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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 to perform the analysis. The STACFIS catch estimations and the Flemish Cap survey indices have been used to fit the model. $B_{lim}$, estimated as the SSB of 2007, gives a median of 15 271 t with the results of this assessment. Results indicate a general increase in SSB since 2005 to the highest value in 2017, decreasing sharply since then. SSB has been above $B_{lim}$ since 2008. Between 2013 and 2018 recruitment was at very low levels, being in 2016 and 2018 among the lowest of the series; as a consequence, 5-year projections indicate that total biomass will decrease during the projected years, while the SSB could increase under some scenarios in the final projected year. Depending on the projected scenario, probability of SSB being below $B_{lim}$ in 2022 and 2023 is very high (≥24%) or very low (≤10%). An increase in recruitment occurred in 2019, reaching the 2008 level.

## 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 *et al.*, 2019) 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 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. Between 1998 and 2008, almost coinciding with the fishing moratorium, yearly catches were below 1 000 tons, being lower than 100 tons from 2000 to 2005, mainly attributed to by-catches from other fisheries. Estimated commercial catches in 2006-2009 were between 339 and 1 161 tons, 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 following years assessments TACs for 2011-2019 between 9 280 and 17 500 tons were established. The STACFIS estimated catches for 2010-2019 were between 9 291 and 17 520 tons (Table 1A and Figure 1).

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 in the period 2003-2007. 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 with a Bayesian SCAA (statistical catch-at-age), that has been being used since then. Another important change introduced at the benchmark is the prior median 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 Bayesian SCAA model are presented here, including the updated input data until 2019.

## Material and Methods

### Data used

#### Commercial data

Total Catch

In 2019 there were catches of 3M cod from EU-Estonia, EU-Portugal, EU-Spain, Faroe Islands (Denmark), Japan, Norway, Russia and St Pierre and Miquelon (France) with a total amount of 17 520 tons from the WG-CESAG estimates (Table 1A, Figure 1).

In 2010 the fishery on this stock was reopened after the moratorium period between 1999 and 2009. Since then, STACFIS estimated catches were used for the stock assessment. To know more details, see González-Costas *et al.* (2018) and NAFO (2018b). Between 2010 and 2012, only trawler vessels were present in the fishery; since 2013, longliners from Faroes and Norway were incorporated to the direct fishery with a variable presence depending on the year. Since 2017, the Faroese fishery has been exclusively conducted by longliners. Since 2016, Norwegian vessels alternate both gears between years, going one year only with trawl and the next year only with longline. This makes that the proportion of trawlers and longliners is variable among the years, ranking since 2013 between 16% and 49% (Table 1B).

Length distributions

In 2019 length sampling of catch was conducted by EU-Estonia (SCS 20/06), EU-Portugal (SCS 20/09), EU-Spain (SCS 20/07), Faroe Islands (SCS 20/08) and Norway (Kjell, personal communication). Length frequency distributions from the commercial catch and from the EU survey (González-Troncoso *et al.*, 2020) are shown in Figure 2A.

EU-Estonia has measured 1479 individuals in a range of 35-126 cm, with mean in 62 cm and mode in 64 cm. The sample of EU-Portugal contains 6324 individuals measured within 36-96 cm, mean 57 cm and mode in the range 60-63 cm. EU-Spain has a 2297 individuals sample in a range of 38-130 with a mode in 64 cm and mean in 65 cm. Faroe Islands has catch only with longliners, measuring 4552 individuals with lengths between 39 and 135 cm. The mean and modal length are at 74 cm. For Norway, a mode in 58 and a mean in 63 cm over a range of 30-115 cm can be seen for a total of 1631 measured individuals. The mean length of the total commercial catch is at 62 cm and the mode at 60. The EU survey has a clear mode at 19-23 cm, following with two lower modes around 60 and 44 cm. The range is from 13 to 126 cm and the mean is at 44 cm.

It is remarkable the difference in the length distributions from 2017 with regards to the period 2010-2016 (Figure 2B). While between the reopening of the fishery and 2016 the bulk of the commercial length distribution was between 40 and 60 cm, in 2017 and 2018 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 and 2018 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 and in 2018 is at 63 cm, which represents a big change. In 2019 the mode and the mean decreased a little bit, being 60 and 62 cm respectively, but they are still higher than before 2016.

<u>Indices by age</u>

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, ALKs from the survey and from the Spanish commercial fleet were available, but the survey one was used for the same reason stated above. In 2018 and 2019, only the survey ALK was available, and it was used for both commercial and survey indices.

<u>Catch-at-age</u>

Catch-at-age in numbers is presented in Table 2. To get this numbers, the available length distributions for trawlers weighted to the total trawl catch, on one hand, and the length distribution for the longliners weighted to the total longliner catch, on the other hand, were added to get the total commercial length distribution, and age distribution was obtained by applying the trawl EU survey ALK to this total length distribution.

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 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 the period 2015-2019, ages 5 to 7 were the most abundant in the catches.

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. We can follow easily the 2009-2011 cohorts, reaching age 8+ in 2019. The catch of the cohorts from 2012 was very poor. As a consequence, since 2015 all the values of the ages less than 4 are negative. It is remarkable the big catch at age 6 in 2019, that corresponds to the 2013 cohort, that was the first of the weak cohorts, and that had never appeared before. Something similar can be seen in the 2011 cohort, that started with a good recruitment in 2012 but then disappeared until age 5, in 2016.

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

For 2019, mean weight-at-age has been computed using length-weight relationships from the commercial sampling. For this year, there are four commercial length-weight relationships available: EU-Estonia, EU-Portugal, EU-Spain and Faroes. All of them are presenting in Figure 4 besides the 2019 EU survey one. The EU-Spain relationship gives the highest weight for the higher lengths. The Portuguese relationship gives the smallest weight to the same length, and the behaviour is quite different as the rest, being more similar to the longliner Faroese one. The Estonian length-weight relationship was applied to the commercial data to calculate the mean weight-at-age in the catch, giving a status-quo vision.

Mean weight-at-age for 1988-2019 is showed in Table 3 and Figure 5. In the period 2007-2017 there is a general decrease in the trend of the mean-weight for the ages older than 2, especially since 2010. In 2018 and 2019 a slight increase with regards 2017 can be seen in all ages until 6 years old (included). It is remarkable the decrease of the mean weight in ages 7 and 8.

The SoP (sum over ages of the product of catch weight-at-age and numbers at age) for the commercial catch differs 1% from the estimated total catch in 2019.

**<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 of this stock, 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 1988-2019 are presented in González-Troncoso *et al.* (2020).

The survey abundance indices besides the total biomass are presented in Table 4. Figure 6 displays the estimated survey biomass and abundance indices over time. Biomass and abundance showed 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 pre-collapse years (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.*, 2020). Since 2012, taking out the 2014 and 2015 values, both biomass and abundance have decreased, due mainly to the failure of the recruitment. In 2019, the decrease in biomass is higher than in abundance, because an increase in the recruitment in the survey.

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. 2015-2018, especially 2016 recruitments, have failed. The 2015 cohort is the worst since the 2003 one.

Age 8+ in 2014-2019 presented a high value, which indicates the strength of the 2006-2010 cohorts. In 2019, a good signal of recruitment can be seen, being the best value since 2012, at the level of the 2006 recruitment, that allowed the recovery of the stock.

Mean weight-at-age

Results are showed in Table 5 and Figure 8. The 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. In 2018 and 2019 an increase with regards 2017 can be seen in all ages until 6 years old (included), being quite important in some of the ages, as age 3 (from 385 grams in 2017 to 776 gram in 2019). For age 8, a rather decrease occurs, being in 2019 the lowest of the time series.

Maturity at age

Maturity ogives are available from the EU survey for years 1990-1998, 2001-2006 and 2008-2019. 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.

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, being since then quite irregular for ages 5-6 and increasing for age 4.

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, being since then quite stable with ups and downs.

## Assessment methodology

A Bayesian SCAA model was applied to the data. Ages are from 1 to A+=8+ and years are from 1988 to 2019. 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 was 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, 2018a). 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 zeros observed in the survey abundance indices at age and those observed in the catch at age matrix for ages > 1 are treated as NAs.

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

**Catch data** for 32 years, from 1988 to 2019

Catch in tonnes in all years; Years with catch-at-age: 1988-2001, 2006-2019

**Tuning** with EU survey for 1988 to 2019

**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. Five years projections were made with three different scenarios, as later described, in order to see the possible evolution of the stock in the medium term. 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 2020 was calculated using the numbers estimated by the assessment at the beginning of 2020, applying the maturity ogive and mean weight at age in stock from 2019.

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, and in 2019 the biomass is at the level of the beginning of the series.

The results for SSB indicate that there was a substantial increase in SSB from 2007. After a small decrease in 2011 and 2012, the SSB between 2013 and 2017 was stable. A substantial decrease since 2018 is displayed, mainly in 2020, although the SSB is still at the highest level of the historical series (starting in 1988) and above $B_{lim}$. The high values of SSB in the period 2013-2017 were 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. In 2019 an increase can be seen, reaching the level of 2008 recruitment.

$F_{bar}$ (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 and it was below $F_{lim}$. Since then until 2018, fishing mortalities slightly decreased. A considerable increase occurred in 2019, reaching the level of the pre-collapse period and being above $F_{lim}$. Table 8 and Figure 11 provide more detailed information on the estimated F-at-age values. Since 2010 the F-at-age has increased for all the ages, and with the age. In 2019, high F values at ages 4-6 can be seen. Figure 12 shows the PR along the years, calculated as the ratio of fishing mortalities to $F_{bar}$. Figure 13A shows the median PR for the years since the reopening of the fishery (2010-2019) and Figure 13B the mean of the three last years (2017-2019) PR *versus* the 2019 PR. In general, except 2018 and 2019 PRs, all the years have a similar and increasing PR. In the case of the 2018 and 2019 PRs, age 6 was the most caught age. The difference between both years is that in 2018 ages 7 and 8+ are the second most caught, being age 4 in the case of 2019. The mean PRs of the last three years is slightly different to the 2019 one, mostly disagreeing in the last two ages.

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 2019, the level of *f* is similar to that in 1999. 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 until 2009, being variable since then, reaching in 2019 a value comparable to the first years of the observed period. For ages 6 and 7 an increasing trend can be observed since 2006, broken for age 7 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 between 2012 and 2018 abundance decreased in a more extent than biomass. In 2019, the decrease in biomass continues, but an increase in the abundance can be seen. Both total biomass and abundance are in 2019 close to the mean values of the series.

Estimates of stock abundance at age for 1988-2019 are presented in Table 9 and Figure 16. It can be seen a general increasing trend in the total number of matures until 2013, due probably to the decreasing in the age of maturity. Since then it has decreased. The maximum numbers-at-age since 2005 in all the ages correspond to the 2010 cohort (reaching 7 years old in 2017 and being incorporated to the 8+ group in 2018 and 2019), followed by the 2011 cohort (reaching 8 years old in 2019). Since those cohorts, all the numbers at age have decreased (ages 1 to 6). It is remarkable the big value of ages 6+ in the 2014-2016, which is the driver to the huge increase in the SSB in those years. The failure in recruitment since 2013 gave low numbers in ages 2-5 in the most years, which led to the decrease in the SSB.

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 seem 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 the XSA assessments prior to 2017 (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 stock-recruit scatter plot can be seen in Figure 23. During the January 2019 June meeting regarding the 3M cod MSE, the meeting agreed to use the 2007 SSB as $B_{lim}$, as this is the highest SSB value of the three years (2005-2007) in which good recruitment leading to stock recovery was observed in the past. The highest value, rather than the mean of the three, was chosen to give a degree of security (NAFO, 2019).

In this way, for the present assessment 1000 values of $B_{lim}$, one for each iteration, are considered, with a median value of 15 271 tons, and an 80% confidence interval between 13 551 and 17 611 tons (Table 7). This value is displayed in Figure 23, showing that this value is rather consistent. SSB is well above $B_{lim}$ in recent years.

Figure 24 shows the SSB-$F_{bar}$ scatter plot. $F_{lim}$ for this stock was estimated based on $F_{30\%SPR}$ calculated with the 2017-2019 data as 0.191. 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 2017-2019 as well as the value of $F_{lim}$ and $F_{statusquo}$ (defining the latter as the mean fishing mortality over 2017-2019).

**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. Between 2007 and 2018 a decreasing trend can be seen, reaching since 2013 very low values. The 2019 value is the highest since 2013, although it is much lower than those between 2005 and 2012.

**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 2020 to 2024 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 2020:** estimated from the assessment.

**Recruitments for 2020-2023:** Recruits per spawner were drawn randomly from 2016-2018. The 2019 value of recruits per spawner was omitted due to uncertainty in estimating the recruitment.

**Maturity ogive for 2020-2023:** Mean of the last three years (2017-2019) maturity ogive.

**Natural mortality for 2020-2023:** Natural mortality from the 2019 assessment results.

**Weight-at-age in stock and weight-at-age in catch for 2020-2023:** Mean of the last three years (2017-2019) weight-at-age.

**PR at age for 2020-2023:** Mean of the last three years (2017-2019) PRs.

**$F_{bar}$(ages 3-5):** Four scenarios were considered:
(*Scenario 1*) $F_{bar}$=3/4$F_{lim}$ (median value = 0.143).
(*Scenario 2*) $F_{bar}$=0 (no catch).
(*Scenario 3*) Catch in 2021-2023=1000 tons.
(*Scenario 4*) Catch in 2021-2023=3000 tons.

All scenarios assumed that the Yield for 2020 is the established TAC (8 531 t).

Results for the four options are presented in Tables 11-18 and Figure 28. They indicate that under all scenarios, total biomass during the projected years will decrease sharply, while the SSB will increase slightly in 2023 and 2024 with the F=0 and the Catch=1000 tons scenarios. The probability of SSB being below $B_{lim}$ in 2022 and 2023 is very high (≥24%) in the scenarios with $F_{bar}$=3/4$F_{lim}$ and Catch=3000 tons, being very low (≤10%) in the rest of the cases. The probability of SSB in 2024 being above that in 2020 is <1%.

Under all scenarios, the probability of F exceeding $F_{lim}$ is less than or equal to 6% in 2022 and 2023, and less or equal to 11% in 2024.

Under 3/4$F_{lim}$, the projected Yield has a decreasing trend in the projected years (2021-2023).

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**Table 1A.** Total commercial cod catch in Division 3M. Reported nominal catches since 1960 and estimated total catch from 1988 to 2019 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 |
| 2018 | 11481 | 4690 | 705 | 726 | | 2972 | | | 1043 | | | 1040 | 11176 |
| 2019 | 17520 | 6319 | 1132 | 2296 | 13 | | | | 1643 | | | 1607 | 13010 |

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

**Table 1B.** Trawlers and longliners catches since the reopening of the fishery in 2010

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| Total catch | 9192 | 9794 | 9003 | 13985 | 14290 | 13785 | 14023 | 13928 | 6447 | 17520 |
| Total trawler | 9192 | 9794 | 9003 | 10095 | 12034 | 10125 | 10208 | 10762 | 4210 | 12968 |
| Total longliner | 0 | 0 | 0 | 3889 | 2256 | 3659 | 3814 | 3166 | 3166 | 4552 |
| % longliner | 0 | 0 | 0 | 28 | 16 | 27 | 27 | 23 | 49 | 26 |

**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 | 1 | 2 | 73 | 407 | 256 | 1954 | 1553 | 961 |
| 2018 | 0 | 77 | 33 | 206 | 800 | 408 | 1392 | 1357 |
| 2019 | 0 | 2 | 676 | 191 | 1752 | 2656 | 188 | 2044 |

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

| | 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 | 0.097 | 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 | 0.082 | 0.191 | 0.550 | 0.787 | 1.237 | 2.157 | 3.439 | 6.719 |
| 2017 | 0.078 | 0.192 | 0.399 | 0.813 | 1.348 | 1.949 | 2.784 | 5.080 |
| 2018 | 0.078 | 0.313 | 0.561 | 0.942 | 1.571 | 1.974 | 2.550 | 4.166 |
| 2019 | 0.078 | 0.365 | 0.802 | 1.158 | 1.528 | 1.940 | 2.150 | 4.056 |

