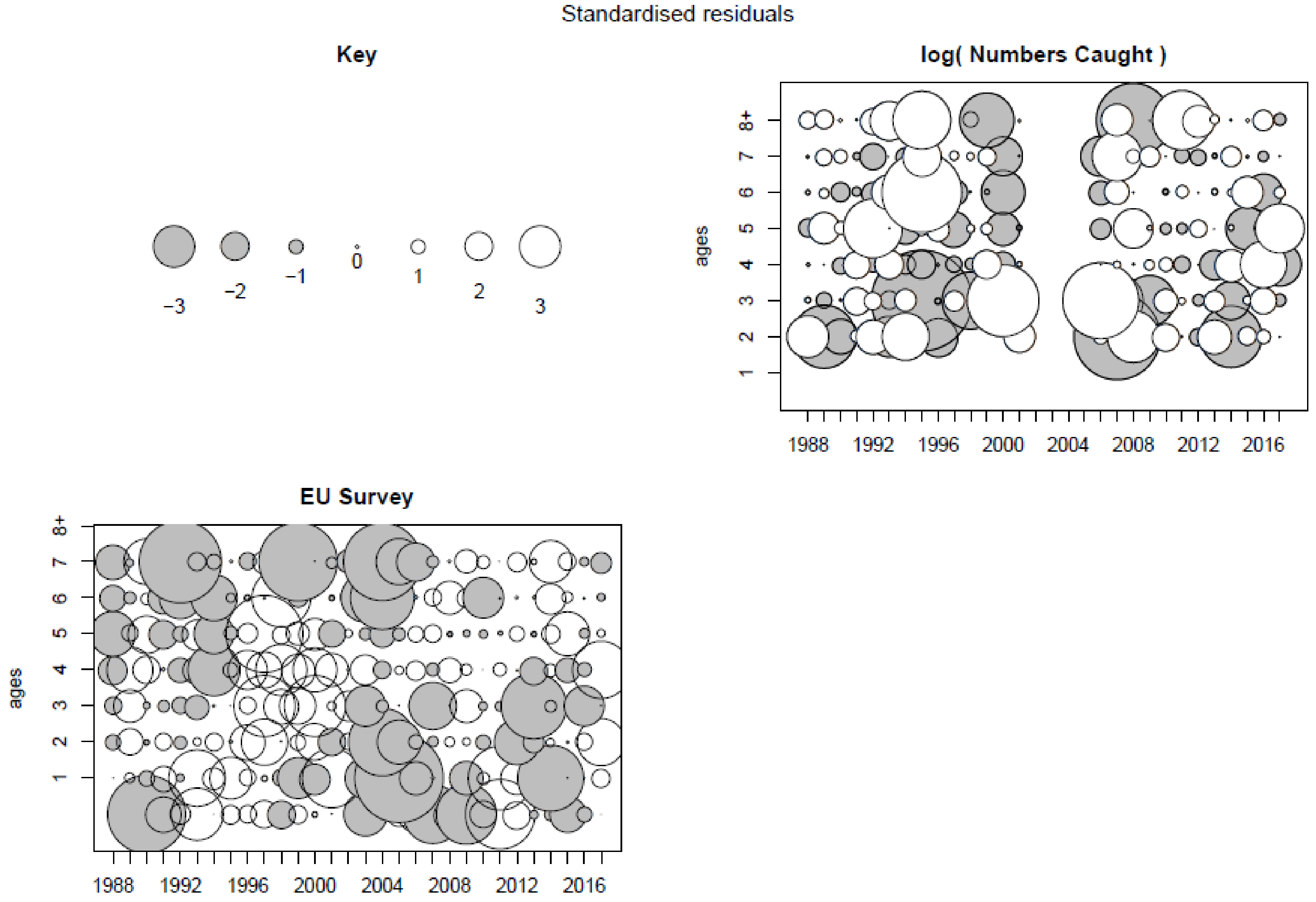

Fig. 21. Standardised residuals (observed minus fitted value) in logarithmic scale of catch numbers at age and EU survey abundance indices at age. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

