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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 was conducted using a Bayesian SCAA (statistical catch-at-age) model. The STACFIS catch estimates and the Flemish Cap survey indices were used to fit the model. SSB declined rapidly since 2017 but it has remained stable during the last 3 years and is estimated to be above B_{lim}. Since 2013, the recruitment has oscillated around intermediate levels, much lower than those observed in 2011-2012. Fishing mortality has remained below F_{lim} since the fishery reopened in 2010. F has generally decreased since 2019 and in 2022 is below F_{lim} with a high probability in the last 2 years.

Introduction

The 3M cod stock was under fishing moratorium from 1999 to 2009 following a decline to well below B_{lim} (Vázquez and Cerviño, 2005). The stock collapse has been attributed to three simultaneous circumstances: 1) overfishing, 2) increased catchability at low abundance levels and 3) a series of very poor recruitments starting in 1993. The relatively good recruitments observed after 2005 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 resulted in a very high stock biomass level in the 2011-2018 period; however, they have been followed by low recruitments and, as a consequence, a decrease in stock biomass.

Since 1974, when a TAC was established for the first time, estimated catches ranged from 48 000 tons in 1989 to 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 2009, almost coinciding with the fishing moratorium, yearly catches were below 1 161 tons. 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 established TACs for 2010-2022 ranged between the maximum of 17 500 tons in 2019 and the minimum of 1 500 tons in 2021, being of 4 000 tons for 2022. The STACFIS estimated catches for 2010-2022 were between 17 520 tons in 2019 and 2 055 tons in 2021, being 3 997 tons in 2022 (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 (NAFO, 2018b). 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 by age, 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 2022.

In 2020 the Commission adopted technical measures, in force since January 2021 (NAFO, 2021a), to try to protect the productivity of Division 3M cod stock. These measures included the closure of the directed fisheries of the 3M cod during the first quarter of the year, as well as the mandatory use of sorting grids in the cod directed trawl fishery.

Material and Methods

<u>Data used</u>

<u>Commercial data</u>

<u>Total Catch</u>

In 2022 the WG-CESAG estimated catch data was 3 997 tons (Table 1A, Figure 1). Information on cod catches from the following countries were available for the estimation in 2022: EU-Estonia, EU-Portugal, EU-Spain, Faroe Islands (Denmark), Norway and Russia.

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 (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 also periodically active. 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 (even years), except in 2021 when a longliner conducted the fishery. This causes the proportion of trawlers and longliners to be variable among the years, ranging between 16% and 53% (Table 1B).

<u>Length distributions</u>

In 2022 length sampling of catch was conducted by EU-Estonia (SCS 23/05REV), EU-Portugal (SCS 23/13), EU-Spain (SCS 23/06), Faroes (SCS 23/08) and Norway (Nedreaas, personal communication). Given the low level of Faroes commercial sampling (two samples), and that the Faroese survey catches are included in the total Faroese commercial catches, it was decided to use the samplings from the longline Faroes survey (Steingrund and Ridao-Cruz, 2023) together with the commercial ones to obtain the length distribution of the commercial Faroes catches. It was also decided not to use the commercial samples from Estonia since many of them represented only the retained or the bycatch catch and not the total catch. 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. The length frequency distributions in 2022 from the commercial catch by country and total and from the EU survey (González-Troncoso *et al.*, 2022) are shown in Figure 2A.

Table 1C shows the number of individuals measured as well as the length range, the mean and the mode for each of the countries with samples, for the total commercial length distribution and for the survey.

Figure 2B shows the total commercial length distribution for the last 5 years. The 2018-2020 length distributions are unimodal with a mode value fairly constant between 60-68 cm. In 2021-2022 the distributions are bimodal. In 2021 we have a main mode between 63-70 cm and a secondary mode, much weaker, between 45-50 cm. In 2022, the two modes are at the same level, one around 51-55 cm and another around 66 cm. The mean lengths (Figure 2C) in the 2017-2022 period was fairly constant between 60-68 cm.

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. An ALK was available for 2009-2011 only from the Portuguese fishery and was applied to the total commercial catch length distribution to derive the total age distribution of the commercial catches.

Since 2012 the ALK from the EU survey has been used for both commercial and survey indices, although some years ALK from the Portuguese and/or the Spanish catches were available. The reason not to use the commercial ALKs to the commercial distribution is that these commercial ALKs have not been validated and more research is needed to completely identify the source of discrepancies observed. ALKs from the 2021 and 2022 Faroese survey (Steingrund and Ridao-Cruz, 2023) and from the 2022 Norwegian commercial catches (Nedreaas, personal communication) are available, but they are not still validated.

Catch-at-age

Catch-at-age in numbers is presented in Table 2. These numbers were obtained by applying the trawl EU survey ALK to the total commercial catch length distribution.

The ages in the catch range 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. Catch proportions at age over time (Figure 3) indicate that the bulk of the catch was comprised of 3-5 years age cod until 2015, although between years 2006 and 2014 the catches contained mostly age 3 and 4 individuals; in the period 2015-2022, ages 5 to 8+ were the most dominant 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. The 2009-2011 cohorts can be easily followed, reaching age 8+ in 2019. The cohorts from 2012 were very poor. As a consequence, since 2015 all the values of the ages less than 4 are negative, except age 4 in 2022. It is remarkable the big catch at age 6 in 2019, age 7 in 2020, that corresponds to the 2013 cohort, that was the first of the weak cohorts, and that had never appeared before 2019. It appears in 2021 as 8+ too, but it is difficult to track the origin of those ages as it is an aggregated group. 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. And the 2014 cohort, that was negative until age 5 in 2019, age 6 in 2020 and age 7 in 2021. The 2016 cohort is positive for the first time at age 5 in 2021, and is quite large in 2022 at age 6.

Mean weight-at-age

For 2022, mean weight-at-age has been computed using length-weight relationships from the commercial sampling. For this year, there are five commercial length-weight relationships available: EU-Estonia, EU-Portugal, EU-Spain, Faroes (commercial and survey) and Norway. All of them are presented in Figure 4 besides the 2022 EU survey one. The Estonia relationship may not be representative of the total catches due to the issues outlined above. The EU-Spain relationship gives the highest weight for the higher lengths. The EU survey gives the lowest weights for higher lengths for trawlers, and the Faroese ones (commercial + survey) for all the samples. As Portugal had the biggest sample size for the commercial catches, its length-weight relationship was applied to the commercial data to calculate the mean weight-at-age in the catch.

Mean weight-at-age for 1988-2022 is showed in Table 3 and Figure 5. In the period 2007-2018 there is a general decrease in the trend of the mean-weight for the ages older than 2, especially since 2010. In 2020, an increase in the average weights of almost all ages was observed and since then it has fluctuated around those levels.

The SoP (sum over ages of the product of catch weight-at-age and numbers at age) for the commercial catch differs around 1% from the estimated total catch in 2022.

EU survey data

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 (Vázquez *et al.*, 2014). 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 1988-2022 are presented in González-Troncoso *et al.* (2023).

The survey abundance indices and the total biomass are presented in Table 4. Figure 6 displays the estimated survey biomass and abundance indices over time. Biomass showed a high increase since 2005, following an extremely low period starting in the mid 1990's. Since 2009 biomass is higher than the level of the first years of the assessment (was approximately twice the mean of the EU series until 2017), reaching the maximum of the series in 2014. This high biomass is due to a big increase in the number of individuals of 3 and 4 years old, those from the 2010-2011 cohorts. Since 2014, a general decreasing trend is observed, to levels previous to the collapse. The abundance follows a similar trend until the reopening of the fishery. The increase in abundance is more gradual until 2009, followed by a sharped increase until 2011, when the maximum of the series is reached. This large abundance in 2011 is due to a big presence of individuals of age 1. The maximum was followed by a sharped decline until 2016, when values lower than those observed in the precollapse period were reached. This low level has remained stable since then.

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. Also, since 2015 to 2018 the failure of recruitment can be observed, mainly in 2016. Cohorts recruited from 2005 to 2014 appear to be above average. In 2010-2012 good recruitments can be seen, especially in 2011, leading to two reasonably good cohorts. In 2021, good signals of recruitment can be seen, being at the level of the 2006 recruitment, that allowed the recovery of the stock. Recruitment in 2022 is weaker, but it is still above the mean. Note that the values of the EU survey since 2020 are all positive. Even ages corresponding to the bad recruitments in 2015-2018 are positive.

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 for ages 1 to 5, until 2009 for age 6 and until 2010 for age 7, being much higher than at the beginning of the series. Since then a deceasing trend was observed for all age groups, being very steep in some cases, until 2017 for ages 1 to 5 and until 2019 for ages 6, 7 and 8+. 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 decrease was followed by a general slight increase, although in younger ages (2-3), continues the decrease by 2022. It should be noted that the trends of the average weights of the commercial catches and those of the survey in recent years are slightly different.

Maturity at age

Maturity ogives are available from the EU survey for years 1990-1998, 2001-2006 and 2008-2022. 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 generally decreased since 2002 to 2016, especially in 2004 and 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. Since then, an oscillating increase has been observed.

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 from 2005 to 2016, remaining since then quite stable around 5 years old with ups and downs.

Faroes survey

Faroes started in 2021 a survey in a commercial vessel with a longline gear with approximately 4 000 hooks in 2022 (Steingrund and Ridao-Cruz, 2023). The objective of the survey was to cover as much as possible the distribution of cod in Division 3M with an alternative fishing gear and contrasts the results with those of the EU groundfish survey and the potential inclusion in the assessment of 3M cod in the future. In 2022, the survey covered depths ranging from 130 m to 450 m on the Flemish Cap with 54 longline sets, but due to operational limitations the eastern area of 3M was not surveyed.

Cod dominated the catch and the overall catch rate of cod was extremely high, 1 018 grams per hook. Biological samples were also taken: individual length, weight and otoliths measurements were collected. An ALK was derived from the samples, ranging from 3 to 10+ years old.

Some problems were raised with regards the methodology of this survey (NAFO, 2021b, 2022). Nevertheless those problems, as only two years of data are available, it was not used in the assessment as a survey input. Moreover, given that the Faroese survey catches are included in the total Faroese commercial catches, it was decided to use the biological samplings from the longline Faroes survey together with the commercial ones to get the Faroese commercial biological indices.

If the methodology problems are solved and the survey is continued, the indices would be used in the assessment model in a future.

Assessment methodology

A Bayesian SCAA model was fitted to the data. Ages are from 1 to A+=8+ and years are from 1988 to 2022. The cohorts are modelled forward 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), 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 35 years, from 1988 to 2022

Catch in tonnes in all years; years with catch-at-age: 1988-2001, 2006-2022

Tuning with EU survey for 1988 to 2022

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* = 45 000, *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 years retrospective analysis was made. Two years projections were made with 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 below.

Results

Assessment results regarding total biomass, SSB, recruitment and F_{bar} (ages 3-5) are presented in Table 7 and Figure 10. SSB in 2023 was calculated using the numbers estimated by the assessment at the beginning of 2023, applying the 2022 maturity ogive and mean weight at age in stock values.

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 since 2020 the biomass remains stable below the level at the beginning of the series.

The results for SSB indicate that there was a substantial increase in SSB from 2007. Between 2013 and 2017 the SSB was stable. A substantial decrease since 2018 is displayed, being since 2021 at the level of the beginning of the series, but it is still above B_{lim}. The high values of SSB in the period 2013-2017 were probably due to the strong 2009-2011 year classes.

Recruitment had an increasing trend from 2005 to 2012, being above the average recruitment of the period between 2007 and 2012. The 2010-2012 values are the highest of the series. Since 2013, the recruitment has oscillated around intermediate levels, much lower than those observed in 2011-2012.

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 slightly below F_{lim}. Fishing mortality remained at such level until 2021, when it decreased again. Table 8 and Figure 11 provide more detailed information on the estimated F-at-age values. With the reopening of the fishery, the F-at-age increased for all the ages, and with the age. In 2022, the F has increased in all ages above 3 with respect to 2021. Figure 12 shows the median PR and its confidence intervals for the entire period, calculated as the ratio of fishing mortalities to F_{bar}, and Figure 13A the median PR for the last five years together for comparative purposes. Figure 13B shows the 2022 PR, the mean of the last three years (2020-2022) PR, and the mean PR of the last two years (2021-2022), in which the technical measures (the temporary closure during the first quarter of the year and the mandatory use of sorting grids in the trawl cod fishery) have been implemented. It is remarkable that for the period 2018-2021, age 6 was the most caught age, especially in 2021, while in 2022 the PR returns to a shape observed before that period, in which the PR increases with the age, being 7 the most caught age. The mean PRs of the last three years and the last two years are different to the 2022 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 2019 and 2020, the level of f is similar to that in 1999, decreasing in 2021 and 2022. 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 bycatches of other fisheries. Age 4 shows a general decreasing trend for the period, with a local sharp increase after 2018. Ages 6 and 7 show a general increasing trend since 2000, with a slight decrease in age 6 in 2022.

Figure 15 shows total biomass and abundance by year, as well as the mean of both indices in all the series. In general, there is a good concordance between biomass and abundance trends until 2020, with an increase between 2005 and 2012 followed by a decrease. Since 2020 the biomass remained stable while the abundance continues showing ups and downs. These is probably due to the variability of the recruitment and the decrease of the older cohorts. The biomass is below the mean biomass of the series since 2020, while the abundance is below the mean abundance of the series since 2015.

Estimates of stock abundance at age for 1988-2022 are presented in Table 9 and Figure 16. 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 since 2018), followed by the 2011 cohort (reaching 8 years old in 2019). Since those cohorts, all the numbers at age have remained unstable, with ups and downs around intermediate levels. It is remarkable the big value of ages 6+ in 2014-2016, which is the driver to the huge increase in the SSB in those years. Intermediate levels of recruitment since 2013 translate in intermediate abundance in ages 2-5 since then, which led to the decrease in the SSB since 2016.

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 updated posterior numbers are higher than the prior median.

In Figure 19, observed versus estimated total catches by year are presented. 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 2 to 5, the posterior median of M is lower 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.

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+.

<u>Biological Referent Points</u>

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 14 755 tons, and an 80% confidence interval between 13 180 and 17 082 tons (Table 7). The median value is displayed in Figure 23, showing that this value is rather consistent. SSB is above B_{lim}.

Figure 24 shows the SSB-F_{bar} scatter plot. F_{lim} for this stock was estimated based on $F_{30\%SPR}$ calculated with the mean 2020-2022 data as 0.157, not a big update from the last assessment value (0.167). The period 2020-2022 was chosen due to the rapid change in biological parameters in the stock.

Figure 25 shows the Yield per Recruit versus F_{bar} curve calculated with the data of years 2020-2022 as well as the value of F_{lim} and $F_{statusquo}$ (defining the latter as the mean fishing mortality over 2020-2022).

<u>Retrospective pattern</u>

A retrospective analysis of five years was made (Figure 26). The analysis shows revisions in the recruitment, mainly regarding the highest values of recruitment in years 2011 and 2012. This downwards revision of the 2011-2012 recruitment estimates results in a downwards revision of the total biomass and SSB in the following years, from 2013 to 2017. There is very little evidence of a retrospective pattern in F, although the 2018 and 2019 values were revised downwards. No directional patterns in retrospective analysis are evident in recent years.

<u>Recruits per Spawner</u>

Figure 27 displays the Recruits per Spawner. The variability over the years of the assessment is very high. Between 2007 and 2013 a decreasing trend can be seen. Since then, it remained at low values showing a slightly increasing trend, except for 2021, when the value was quite high, at the 2012 level.

<u>Projections</u>

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 for two years, from 2023 to the start of 2026, were conducted. Only two years are presented due to the high uncertainty in the parameters of the stock. 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 2023: estimated from the assessment.

Recruitments for 2023-2026: Recruits per spawner were drawn randomly from 2019-2021 (corresponding to the recruitment of 2019-2021 and number of matures of 2018-2020). The 2022 value of recruits per spawner was omitted due to uncertainty in estimating the recruitment.

Maturity ogive for 2023-2026: Mean of the last three years (2020-2022) maturity ogive.

Natural mortality for 2023-2026: Natural mortality from the 2022 assessment results.

Weight-at-age in stock and weight-at-age in catch for 2023-2026: Mean of the last three years (2020-2022) weight-at-age.

PR at age for 2023-2026: Last year (2022) PR. Due to the different shape of the 2022 PR with regards to last years (2018-2021), it was decided to use the last year PR in the projected years.

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

(Scenario 1) F_{bar} =0 (no catch).

(Scenario 2) F_{bar} = F_{2022} (median value = 0.038).

(Scenario 3) F_{bar} = F_{sq} (median value = 0.053).

(Scenario 4) F_{bar} =1/2 F_{lim} (median value = 0.078).

(Scenario 5) F_{bar} =2/3 F_{lim} (median value = 0.104).

(Scenario 6) F_{bar} =3/4 F_{lim} (median value = 0.117).

(Scenario 7) F_{bar} =F_{lim} (median value = 0.157).

All scenarios assumed that the Yield for 2023 is the established TAC (4 000 t).

Results for the seven options are presented in Tables 11a-17b and Figure 28. They indicate that, under all scenarios with $F_{bar}\leq 2/3F_{lim}$, total biomass during the projected years will increase, whereas the SSB is projected to increase in 2025 except with $F=F_{lim}$. The probability of SSB being below B_{lim} is very low (≤1%) in all the scenarios and projected years. The probability of SSB in 2025 being above that in 2023 ranges between 14% and 100%, depending on the scenario.

Under all scenarios, the probability of F_{bar} exceeding F_{lim} is less than or equal to 2% in 2024.

To note that projections of risk, in particular more than one year ahead (Tables 12-17b), will inherently include more uncertainty than projected median stock sizes (Tables 12-17a). The risks are typically derived from the tails of a probability distribution which are less precisely estimated compared to the median (centre) of the same distribution.

References

Cerviño, S. and A. Vázquez, 2003. Re-opening criteria for Flemish Cap cod: a survey-based method. NAFO SCR Doc. 03/38, Serial No. N4856.

Fernández, C., S. Cerviño and A. Vázquez, 2007. A Survey-based assessment of cod in division 3M. NAFO SCR Doc. 07/39, Serial No. N5526.

Fernández, C., S. Cerviño and A. Vázquez, 2008. Assessment of the Cod Stock in NAFO Division 3M. NAFO SCR Doc. 08/26, Serial No. N5391.

Fernández, D. González-Troncoso, F. González-Costas, C. Hvingel, R. Alpoim, S. Cerviño, M. Mandado and A. Pérez, 2017. Cod 3M Projections: risk estimation and inputs NAFO SCR Doc. 17/17, Serial No. N6669.

González-Costas, F., G. Ramilo, E. Román, J. Lorenzo, D. González-Troncoso, M. Sacau, P. Durán, J.L. del Río and R. Blanco, 2023. Spanish Research Report for 2022. NAFO SCS Doc. 23/06, Serial No. N7380.