**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 | 17 | 18 | 19 | Total Abundance | Total Biomass |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 4868 | 79905 | 49496 | 13448 | 1457 | 211 | 225 | 72 | 0 | 0 | 0 | 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 | 0 | 0 | 0 | 198363 | 114050 |
| 1990 | 2303 | 12348 | 5121 | 16952 | 15834 | 4492 | 340 | 146 | 77 | 25 | 0 | 0 | 0 | 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 | 0 | 0 | 0 | 183181 | 40248 |
| 1992 | 71533 | 41923 | 5578 | 2385 | 385 | 1398 | 244 | 14 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 123468 | 26719 |
| 1993 | 4075 | 138357 | 31096 | 1099 | 1317 | 173 | 489 | 87 | 0 | 0 | 0 | 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 | 0 | 0 | 0 | 40319 | 26463 |
| 1995 | 1425 | 11901 | 1338 | 3892 | 928 | 33 | 23 | 0 | 21 | 5 | 0 | 0 | 0 | 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 | 0 | 0 | 0 | 13320 | 9013 |
| 1997 | 37 | 150 | 3478 | 4803 | 391 | 952 | 21 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9837 | 9966 |
| 1998 | 23 | 83 | 95 | 1256 | 1572 | 78 | 146 | 0 | 6 | 0 | 0 | 0 | 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 | 0 | 0 | 0 | 1507 | 2854 |
| 2000 | 178 | 16 | 327 | 198 | 96 | 446 | 172 | 11 | 17 | 0 | 0 | 5 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 1470 | 3062 |
| 2001 | 473 | 1990 | 13 | 122 | 79 | 15 | 142 | 99 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2951 | 2695 |
| 2002 | 0 | 1330 | 641 | 29 | 70 | 33 | 26 | 96 | 30 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2261 | 2496 |
| 2003 | 684 | 54 | 628 | 134 | 22 | 42 | 7 | 8 | 39 | 24 | 0 | 0 | 0 | 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 | 0 | 0 | 0 | 4226 | 4071 |
| 2005 | 8069 | 16 | 1118 | 78 | 709 | 136 | | 17 | 16 | 8 | 0 | 0 | 0 | 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 | 0 | 0 | 0 | 25965 | 12505 |
| 2007 | 3917 | 11620 | 5022 | 21 | 1138 | 58 | 425 | 74 | 13 | 20 | 0 | 0 | 0 | 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 | 0 | 0 | 0 | 41124 | 43676 |
| 2009 | 5139 | 7479 | 16150 | 14310 | 4154 | 26 | 1091 | 0 | 335 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 48697 | 75228 |
| 2010 | 66370 | 27689 | 8654 | 7633 | 4911 | 1780 | 8 | 442 | 46 | 251 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 117810 | 69295 |
| 2011 | 347674 | 142999 | 16993 | 6309 | 7739 | 3089 | 1191 | 0 | 215 | 0 | 89 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 526300 | 106151 |
| 2012 | 103494 | 128087 | 10942 | 11721 | 4967 | 4781 | 1630 | 832 | 24 | 93 | 30 | 101 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 266720 | 113227 |
| 2013 | 5525 | 67521 | 32339 | 4776 | 4185 | 2782 | 1807 | 963 | 278 | 40 | 29 | 32 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 120280 | 72289 |
| 2014 | 7282 | 2372 | 48564 | 43168 | 17861 | 6842 | 3447 | 1931 | 1551 | 600 | 79 | 54 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 133760 | 159939 |
| 2015 | 1141 | 12952 | 7250 | 25614 | 14107 | 21854 | 3434 | 1426 | 762 | 366 | 194 | 14 | 21 | 21 | 0 | 7 | 0 | 0 | 0 | 89164 | 114807 |
| 2016 | 56 | 4485 | 14356 | 2230 | 14540 | 12375 | 4814 | 1157 | 522 | 303 | 145 | 28 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 55032 | 80583 |
| 2017 | 2010 | 314 | 6516 | 16645 | 3267 | 15842 | 8519 | 2765 | 789 | 345 | 137 | 53 | 27 | 6 | 7 | 0 | 0 | 0 | 0 | 57241 | 89414 |
| 2018 | 366 | 4308 | 309 | 6082 | 12996 | 3447 | 7090 | 3933 | 1046 | 306 | 165 | 59 | 10 | 0 | | 11 | 8 | 0 | 0 | 40139 | 75795 |
| 2019 | 11896 | 1737 | 5213 | 295 | 3252 | 5733 | 417 | 1495 | 1956 | 822 | 122 | 33 | 14 | 7 | 0 | 0 | 0 | 0 | 8 | 33002 | 42460 |

**Table 5.** Weight-at-age (kg) in stock.

| | 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 | 0.071 | 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 | 0.044 | 0.205 | 0.385 | 0.709 | 1.204 | 1.831 | 2.573 | 5.111 |
| 2018 | 0.049 | 0.277 | 0.656 | 0.981 | 1.497 | 1.937 | 2.646 | 4.493 |
| 2019 | 0.076 | 0.278 | 0.776 | 1.275 | 1.733 | 2.151 | 2.389 | 4.043 |

**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 | 5.385 |
| 1989 | 0.053 | 0.097 | 0.172 | 0.286 | 0.438 | 0.599 | 0.742 | 0.878 | 5.385 |
| 1990 | 0.053 | 0.097 | 0.172 | 0.286 | 0.438 | 0.599 | 0.742 | 0.878 | 5.385 |
| 1991 | 0.019 | 0.046 | 0.110 | 0.246 | 0.461 | 0.673 | 0.829 | 0.939 | 5.179 |
| 1992 | 0.002 | 0.011 | 0.046 | 0.181 | 0.499 | 0.818 | 0.953 | 0.993 | 5.004 |
| 1993 | 0.001 | 0.006 | 0.047 | 0.280 | 0.750 | 0.959 | 0.995 | 1.000 | 4.467 |
| 1994 | 0.000 | 0.001 | 0.049 | 0.655 | 0.986 | 1.000 | 1.000 | 1.000 | 3.823 |
| 1995 | 0.000 | 0.000 | 0.005 | 0.801 | 1.000 | 1.000 | 1.000 | 1.000 | 3.788 |
| 1996 | 0.000 | 0.000 | 0.028 | 0.666 | 0.993 | 1.000 | 1.000 | 1.000 | 3.839 |
| 1997 | 0.000 | 0.007 | 0.109 | 0.670 | 0.972 | 0.998 | 1.000 | 1.000 | 3.749 |
| 1998 | 0.000 | 0.001 | 0.087 | 0.872 | 0.998 | 1.000 | 1.000 | 1.000 | 3.552 |
| 1999 | 0.000 | 0.001 | 0.118 | 0.898 | 0.999 | 1.000 | 1.000 | 1.000 | 3.477 |
| 2000 | 0.000 | 0.001 | 0.146 | 0.959 | 1.000 | 1.000 | 1.000 | 1.000 | 3.382 |
| 2001 | 0.000 | 0.000 | 0.271 | 0.997 | 1.000 | 1.000 | 1.000 | 1.000 | 3.151 |
| 2002 | 0.000 | 0.010 | 0.633 | 0.997 | 1.000 | 1.000 | 1.000 | 1.000 | 2.896 |
| 2003 | 0.000 | 0.022 | 0.515 | 0.979 | 1.000 | 1.000 | 1.000 | 1.000 | 2.985 |
| 2004 | 0.000 | 0.000 | 0.092 | 0.966 | 1.000 | 1.000 | 1.000 | 1.000 | 3.408 |
| 2005 | 0.038 | 0.165 | 0.500 | 0.830 | 0.959 | 0.991 | 0.998 | 1.000 | 2.999 |
| 2006 | 0.000 | 0.013 | 0.354 | 0.959 | 0.999 | 1.000 | 1.000 | 1.000 | 3.160 |
| 2007 | 0.000 | 0.012 | 0.262 | 0.916 | 0.997 | 1.000 | 1.000 | 1.000 | 3.297 |
| 2008 | 0.000 | 0.012 | 0.232 | 0.883 | 0.995 | 1.000 | 1.000 | 1.000 | 3.373 |
| 2009 | 0.000 | 0.010 | 0.181 | 0.829 | 0.991 | 1.000 | 1.000 | 1.000 | 3.489 |
| 2010 | 0.000 | 0.009 | 0.164 | 0.810 | 0.989 | 1.000 | 1.000 | 1.000 | 3.533 |
| 2011 | 0.001 | 0.008 | 0.071 | 0.424 | 0.877 | 0.986 | 0.999 | 1.000 | 4.136 |
| 2012 | 0.000 | 0.000 | 0.016 | 0.572 | 0.991 | 1.000 | 1.000 | 1.000 | 3.935 |
| 2013 | 0.003 | 0.035 | 0.283 | 0.802 | 0.977 | 0.998 | 1.000 | 1.000 | 3.400 |
| 2014 | 0.000 | 0.003 | 0.044 | 0.397 | 0.901 | 0.992 | 0.999 | 1.000 | 4.158 |
| 2015 | 0.000 | 0.000 | 0.004 | 0.113 | 0.790 | 0.991 | 1.000 | 1.000 | 4.605 |
| 2016 | 0.000 | 0.000 | 0.004 | 0.046 | 0.388 | 0.892 | 0.991 | 1.000 | 5.177 |
| 2017 | 0.000 | 0.000 | 0.000 | 0.017 | 0.829 | 0.999 | 1.000 | 1.000 | 4.720 |
| 2018 | 0.000 | 0.001 | 0.007 | 0.067 | 0.425 | 0.880 | 0.986 | 0.999 | 5.132 |
| 2019 | 0.000 | 0.000 | 0.005 | 0.083 | 0.615 | 0.966 | 0.998 | 1.000 | 4.837 |

**Table 7.** Posterior results: total biomass, SSB, recruitment (tons) and $F_{bar}$.

| | B quantiles | | | SSB quantiles | | | R quantiles | | | $F_{bar}$ quantiles | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **50%** | **10%** | **90%** | **50%** | **10%** | **90%** | **50%** | **10%** | **90%** | **50%** | **10%** | **90%** |
| **1988** | 86443 | 82004 | 91502 | 23435 | 19727 | 27997 | 64382 | 49253 | 86085 | 0.517 | 0.474 | 0.561 |
| **1989** | 97515 | 92315 | 102747 | 29532 | 25038 | 34790 | 127697 | 98008 | 168359 | 0.622 | 0.578 | 0.668 |
| **1990** | 89038 | 84266 | 93980 | 32607 | 28763 | 36947 | 114236 | 87568 | 151604 | 0.728 | 0.680 | 0.782 |
| **1991** | 75706 | 70116 | 83578 | 24938 | 22141 | 28362 | 387660 | 301538 | 519474 | 0.436 | 0.397 | 0.478 |
| **1992** | 88637 | 82499 | 96603 | 25570 | 23010 | 28499 | 314293 | 239538 | 417466 | 1.403 | 1.305 | 1.495 |
| **1993** | 62092 | 58272 | 66832 | 10372 | 9227 | 11843 | 21008 | 16242 | 27632 | 0.959 | 0.894 | 1.031 |
| **1994** | 54684 | 51318 | 58211 | 21299 | 18912 | 24047 | 38722 | 30268 | 50820 | 1.369 | 1.294 | 1.443 |
| **1995** | 19849 | 18715 | 21110 | 13574 | 12568 | 14630 | 16529 | 12768 | 21924 | 1.297 | 1.214 | 1.377 |
| **1996** | 7339 | 6944 | 7747 | 3613 | 3305 | 3936 | 1013 | 780 | 1351 | 0.475 | 0.435 | 0.518 |
| **1997** | 6215 | 5867 | 6573 | 3995 | 3694 | 4302 | 893 | 684 | 1185 | 0.916 | 0.840 | 0.996 |
| **1998** | 3085 | 2847 | 3376 | 2668 | 2450 | 2927 | 1505 | 1129 | 1997 | 0.323 | 0.285 | 0.364 |
| **1999** | 2491 | 2225 | 2783 | 2218 | 1968 | 2511 | 222 | 168 | 304 | 0.208 | 0.18 | 0.241 |
| **2000** | 2779 | 2470 | 3137 | 2142 | 1883 | 2456 | 4186 | 3174 | 5589 | 0.064 | 0.054 | 0.075 |
| **2001** | 3517 | 3140 | 3972 | 2121 | 1890 | 2399 | 9837 | 7560 | 13276 | 0.075 | 0.061 | 0.094 |
| **2002** | 3799 | 3455 | 4201 | 2406 | 2165 | 2676 | 941 | 709 | 1256 | 0.020 | 0.017 | 0.024 |
| **2003** | 5080 | 4551 | 5734 | 2858 | 2600 | 3148 | 26104 | 20067 | 34451 | 0.006 | 0.005 | 0.007 |
| **2004** | 8647 | 7837 | 9639 | 4313 | 3927 | 4736 | 782 | 607 | 1039 | 0.002 | 0.002 | 0.002 |
| **2005** | 13610 | 12156 | 15436 | 6550 | 5884 | 7393 | 57351 | 44040 | 75720 | 0.002 | 0.002 | 0.002 |
| **2006** | 30239 | 27003 | 34826 | 10685 | 9801 | 11737 | 92470 | 71884 | 123731 | 0.053 | 0.046 | 0.061 |
| **2007** | 45198 | 41106 | 50169 | 15271 | 13551 | 17611 | 124907 | 96600 | 166591 | 0.014 | 0.013 | 0.016 |
| **2008** | 60970 | 56042 | 66981 | 26720 | 24690 | 28938 | 112222 | 84915 | 146288 | 0.027 | 0.024 | 0.031 |
| **2009** | 82210 | 76031 | 89814 | 41661 | 38614 | 44958 | 157699 | 122556 | 210698 | 0.020 | 0.018 | 0.023 |
| **2010** | 110805 | 102528 | 120266 | 60689 | 55915 | 65978 | 279370 | 214102 | 369261 | 0.127 | 0.113 | 0.141 |
| **2011** | 114435 | 106207 | 124198 | 53173 | 48874 | 57388 | 448234 | 339592 | 584405 | 0.136 | 0.122 | 0.152 |
| **2012** | 157532 | 143841 | 174315 | 55602 | 51280 | 60506 | 353125 | 269933 | 466687 | 0.092 | 0.082 | 0.104 |
| **2013** | 144393 | 133711 | 155692 | 89851 | 82769 | 97786 | 49710 | 37771 | 66127 | 0.093 | 0.082 | 0.105 |
| **2014** | 140542 | 129967 | 151786 | 87884 | 80074 | 95471 | 134083 | 103811 | 178036 | 0.071 | 0.063 | 0.082 |
| **2015** | 121196 | 112101 | 130516 | 81973 | 74395 | 89855 | 43591 | 33496 | 59287 | 0.081 | 0.071 | 0.092 |
| **2016** | 124576 | 114785 | 135335 | 89152 | 80704 | 98448 | 4184 | 3126 | 5549 | 0.088 | 0.077 | 0.101 |
| **2017** | 104070 | 95380 | 113616 | 90145 | 81710 | 98923 | 52636 | 38910 | 70033 | 0.058 | 0.050 | 0.066 |
| **2018** | 94605 | 85559 | 103382 | 78010 | 70284 | 86387 | 5210 | 3761 | 7427 | 0.099 | 0.086 | 0.112 |
| **2019** | 80172 | 71765 | 88531 | 62397 | 55192 | 69233 | 115337 | 78662 | 173384 | 0.289 | 0.246 | 0.344 |

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

| Year | F at age 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8+ |
|---|---|---|---|---|---|---|---|---|
| **1988** | 0.000 | 0.018 | 0.332 | 0.584 | 0.628 | 0.647 | 0.780 | 0.780 |
| **1989** | 0.000 | 0.011 | 0.355 | 0.791 | 0.715 | 0.782 | 0.856 | 0.856 |
| **1990** | 0.000 | 0.018 | 0.378 | 0.905 | 0.898 | 1.220 | 1.031 | 1.031 |
| **1991** | 0.000 | 0.023 | 0.295 | 0.471 | 0.536 | 0.561 | 0.662 | 0.662 |
| **1992** | 0.000 | 0.140 | 0.978 | 1.471 | 1.753 | 1.421 | 1.970 | 1.970 |
| **1993** | 0.000 | 0.084 | 0.666 | 1.131 | 1.070 | 1.523 | 0.857 | 0.857 |
| **1994** | 0.000 | 0.188 | 0.979 | 1.745 | 1.379 | 1.333 | 0.988 | 0.988 |
| **1995** | 0.000 | 0.178 | 0.533 | 1.497 | 1.861 | 2.296 | 2.162 | 2.162 |
| **1996** | 0.000 | 0.046 | 0.241 | 0.491 | 0.688 | 0.910 | 0.819 | 0.819 |
| **1997** | 0.000 | 0.107 | 0.560 | 0.829 | 1.353 | 2.003 | 1.830 | 1.830 |
| **1998** | 0.000 | 0.041 | 0.192 | 0.316 | 0.453 | 0.534 | 0.393 | 0.393 |
| **1999** | 0.000 | 0.023 | 0.221 | 0.179 | 0.224 | 0.222 | 0.080 | 0.080 |
| **2000** | 0.000 | 0.005 | 0.124 | 0.026 | 0.042 | 0.032 | 0.010 | 0.010 |
| **2001** | 0.000 | 0.007 | 0.136 | 0.036 | 0.053 | 0.040 | 0.013 | 0.013 |
| **2002** | 0.000 | 0.002 | 0.034 | 0.010 | 0.015 | 0.011 | 0.004 | 0.004 |
| **2003** | 0.000 | 0.000 | 0.010 | 0.003 | 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 | 0.074 | 0.038 | 0.046 | 0.032 | 0.028 | 0.028 |
| **2007** | 0.000 | 0.000 | 0.010 | 0.015 | 0.018 | 0.017 | 0.023 | 0.023 |
| **2008** | 0.000 | 0.002 | 0.014 | 0.030 | 0.039 | 0.036 | 0.030 | 0.030 |
| **2009** | 0.000 | 0.001 | 0.007 | 0.025 | 0.029 | 0.029 | 0.033 | 0.033 |
| **2010** | 0.000 | 0.011 | 0.068 | 0.129 | 0.182 | 0.192 | 0.210 | 0.210 |
| **2011** | 0.000 | 0.010 | 0.086 | 0.110 | 0.211 | 0.275 | 0.367 | 0.367 |
| **2012** | 0.000 | 0.006 | 0.058 | 0.074 | 0.144 | 0.195 | 0.286 | 0.286 |
| **2013** | 0.000 | 0.006 | 0.063 | 0.074 | 0.142 | 0.205 | 0.277 | 0.277 |
| **2014** | 0.000 | 0.003 | 0.033 | 0.083 | 0.097 | 0.163 | 0.224 | 0.224 |
| **2015** | 0.000 | 0.003 | 0.049 | 0.083 | 0.110 | 0.190 | 0.223 | 0.223 |
| **2016** | 0.000 | 0.004 | 0.046 | 0.106 | 0.113 | 0.138 | 0.212 | 0.212 |
| **2017** | 0.000 | 0.003 | 0.026 | 0.057 | 0.089 | 0.150 | 0.181 | 0.181 |
| **2018** | 0.000 | 0.004 | 0.054 | 0.093 | 0.147 | 0.271 | 0.186 | 0.186 |
| **2019** | 0.000 | 0.004 | 0.127 | 0.377 | 0.362 | 0.662 | 0.322 | 0.322 |