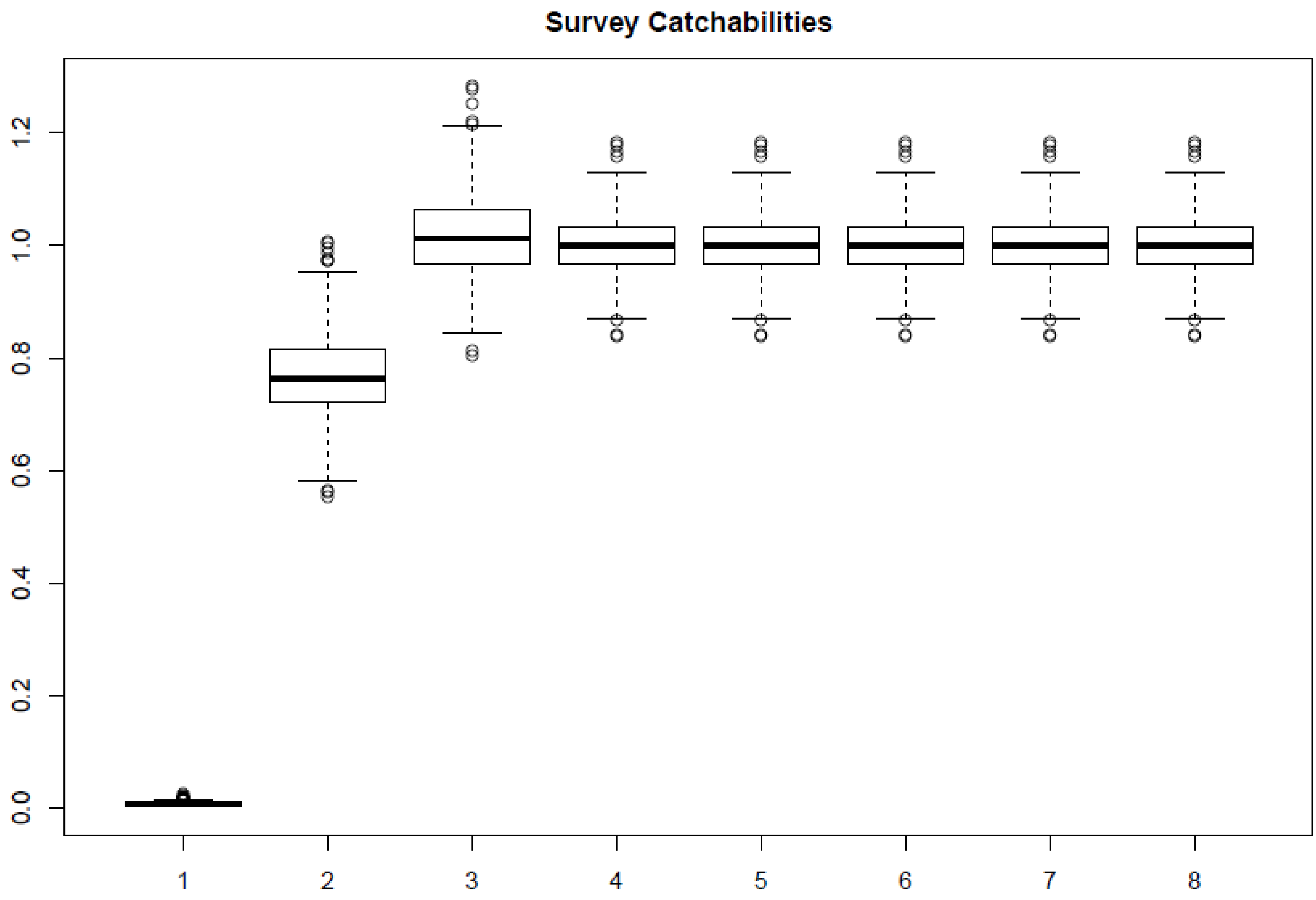

Fig. 22. EU survey catchabilities distribution

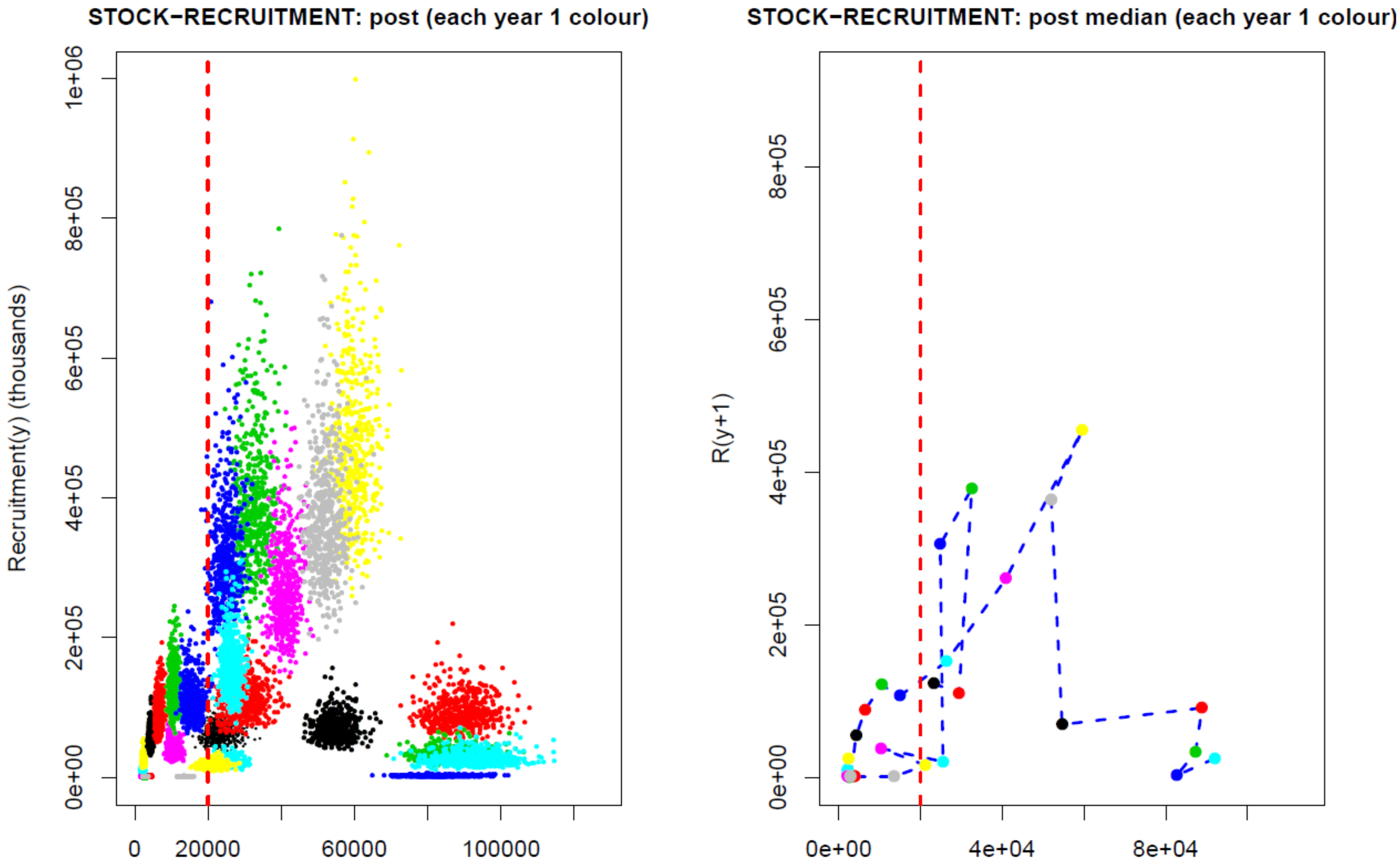

Fig. 23. Stock-Recruitment plots. A tentative value of B_{lim}=20000 is shown as the red vertical line.