González-Costas, F., D. González-Troncoso, A. Ávila de Melo and R. Alpoim, 2018. 3M cod assessment input data. NAFO SCR Doc. 18/001, Serial No. N6778

González-Troncoso, D. and J. M. Casas, 2005. Calculation of the calibration factors from the comparative experience between the R/V *Cornide de Saavedra* and the R/V *Vizconde de Eza* in Flemish Cap in 2003 and 2004. SCR Doc. 05/29, Serial No. N5115.

González-Troncoso, D., S. Rábade, J.M. Casas Sánchez, I. Garrido, , M. Fabeiro, E. Román, and Ricardo Alpoim, 2023. Results from Bottom Trawl Survey on Flemish Cap of June-July 2022. NAFO SCR Doc. 23/003, Serial No. N7381.

Näks, L., 2023. Estonian research report for 2022. NAFO SCS Doc. 23/05REV, Serial No. N7378.

NAFO, 2018a. Report of the review of input data for 3M cod benchmark assessment. NAFO SCS Serial Doc. 18/04, Serial No. N6783.

NAFO, 2018b. Report of the 3M cod benchmark assessment. NAFO SCS Serial Doc. 18/18, Serial No. N6841.

NAFO, 2019. Report of the NAFO Scientific Council Flemish Cap (NAFO Div. 3M) Cod Stock Management Strategy Evaluation (MSE). NAFO SCS Doc. 19/04, Serial No. N6911.

NAFO, 2021a. Conservation and Enforcement Measures 2021. NAFO/COM Doc. 21-01. Serial No. N7153.

NAFO, 2021b. Report of the Scientific Council meeting 20 - 24 September 2021 by WebEx. NAFO SCS Doc. 21/17, Serial N0. N7249.

NAFO, 2022. Report of the Scientific Council Meeting 03 -16 June 2022 in Halifax, Nova Scotia. NAFO SCS Doc. 22/18, Serial No. N7322.

Ridao-Cruz, L., 2023. Faroese Research Report for 2022. NAFO SCS Doc. 23/08, Serial No. N7383.

Ridao Cruz, L. and P. Steingrund, , 2023. Survey results of the longline survey on NAFO Division 3M. NAFO SCR Doc. 23/004. Serial No. N7384.

Vargas J. and R. Alpoim, 2023. Portuguese research report for 2022. NAFO SCS Doc. 23/13, Serial No. N7393.

Vázquez, A. and S. Cerviño, 2005. A review of the status of the cod stock in NAFO division 3M. NAFO SCR Doc. 05/38. Serial No. N5124.

Vázquez, A., J. Miguel Casas and R. Alpoim. 2014. Protocols of the EU bottom trawl survey of Flemish Cap. Scientific Council Studies, 46: 1–42. doi:10.2960/S.v46.m1.

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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 2022 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	9192	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	1232		3124	1198		1336			72	13339
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	4371			1643			1607	17381
2020	8458	4234	545	477		2263			786			204	8509
2021	2055	571	92	86		961			138			73	1921
2022	3997												

[1] Recalculated from NAFO Statistical data base using the NAFO 21A Extraction Tool. No estimates available for 2022.
[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	2020	2021	2022
Total catch	9192	9794	9003	13985	14290	13785	14023	13928	6447	17520	8458	2055	3997
Total trawler	9192	9794	9003	10095	12034	10125	10208	10762	4210	12968	5416	961	2338
Total longliner	0	0	0	3889	2256	3659	3814	3166	3166	4552	3042	1094	1658
% longliner	0	0	0	28	16	27	27	23	49	26	36	53	41

Table 1C. Summary of the length distributions in 2022 of each country with samples, the total commercial and the survey.

Country	EU-Estonia	EU-Portugal	EU-Spain	Faroes	Norway	Total commercial	Survey
Number of sampled individuals	1086	1718	2878	1875	4622	10304	3223
Gear	Trawl	Trawl	Trawl	Longline	Longline		Trawl
Range (cm)	42-116	42-114	31-106	34-127	36-140	31-140	11-142
Mean (cm)	--	60	60	70	75	63	40
Mode (cm)	--	66	73	55	73	51	27

Table 1D. Mean and mode length of the total commercial and the survey length distribution for 2010-2022.

	Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Mean	Commercial	57	59	59	51	53	54	56	64	64	61	64	68	63
	Survey	30	21	30	34	44	46	49	52	55	42	41	36	40
Mode	Commercial	54	54	54	42	51	54	39	63	63	60	63	66	51
	Survey	18	15	18	24	33	42	36	42	54	21	33	45	27

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
2020	0	0	41	541	440	734	616	687
2021	0	1	14	60	134	70	90	240
2022	0	0	2	396	315	380	80	365

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
2020	0.078	0.266	0.735	1.346	1.843	2.551	2.991	4.636
2021	0.062	0.264	0.772	1.147	2.284	2.751	3.452	5.283
2022	0.062	0.234	0.475	1.160	1.619	2.587	3.268	4.804

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	1742	5208	311	3301	5688	400	1470	1970	832	125	30	14	8	0	0	0	0	8	33002	42460
2020	7063	5008	24696	13732	5593	4271	3326	675	623	938	573	140	47	14	39	0	0	8	0	66744	67130
2021	18966	9031	9263	19122	3958	943	1064	1040	283	562	639	192	29	36	0	7	0	0	0	65149	51501
2022	3871	16954	14132	19178	7043	2525	514	1248	496	206	380	498	119	34	7	0	0	0	0	67204	62206

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
2020	0.054	0.209	0.364	1.015	1.667	2.470	2.982	4.703
2021	0.045	0.188	0.665	0.842	1.604	2.428	3.134	5.021
2022	0.046	0.150	0.294	1.067	1.500	2.610	3.532	4.981

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	0.052	0.097	0.172	0.286	0.437	0.599	0.742	0.877	5.38
1990	0.052	0.097	0.172	0.286	0.437	0.599	0.742	0.877	5.38
1991	0.022	0.052	0.114	0.244	0.460	0.660	0.812	0.931	5.17
1992	0.002	0.010	0.046	0.180	0.498	0.817	0.953	0.992	5.00
1993	0.000	0.006	0.047	0.279	0.749	0.958	0.994	0.999	4.47
1994	0.000	0.001	0.049	0.654	0.986	0.999	0.999	0.999	3.82
1995	0.000	0.000	0.005	0.801	0.999	0.999	1.000	1.000	3.79
1996	0.000	0.000	0.028	0.665	0.993	0.999	0.999	1.000	3.84
1997	0.000	0.007	0.109	0.670	0.971	0.998	0.999	0.999	3.75
1998	0.000	0.001	0.087	0.872	0.997	0.999	0.999	1.000	3.55
1999	0.000	0.000	0.118	0.896	0.999	0.999	1.000	1.000	3.45
2000	0.000	0.000	0.156	0.970	0.999	0.999	1.000	1.000	3.35
2001	0.000	0.000	0.270	0.997	0.999	1.000	1.000	1.000	3.15
2002	0.000	0.009	0.633	0.996	0.999	0.999	1.000	1.000	2.90
2003	0.000	0.021	0.514	0.979	0.999	0.999	0.999	1.000	2.99
2004	0.000	0.000	0.092	0.966	0.999	0.999	1.000	1.000	3.41
2005	0.038	0.164	0.500	0.830	0.959	0.991	0.998	0.999	3.00
2006	0.000	0.013	0.354	0.958	0.998	0.999	0.999	1.000	3.16
2007	0.000	0.012	0.266	0.917	0.997	0.999	0.999	0.999	3.32
2008	0.000	0.011	0.231	0.883	0.994	0.999	0.999	0.999	3.37
2009	0.000	0.009	0.180	0.829	0.990	0.999	0.999	0.999	3.49
2010	0.000	0.008	0.164	0.810	0.989	0.999	0.999	0.999	3.53
2011	0.000	0.007	0.070	0.424	0.876	0.985	0.998	0.999	4.14
2012	0.000	0.000	0.016	0.571	0.991	0.999	0.999	1.000	3.94
2013	0.003	0.035	0.283	0.802	0.977	0.997	0.999	0.999	3.40
2014	0.000	0.003	0.044	0.396	0.901	0.992	0.999	0.999	4.16
2015	0.000	0.000	0.004	0.112	0.789	0.991	0.999	0.999	4.60
2016	0.000	0.000	0.003	0.045	0.387	0.891	0.990	0.999	5.18
2017	0.000	0.000	0.000	0.017	0.828	0.999	0.999	1.000	4.72
2018	0.000	0.000	0.007	0.067	0.425	0.879	0.986	0.999	5.13
2019	0.000	0.000	0.005	0.083	0.615	0.966	0.998	0.999	4.84
2020	0.000	0.000	0.002	0.041	0.401	0.908	0.993	0.999	5.15
2021	0.000	0.002	0.017	0.117	0.498	0.883	0.982	0.998	5.00
2022	0.000	0.000	0.007	0.109	0.655	0.966	0.997	0.999	4.76

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	83131	78951	88092	22632	19217	27014	58069	45546	75332	0.535	0.492	0.583
1989	94016	89364	99199	28515	24287	33619	116399	90517	152437	0.641	0.594	0.688
1990	86399	82229	91195	31778	27966	35791	105553	81994	137392	0.754	0.701	0.806
1991	72462	66892	78651	24250	21321	27536	355170	279954	456638	0.452	0.410	0.491
1992	86077	80083	92237	24850	22503	27881	291397	228540	375578	1.444	1.350	1.543
1993	60810	57201	64817	10167	8989	11497	19178	15255	24668	0.982	0.914	1.063
1994	53566	50599	57018	20804	18458	23534	35348	28253	46029	1.392	1.311	1.472
1995	19326	18211	20500	13233	12221	14320	14653	11521	18963	1.336	1.252	1.420
1996	7069	6675	7494	3478	3161	3807	894	695	1181	0.491	0.448	0.537
1997	6013	5673	6384	3875	3574	4198	772	610	1020	0.967	0.888	1.040
1998	2897	2669	3163	2518	2299	2763	1297	1022	1687	0.349	0.306	0.393
1999	2318	2082	2595	2061	1850	2340	200	153	266	0.226	0.197	0.264
2000	2549	2280	2891	1983	1750	2280	3654	2810	4825	0.069	0.058	0.082
2001	3233	2898	3638	1981	1763	2264	8486	6674	11166	0.081	0.065	0.102
2002	3533	3207	3913	2248	2020	2524	802	616	1041	0.021	0.018	0.025
2003	4615	4194	5183	2668	2414	2943	22402	17404	29301	0.006	0.005	0.007
2004	8057	7318	8989	4090	3727	4481	670	529	872	0.002	0.002	0.002
2005	12412	11247	13996	6236	5590	6966	48454	38265	63468	0.002	0.002	0.002
2006	27533	24878	31194	10304	9491	11371	78832	62848	102712	0.056	0.049	0.064
2007	41744	38172	45958	14755	13180	17082	106971	85148	140249	0.015	0.013	0.017
2008	56557	52563	61410	25617	23664	27732	94422	74576	123507	0.029	0.025	0.032
2009	76414	71348	82719	39993	37287	43204	134279	105845	171106	0.021	0.019	0.024
2010	102715	96129	110797	58518	54374	63341	228006	181144	297122	0.134	0.120	0.148
2011	105265	98413	113734	51228	47488	55257	359470	288964	468541	0.147	0.130	0.165
2012	141172	130400	153836	53313	49294	57942	285778	226007	368484	0.102	0.091	0.115
2013	131050	122298	140556	83771	77454	91157	42066	32602	55330	0.106	0.093	0.118
2014	128560	120175	137917	81329	74815	88781	131017	103447	169757	0.082	0.072	0.093
2015	111491	104227	119629	75336	69075	82012	53835	42640	70679	0.093	0.082	0.105
2016	114666	106944	123449	80531	73754	88547	12482	9726	16259	0.095	0.083	0.108
2017	96660	89727	104948	79854	73421	87789	73375	57218	94907	0.053	0.047	0.061
2018	91619	85294	99523	69012	63356	76162	33057	25969	43875	0.076	0.066	0.086
2019	80297	74343	87296	57129	52381	62656	99585	75995	133371	0.143	0.127	0.163
2020	53925	49195	58908	35155	31408	39409	46423	35741	63408	0.101	0.088	0.116
2021	53456	48474	58933	27600	24376	31225	146714	106179	202840	0.021	0.018	0.024
2022	51578	47036	56369	29545	26684	32843	47975	33521	68668	0.038	0.032	0.044

Table 8. F at age (posterior median).

	F at age							
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**
1988	0.000	0.018	0.348	0.604	0.648	0.653	0.787	0.787
1989	0.000	0.011	0.370	0.808	0.735	0.784	0.868	0.868
1990	0.000	0.018	0.393	0.943	0.924	1.219	1.048	1.048
1991	0.000	0.023	0.308	0.493	0.548	0.564	0.678	0.678
1992	0.000	0.147	1.021	1.515	1.793	1.429	1.974	1.974
1993	0.000	0.087	0.694	1.166	1.090	1.530	0.862	0.862
1994	0.000	0.198	1.021	1.762	1.385	1.347	0.990	0.990
1995	0.000	0.196	0.574	1.532	1.897	2.351	2.177	2.177
1996	0.000	0.050	0.260	0.511	0.698	0.923	0.813	0.813
1997	0.000	0.118	0.609	0.888	1.389	2.056	1.835	1.835
1998	0.000	0.047	0.216	0.342	0.487	0.570	0.423	0.423
1999	0.000	0.026	0.247	0.191	0.238	0.240	0.088	0.088
2000	0.000	0.005	0.136	0.027	0.043	0.033	0.011	0.011
2001	0.000	0.008	0.148	0.037	0.056	0.040	0.014	0.014
2002	0.000	0.002	0.037	0.011	0.016	0.011	0.005	0.005
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	0.080	0.040	0.046	0.032	0.028	0.028
2007	0.000	0.000	0.011	0.016	0.018	0.017	0.024	0.024
2008	0.000	0.002	0.015	0.031	0.040	0.036	0.030	0.030
2009	0.000	0.001	0.008	0.026	0.030	0.029	0.033	0.033
2010	0.000	0.011	0.073	0.135	0.192	0.192	0.213	0.213
2011	0.000	0.012	0.094	0.116	0.229	0.277	0.378	0.378
2012	0.000	0.007	0.064	0.081	0.160	0.203	0.299	0.299
2013	0.000	0.007	0.071	0.082	0.163	0.217	0.286	0.286
2014	0.000	0.003	0.037	0.094	0.114	0.176	0.237	0.237
2015	0.000	0.003	0.051	0.092	0.135	0.212	0.242	0.242
2016	0.000	0.003	0.040	0.108	0.136	0.160	0.238	0.238
2017	0.000	0.001	0.016	0.047	0.096	0.168	0.212	0.212
2018	0.000	0.002	0.021	0.056	0.149	0.290	0.229	0.229
2019	0.000	0.001	0.036	0.117	0.276	0.548	0.396	0.396
2020	0.000	0.001	0.011	0.091	0.201	0.405	0.289	0.289
2021	0.000	0.000	0.001	0.020	0.042	0.100	0.082	0.082
2022	0.000	0.000	0.001	0.039	0.073	0.150	0.184	0.184

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	58069	139099	94203	29623	4248	950	702	280	328374	44872
1989	116399	15531	75134	47232	12726	1708	338	311	270403	41383
1990	105553	31162	8406	36785	16485	4695	536	188	204316	31623
1991	355170	28118	16759	4034	11278	5074	961	179	420927	21276
1992	291397	94106	15028	8710	1927	5035	1990	409	418633	11465
1993	19178	77914	44528	3834	1492	250	838	237	148976	6150
1994	35348	5132	39050	15831	936	390	37	319	97626	14073
1995	14653	9473	2305	9951	2126	181	70	88	39068	10489
1996	894	3921	4254	920	1694	247	12	12	11982	2703
1997	772	238	2040	2333	433	653	68	7	6550	2945
1998	1297	206	115	784	750	83	58	9	3320	1602
1999	200	348	108	66	437	357	32	31	1587	947
2000	3654	54	185	60	43	267	195	40	4503	649
2001	8486	977	29	114	45	32	178	164	10004	548
2002	802	2276	531	18	87	33	21	233	4023	757
2003	22402	214	1248	362	14	66	23	168	24427	1303
2004	670	5974	117	875	284	11	46	127	8122	1329
2005	48454	180	3279	83	686	220	7	117	53255	4626
2006	78832	13064	98	2320	65	530	152	82	95242	3317
2007	106971	21117	7166	64	1759	48	357	159	138158	4676
2008	94422	28750	11535	5015	50	1334	33	353	141862	9323
2009	134279	25307	15671	8099	3832	37	890	248	188759	14886
2010	228006	35476	13836	11083	6208	2884	25	780	298629	21555
2011	359470	61045	19394	9136	7594	3967	1639	428	464552	18686
2012	285778	95852	33065	12477	6385	4683	2076	1003	441864	21913
2013	42066	76066	51881	22072	9034	4219	2651	1598	210266	52674
2014	131017	11202	41245	34560	15961	5965	2343	2216	245077	40612
2015	53835	35001	6119	28320	24663	11030	3455	2494	165910	39826
2016	12482	14475	19058	4156	20273	16704	6156	3235	96667	32342
2017	73375	3318	7895	13041	2923	13764	9817	5169	129846	31370
2018	33057	19634	1818	5538	9761	2058	8008	8478	88958	22714
2019	99585	8885	10689	1261	4105	6535	1063	9011	141688	19125
2020	46423	26637	4835	7356	885	2406	2606	4507	96417	9977
2021	146714	12553	14649	3398	5282	561	1107	3620	188887	8685
2022	47975	39193	6924	10312	2624	3931	351	2939	115986	10081.5

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	1.31	0.60	0.34	0.24	0.25	0.37	0.33	0.42

Table 11a. 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
2023	44615	12838	21393	4889	7797	1889	2339	1809	99284	10683
2024	48541	11664	7018	15157	3613	5402	1040	2157	111005	11609
2025	52161	12529	6421	5023	11906	2802	3758	2172	116028	15414
2026	66696	13365	6847	4559	3950	9261	1940	4136	133522	17606

Table 11b. Projections results (median and 80% CI) with F_{bar}=0.

Year	Total Biomass		SSB		P(SSB<B_{lim})	P(SSB_{26} >SSB_{23})	Yield	P(F>F_{lim})
2023	53812	(47944 - 61013)	27709	(24790 - 30794)	<1%		6100	<1%
2024	58438	(51161 - 68867)	30747	(27207 - 34601)	<1%	100%	0	<1%
2025	65890	(56510 - 78568)	39660	(34924 - 44681)	<1%		0	<1%
2026	77315	(63756 - 94791)	52118	(45332 - 59308)	<1%			

Table 12a. N-at-age in prediction years (medians) with F_{bar}=F_{sq}=0.053 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2023	44615	12838	21393	4889	7797	1889	2339	1809	99284	10683
2024	48541	11664	7018	15157	3613	5402	1040	2157	111005	11609
2025	52161	12529	6420	5018	11216	2522	3030	1671	113941	13584
2026	58603	13365	6845	4552	3719	7884	1414	2521	121323	14086

Table 12b. Projections results (median and 80% CI) with F_{bar}=F_{sq}=0.053.