**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** | 64382 | 144614 | 98165 | 30684 | 4373 | 970 | 708 | 283 | 344179 | 46451 |
| **1989** | 127697 | 16111 | 77246 | 48862 | 13091 | 1776 | 346 | 325 | 285452 | 42968 |
| **1990** | 114236 | 31996 | 8623 | 37444 | 16936 | 4872 | 555 | 199 | 214861 | 32239 |
| **1991** | 387660 | 28634 | 17066 | 4092 | 11594 | 5252 | 983 | 190 | 455470 | 21850 |
| **1992** | 314293 | 97117 | 15121 | 8774 | 1954 | 5138 | 2052 | 430 | 444879 | 11658 |
| **1993** | 21008 | 79025 | 45438 | 3940 | 1533 | 258 | 853 | 245 | 152300 | 6261 |
| **1994** | 38722 | 5256 | 39082 | 16197 | 968 | 398 | 38 | 329 | 100989 | 14220 |
| **1995** | 16529 | 9780 | 2334 | 10231 | 2190 | 186 | 72 | 93 | 41415 | 10716 |
| **1996** | 1013 | 4113 | 4389 | 950 | 1753 | 258 | 13 | 13 | 12502 | 2779 |
| **1997** | 893 | 254 | 2126 | 2396 | 447 | 666 | 70 | 8 | 6862 | 3009 |
| **1998** | 1505 | 225 | 123 | 836 | 796 | 88 | 61 | 9 | 3643 | 1691 |
| **1999** | 222 | 375 | 115 | 70 | 469 | 383 | 35 | 34 | 1704 | 998 |
| **2000** | 4186 | 56 | 197 | 64 | 45 | 286 | 209 | 45 | 5087 | 673 |
| **2001** | 9837 | 1044 | 30 | 121 | 48 | 33 | 189 | 180 | 11481 | 576 |
| **2002** | 941 | 2475 | 562 | 18 | 89 | 34 | 22 | 255 | 4397 | 796 |
| **2003** | 26104 | 235 | 1331 | 375 | 14 | 67 | 23 | 188 | 28338 | 1351 |
| **2004** | 782 | 6518 | 127 | 917 | 287 | 10 | 46 | 145 | 8832 | 1381 |
| **2005** | 57351 | 196 | 3506 | 88 | 702 | 218 | 7 | 131 | 62200 | 5082 |
| **2006** | 92470 | 14367 | 106 | 2417 | 67 | 535 | 149 | 94 | 110206 | 3411 |
| **2007** | 124907 | 23240 | 7719 | 68 | 1790 | 49 | 353 | 167 | 158294 | 4816 |
| **2008** | 112222 | 31307 | 12582 | 5313 | 52 | 1340 | 33 | 360 | 163208 | 9795 |
| **2009** | 157699 | 27789 | 16880 | 8573 | 3945 | 38 | 888 | 261 | 216073 | 15590 |
| **2010** | 279370 | 39604 | 15022 | 11639 | 6443 | 2921 | 25 | 788 | 355813 | 22383 |
| **2011** | 448234 | 69259 | 21184 | 9742 | 7855 | 4069 | 1653 | 448 | 562445 | 19479 |
| **2012** | 353125 | 111445 | 37112 | 13466 | 6685 | 4836 | 2120 | 1028 | 529816 | 22872 |
| **2013** | 49710 | 88396 | 59860 | 24245 | 9579 | 4402 | 2722 | 1673 | 240587 | 57474 |
| **2014** | 134083 | 12353 | 47336 | 38877 | 17245 | 6324 | 2465 | 2341 | 261025 | 44002 |
| **2015** | 43591 | 33880 | 6686 | 31820 | 27318 | 11898 | 3688 | 2692 | 161573 | 43316 |
| **2016** | 4184 | 11067 | 18091 | 4413 | 22462 | 18672 | 6746 | 3592 | 89227 | 35810 |
| **2017** | 52636 | 1036 | 5938 | 12042 | 3038 | 15232 | 11137 | 5923 | 106982 | 34948 |
| **2018** | 5210 | 13085 | 560 | 4012 | 8704 | 2112 | 9024 | 10073 | 52780 | 24733 |
| **2019** | 115337 | 1301 | 7041 | 369 | 2813 | 5713 | 1104 | 11071 | 144749 | 19442 |

**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 | 1.38 | 0.61 | 0.36 | 0.26 | 0.27 | 0.38 | 0.33 | 0.39 |

**Table 11.** N-at-age in prediction years (medians) with $F_{bar}$=3/4$F_{lim}$=0.143 including total number and number of matures.

| Year/Age | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8+ | Total | Matures |
|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 3065 | 28711 | 704 | 4279 | 192 | 1491 | 2001 | 6028 | 52281 | 9870 |
| 2021 | 1467 | 745 | 15521 | 452 | 2778 | 118 | 691 | 4081 | 30859 | 6745 |
| 2022 | 1020 | 357 | 394 | 10221 | 305 | 1809 | 60 | 2600 | 20841 | 5244 |
| 2023 | 797 | 248 | 191 | 259 | 6937 | 198 | 925 | 1448 | 14595 | 6957 |
| 2024 | 1118 | 195 | 133 | 125 | 176 | 4506 | 102 | 1318 | 11018 | 6132 |

**Table 12.** Projections results (median and 80% CI) with $F_{bar}$=3/4$F_{lim}$=0.143.

| Year | Total Biomass | | SSB | | P(SSB<$B_{lim}$) | P($SSB_{24}$ >$SSB_{19}$) | Yield | P(F>$F_{lim}$) |
|---|---|---|---|---|---|---|---|---|
| 2020 | 48777 | (42258 - 55350) | 35725 | (30140 - 41365) | <1% | | 8531 | 4% |
| 2021 | 35857 | (30252 - 41757) | 23121 | (18576 - 27867) | 1% | | 5595 | 5% |
| 2022 | 26786 | (21764 - 32499) | 15472 | (11920 - 19144) | 50% | <1% | 4622 | 6% |
| 2023 | 19902 | (15130 - 25556) | 14280 | (10838 - 18316) | 62% | | 3494 | 11% |
| 2024 | 15396 | (10877 - 21078) | 13556 | (9424 - 18349) | 69% | | | |

**Table 13.** N-at-age in prediction years (medians) with $F_{bar}$=0 including total number and number of matures.

| Year/Age | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8+ | Total | Matures |
|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 3065 | 28711 | 704 | 4279 | 192 | 1491 | 2001 | 6028 | 52281 | 9870 |
| 2021 | 1467 | 745 | 15521 | 452 | 2778 | 118 | 691 | 4081 | 30859 | 6745 |
| 2022 | 1020 | 357 | 395 | 10825 | 346 | 2134 | 81 | 3273 | 22508 | 6283 |
| 2023 | 956 | 248 | 191 | 274 | 8313 | 264 | 1453 | 2288 | 17960 | 9226 |
| 2024 | 1458 | 235 | 134 | 132 | 212 | 6302 | 181 | 2619 | 15032 | 9306 |

**Table 14.** Projections results (median and 80% CI) with $F_{bar}$=0.

| Year | Total Biomass | | SSB | | P(SSB<$B_{lim}$) | P($SSB_{24}$ >$SSB_{19}$) | Yield | P(F>$F_{lim}$) |
|---|---|---|---|---|---|---|---|---|
| 2020 | 48777 | (42258 - 55350) | 35725 | (30140 - 41365) | <1% | | 8531 | 4% |
| 2021 | 35857 | (30252 - 41757) | 23121 | (18576 - 27867) | 1% | | 0 | 0% |
| 2022 | 32245 | (27255 - 37930) | 20159 | (16445 - 23914) | 6% | <1% | 0 | 0% |
| 2023 | 28937 | (24157 - 34759) | 22321 | (18764 - 26370) | 1% | | 0 | 0% |
| 2024 | 27386 | (22667 - 33174) | 25006 | (20842 - 29872) | <1% | | | |

**Table 15.** N-at-age in prediction years (medians) with Catch=1000 tons including total number and number of matures.

| Year/Age | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8+ | Total | Matures |
|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 3065 | 28711 | 704 | 4279 | 192 | 1491 | 2001 | 6028 | 52281 | 9870 |
| 2021 | 1467 | 745 | 15521 | 452 | 2778 | 118 | 691 | 4081 | 30859 | 6745 |
| 2022 | 1020 | 357 | 395 | 10704 | 337 | 2060 | 76 | 3119 | 22136 | 6047 |
| 2023 | 917 | 248 | 191 | 271 | 7990 | 248 | 1323 | 2077 | 17120 | 8692 |
| 2024 | 1383 | 225 | 134 | 130 | 203 | 5839 | 159 | 2254 | 14035 | 8473 |

**Table 16.** Projections results (median and 80% CI) with Catch=1000 tons.

| Year | Total Biomass | | SSB | | P(SSB<$B_{lim}$) | P($SSB_{24}$ >$SSB_{19}$) | Yield | P(F>$F_{lim}$) |
|---|---|---|---|---|---|---|---|---|
| 2020 | 48777 | (42258 - 55350) | 35725 | (30140 - 41365) | <1% | | 8531 | 4% |
| 2021 | 35857 | (30252 - 41757) | 23121 | (18576 - 27867) | 1% | | 1000 | <1% |
| 2022 | 31265 | (26251 - 36956) | 19317 | (15655 - 23065) | 10% | <1% | 1000 | <1% |
| 2023 | 27176 | (22347 - 32982) | 20743 | (17192 - 24760) | 4% | | 1000 | <1% |
| 2024 | 24680 | (19993 - 30474) | 22430 | (18278 - 27230) | 2% | | | |

**Table 17.** N-at-age in prediction years (medians) with Catch=3000 tons including total number and number of matures.

| Year/Age | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8+ | Total | Matures |
|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 3065 | 28711 | 704 | 4279 | 192 | 1491 | 2001 | 6028 | 52281 | 9870 |
| 2021 | 1467 | 745 | 15521 | 452 | 2778 | 118 | 691 | 4081 | 30859 | 6745 |
| 2022 | 1020 | 357 | 394 | 10427 | 319 | 1913 | 67 | 2817 | 21375 | 5587 |
| 2023 | 845 | 248 | 191 | 263 | 7324 | 217 | 1063 | 1670 | 15506 | 7565 |
| 2024 | 1216 | 207 | 134 | 126 | 182 | 4839 | 116 | 1565 | 11870 | 6737 |

**Table 18.** Projections results (median and 80% CI) with Catch=3000 tons.

| Year | Total Biomass | | SSB | | P(SSB<$B_{lim}$) | P($SSB_{24}$ >$SSB_{19}$) | Yield | P(F>$F_{lim}$) |
|---|---|---|---|---|---|---|---|---|
| 2020 | 48777 | (42258 - 55350) | 35725 | (30140 - 41365) | <1% | | 8531 | 4% |
| 2021 | 35857 | (30252 - 41757) | 23121 | (18576 - 27867) | 1% | | 3000 | <1% |
| 2022 | 29305 | (24278 - 35017) | 17616 | (13964 - 21334) | 24% | <1% | 3000 | <1% |
| 2023 | 23596 | (18837 - 29285) | 17549 | (14040 - 21560) | 24% | | 3000 | <1% |
| 2024 | 19249 | (14646 - 24980) | 17264 | (13095 - 22048) | 30% | | | |

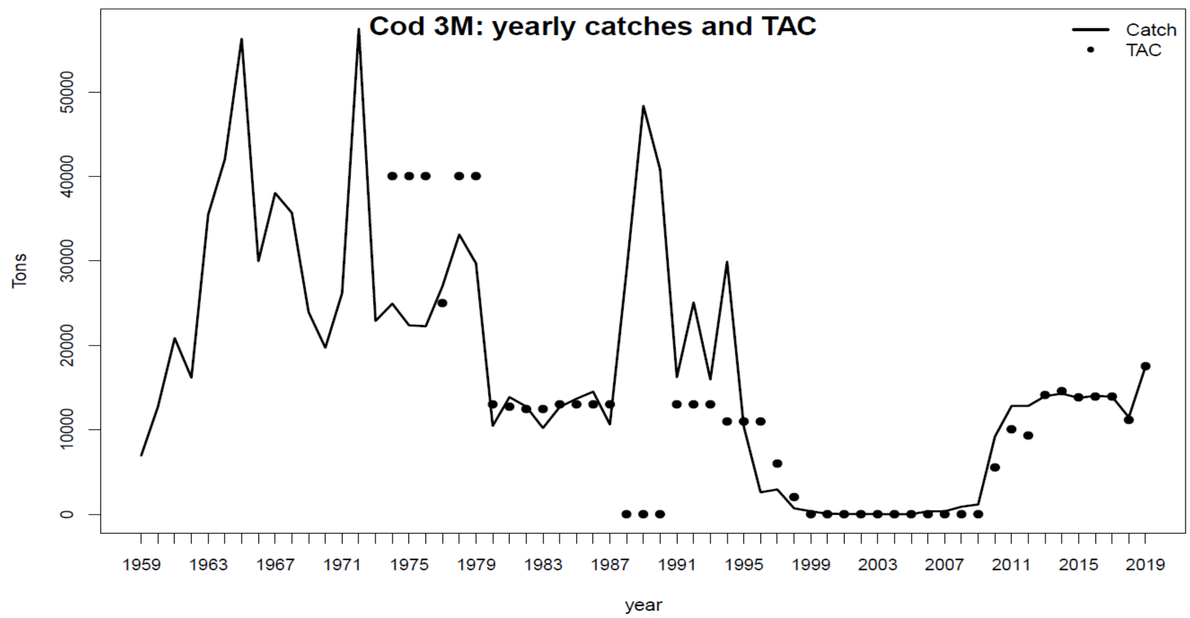
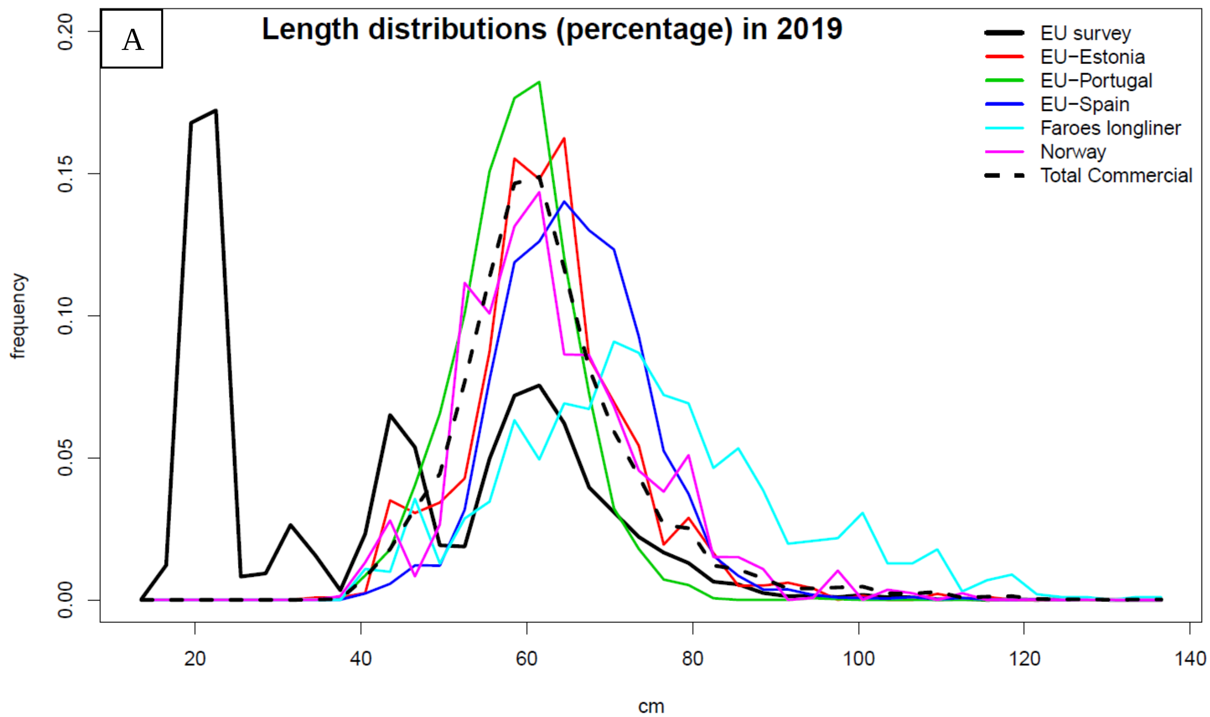



**Figure 1.** Catch and TAC of the 3M cod for the period 1959-2019.



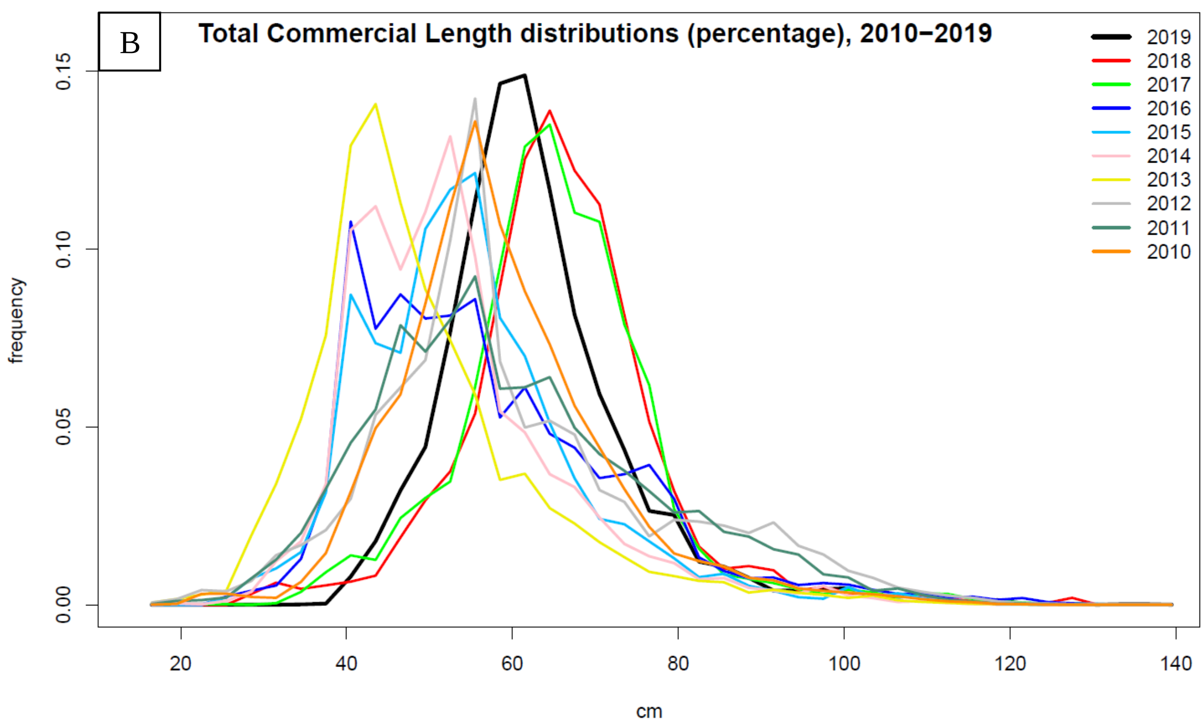




**Figure 2.** Length frequencies in commercial catches and EU survey in 2019 (A), and for the last fishery period (2010-2019) and the total commercial (B).