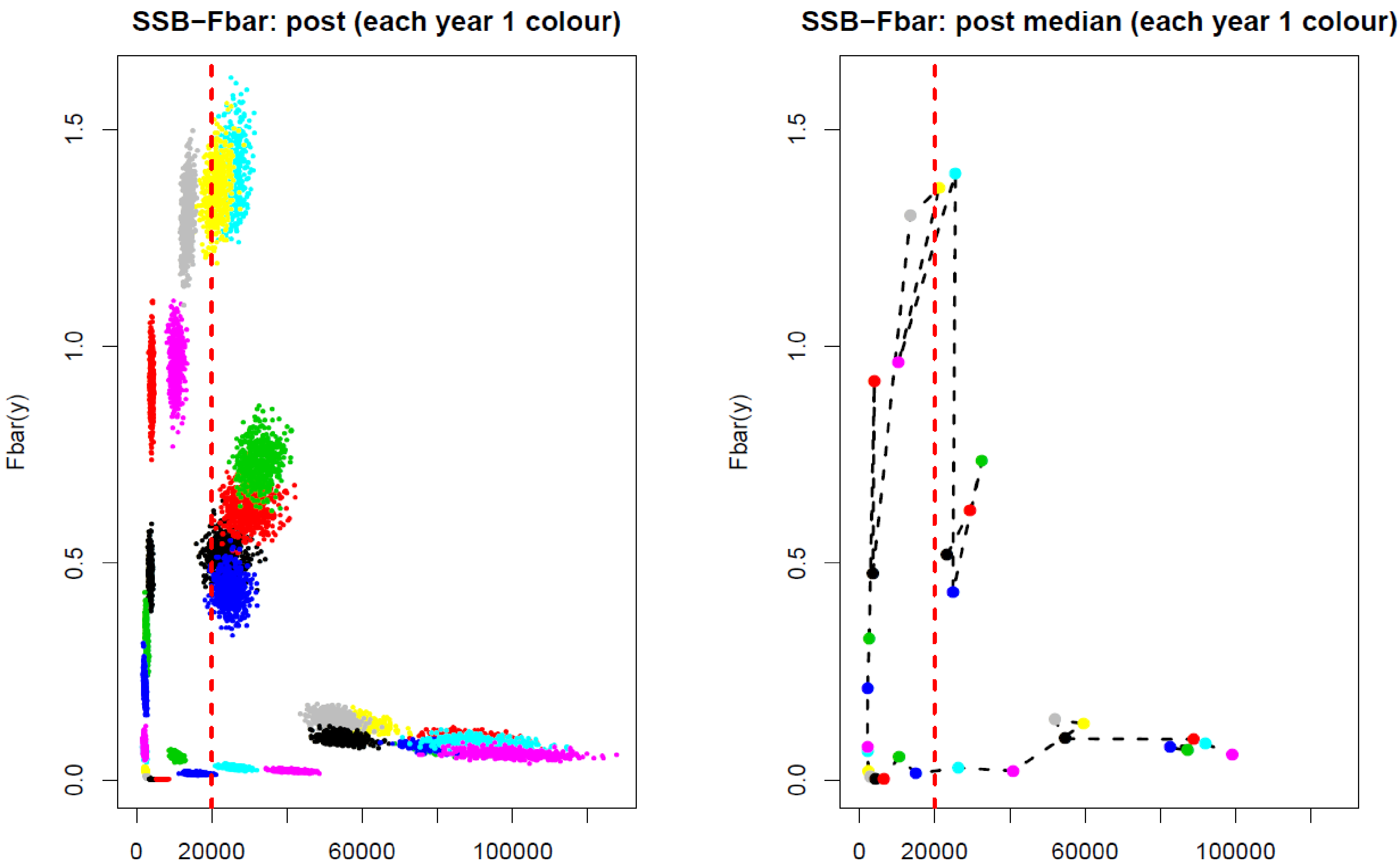

Fig. 24. F_{bar} versus SSB plots. A tentative value of B_{lim}=20000 is shown as the red vertical line.