Year	Total Biomass		SSB		P(SSB<B_{lim})	P(SSB_{26} >SSB_{23})	Yield	P(F>F_{lim})
2023	53812	(47944 - 61013)	27709	(24790 - 30794)	<1%		6100	<1%
2024	58438	(51161 - 68867)	30747	(27207 - 34601)	<1%	100%	6509	<1%
2025	59324	(50003 - 72050)	33696	(29110 - 38825)	<1%		6788	<1%
2026	63225	(49978 - 80741)	39206	(32587 - 46263)	<1%			

Table 13a. N-at-age in prediction years (medians) with F_{bar}=F_{2023}=0.058 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2023	44615	12838	21393	4889	7797	1889	2339	1809	99284	10683
2024	48541	11664	7018	15157	3613	5402	1040	2157	111005	11609
2025	52161	12529	6420	5018	11164	2498	2965	1632	113755	13437
2026	57854	13365	6844	4551	3699	7764	1370	2404	120220	13806

Table 13b. Projections results (median and 80% CI) with F_{bar}=F_{2023}=0.058.

Year	Total Biomass		SSB		P(SSB<B_{lim})	P(SSB_{26} >SSB_{23})	Yield	P(F>F_{lim})
2023	53812	(47944 - 61013)	27709	(24790 - 30794)	<1%		6100	<1%
2024	58438	(51161 - 68867)	30747	(27207 - 34601)	<1%	100%	7079	<1%
2025	58752	(49433 - 71480)	33199	(28505 - 38167)	<1%		7294	<1%
2026	62098	(48886 - 79547)	38220	(31615 - 45378)	<1%			

Table 14a. N-at-age in prediction years (medians) with F_{bar}=1/2F_{lim}= 0.078 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2023	44615	12838	21393	4889	7797	1889	2339	1809	99284	10683
2024	48541	11664	7018	15157	3613	5402	1040	2157	111005	11609
2025	52161	12529	6419	5015	10922	2402	2741	1477	113069	12862
2026	55282	13365	6844	4548	3618	7307	1219	2005	116354	12818

Table 14b. Projections results (median and 80% CI) with F_{bar}=1/2F_{lim}= 0.078.

Year	Total Biomass		SSB		P(SSB<B_{lim})	P(SSB_{26} >SSB_{23})	Yield	P(F>F_{lim})
2023	53812	(47944 - 61013)	27709	(24790 - 30794)	<1%		6100	<1%
2024	58438	(51161 - 68867)	30747	(27207 - 34601)	<1%	87%	9176	<1%
2025	56673	(47350 - 69385)	31352	(26697 - 36365)	<1%		8932	<1%
2026	58207	(44956 - 75456)	34599	(28098 - 41635)	<1%			

Table 15a. N-at-age in prediction years (medians) with F_{bar}=2/3F_{lim}=0.104 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2023	44615	12838	21393	4889	7797	1889	2339	1809	99284	10683
2024	48541	11664	7018	15157	3613	5402	1040	2157	111005	11609
2025	52161	12529	6419	5012	10648	2271	2483	1295	112221	12137
2026	51801	13365	6842	4545	3511	6769	1049	1585	111908	11648

Table 15b. Projections results (median and 80% CI) with F_{bar}=2/3F_{lim}=0.104.

Year	Total Biomass		SSB		P(SSB<B_{lim})	P(SSB_{26} >SSB_{23})	Yield	P(F>F_{lim})
2023	53812	(47944 - 61013)	27709	(24790 - 30794)	<1%		6100	<1%
2024	58438	(51161 - 68867)	30747	(27207 - 34601)	<1%	75%	11708	<1%
2025	54177	(44843 - 66893)	29127	(24423 - 34096)	<1%		10609	1%
2026	53777	(40713 - 70897)	30586	(24211 - 37687)	<1%			

Table 16a. N-at-age in prediction years (medians) with F_{bar}=3/4F_{lim}=0.117 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2023	44615	12838	21393	4889	7797	1889	2339	1809	99284	10683
2024	48541	11664	7018	15157	3613	5402	1040	2157	111005	11609
2025	52161	12529	6419	5011	10511	2213	2353	1214	111800	11775
2026	50385	13365	6842	4544	3466	6503	968	1409	110005	11125

Table 16b. Projections results (median and 80% CI) with F_{bar}=3/4F_{lim}=0.117.

Year	Total Biomass		SSB		P(SSB<B_{lim})	P(SSB_{26} >SSB_{23})	Yield	P(F>F_{lim})
2023	53812	(47944 - 61013)	27709	(24790 - 30794)	<1%		6100	<1%
2024	58438	(51161 - 68867)	30747	(27207 - 34601)	<1%	57%	12903	2%
2025	53003	(43651 - 65719)	28064	(23409 - 33003)	<1%		11310	6%
2026	51812	(38786 - 68825)	28840	(22412 - 35859)	<1%			

Table 17a. N-at-age in prediction years (medians) with F_{bar}=F_{lim}=0.157 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2023	44615	12838	21393	4889	7797	1889	2339	1809	99284	10683
2024	48541	11664	7018	15157	3613	5402	1040	2157	111005	11609
2025	52161	12529	6418	5005	10072	2055	2012	1002	110636	10891
2026	46496	13365	6840	4538	3320	5762	768	984	104235	9759

Table 17b. Projections results (median and 80% CI) with F_{bar}=F_{lim}=0.157.

Year	Total Biomass		SSB		P(SSB<B_{lim})	P(SSB_{26} >SSB_{23})	Yield	P(F>F_{lim})
2023	53812	(47944 - 61013)	27709	(24790 - 30794)	<1%		6100	<1%
2024	58438	(51161 - 68867)	30747	(27207 - 34601)	<1%	21%	16163	50%
2025	49790	(40459 - 62527)	25247	(20608 - 30117)	<1%		12892	50%
2026	46682	(33789 - 63405)	24314	(17976 - 31362)	2%			

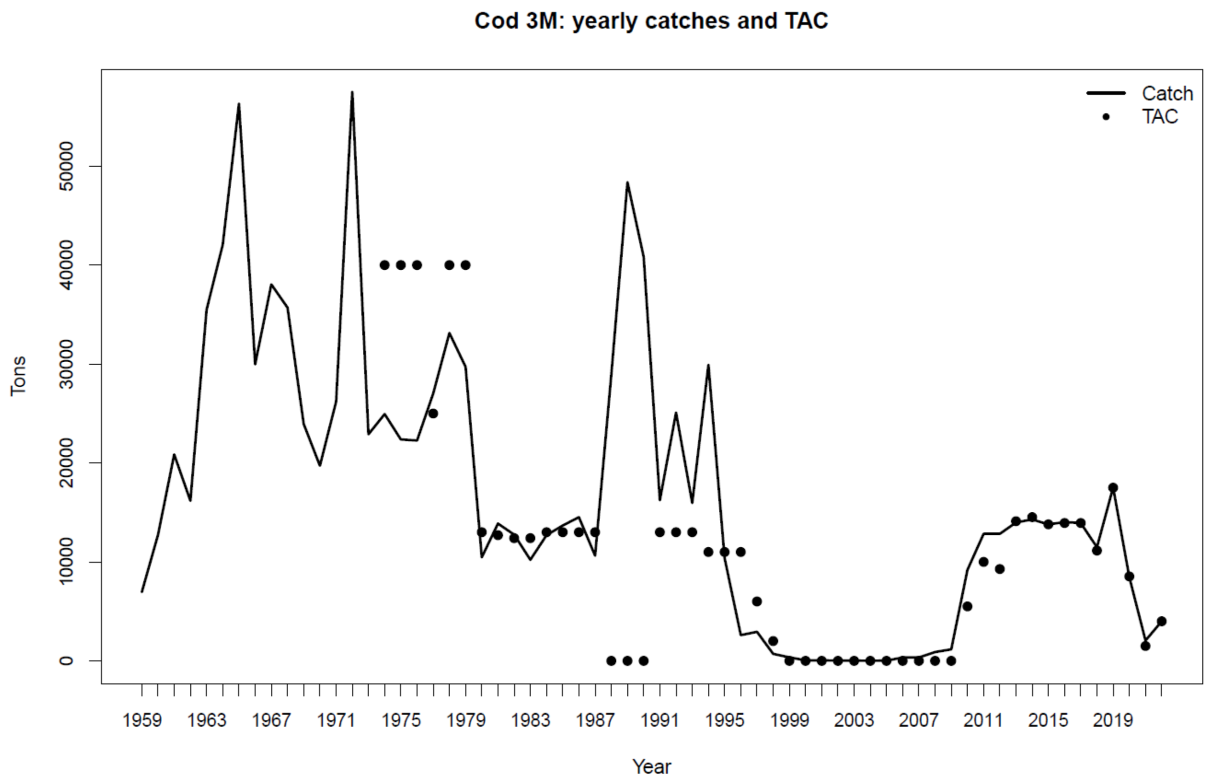
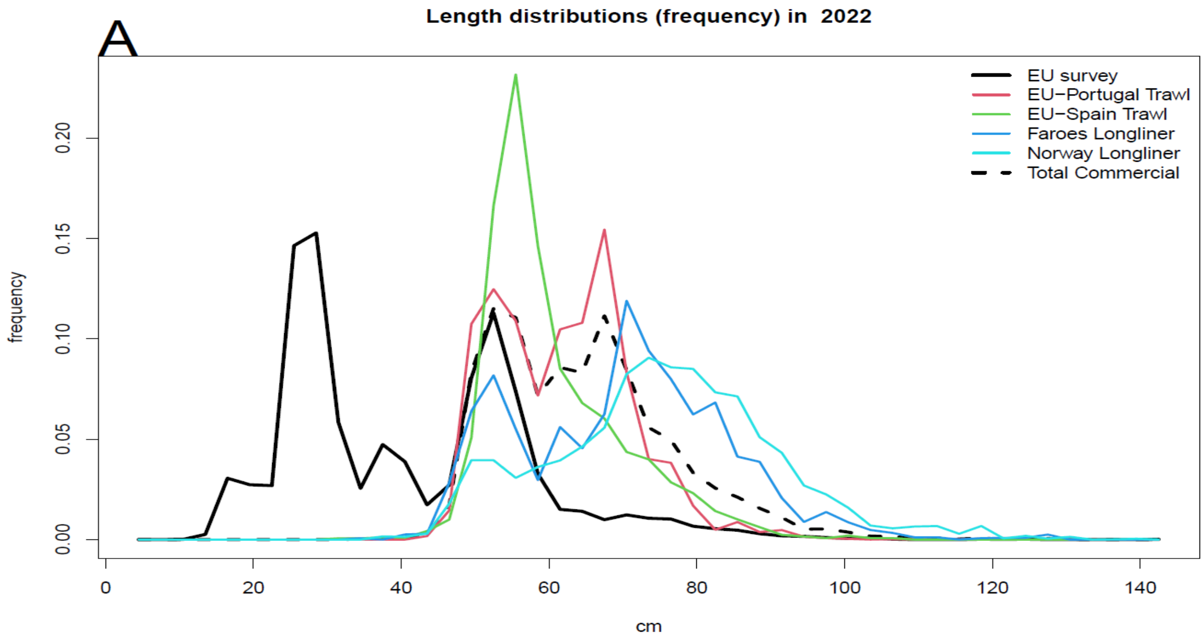


Figure 1. Catch and TAC of the 3M cod for the period 1959-2022.



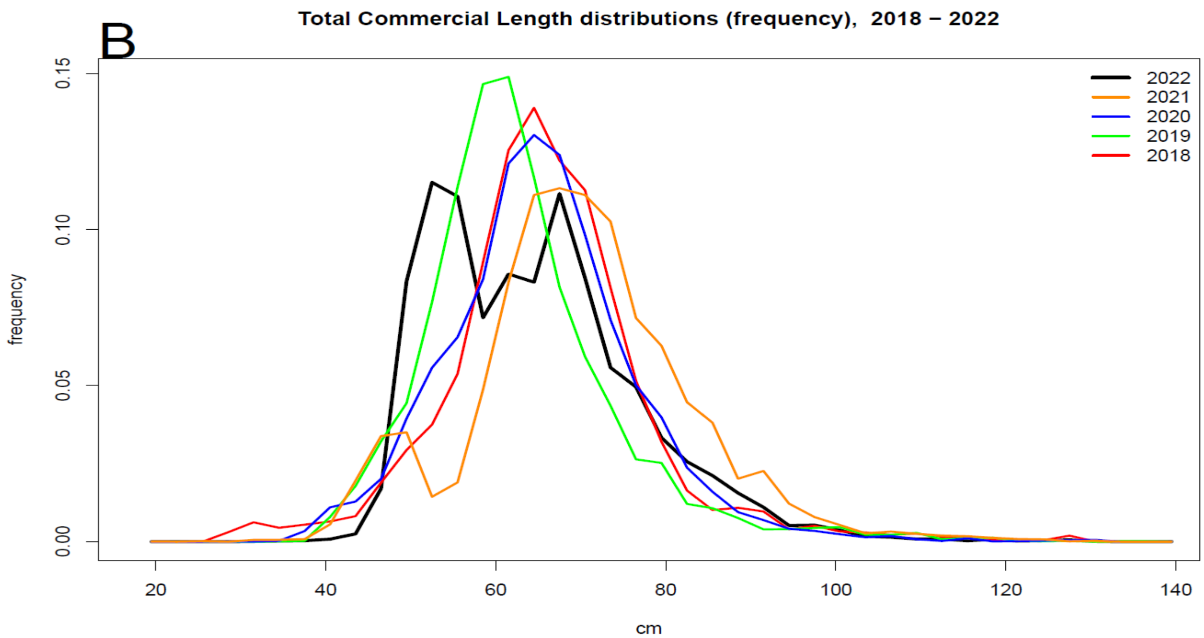


Figure 2. Length distributions in commercial catches (Faroes longliner includes the length distribution of the Faroese survey) and EU survey in 2022 (A), and the total commercial for the last five years (2018-2022) (B). In (C), the mean and the mode length of the commercial length distribution is shown (2010-2022).

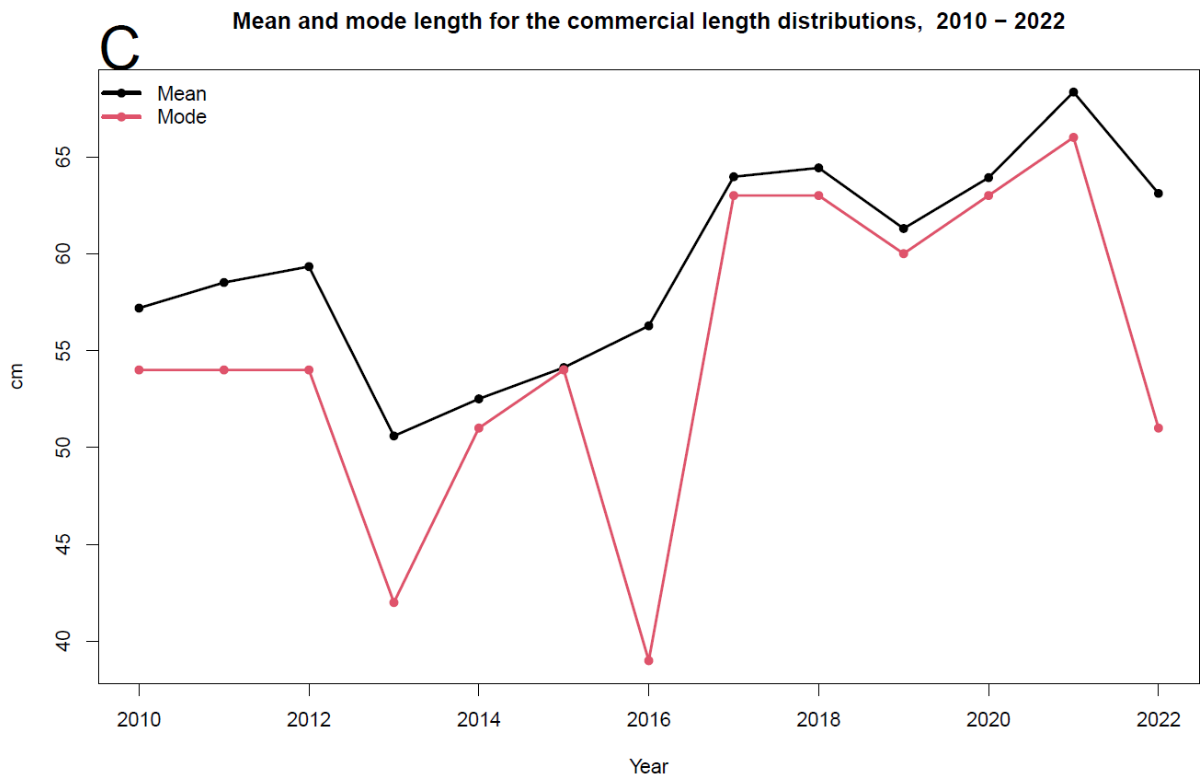


Figure 2 (cont.). Length distributions in commercial catches (Faroes longliner includes the length distribution of the Faroese survey) and EU survey in 2022 (A), and the total commercial for the last five years (2018-2022) (B). In (C), the mean and the mode length of the commercial length distribution is shown (2010-2022).