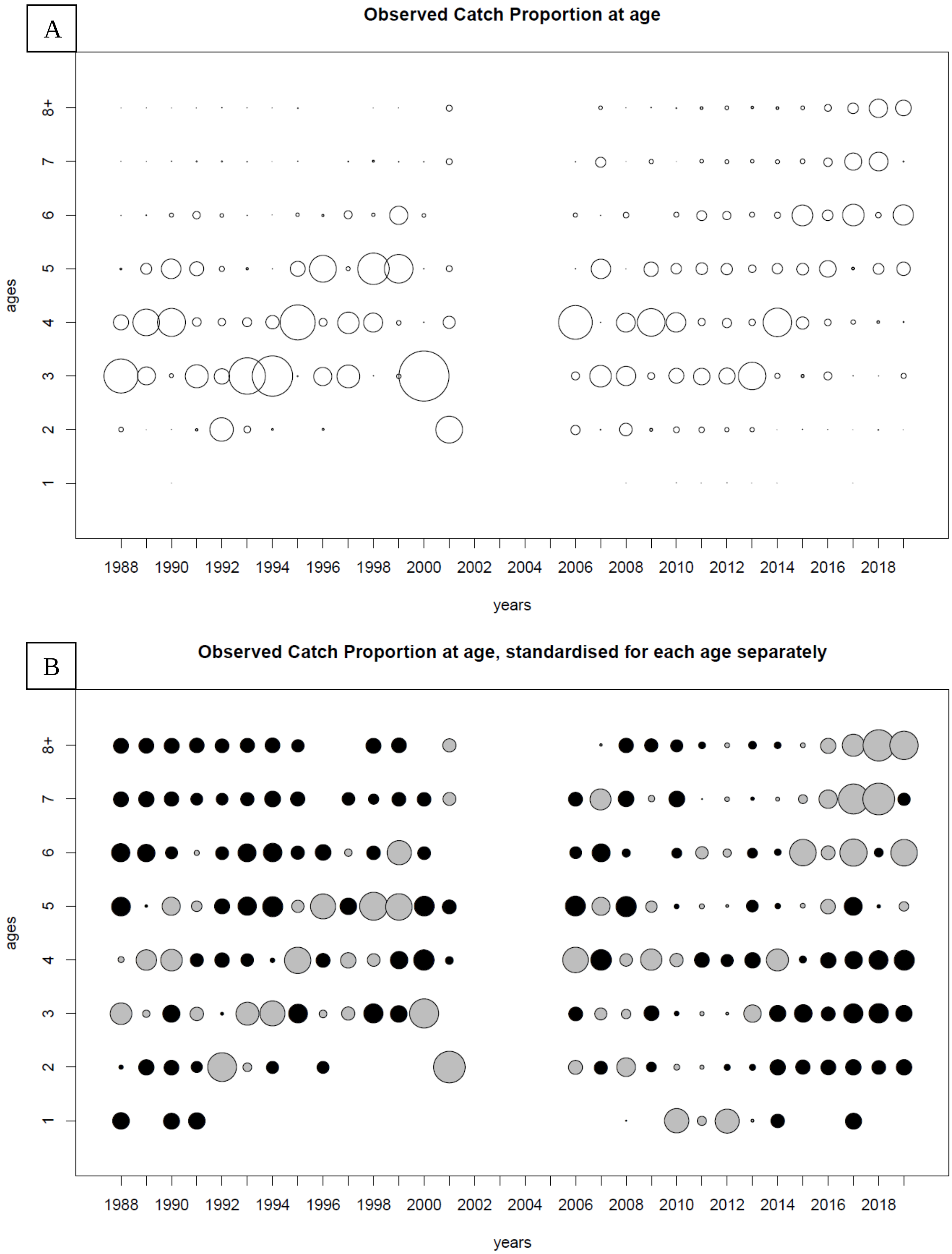



**Figure 3.** Commercial catch proportions at age (A) and standardised proportions at age (B). In B, grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

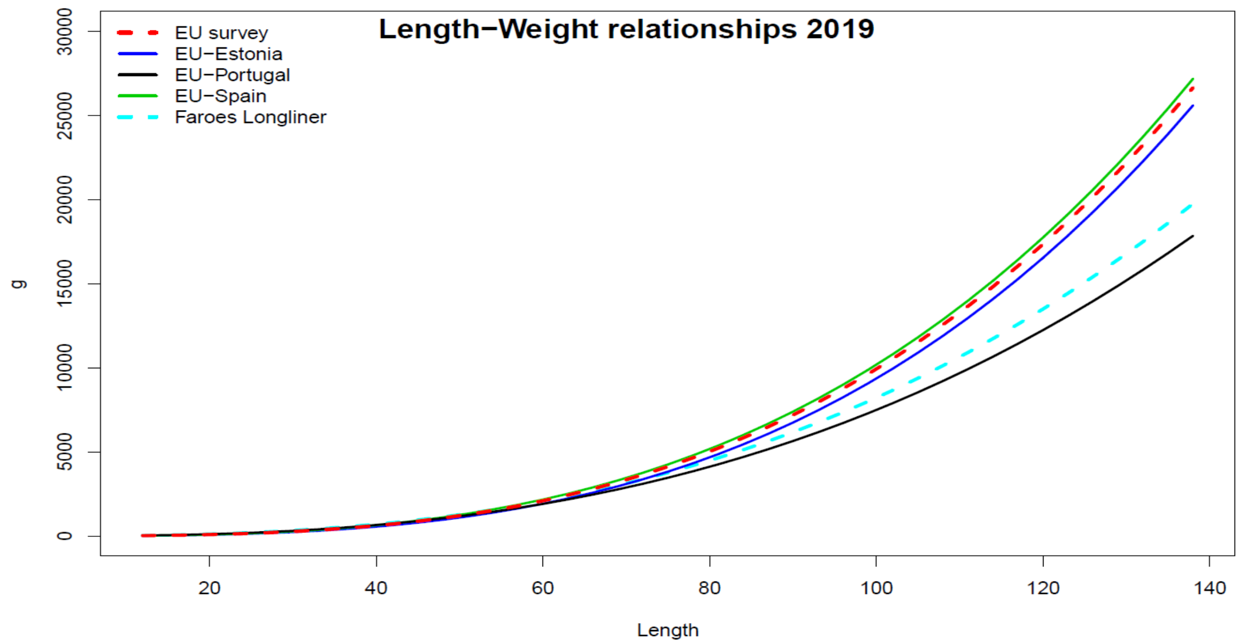



**Figure 4.** Length-weight relationships for commercial catches and EU survey in 2019.

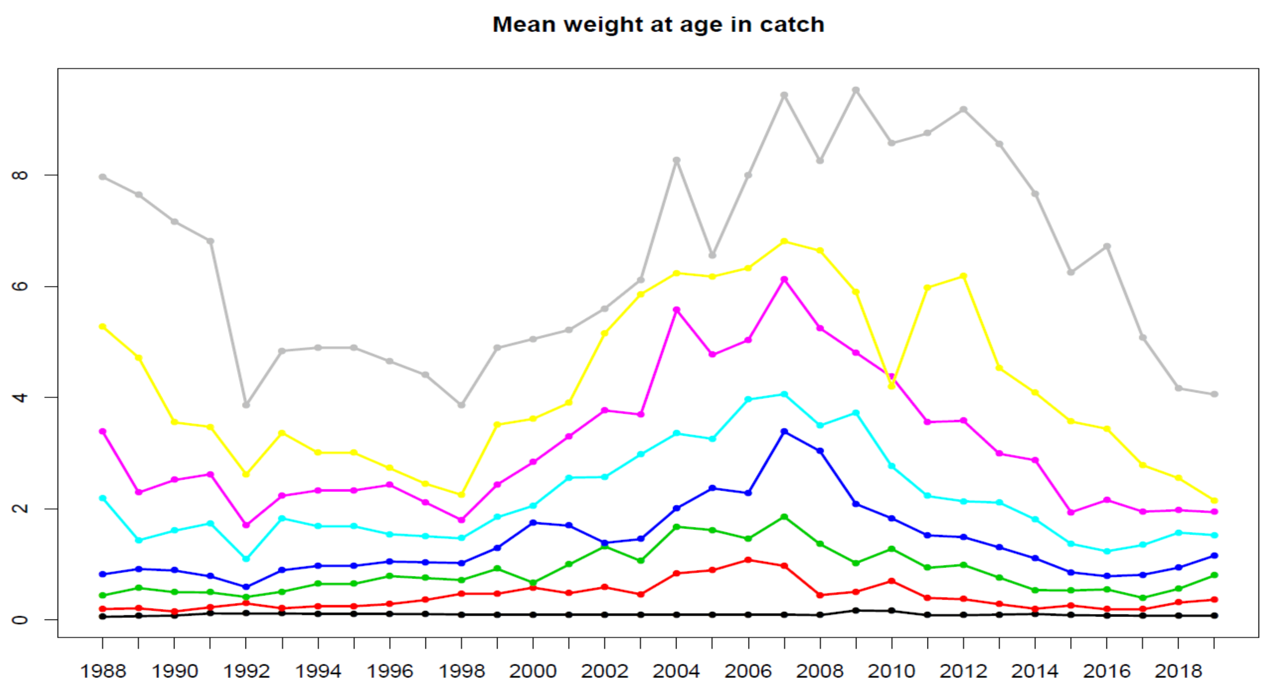



**Figure 5.** Catch mean weight at age.

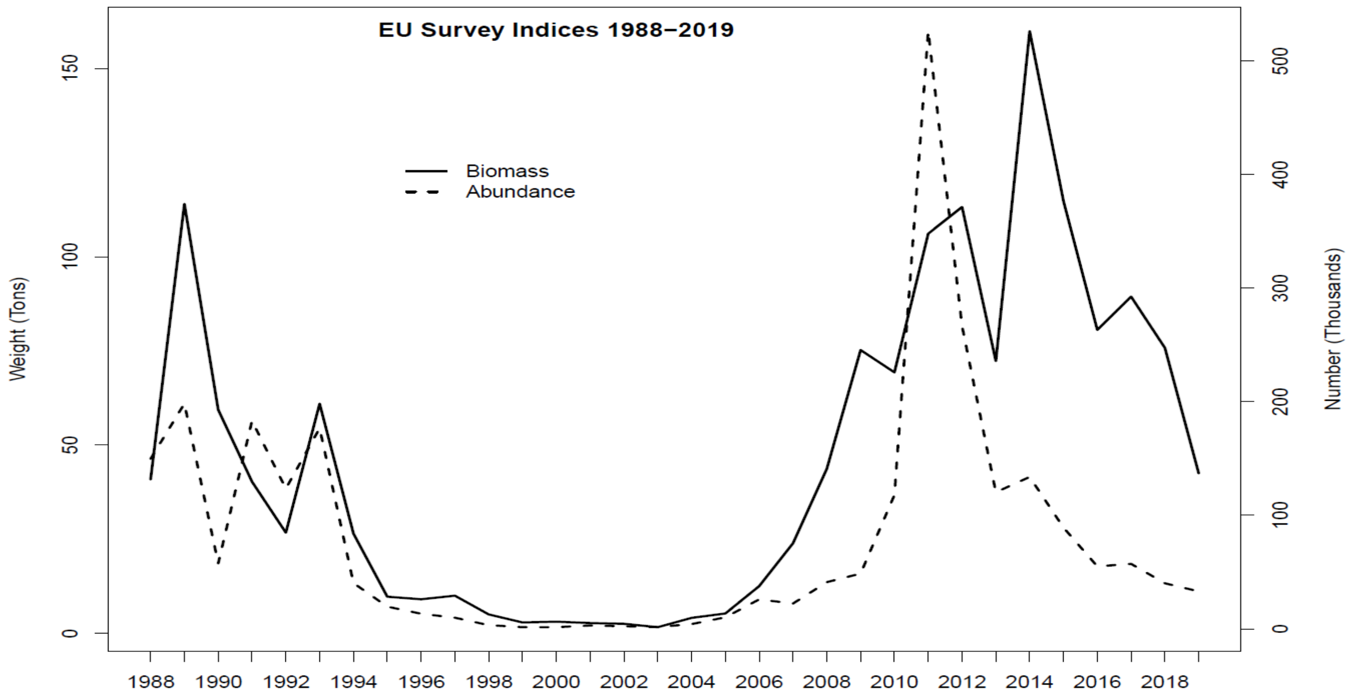



**Figure 6.** Biomass and abundance from EU surveys.

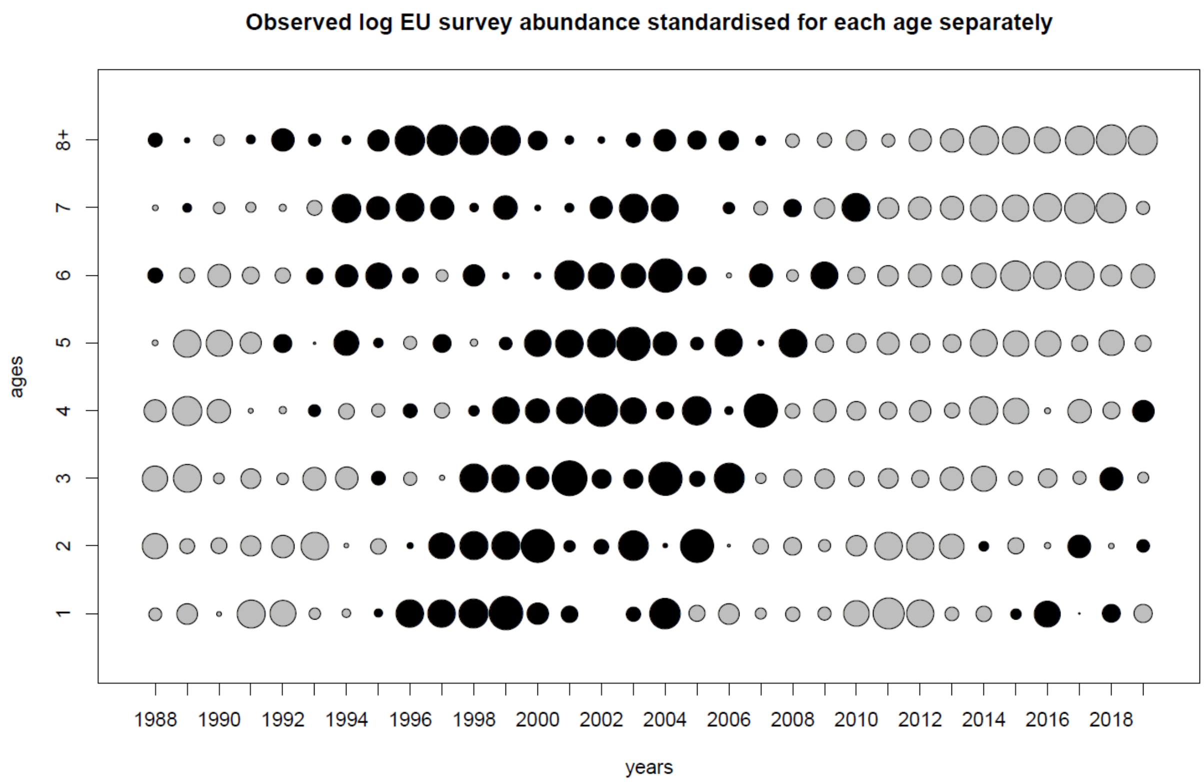



**Figure 7.** Standardised log(Abundance at age) indices from EU survey. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