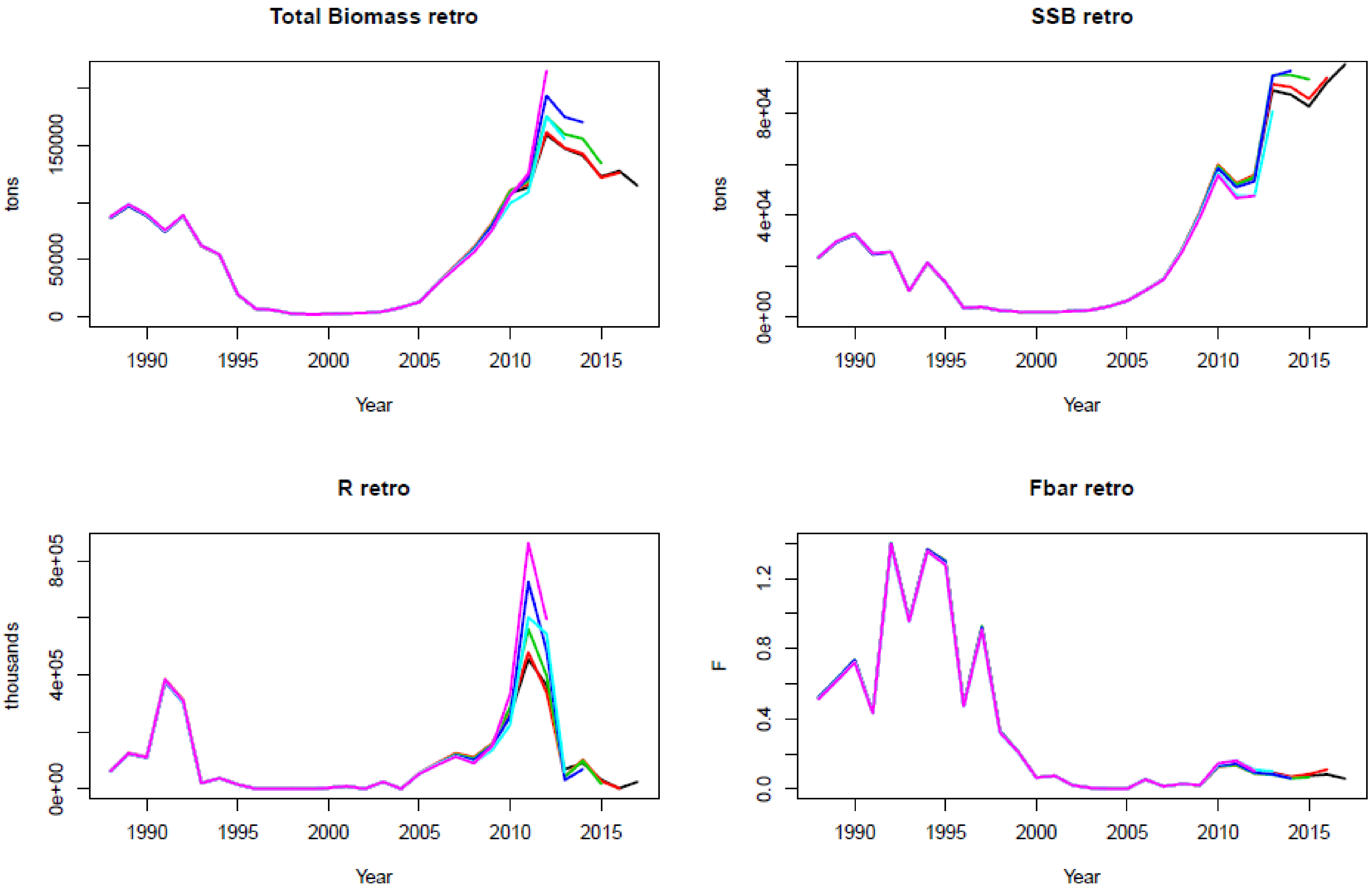

Fig. 25. Retrospective patterns.