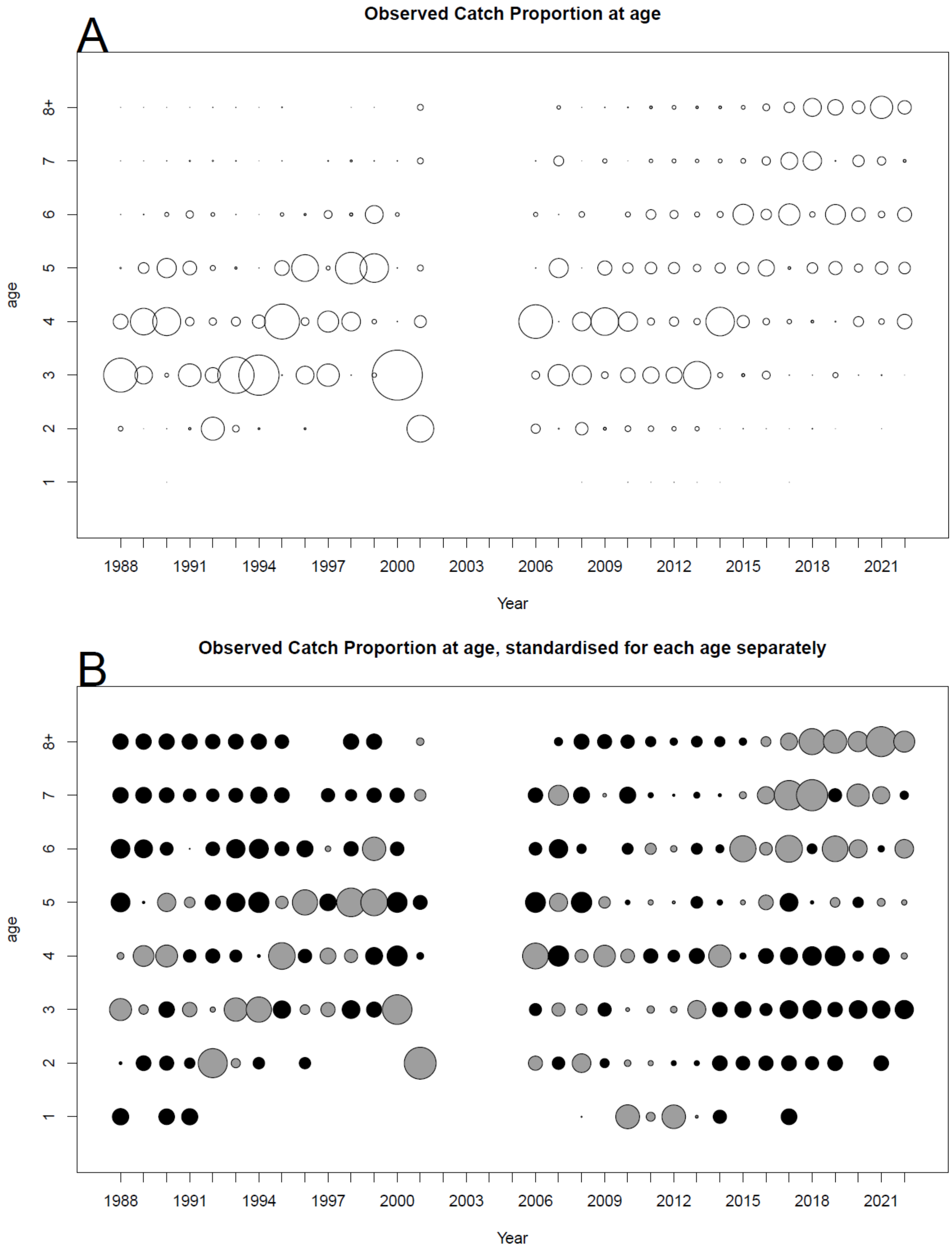


Figure 3. Commercial catch proportions at age (A) and standardised proportions at age (B). In B, grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

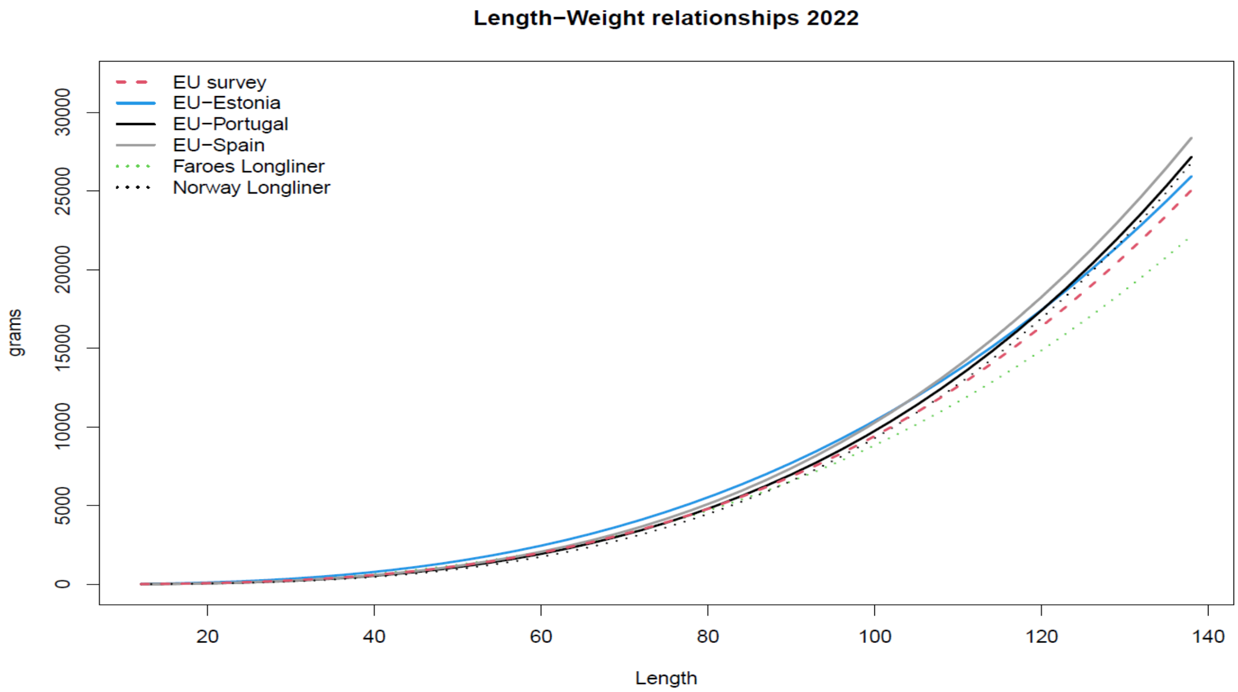


Figure 4. Length-weight relationships for commercial catches and EU survey.

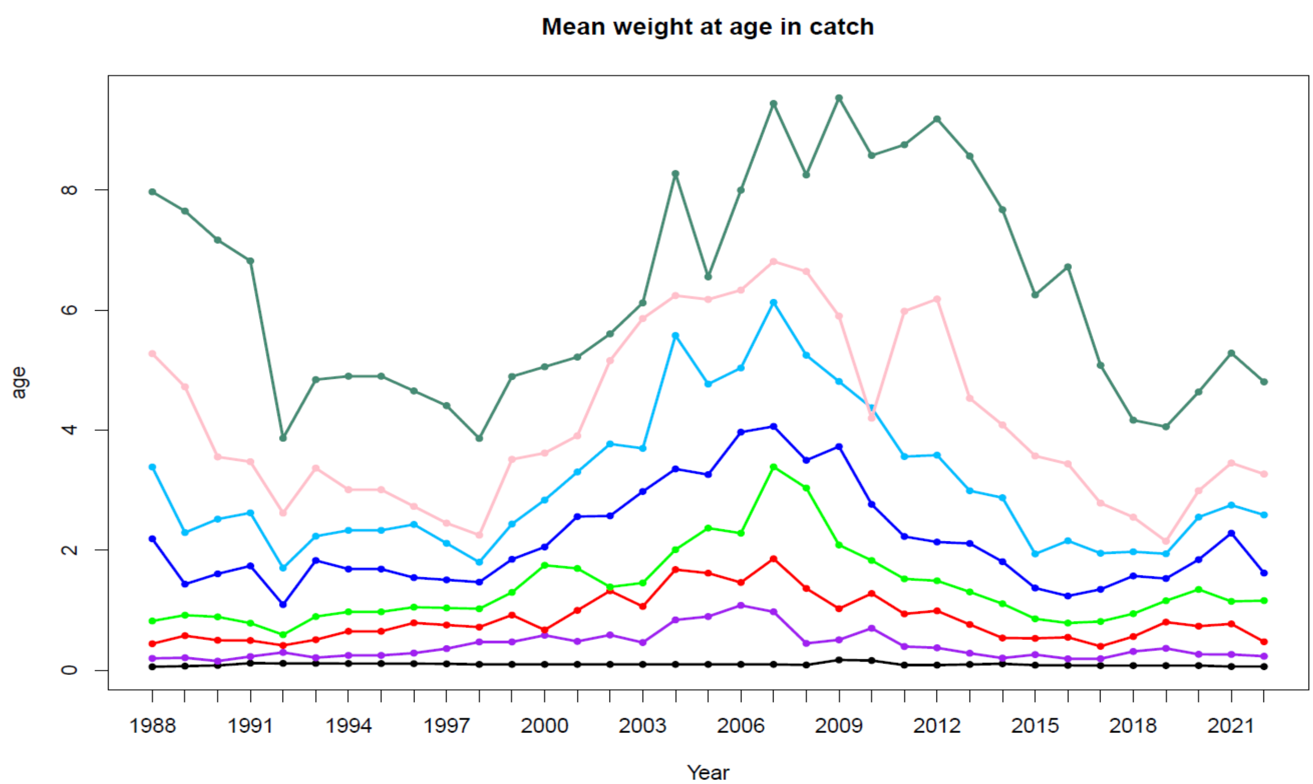


Figure 5. Catch mean weight at age.

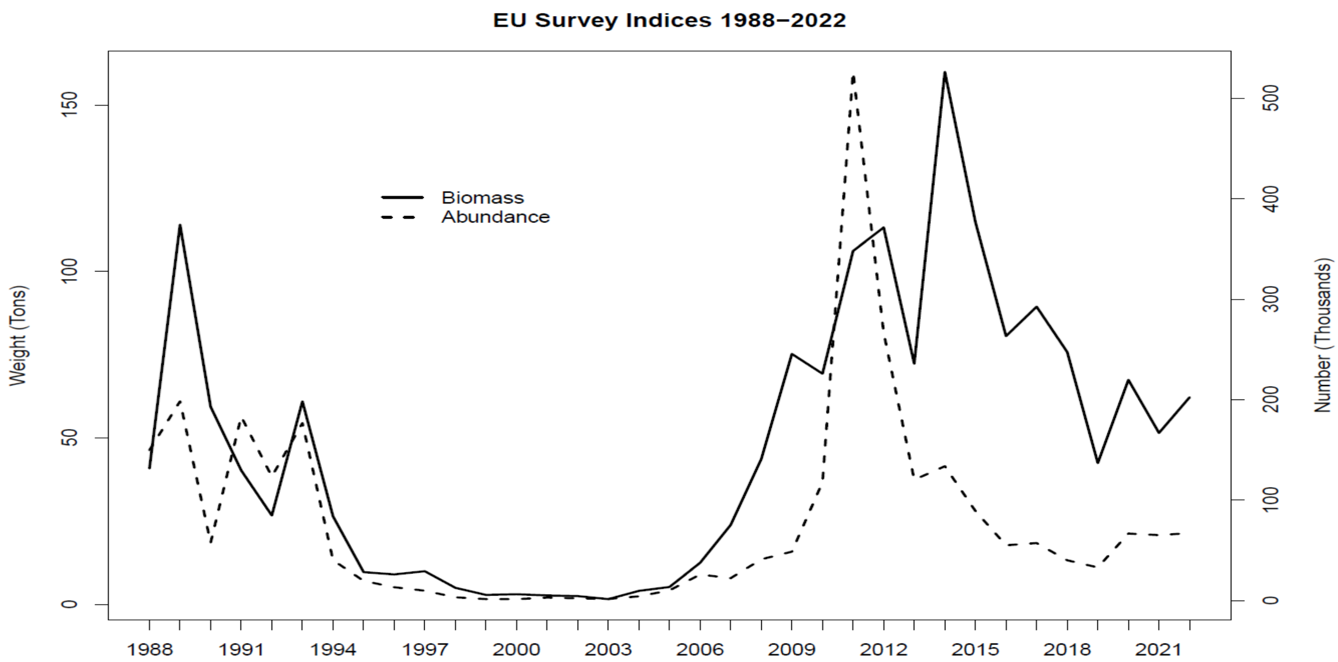


Figure 6. Biomass and abundance from EU surveys.

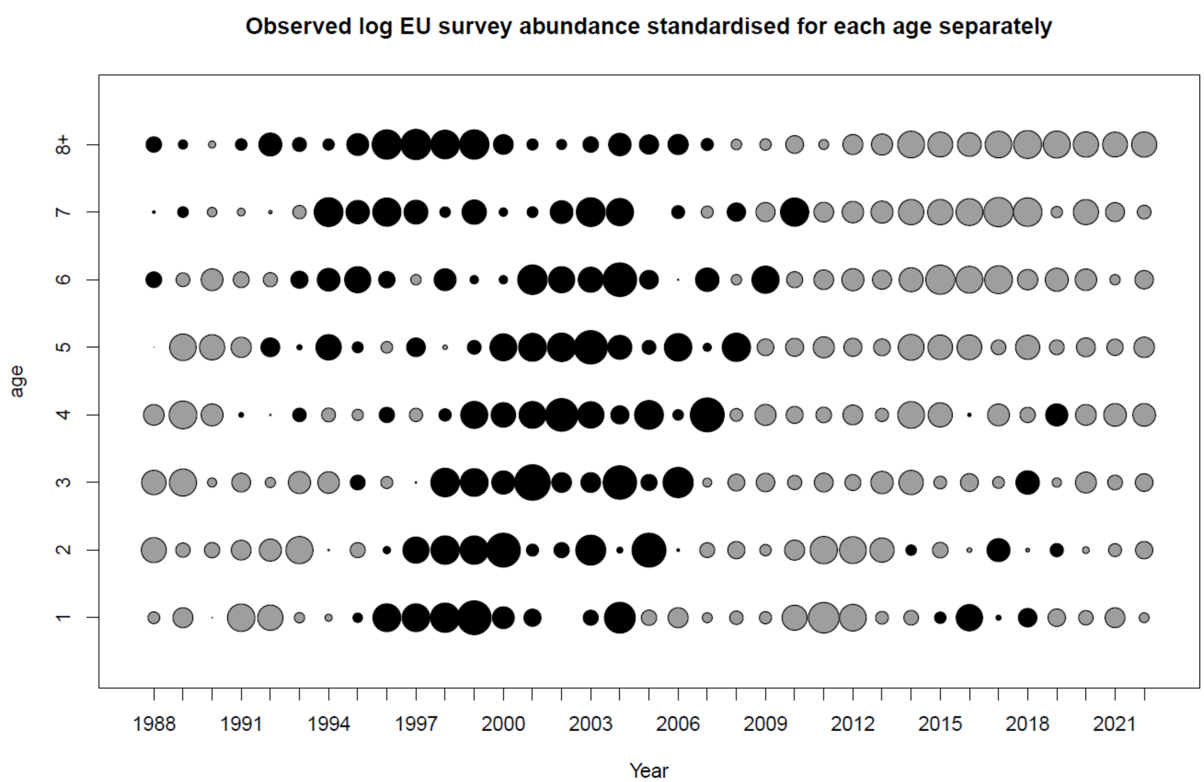


Figure 7. Standardised log(Abundance at age) indices from EU survey. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

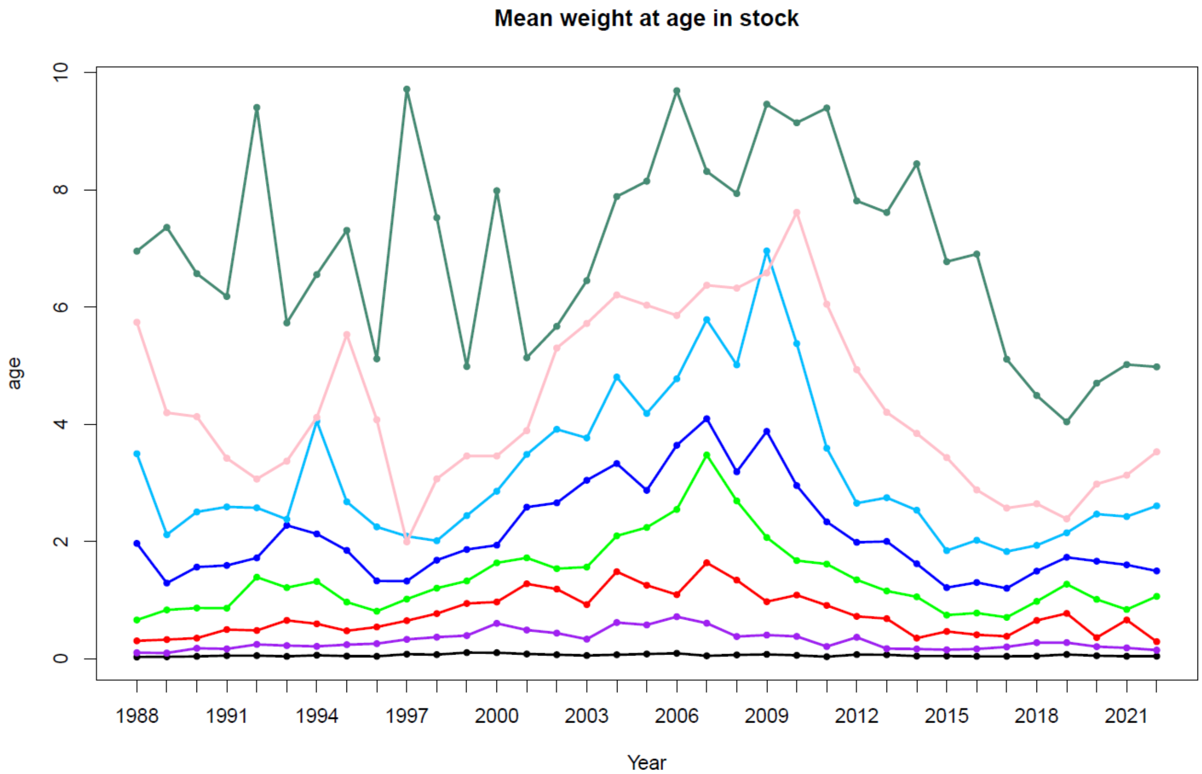


Figure 8. Stock mean weight at age.