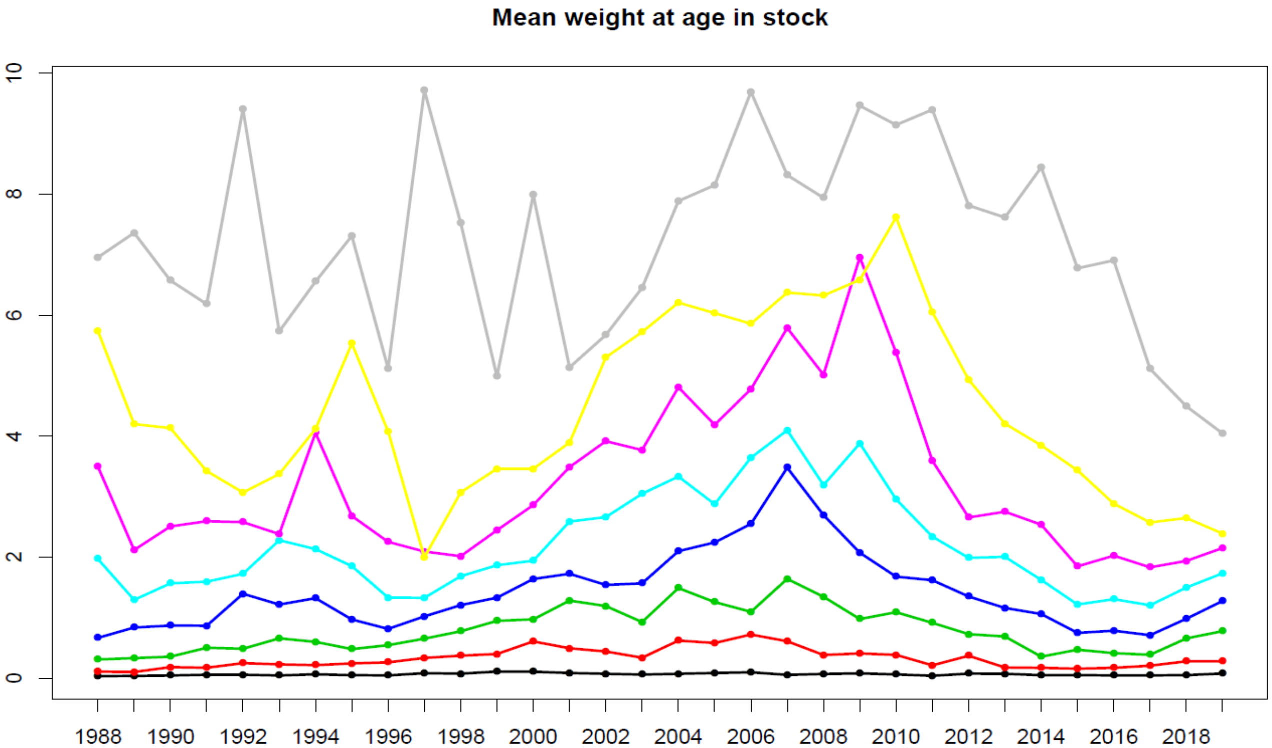



**Figure 8.** Stock mean weight at age.

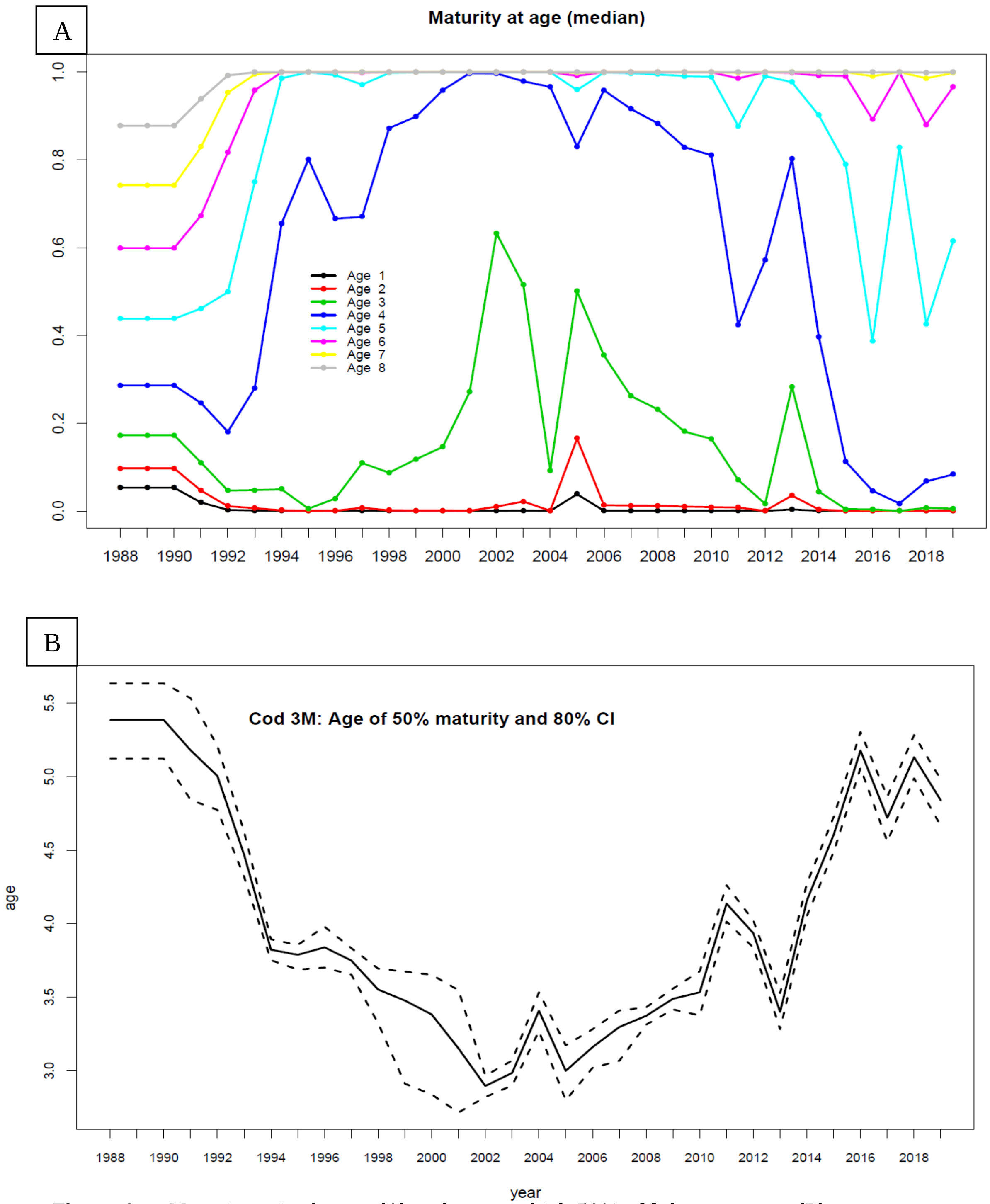



**Figure 9.** Maturity ogive by age (A) and age at which 50% of fish are mature (B).

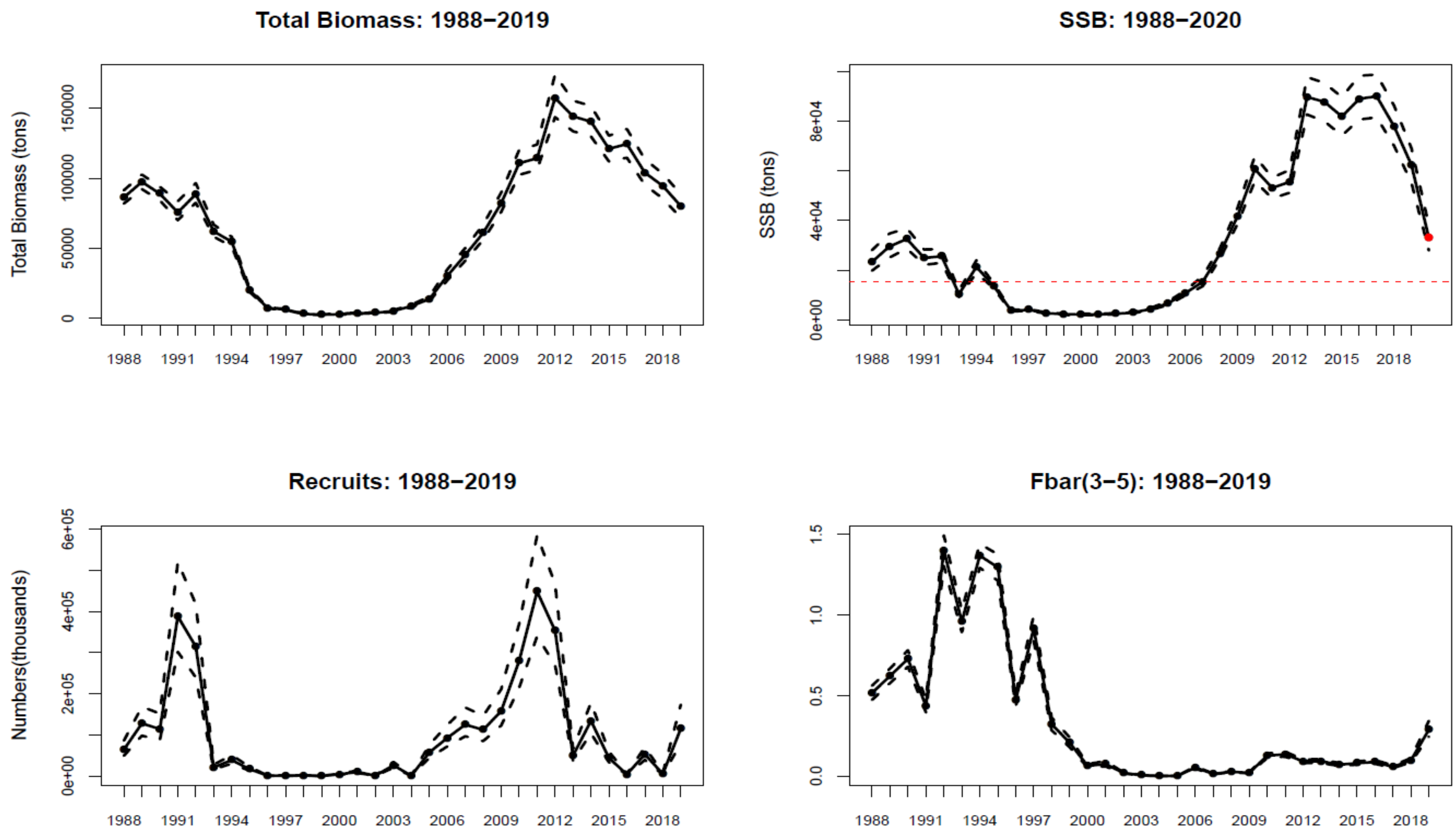



**Figure 10.** Estimated trends in biomass, SSB, recruitment and $F_{bar}$. The solid lines are the posterior medians and the dashed lines show the limits of 80% posterior credible intervals. Red point in the SSB plot indicates the SSB in 2020. Red horizontal line in the SSB graph represents median $B_{lim}$ = median$SSB_{07}$ = 15 271 tons.