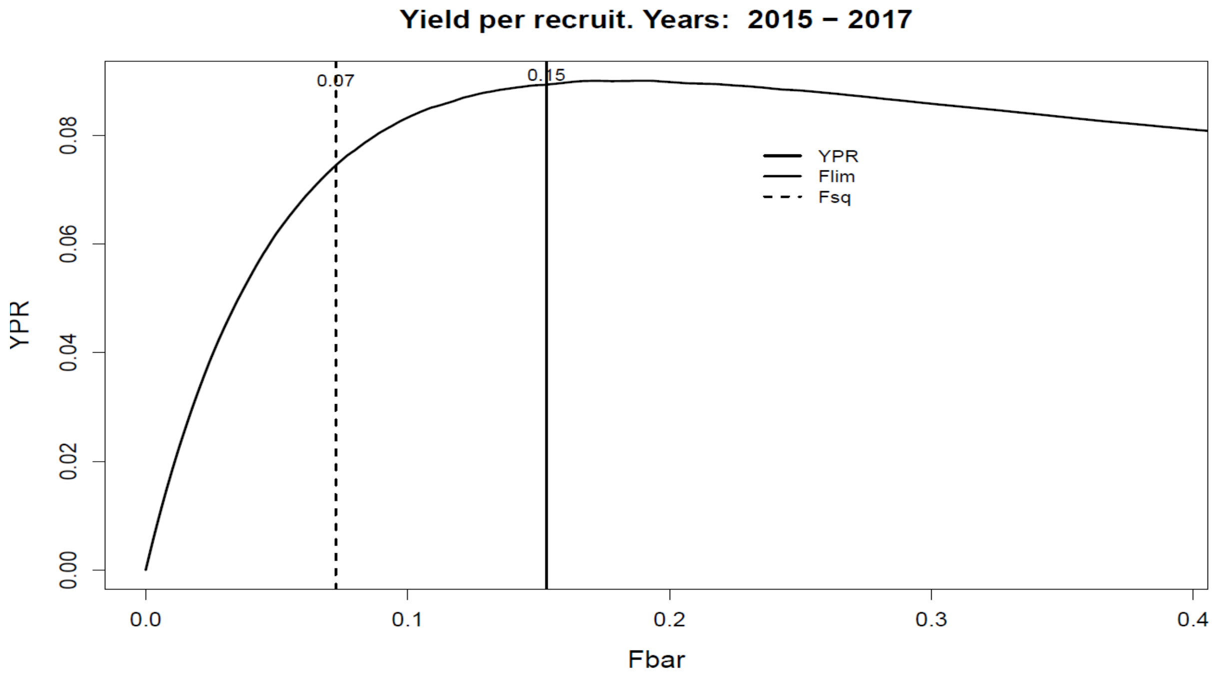

Fig. 26. Yield per Recruit (2015-2017) versus F_{bar}. The values of F_{lim} ($F_{30\%SPR}$) and $F_{statusquo}$ (mean F over 2015-2017) are indicated.

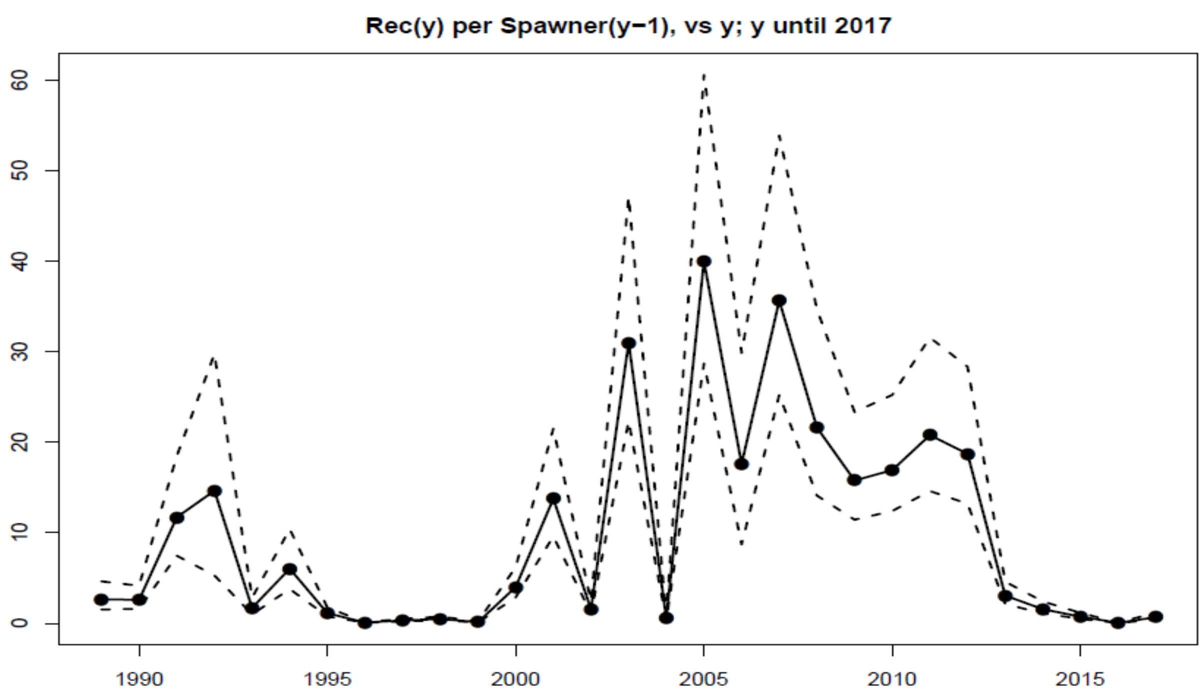

Fig. 27. Estimated recruits (age 1) per spawner.