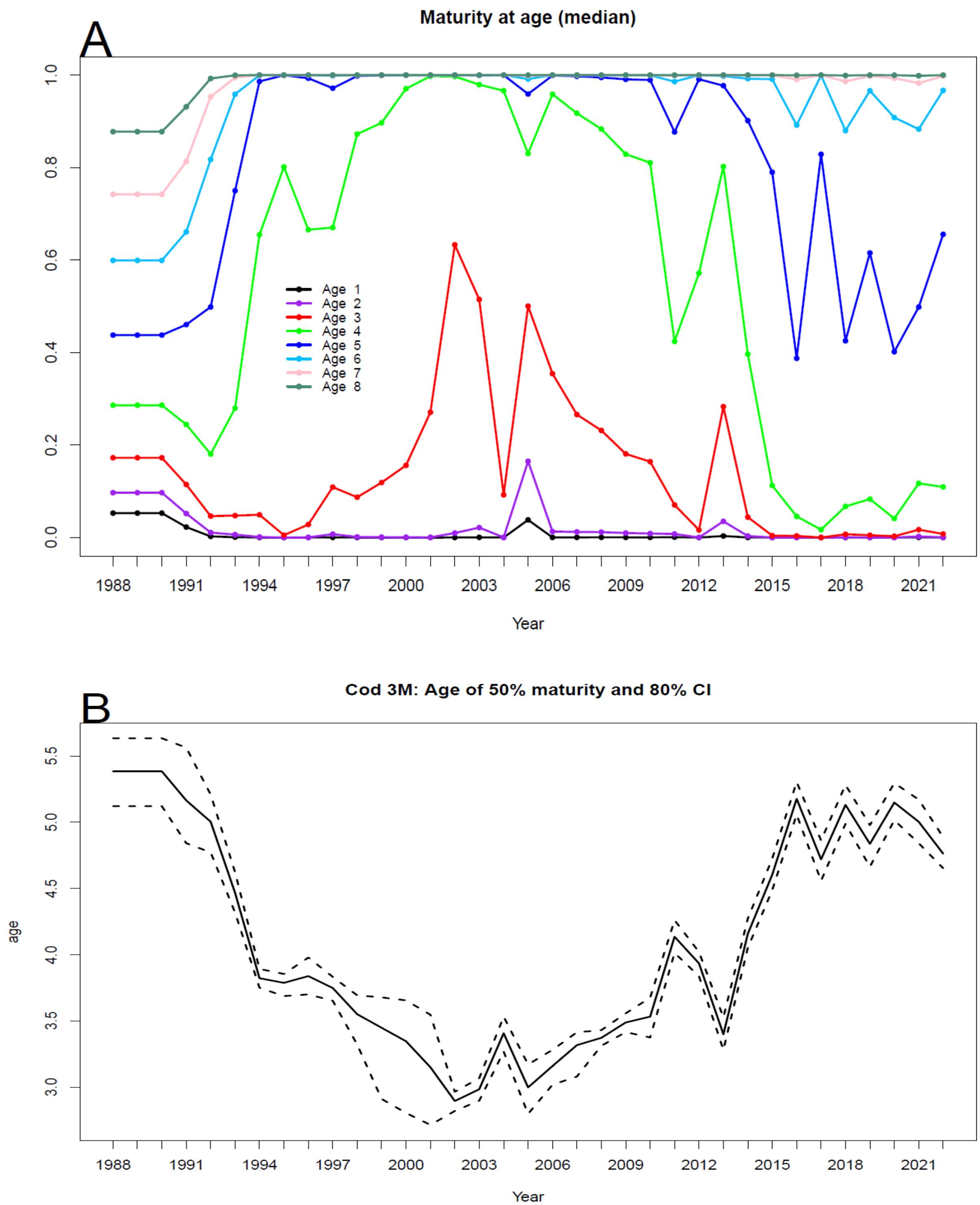


Figure 9. Maturity ogive by age (A) and age at which 50% of fish are mature (B).

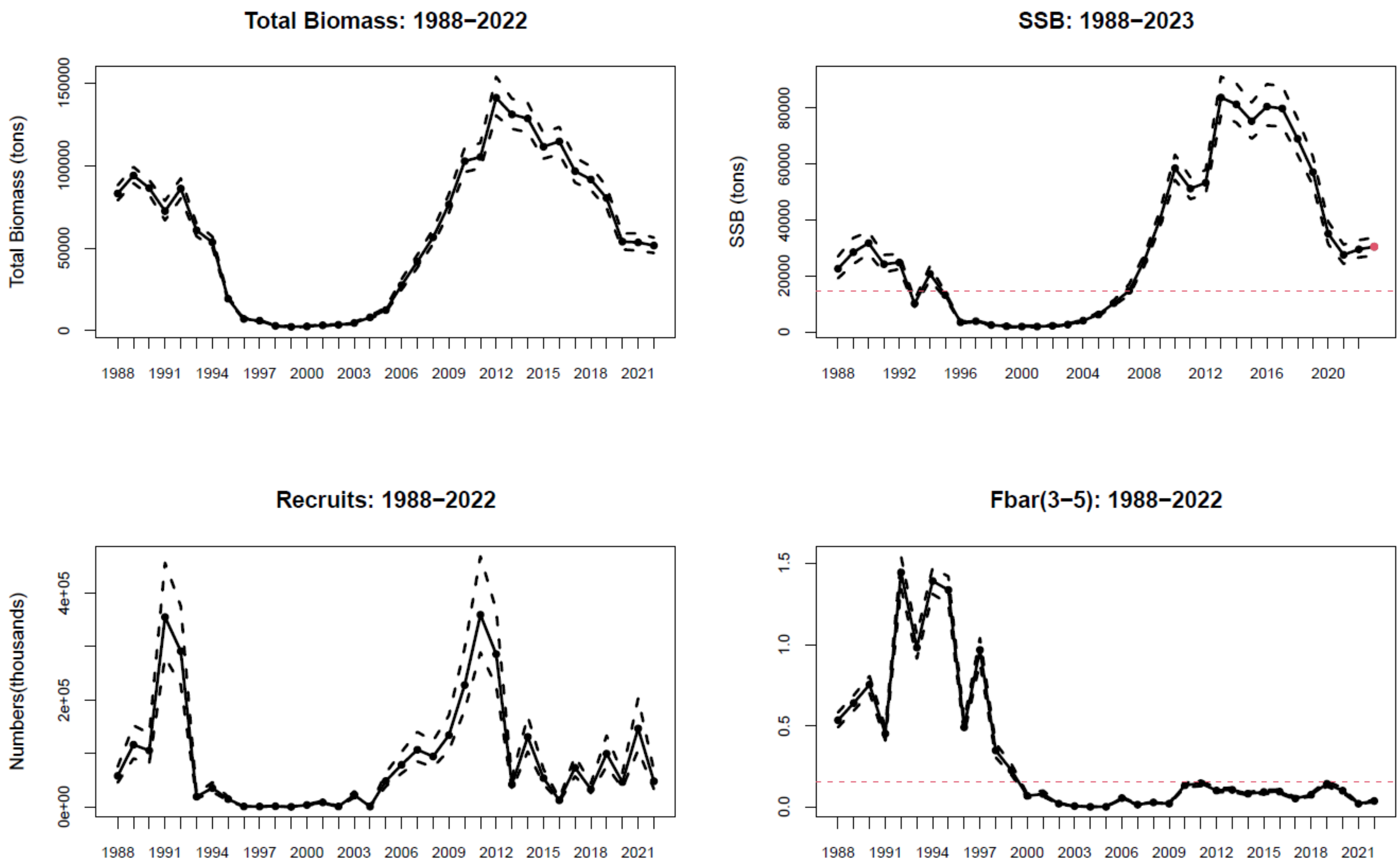


Figure 10. Estimated trends in biomass, SSB, recruitment and F_{bar}. The solid lines are the posterior medians and the dashed lines show the limits of 80% posterior credible intervals. Red point in the SSB plot indicates the SSB in 2023. Red horizontal line in the SSB graph represents median B_{lim} = medianSSB_{2007} = 14 755 tons. Red horizontal line in the F_{bar} graph represents median F_{lim} = 0.157 (with the last three years parameters).

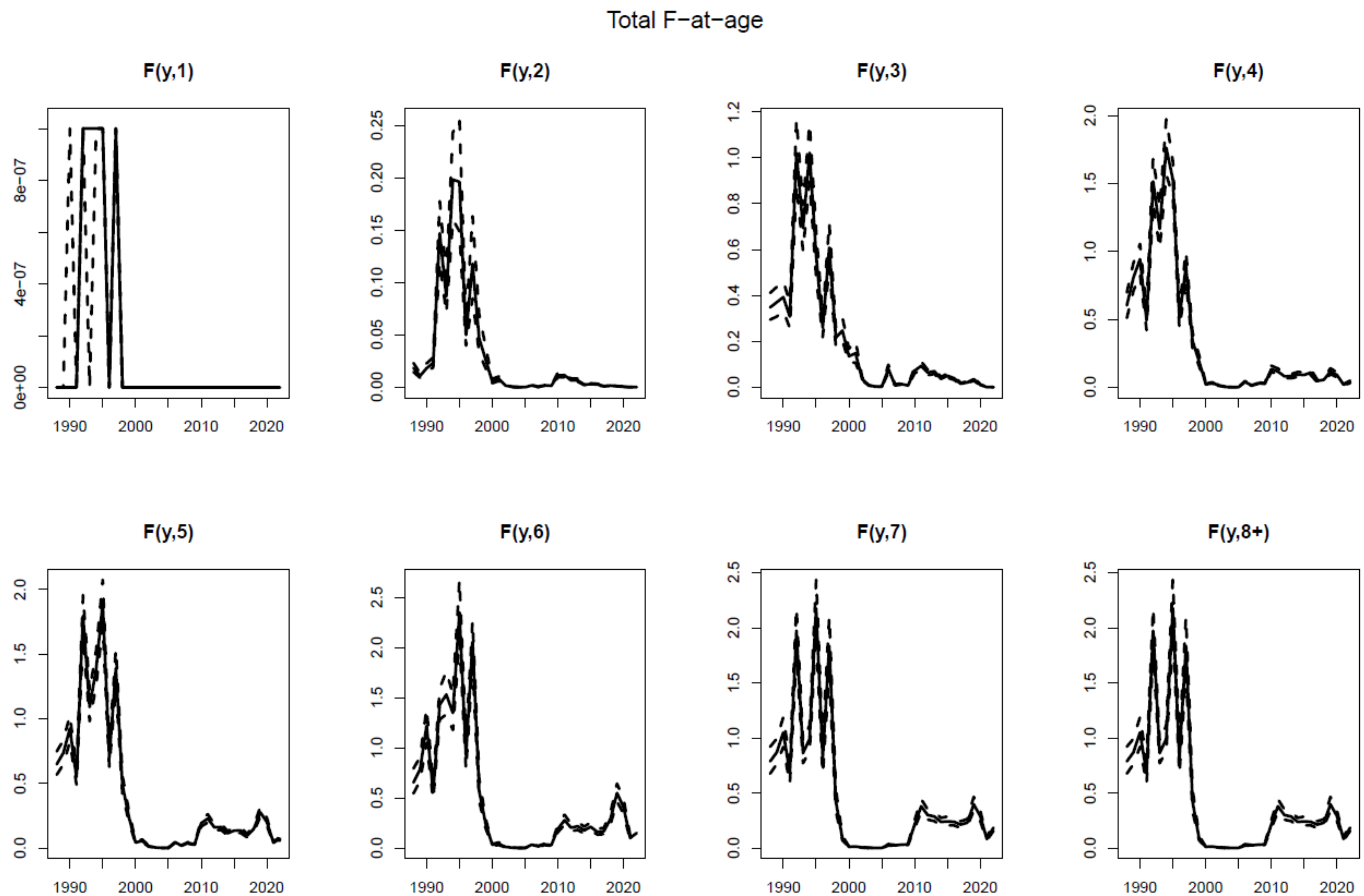


Figure 11. Estimated fishing mortality at age. The y-axis scale is different in all the graphs.

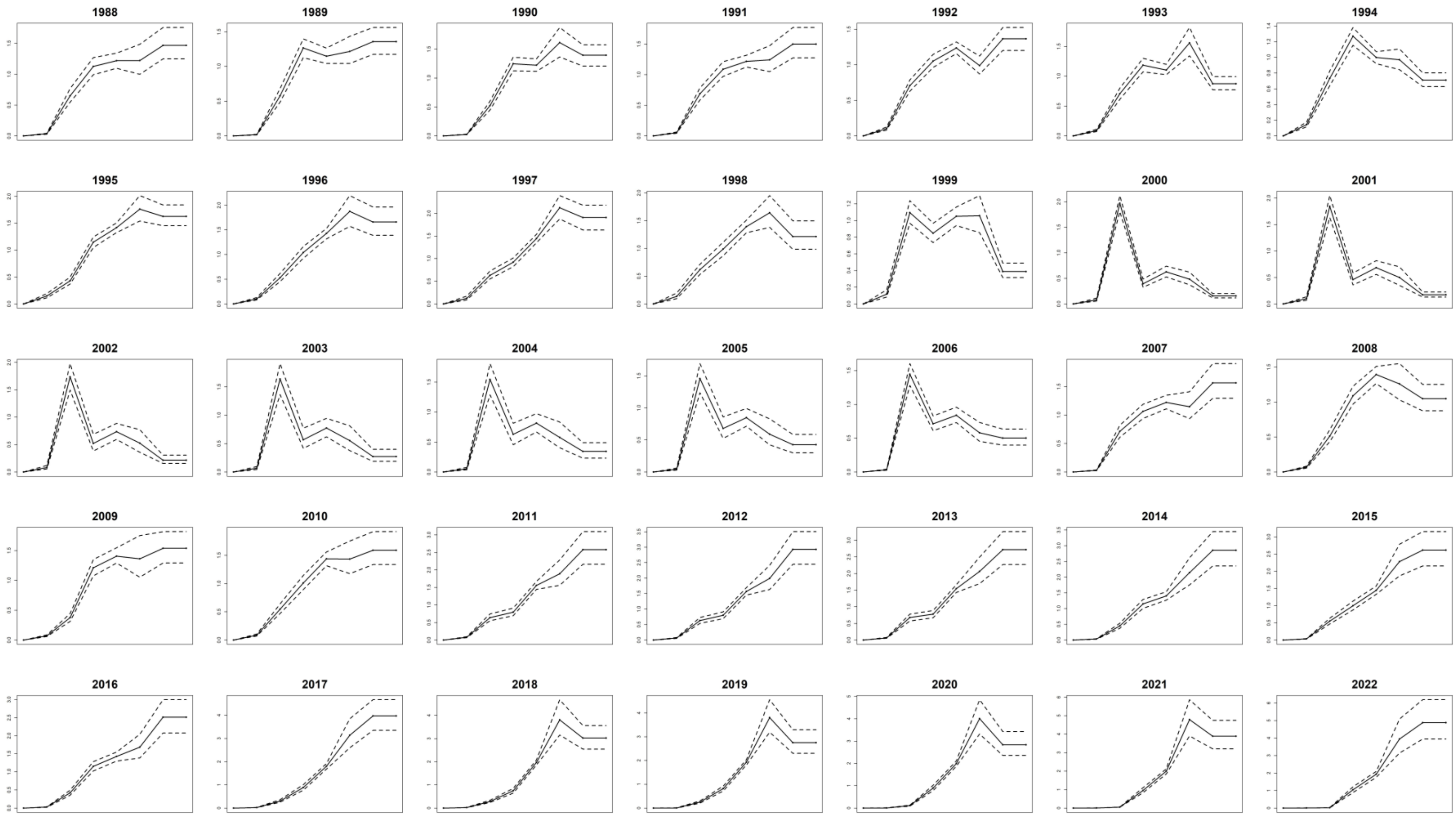
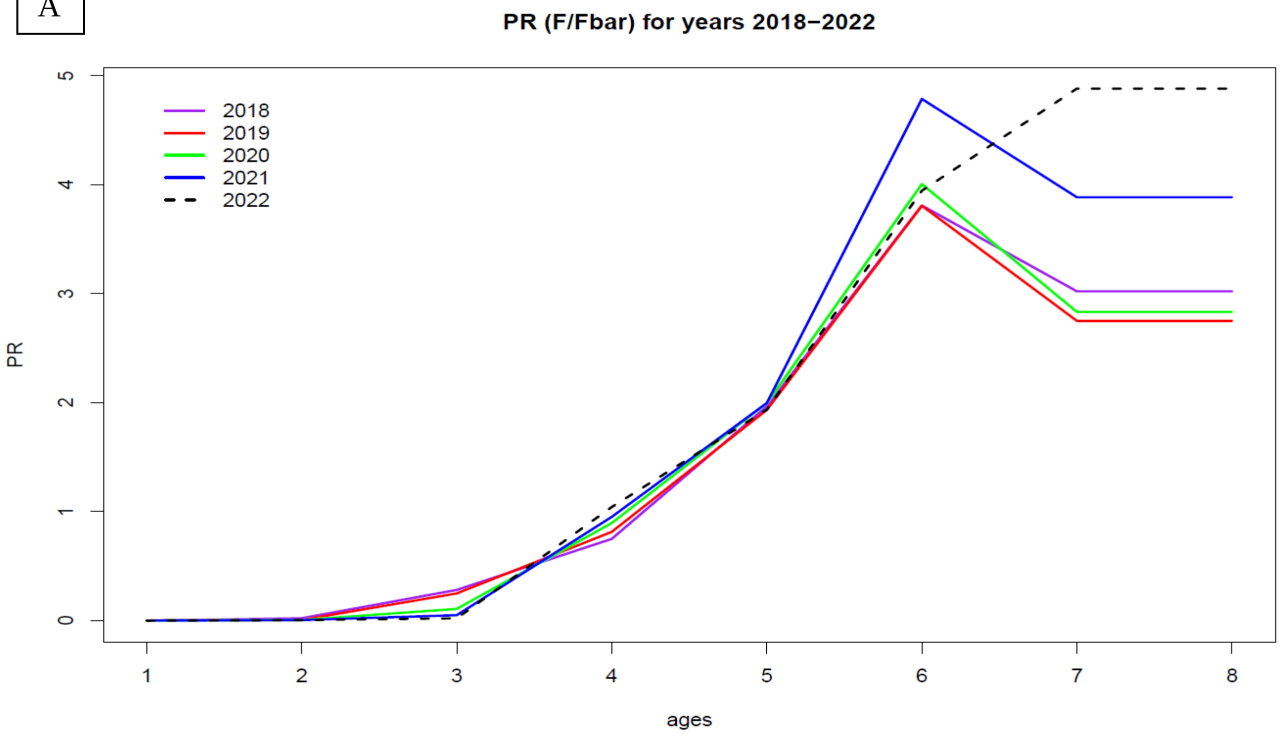


Figure 12. Estimated PR (F/F_{bar}) per age and year.