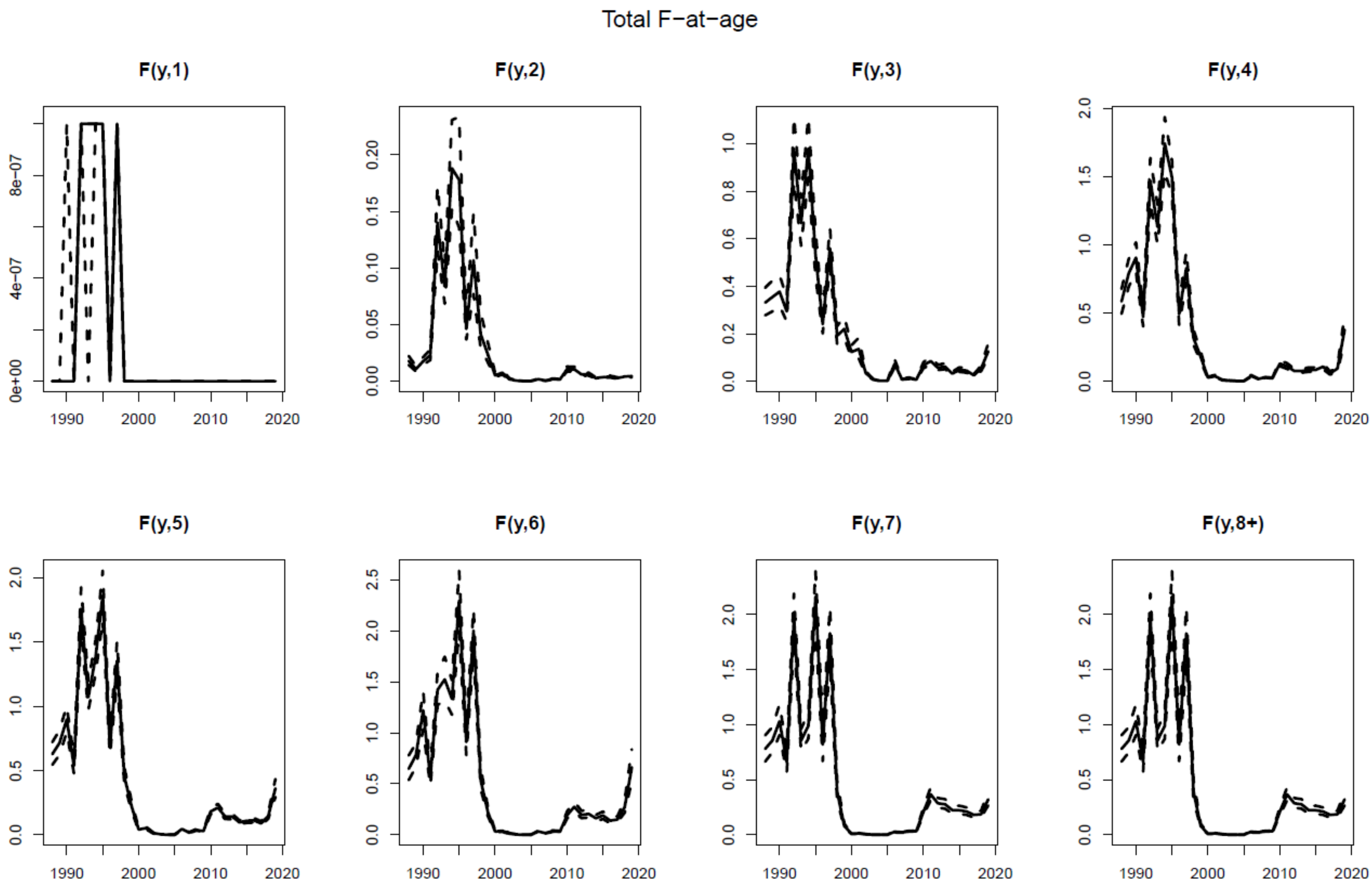



**Figure 11.** Estimated fishing mortality at age. The y-axis scale is different in all the graphs.

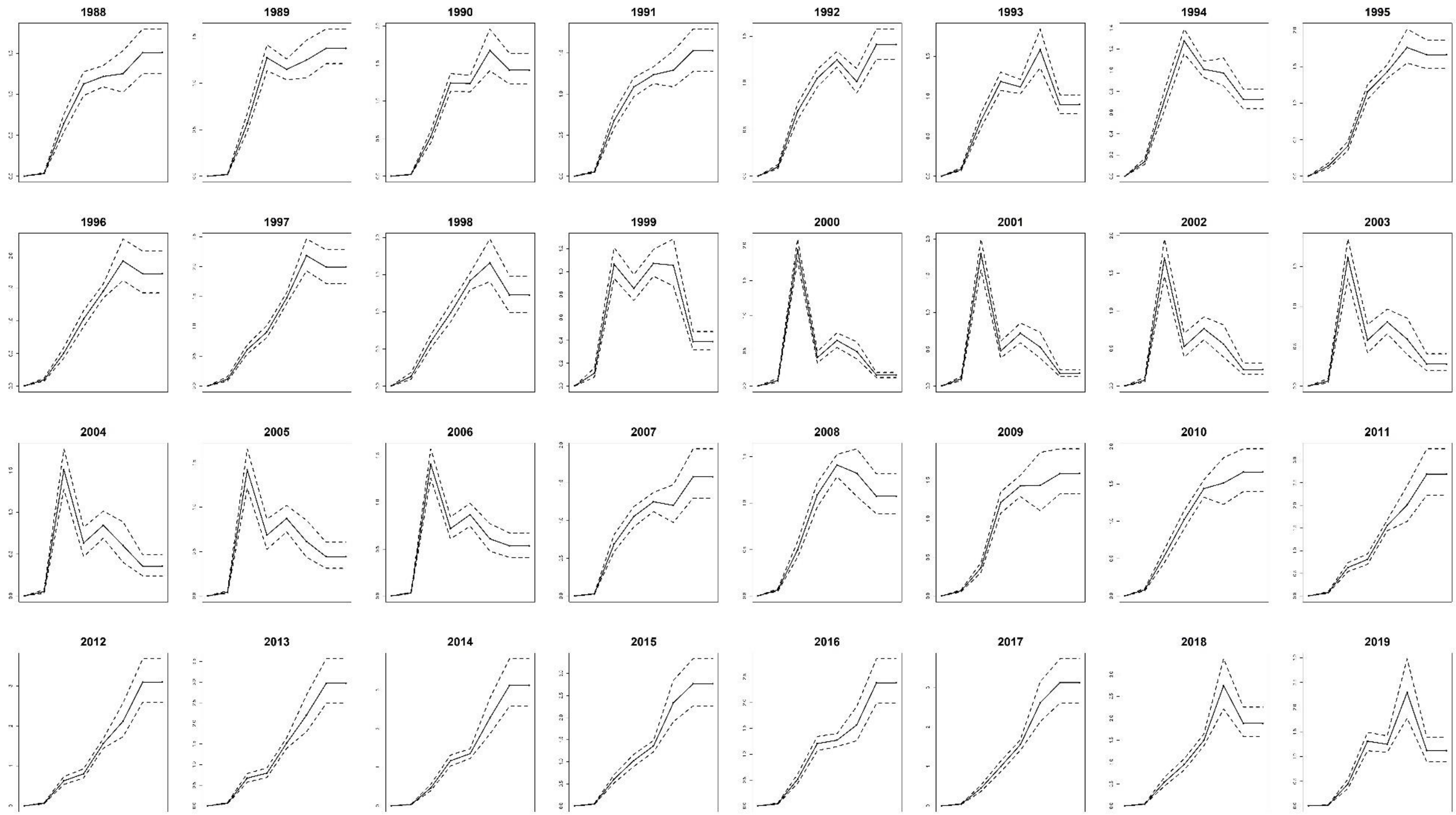



**Figure 12.** Estimated PR ($F/F_{bar}$) per age and year. The y-axis scale is different in all the graphs.

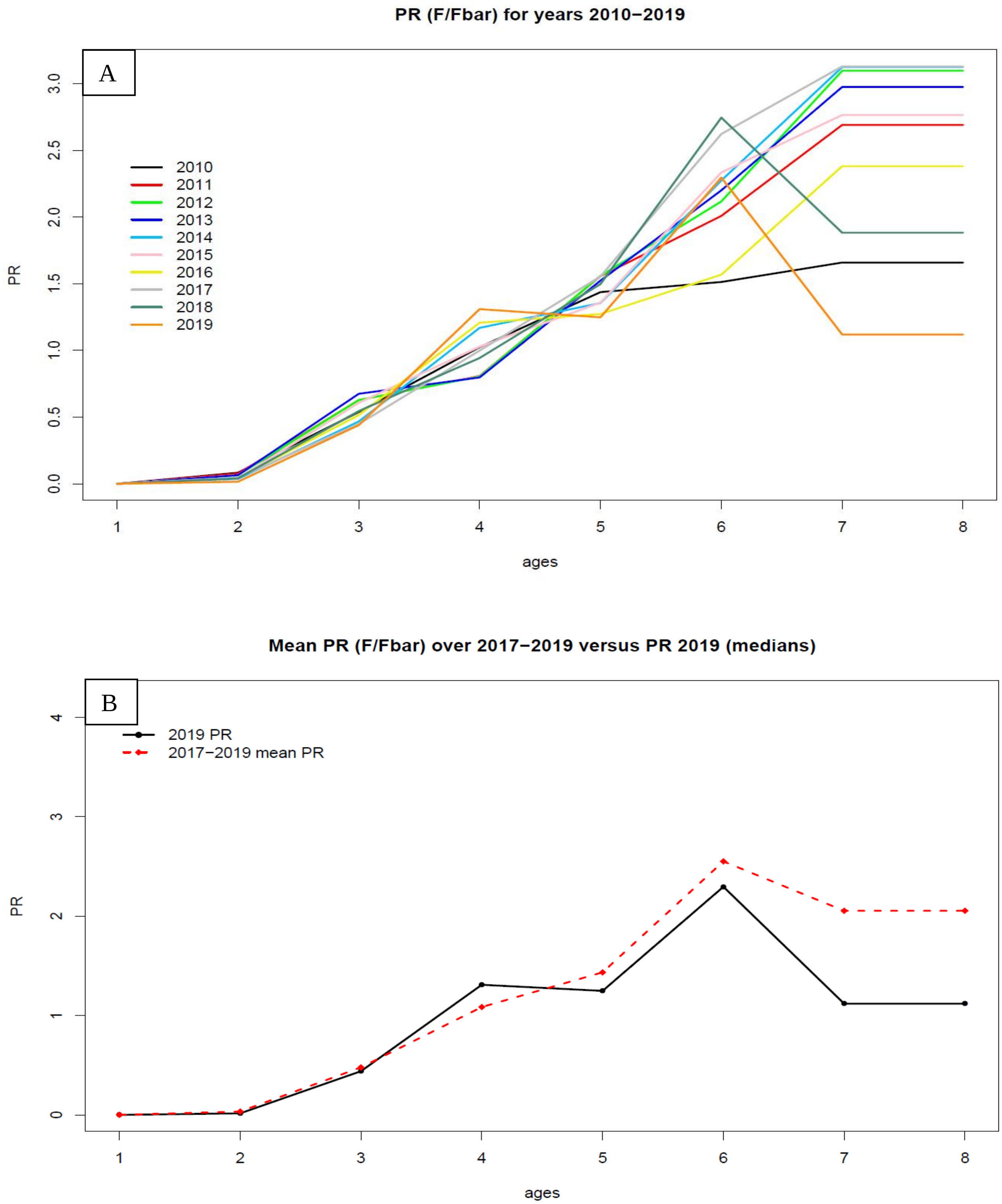



**Figure 13.** A) Estimated PR ($F/F_{bar}$) per age for the last ten years and (B) mean of 2017-2019 PR versus 2019 PR (posterior medians).

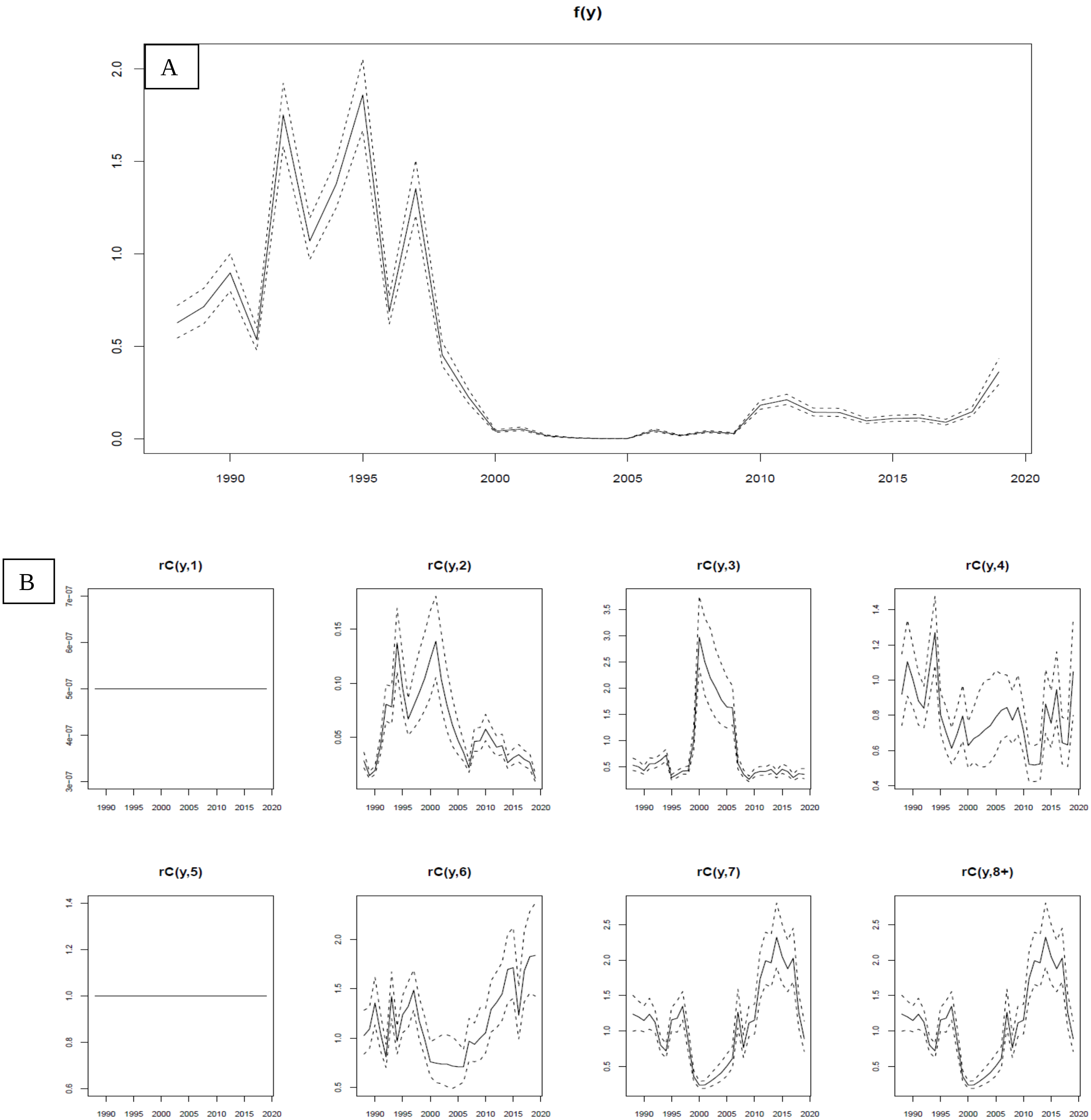



**Figure 14.** Components of the semi-separable model for Fishing Mortality: F[y,a]=*f*[y]**rC*[y,a].

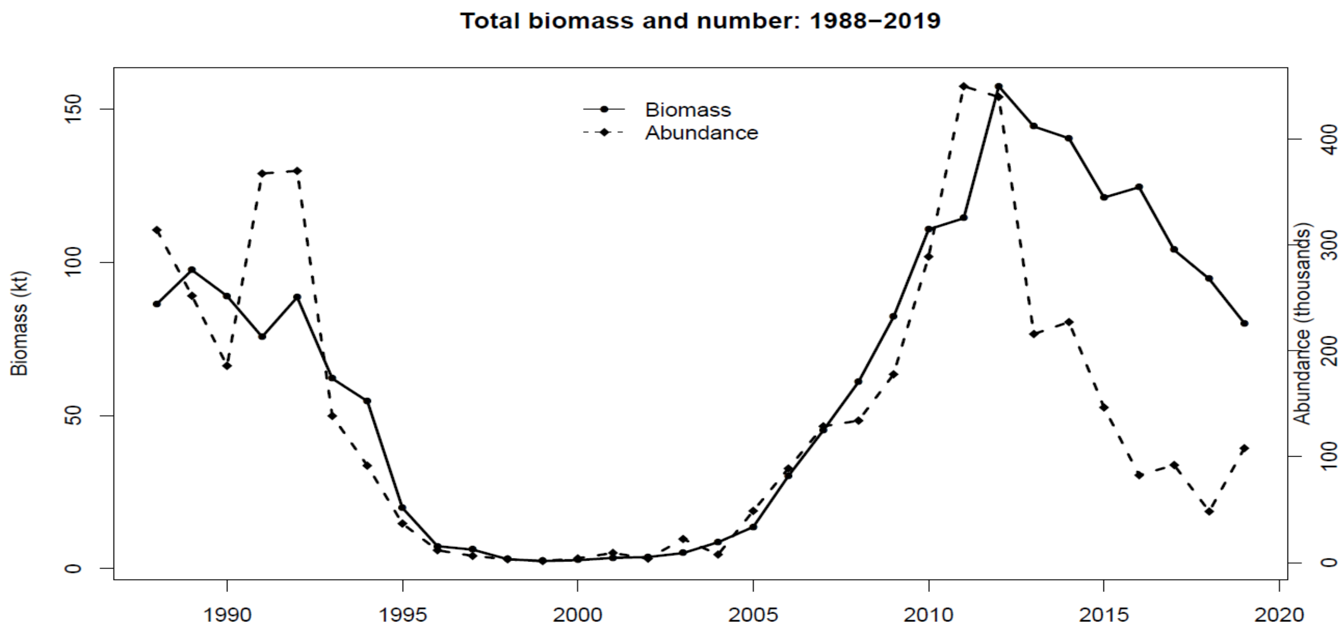



**Figure 15.** Estimated trends in biomass and abundance.

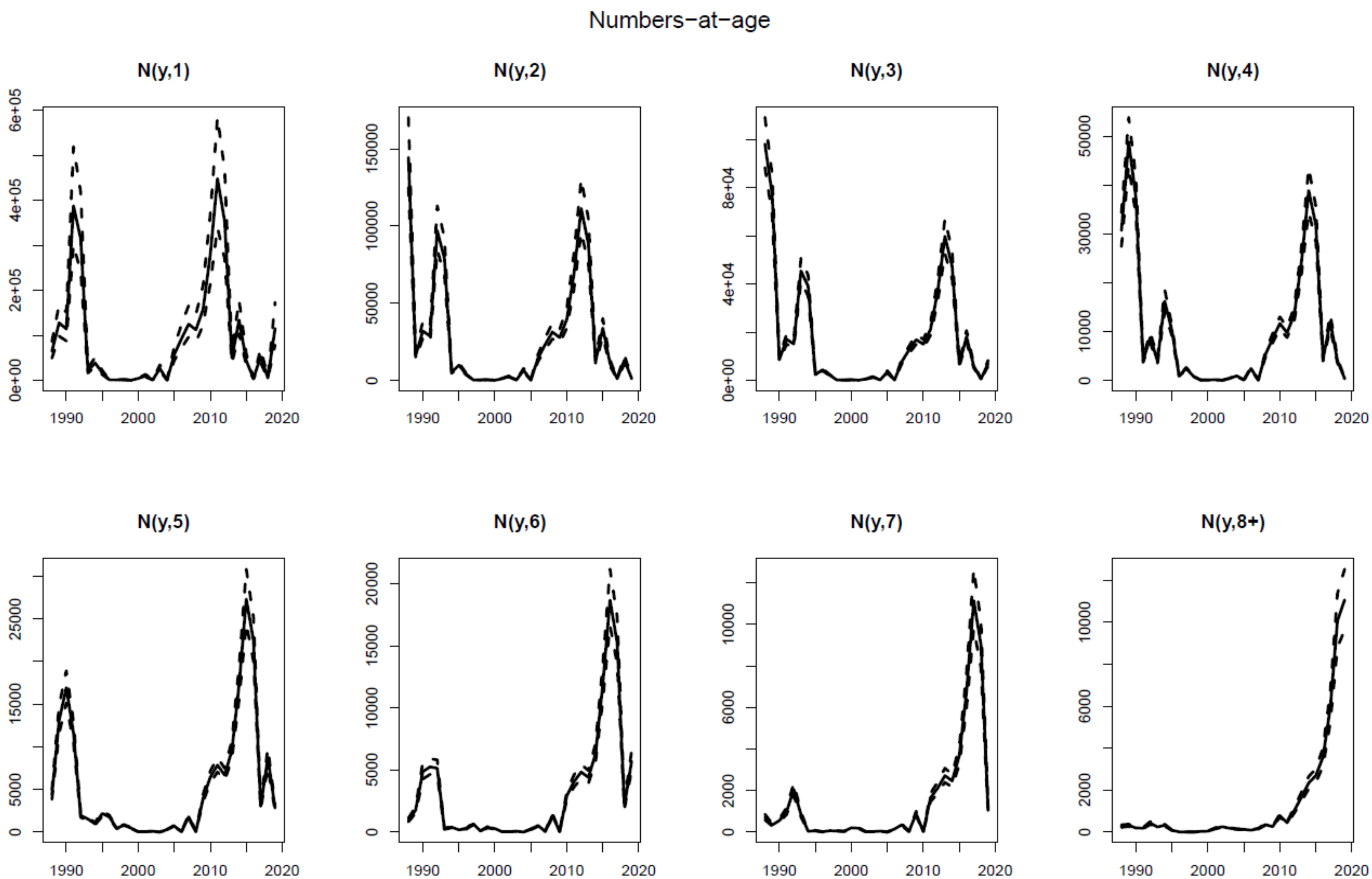



**Figure 16.** Estimated numbers at age. The y-axis scale is different in all the graphs.

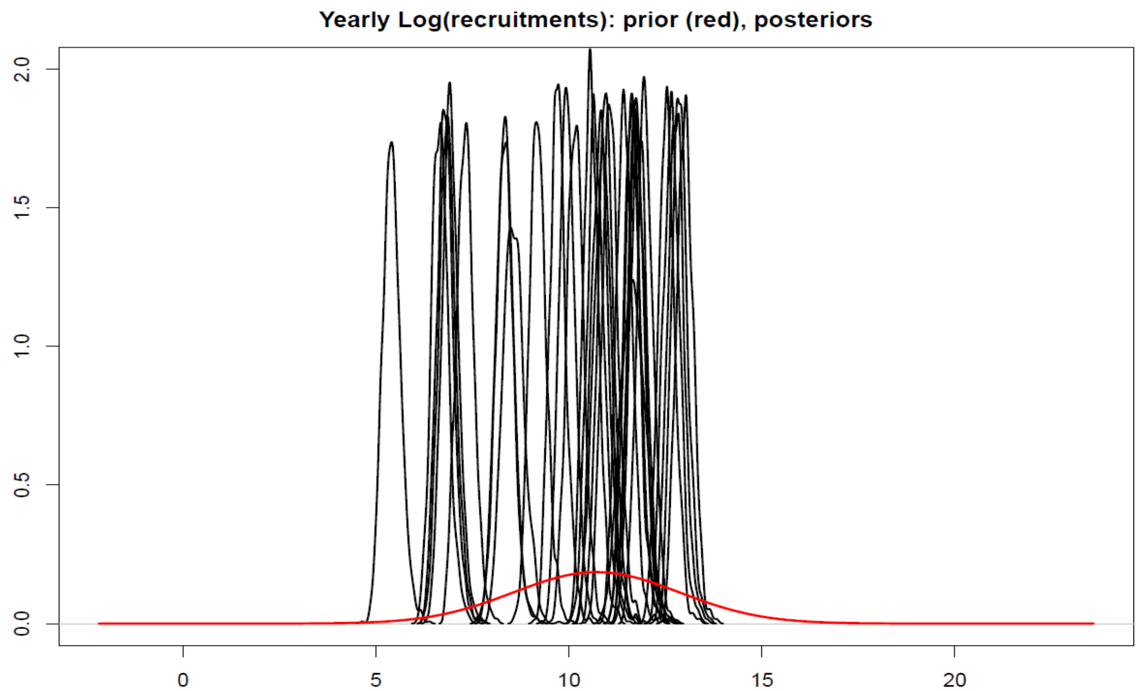



**Figure 17.** Prior and posterior of recruitment by year.

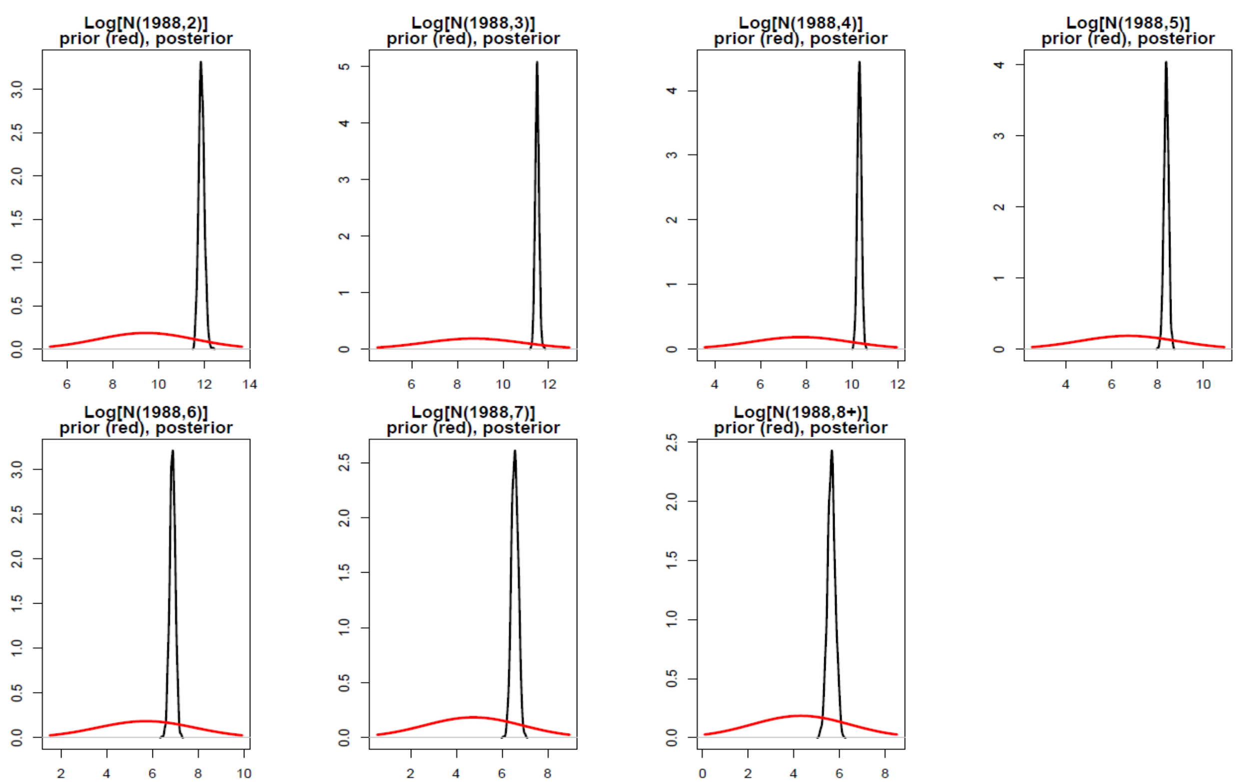



**Figure 18.** Prior and posterior of the numbers in the first year (1988) from age 2 to 8+.The x- and y-axis scales are different in all the graphs.