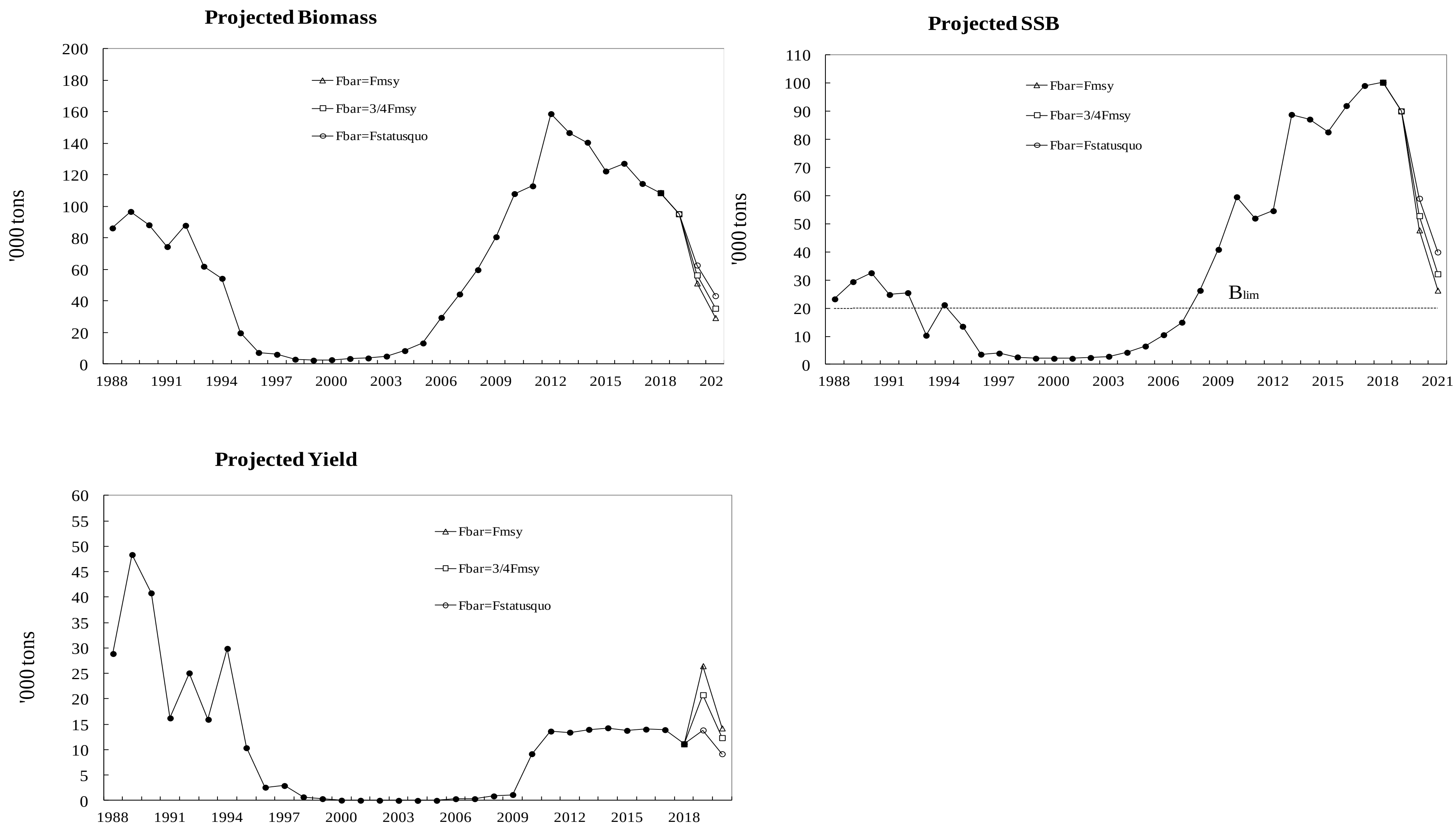

Fig. 28. Projections for total Biomass, SSB and Yield with different scenarios.

ANNEX I

The settings of the Bayesian SCAA model with ages *a* from 1 to A+ and years *y* from 1 (i.e. 1988) to Y (i.e. 2017) are:

1. **Recruits (age 1) each year**, N[y,1], for y=1,...,Y. The following prior is taken:

$$N[y,1] \sim LogN\,(\,median = medrec, CV = cvrec\,),$$

   - *medrec* and *cvrec* are some suitably chosen values.

2. **Numbers at age in the first year**, N[1,a], for a=2,...,A+. The following priors are taken:

$$N[1,a] \sim LogN\,(\,median = medrec \times e^{-\sum_{i=1}^{a-1}(M[1,i]+medF\,[i])}, CV = cvyear1\,) \text{ for } a=2,\ldots,A\text{-}1,$$

$$N[1,A+] \sim LogN\,(\,median = medrec \times \frac{e^{-\sum_{i=1}^{A-1}(M[1,i]+medF\,[i])}}{1-e^{-(M[1,A+]+medF\,[A+])}}, CV = cvyear1\,), \text{ for } a=A+,$$

   - *medF[a]*, a=1,…A+, and *cvyear1* are some suitably chosen values.