A



B

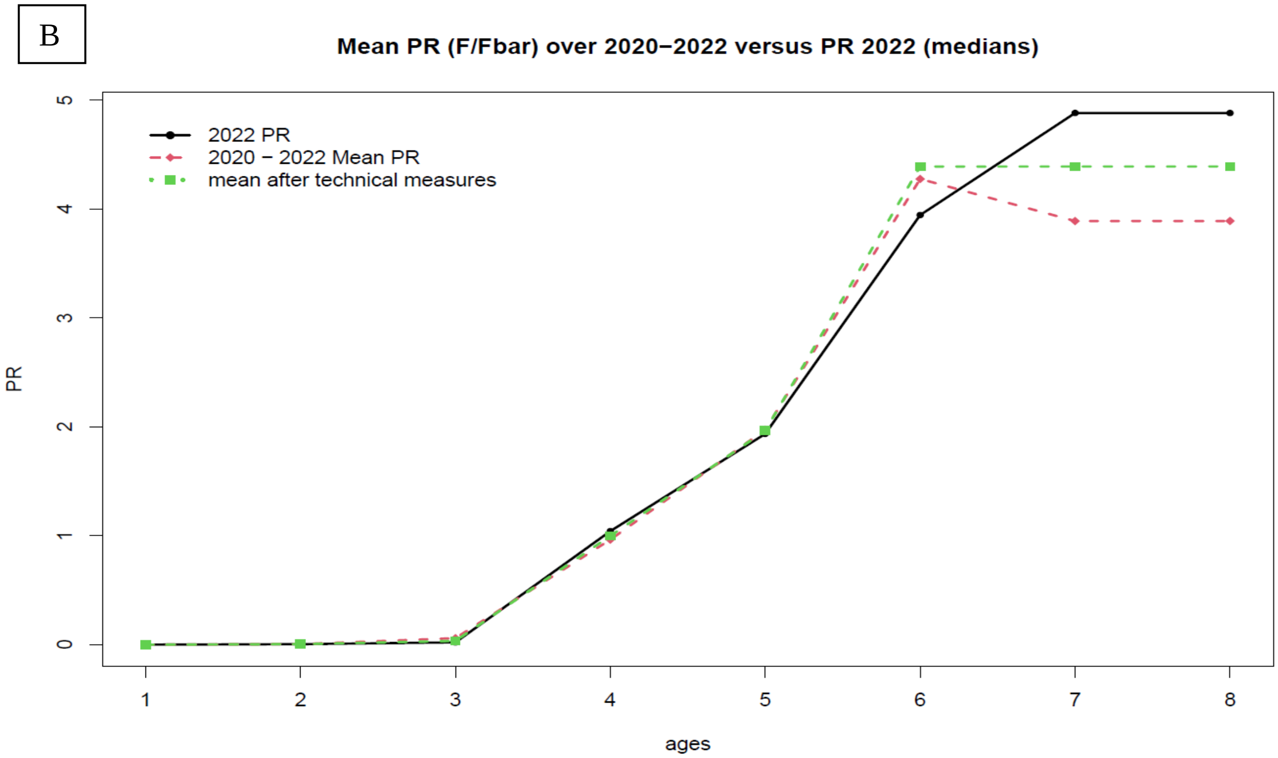
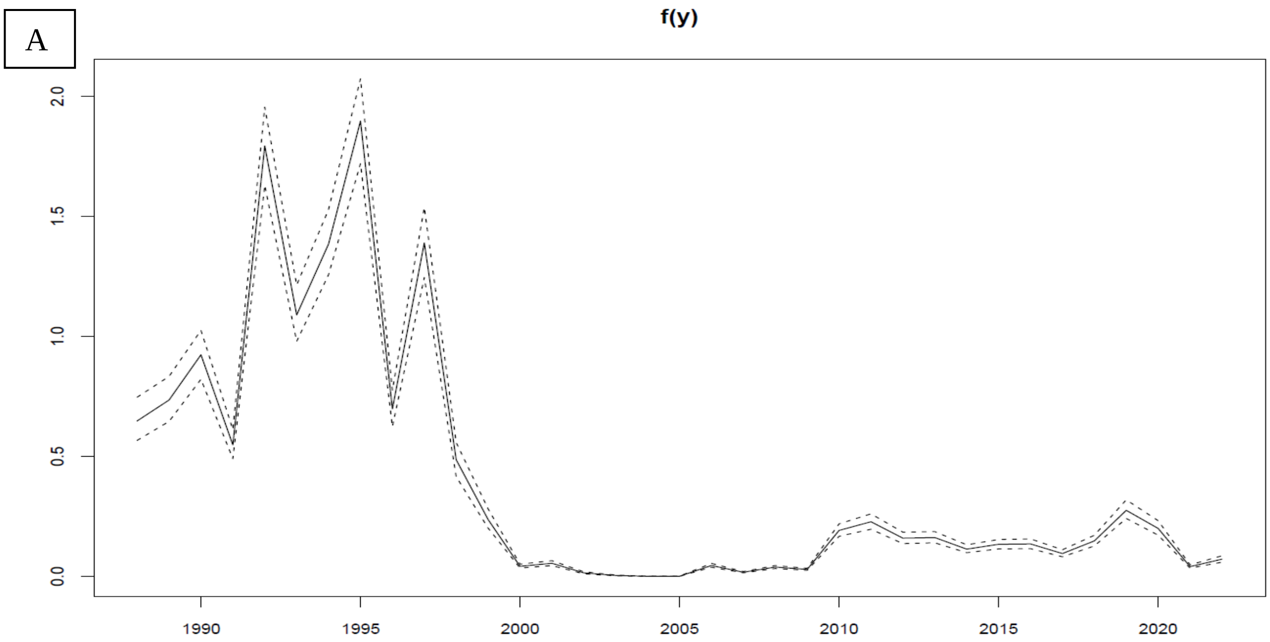


Figure 13. A) Estimated PR (F/F_{bar}) per age for the last five years and (B) mean of 2020-2022 PR, mean of 2021-2022 PR (after the implementation of the technical measures) versus 2022 PR (posterior medians).



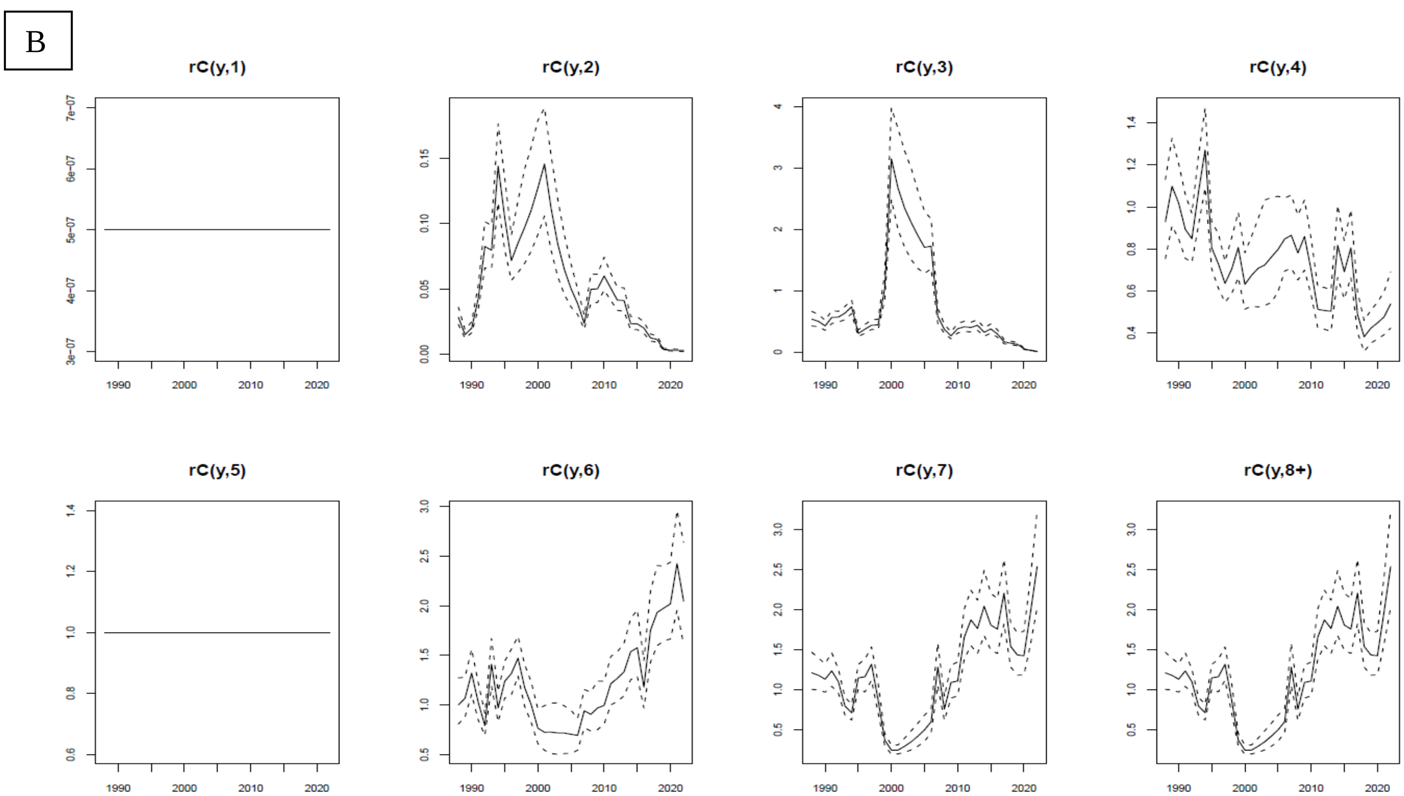


Figure 14. Components of the semi-separable model for Fishing Mortality: F[y,a]=*f*[y]**rC*[y,a].

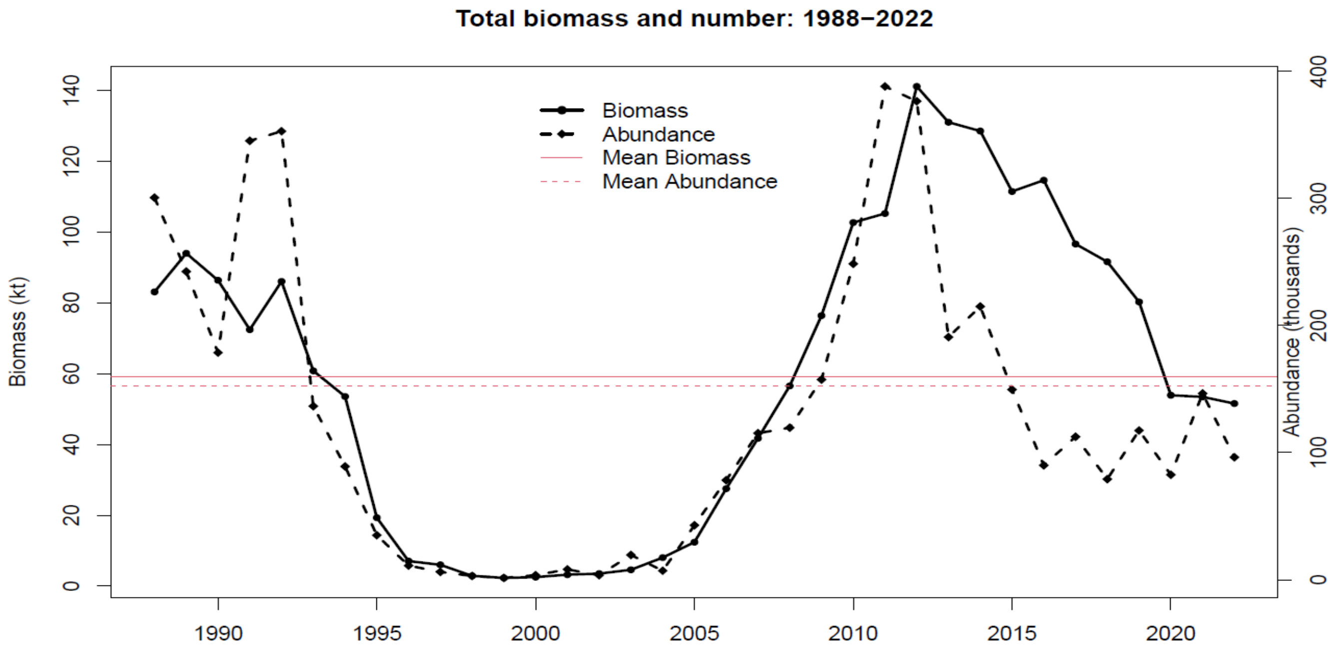


Figure 15. Estimated trends in biomass and abundance. The red lines indicate the means over the whole period.

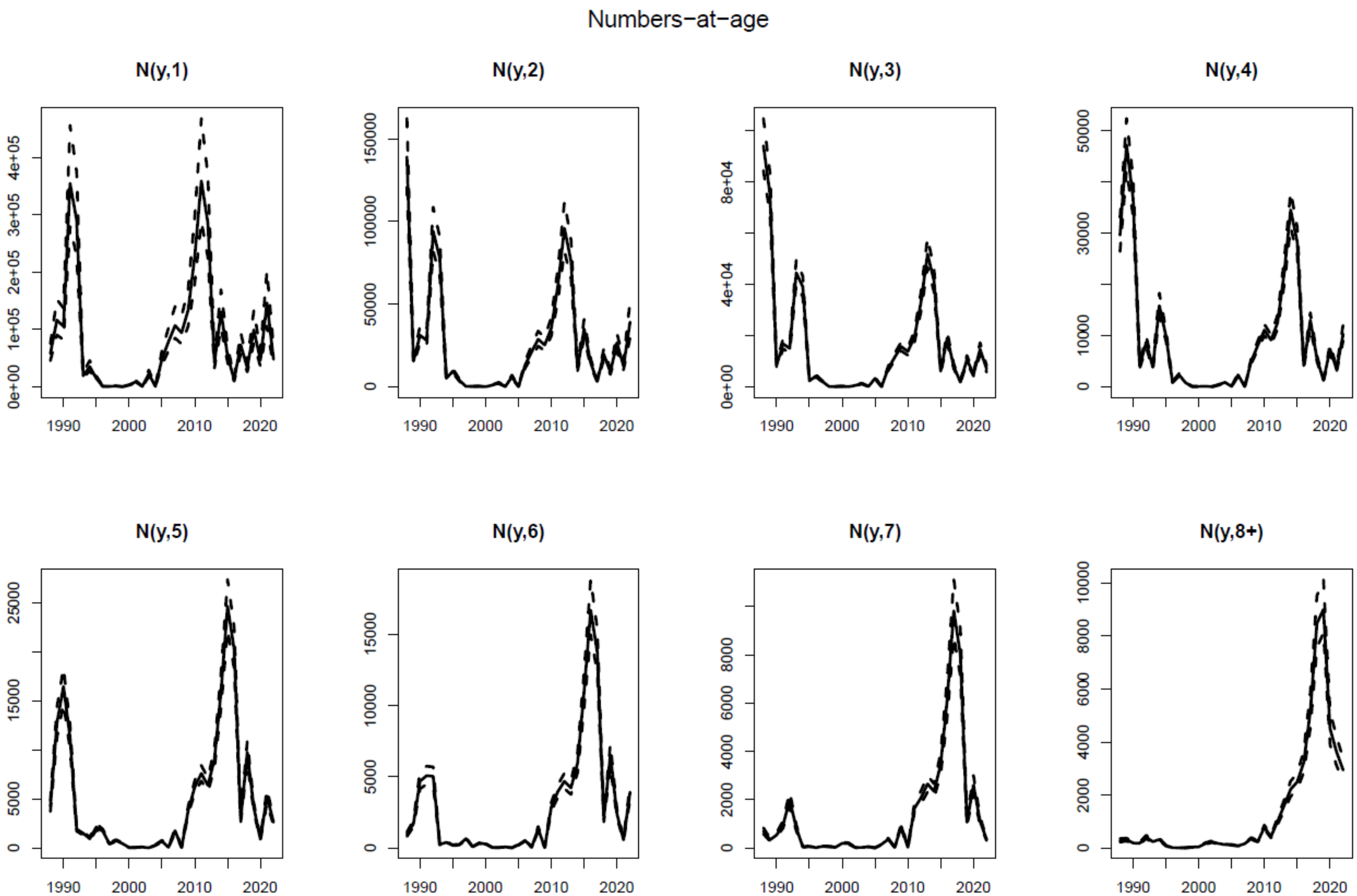


Figure 16. Estimated numbers at age. The y-axis scale is different in all the graphs.

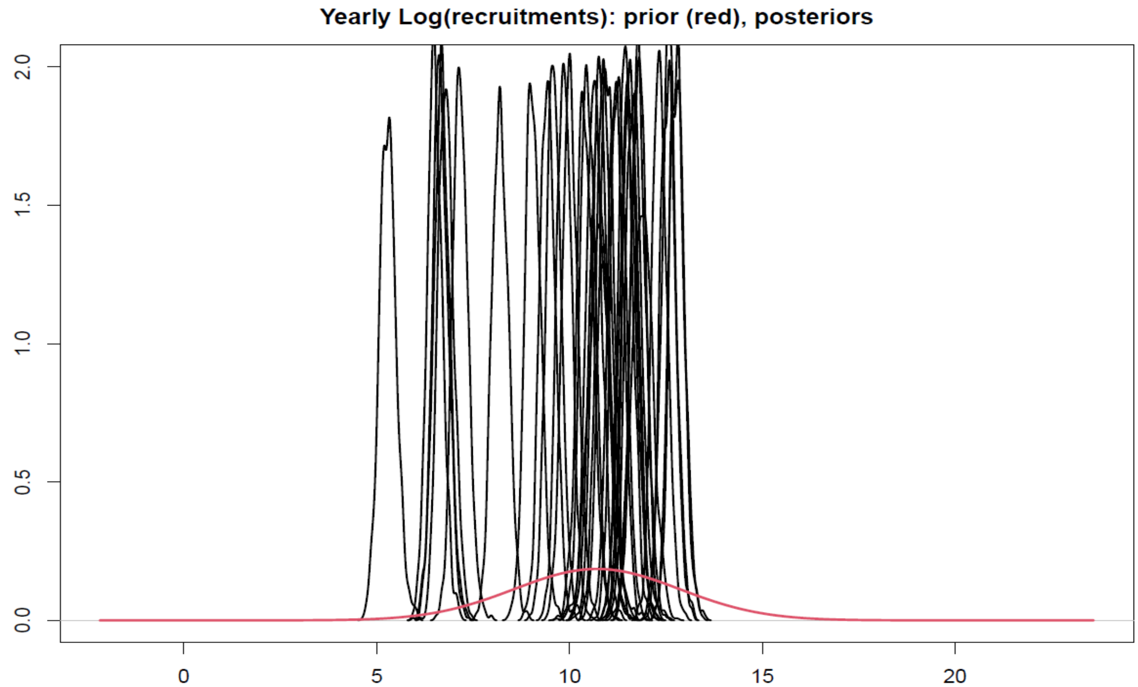


Figure 17. Prior and posterior of recruitment by year.