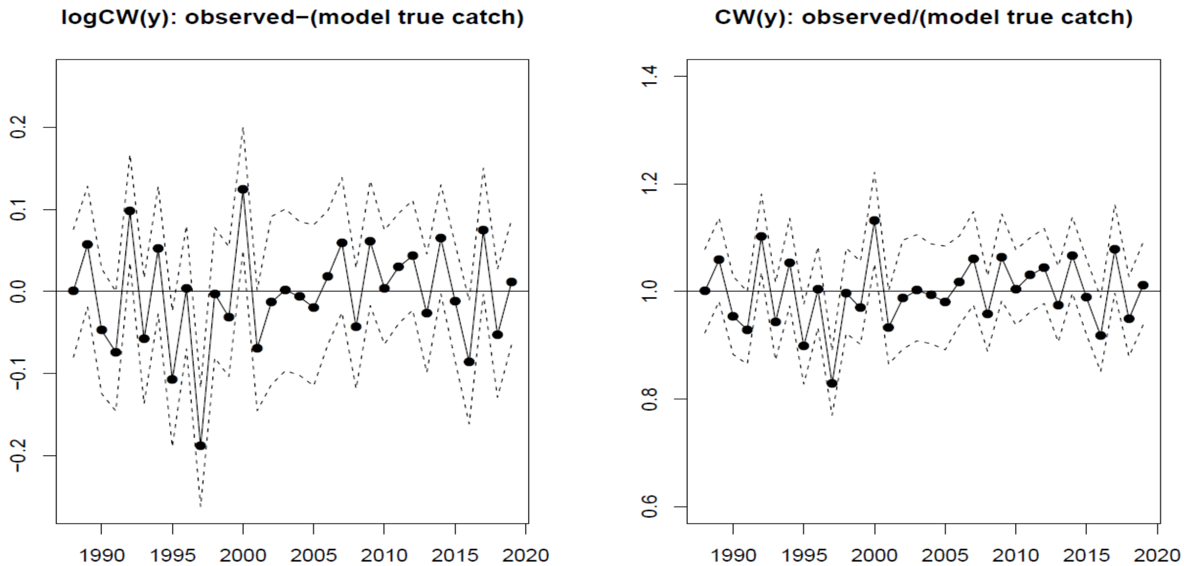



**Figure 19.** Observed versus estimated total catches by year.

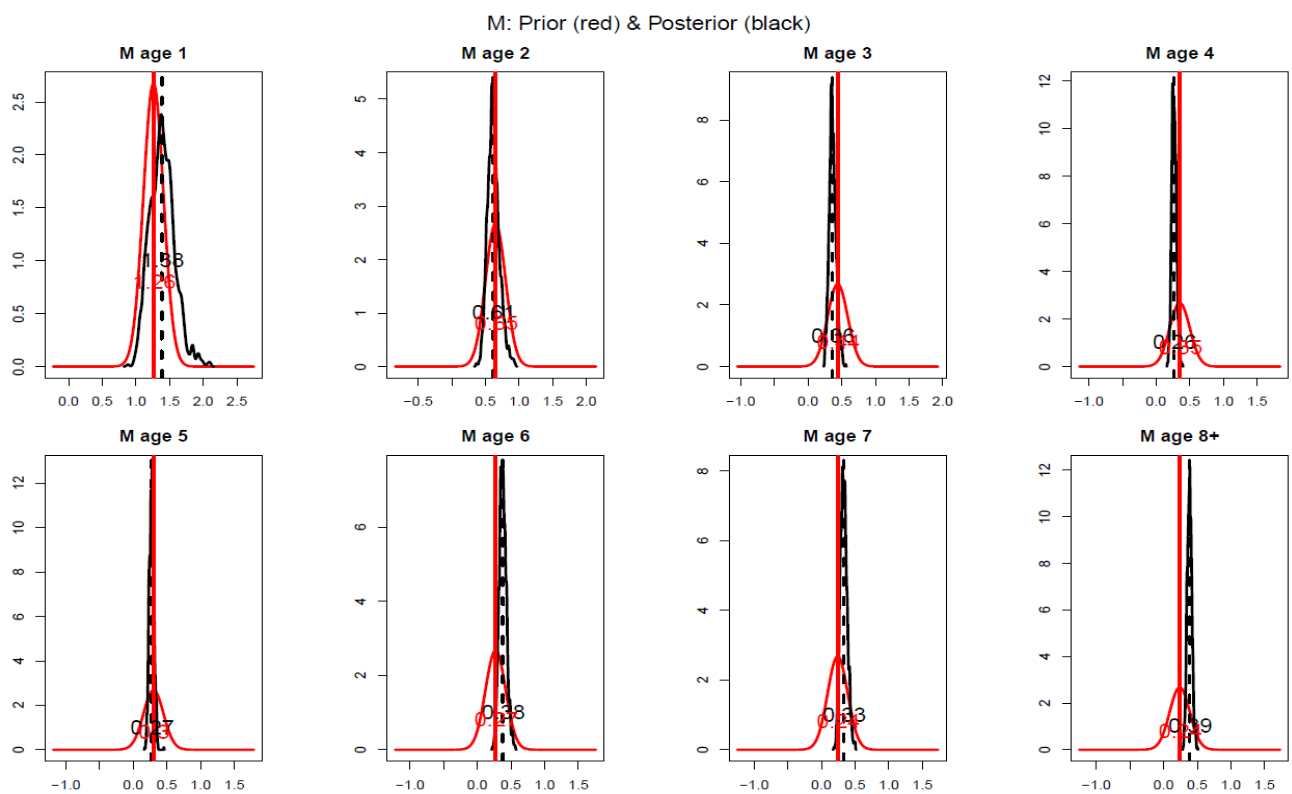



**Figure 20.** Estimated natural mortality by age in 2019.

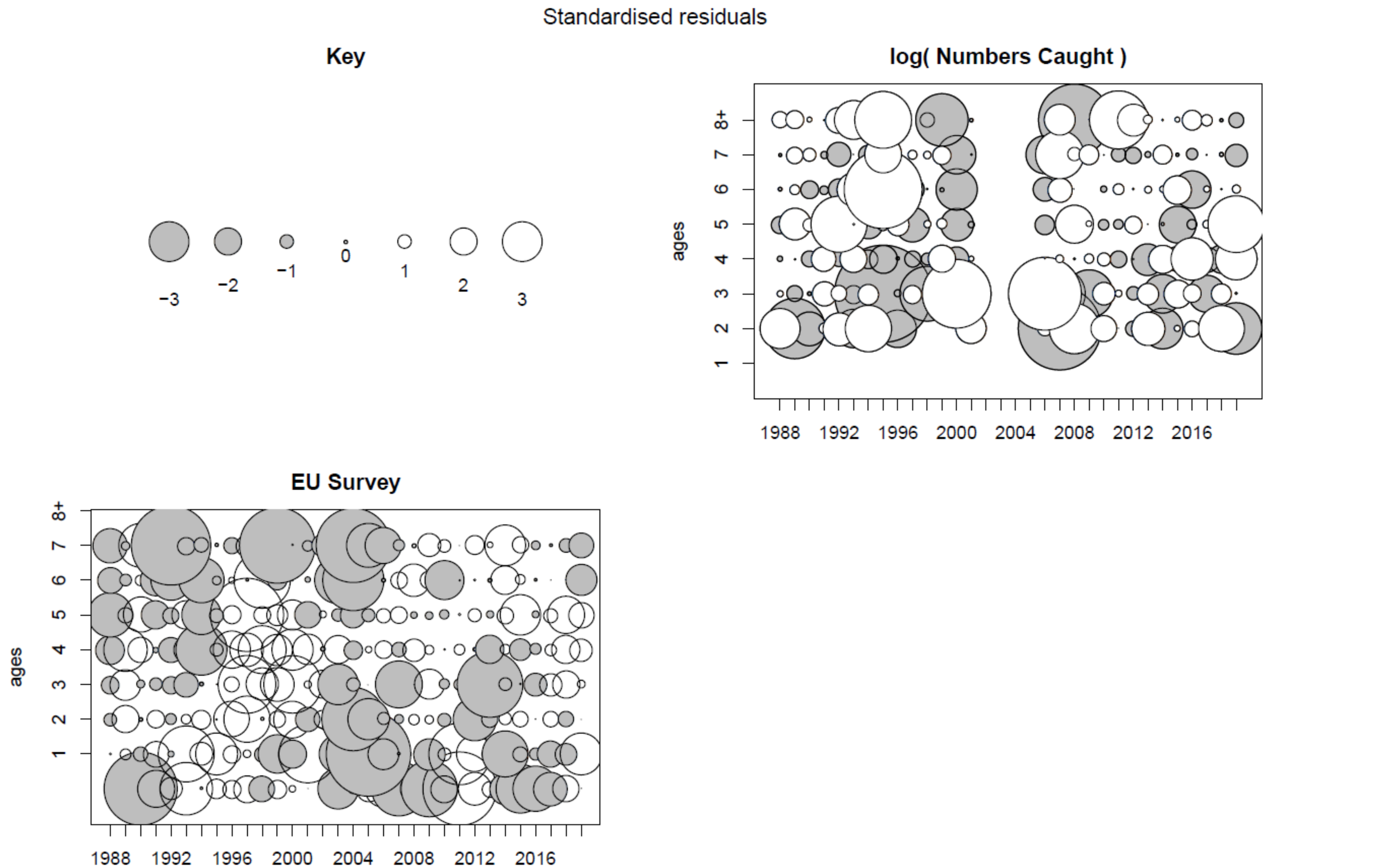



**Figure 21.** Standardised residuals (observed minus fitted value) in logarithmic scale of catch numbers at age and EU survey abundance indices at age. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

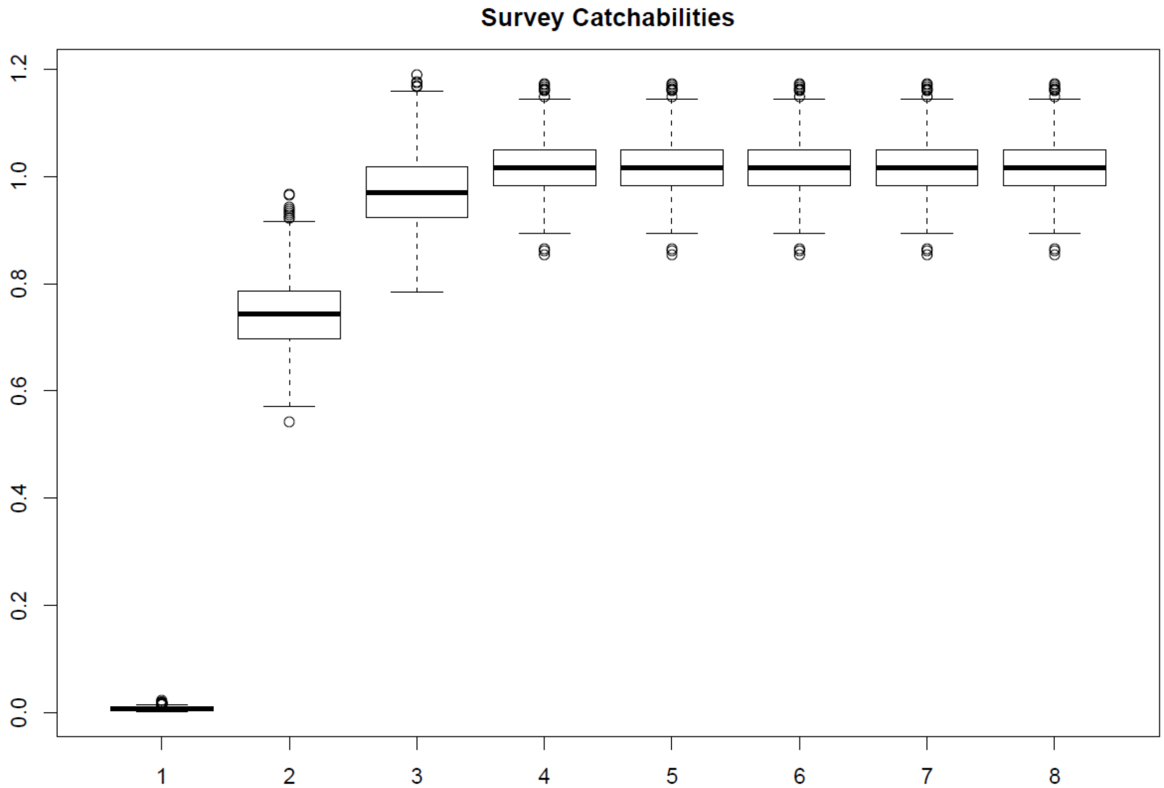



**Figure 22.** EU survey catchabilities distribution

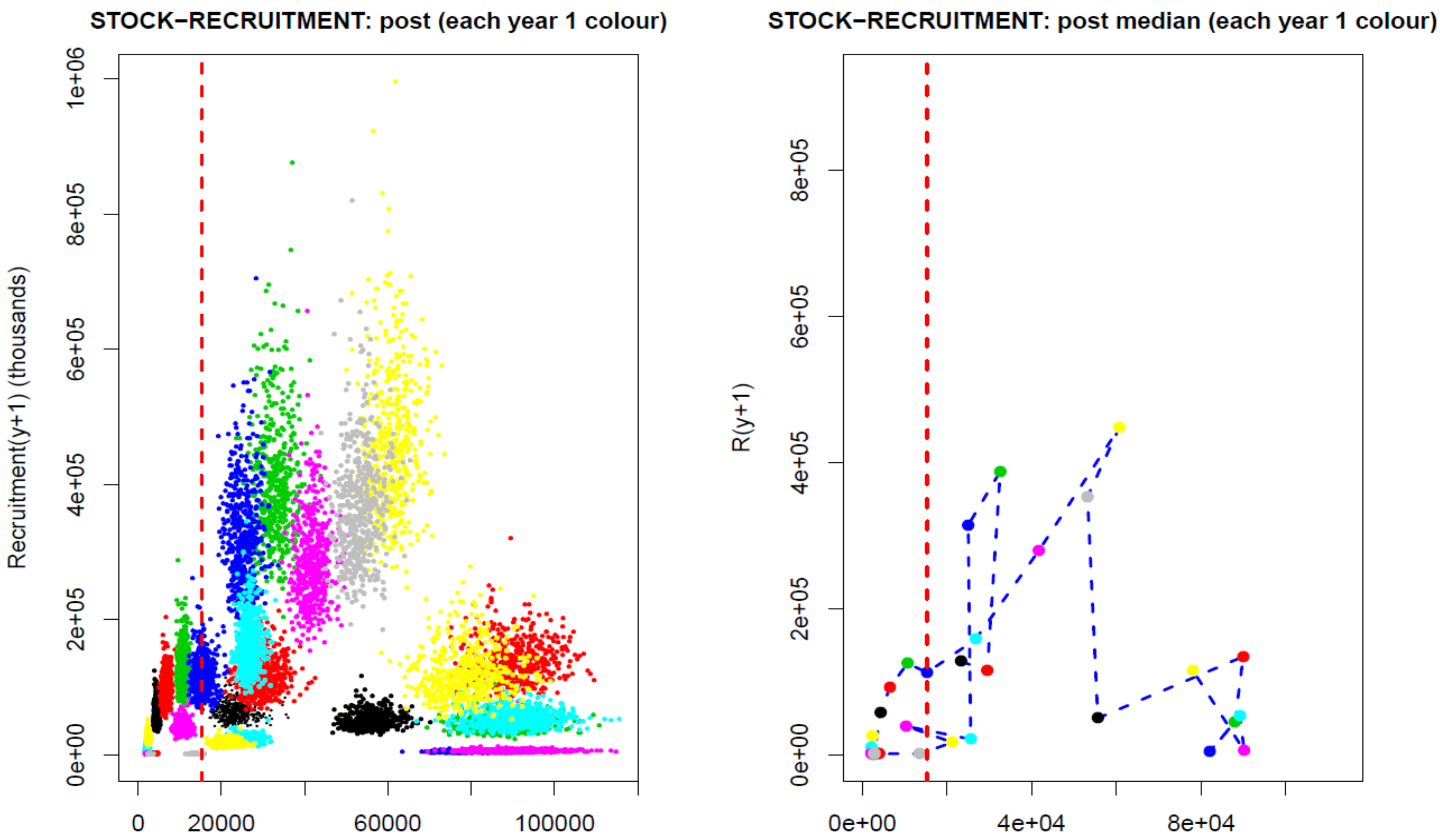



**Figure 23.** Stock-Recruitment plots. The value of median $B_{lim}$=median$SSB_{2007}$=15 271 tons is shown as the red vertical line.