3. **Forward population each year and age**, N[y,a], for y=2,...,Y and a=2,...,A+. Standard exponential decay equations:

$$N[y,a] = N[y-1,a-1]\,e^{-Z[y-1,a-1]}, \text{ for } a=2,\ldots,A\text{-}1,$$

$$N[y,A+] = N[y-1,A-1]\,e^{-Z[y-1,A-1]} + N[y-1,A+]\,e^{-Z[y-1,A+]}, \text{ for } a=A+,$$

$$Z[y,a] = M[y,a] + F[y,a].$$

4. **Fishing mortality is modelled as** *F[y,a]=f[y]*rC[y,a]*, for y=1,…,Y and a=1,…,A+.

   It is assumed that *rC(y,A+) = rC(y,A-1)* and that *rC(y, a=aref) =1*, for a chosen reference age *aref*.

   The factors *f[y]* and *rC(y,a)* are modelled as follows:

   a. ln(*f[y]*) is modelled as an AR(1) process over the years, with autocorrelation parameter *rhof*. The median and CV of the marginal prior distribution of *f[y]* in each year are *medf* and *cvf*, respectively.

      - *rhof* is assigned a Uniform(0,1) prior distribution,
      - *medf* and *cvf* are some suitably chosen values

   b. For each age different from *aref* and A+, ln(*rC[y,a]*) is modelled as random walk over the years, independently from age to age.

      The distribution in the first assessment year (y=1) is:

$$rC[1,a] \sim LogN(median = medrC[a], CV = cvrC[a])$$

      - *medrC[a]* and *cvrC[a]* are some suitably chosen values.

      The distribution in subsequent years (y>1) is given by a random walk in log scale:

$$\ln(\,rC[y,a]\,) \sim N(mean = \ln(\,rC[y-1,a]\,)\,, CV = cvrCcond)$$

- *cvrCcond* is a suitable chosen value.

5. **Observation equation for annual commercial total catch in weight**, Cton[y], for y=1,...,Y:

$$Cton[y] \sim LogN\left(median = \sum_{a=1}^{A+} mu.C[y,a] \times wcatch[y,a], CV = cvCW\right),$$

$$mu.C[y,a] = N[y,a]\left(1 - e^{-Z[y,a]}\right)\frac{F[y,a]}{Z[y,a]}$$ is the standard Baranov catch equation,

- *cvCW* is some suitably chosen value.

6. **Observation equations for commercial catch numbers-at-age**, C[y,a], for each year y, excluding 2002 -2005, and age a=1,…,A+:

$$\ln(C[y,a]) \sim N(mean = \ln(mu.C[y,a]), CV = psi.C)$$

- *psi.C is some suitable value chosen*

7. **Observation equations for survey indices**, CPUE.EU[y,a], y=1,…,Y and a=1,…,A+:

$$\ln(CPUE.EU[y,a]) \sim N(mean = \ln(mu.CPUE.EU[y,a]), CV = psi.EU)$$

where

$$mu.CPUE.EU[y,a] = phi.EU[a]\left\{N[y,a]\,\frac{\exp(-alpha.EU * Z[y,a]) - \exp(-alpha.EU * Z[y,a])}{(beta.EU - alpha.EU) * Z[y,a]}\right\}^{gama.EU[a]}$$

,

- *alpha.EU=0.50* and *beta.EU=0.58* correspond to the timing of the survey (July),
- *psi.EU is some suitable value chosen*

<u>Prior on *phi.EU[a]*:</u>

$$\ln(phi.EU[a]) \sim N\left(mean = medlogphi, \frac{1}{variance} = taulogphi\right),$$

- *medlogphi* and *taulogphi* are some suitably chosen values,

<u>Prior on *gama.EU[a]*:</u>

For ages *a* in the set *adep*, *gama.EU[a]*= 1, whereas for other ages *a*:

$$gama.EU[a] \sim N\left(mean = medgama, \frac{1}{variance} = taugama\right)$$

- *medgama* and *taugama* are some suitably chosen values

8. **Natural Mortality** is assumed to be age-dependent but the same in all years, i.e. *M[y,a]=M[a]*, a=1,…,A+, with the following prior distribution by age:

$$\ln(M[a]) \sim N(mean = \ln(medM[a]), CV = cvM)$$

- *medM* and *cvM* are some suitably chosen values