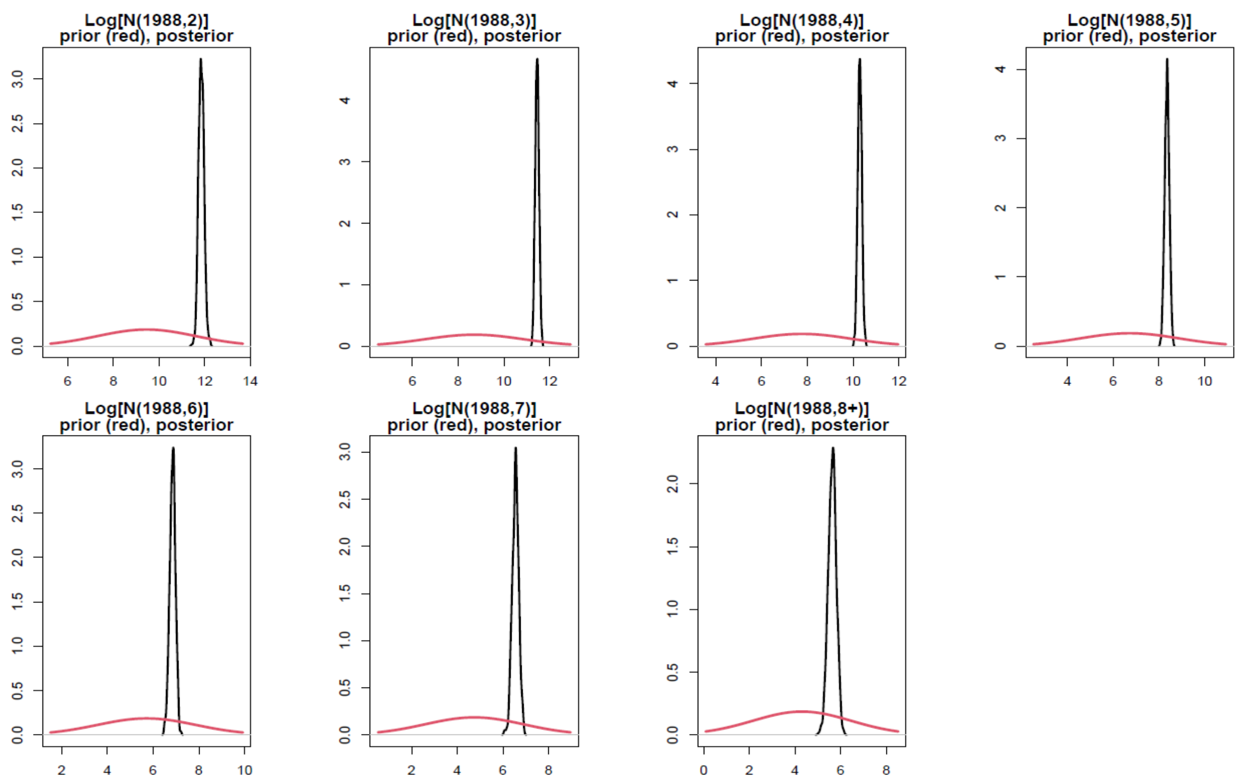


Figure 18. Prior and posterior of the numbers in the first year (1988) from age 2 to 8+.The x- and y-axis scales are different in all the graphs.

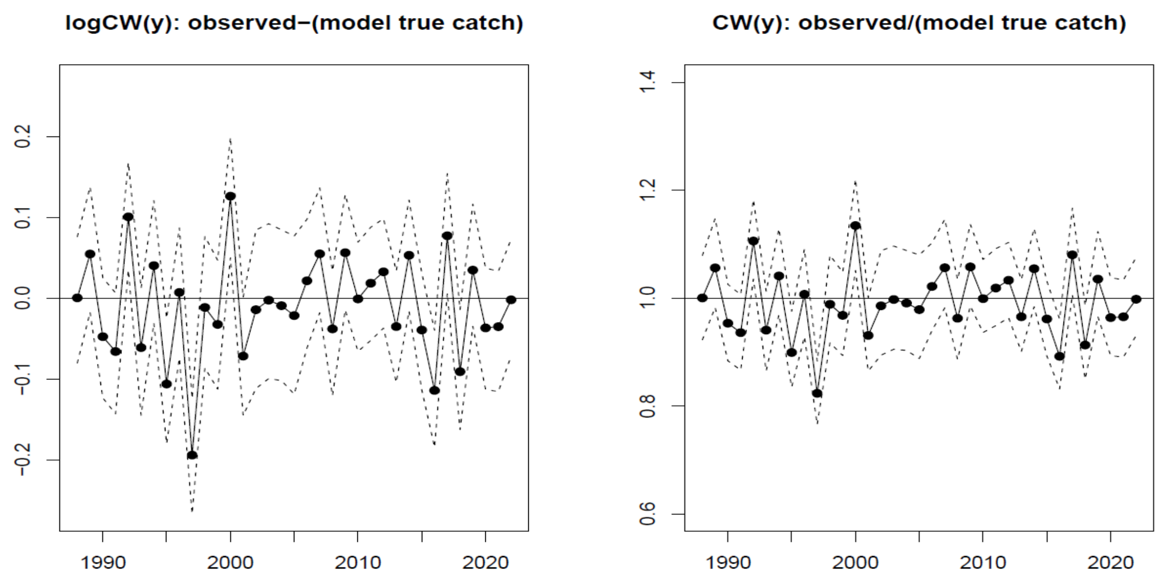


Figure 19. Observed versus estimated total catches by year.

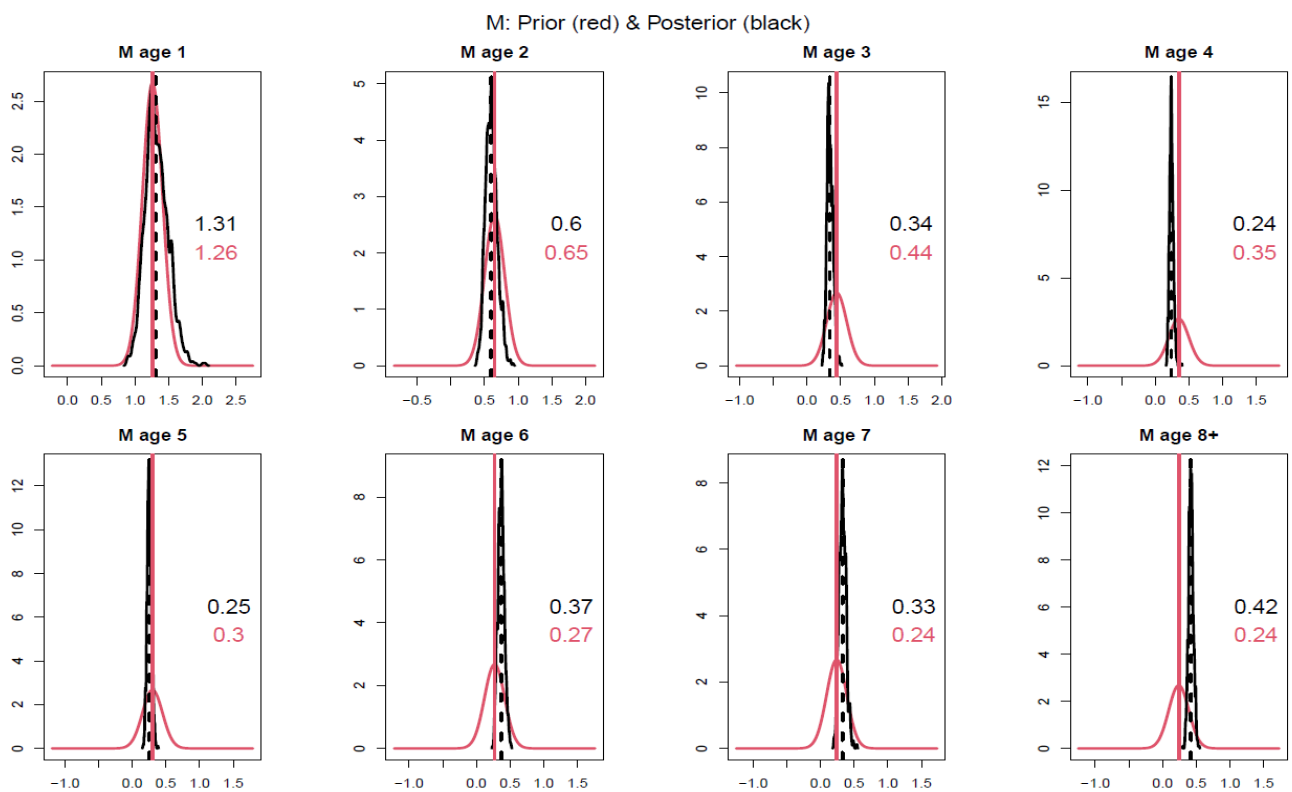


Figure 20. Estimated natural mortality by age in 2022. In black, the prior distribution; in red, the posterior distribution. The numbers inside the graph represent the median value of the distribution in each case.

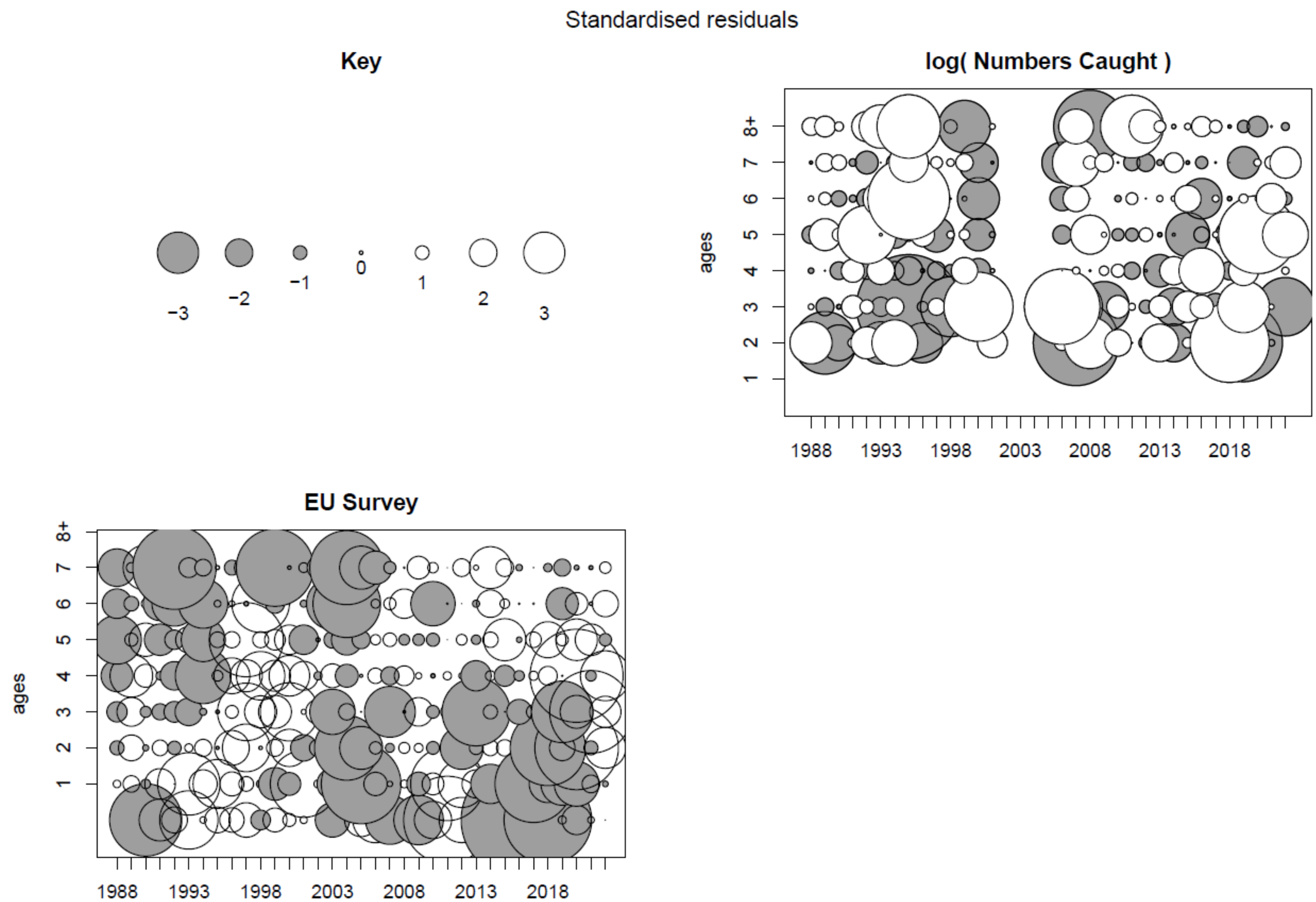


Figure 21. Standardised residuals (observed minus fitted value) in logarithmic scale of catch numbers at age and EU survey abundance indices at age. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

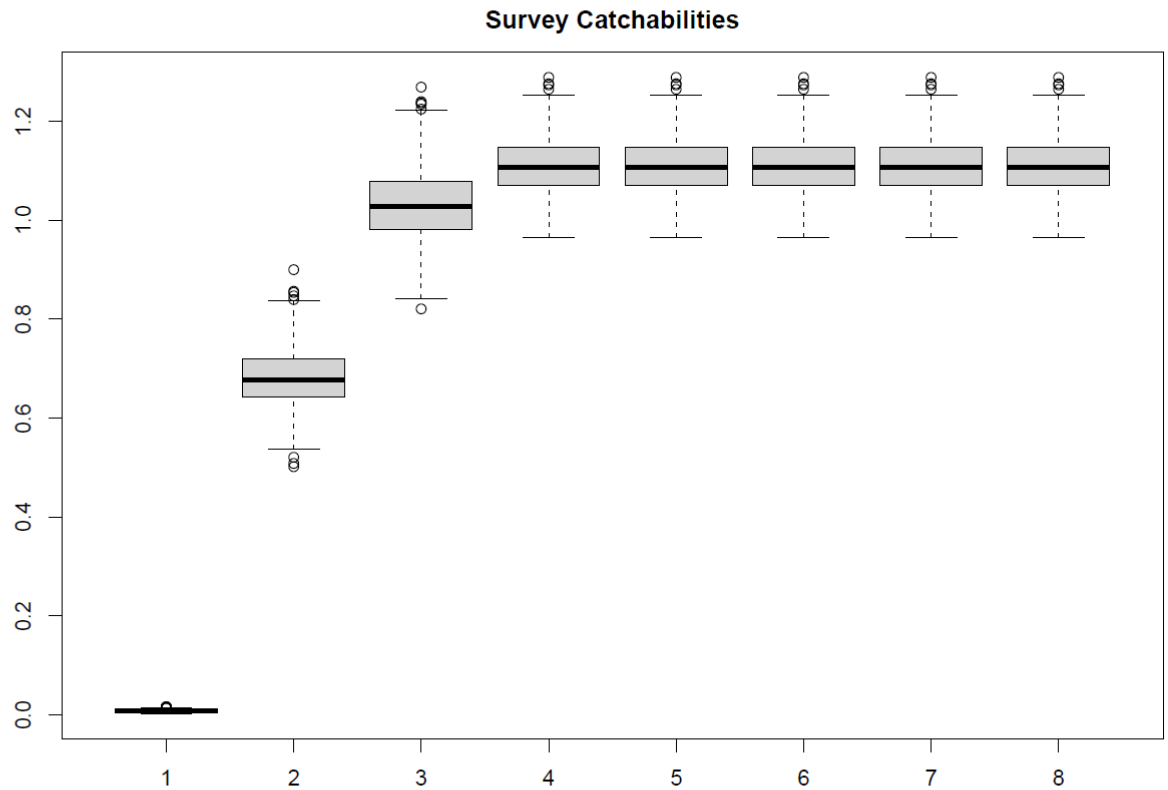
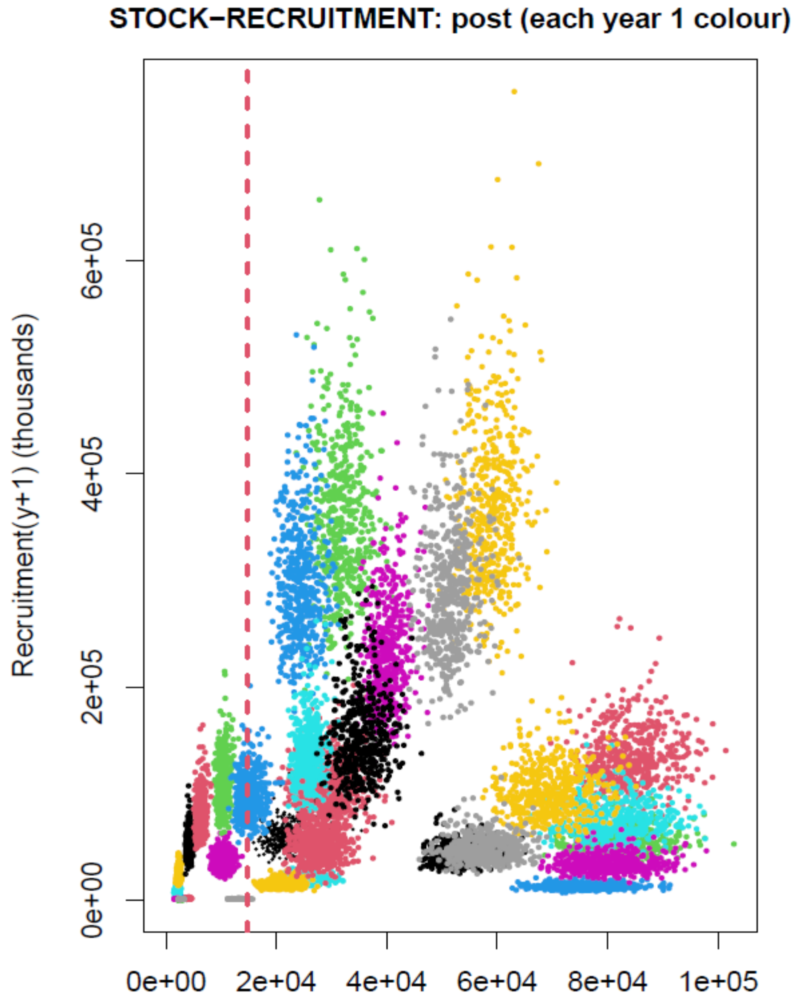


Figure 22. EU survey catchabilities distribution.



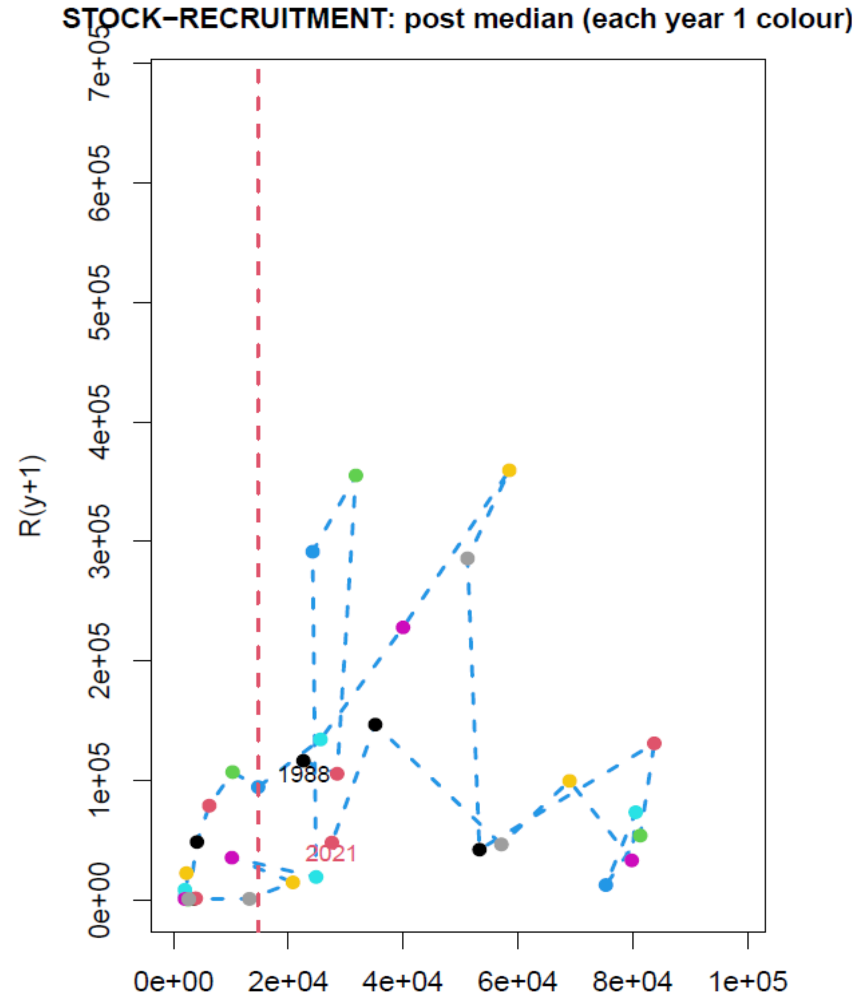


Figure 23. Stock-Recruitment plots. The value of median B_{lim}=medianSSB_{2007}=14 755 tons is shown as the red vertical line.