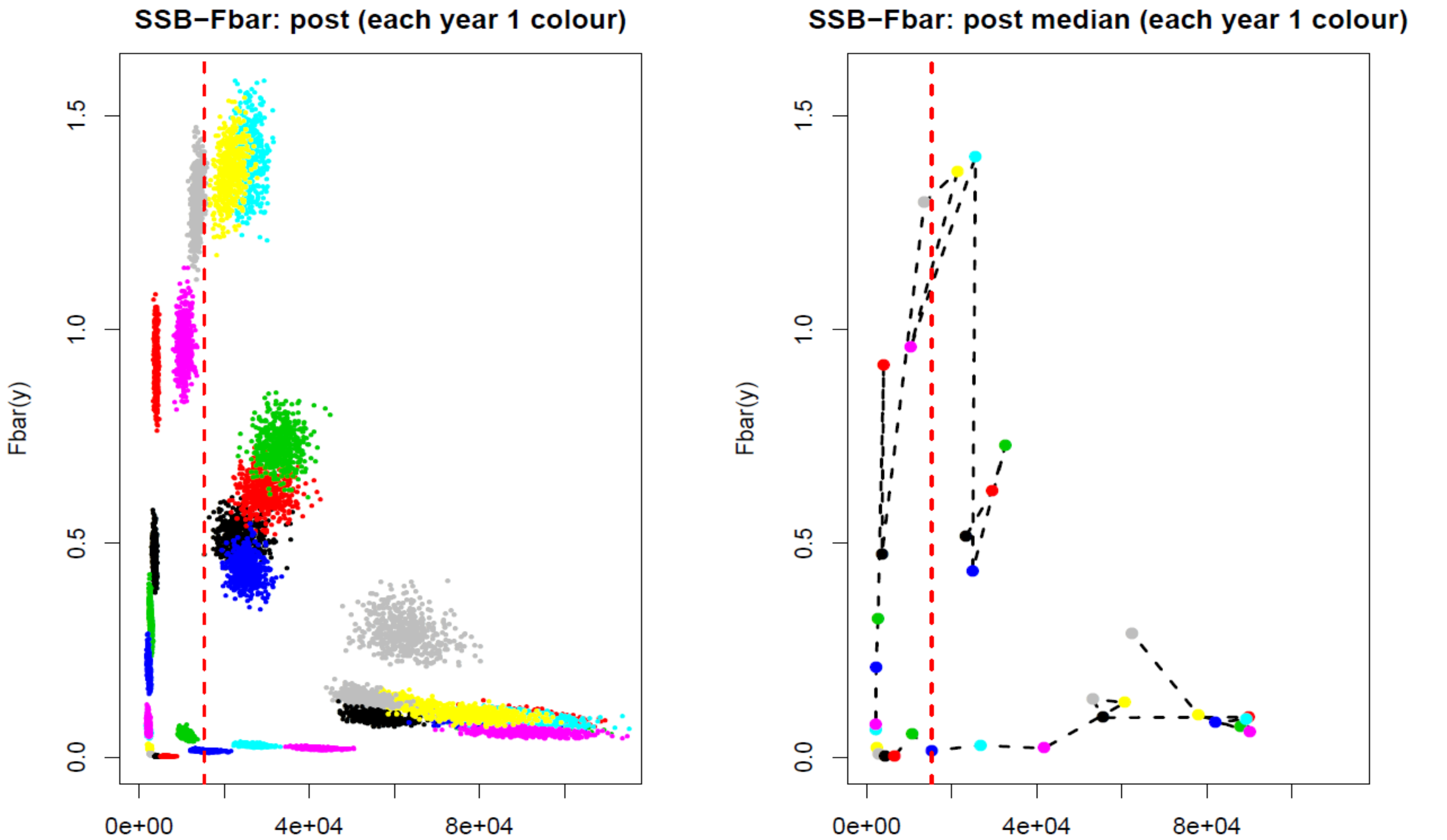



**Figure 24.** $F_{bar}$ versus SSB plots. The value of median $B_{lim}$=median$SSB_{07}$=15 271 tons is shown as the red vertical line.

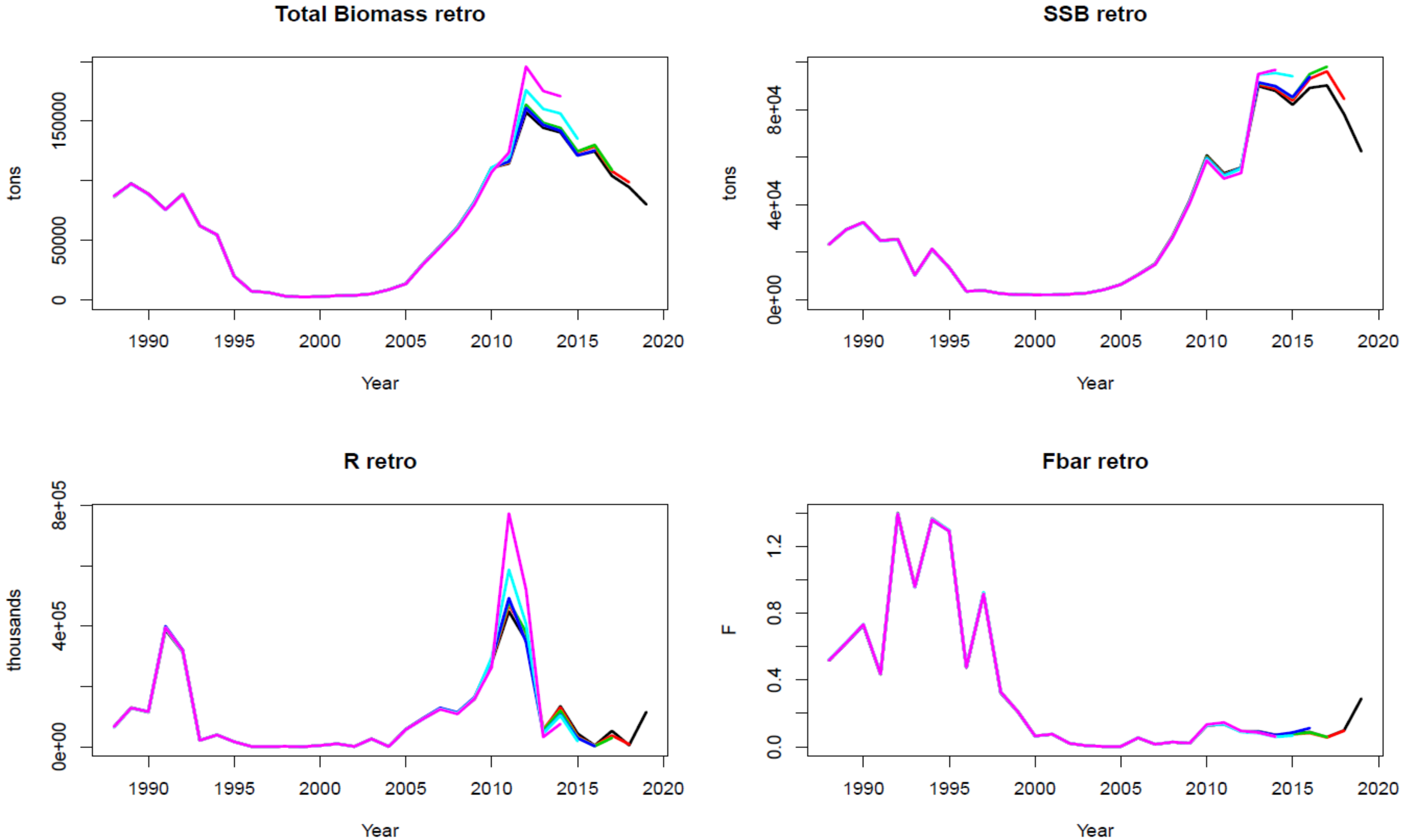



**Figure 25.** Retrospective patterns.

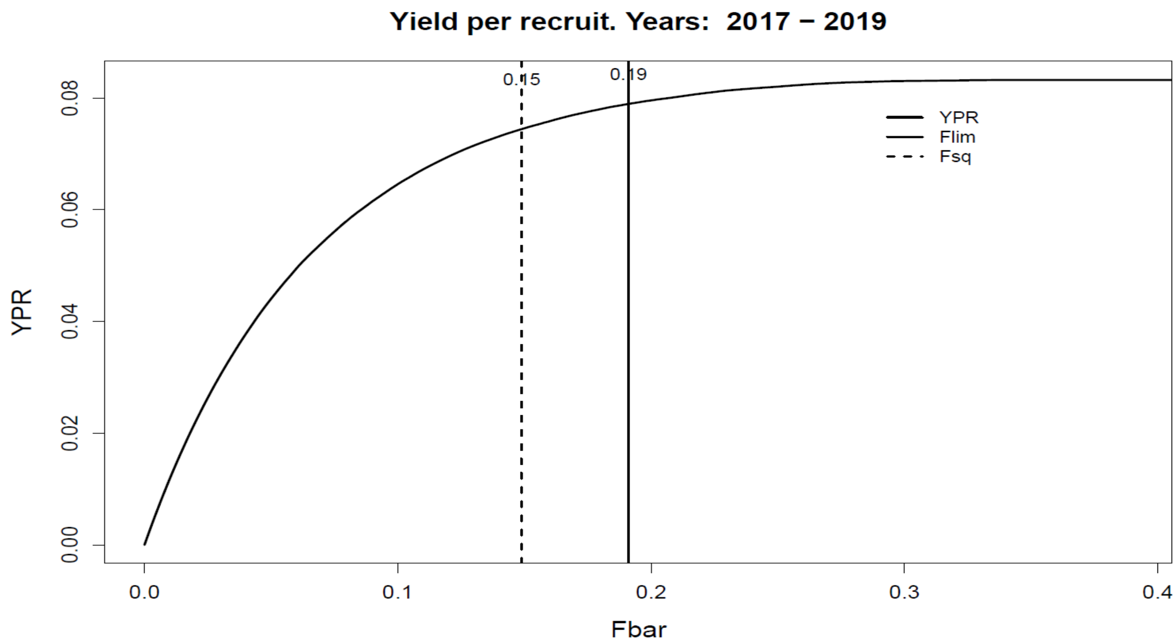



**Figure 26.** Yield per Recruit (2017-2019) versus $F_{bar}$. The values of $F_{lim}$ ($F_{30\%SPR}$)and $F_{statusquo}$ (mean F over 2017-2019) are indicated.

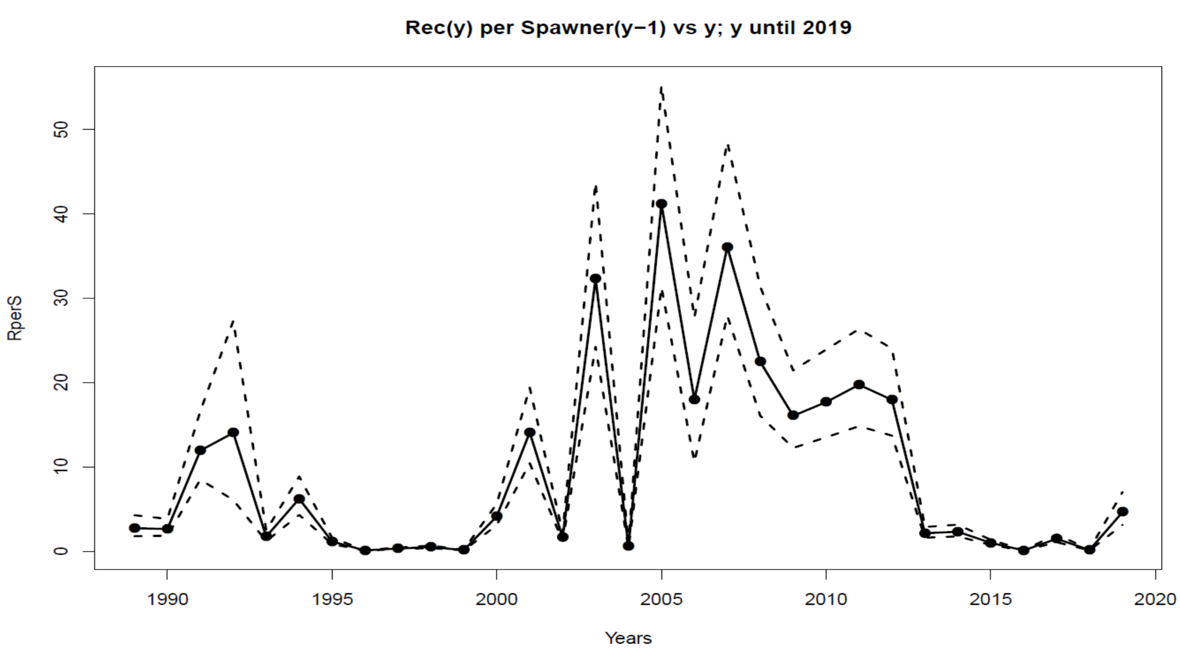



**Figure 27.** Estimated recruits (age 1) per spawner.

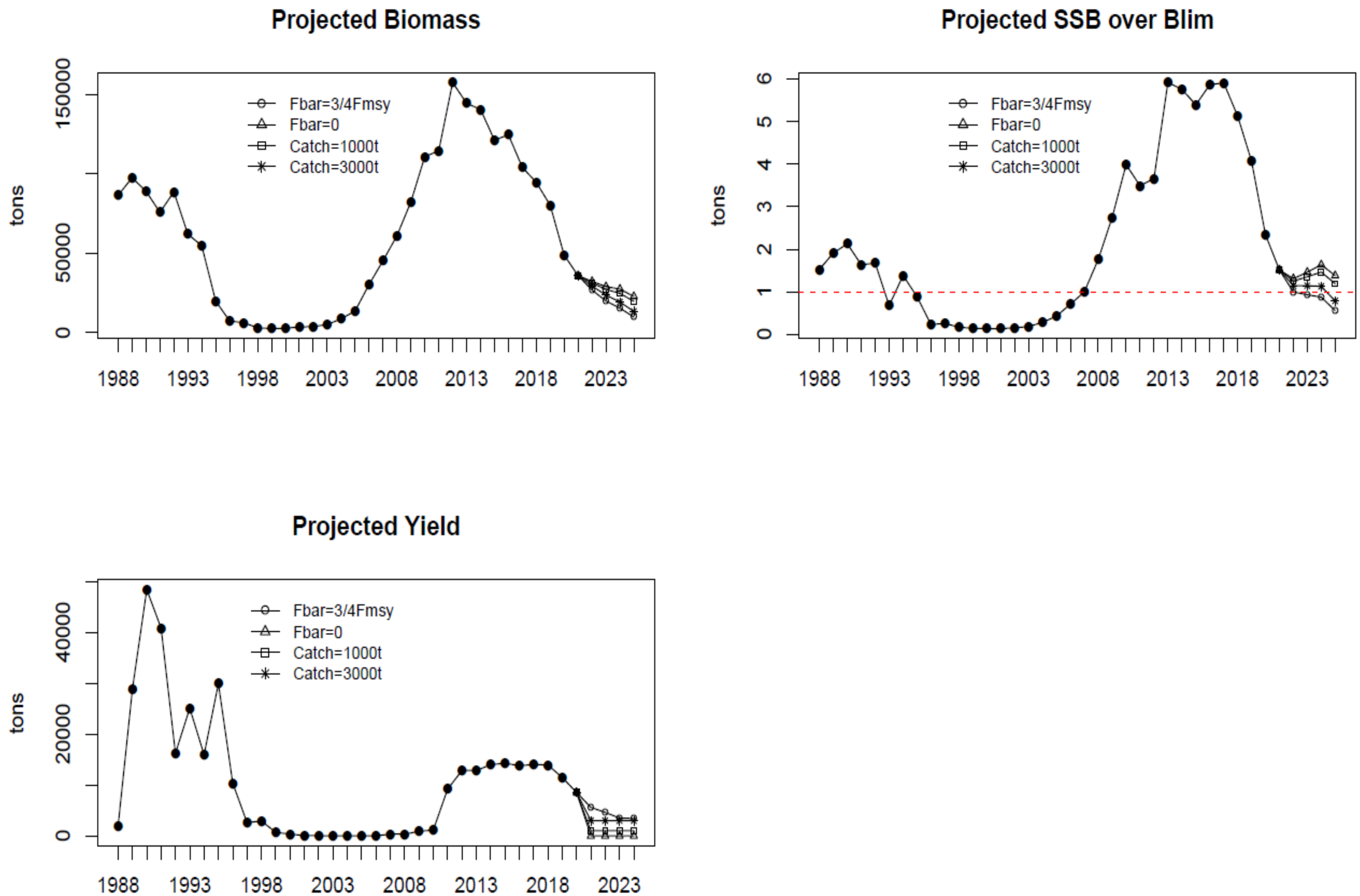



**Figure 28.** Projections for total Biomass, SSB/$B_{lim}$ and Yield with different scenarios.

**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. 2019) 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:

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

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

- *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:

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

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

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

4. **Fishing mortality is modeled 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 modeled 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 modeled 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