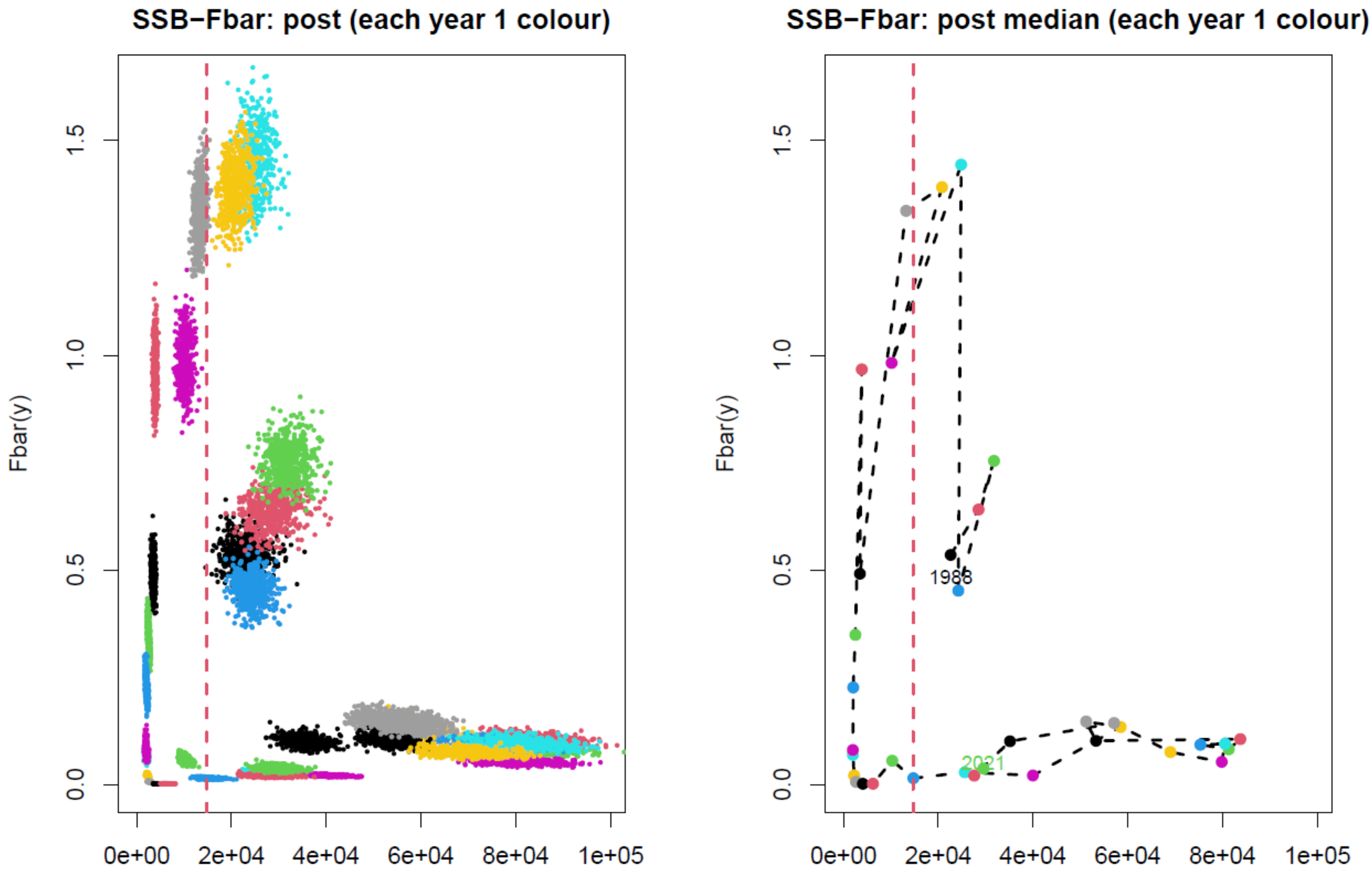


Figure 24. F_{bar} versus SSB plots. The value of median B_{lim}=medianSSB_{2007}=14 755 tons is shown as the red vertical line.

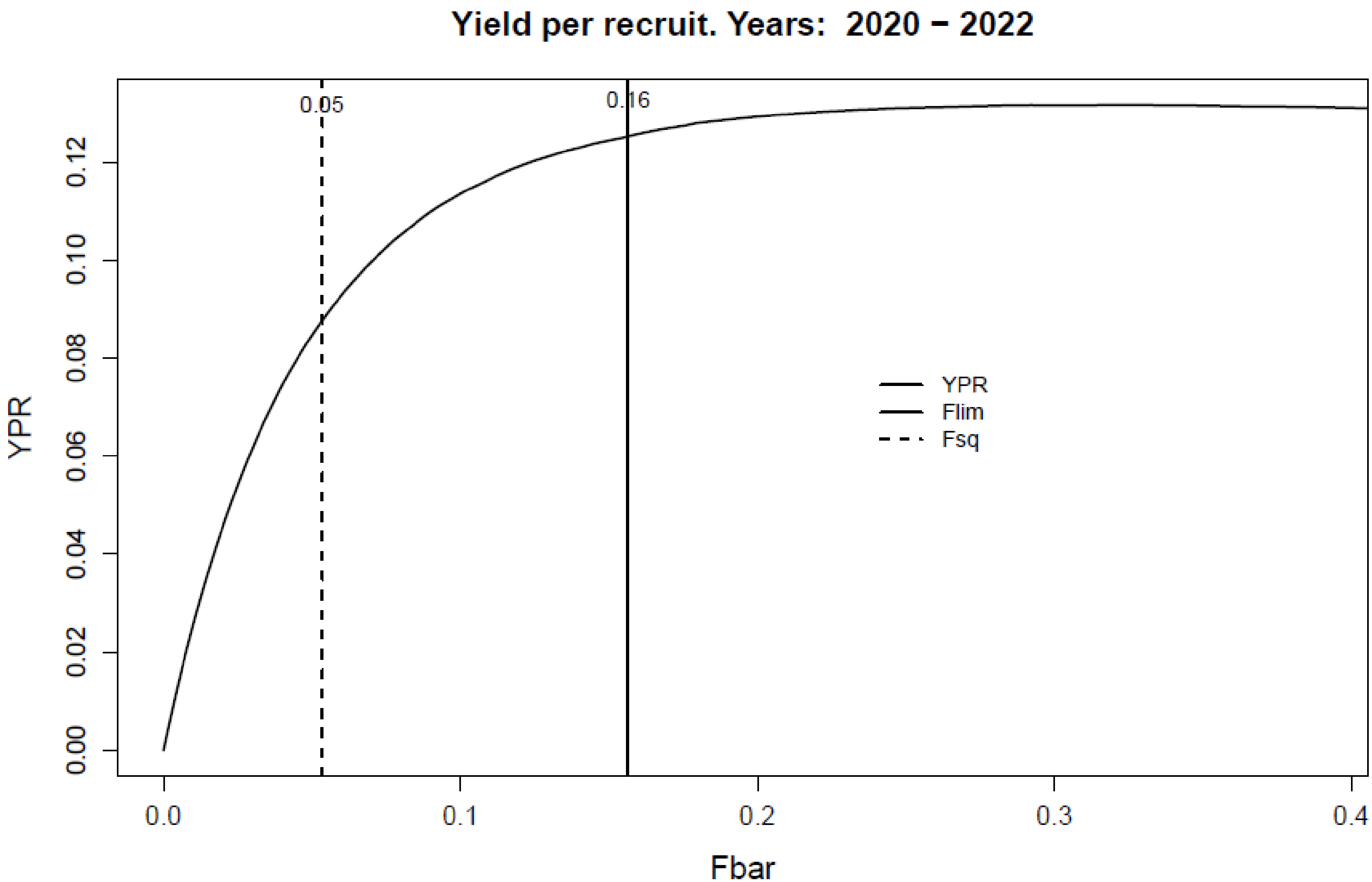


Figure 25. Yield per Recruit (2020-2020) versus F_{bar}. The values of F_{lim} ($F_{30\%SPR}$) and $F_{statusquo}$ (mean F over 2020-2022) are indicated.

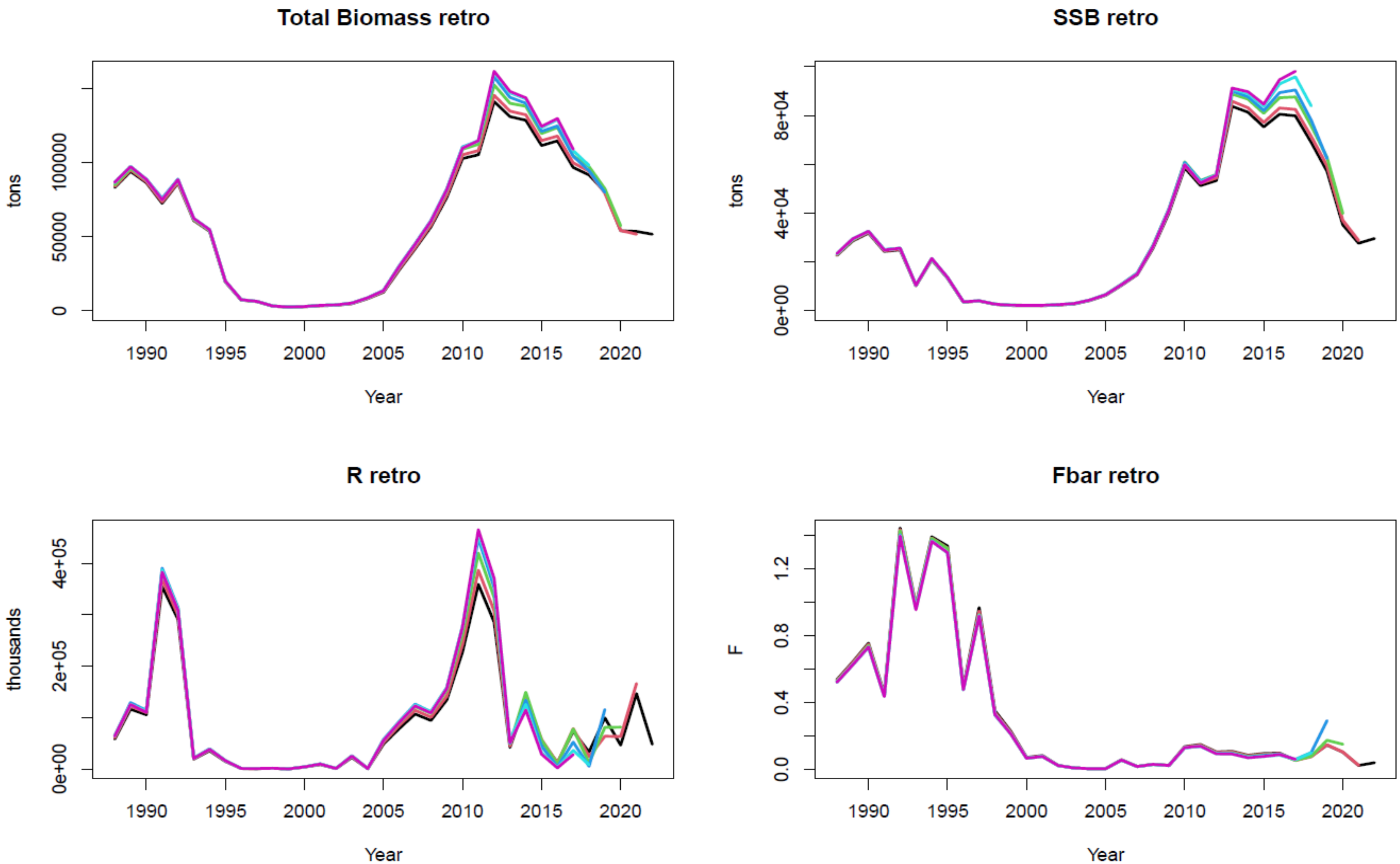


Figure 26. Retrospective patterns.

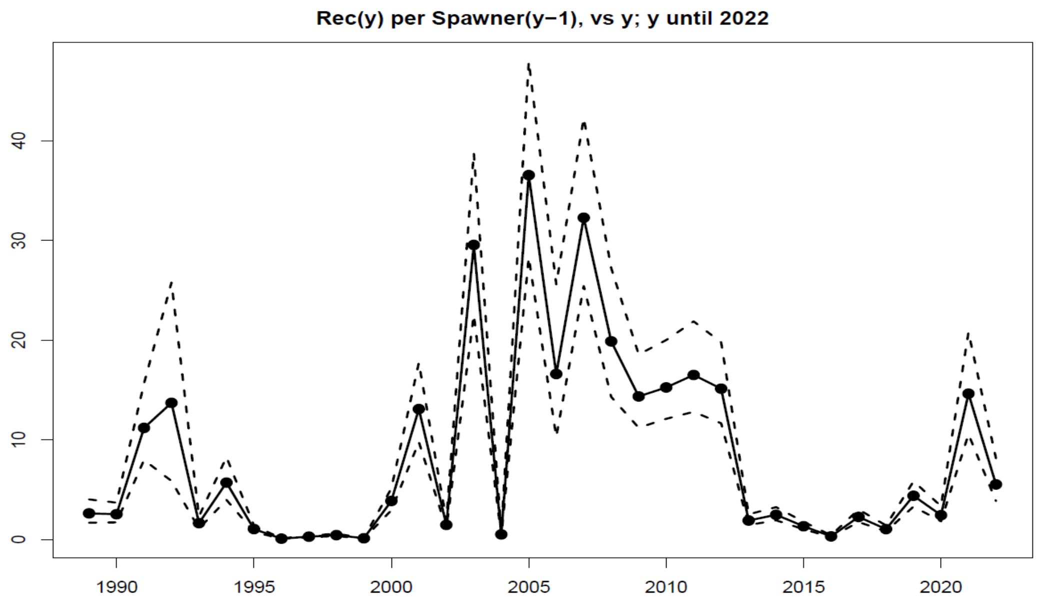


Figure 27. Estimated recruits (age 1) per spawner. First point: R_{1989}/SSB_{1988}.

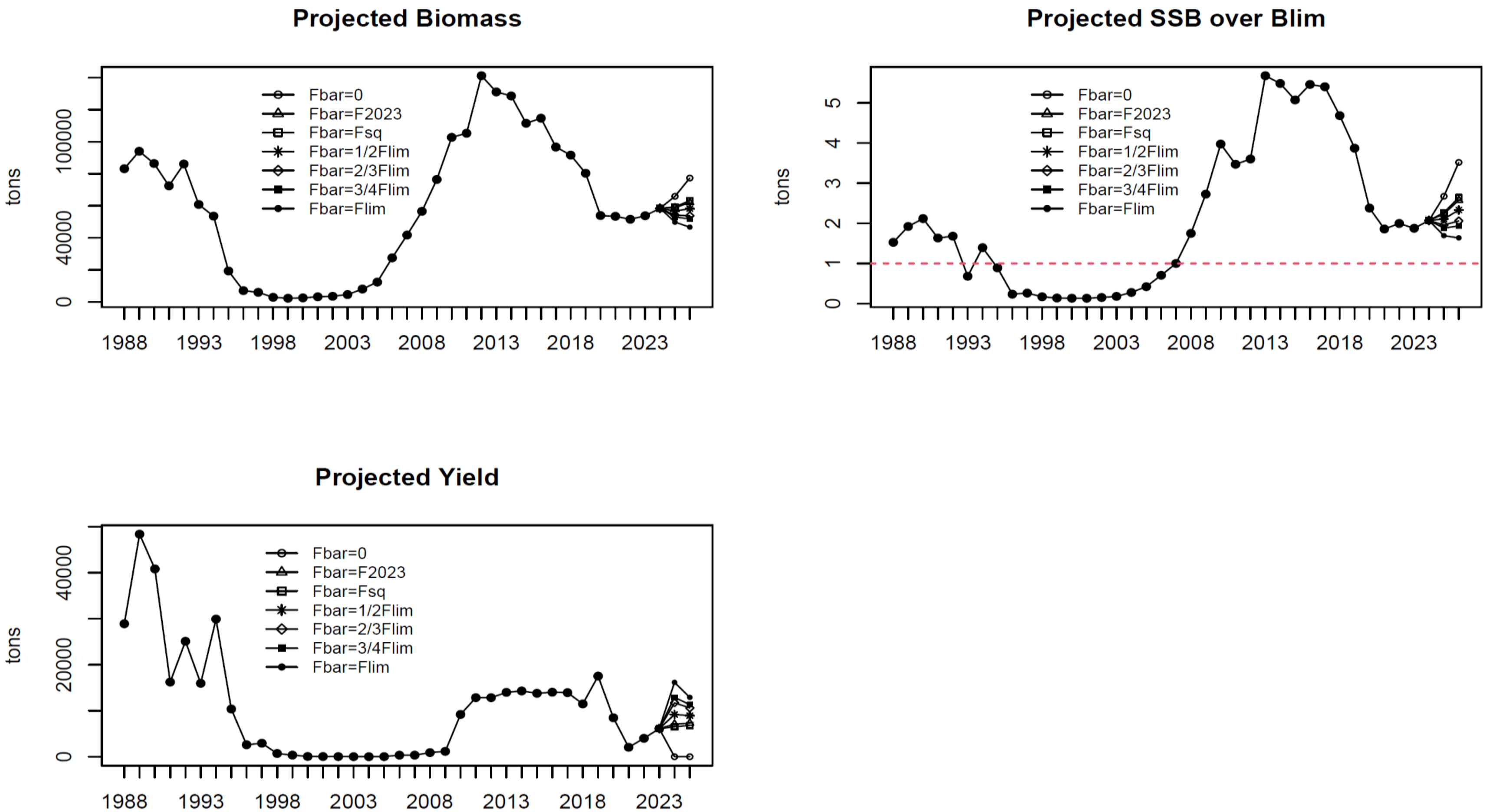


Figure 28. Projections for total Biomass, SSB/B_{lim} and Yield with different scenarios.

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. 2022) 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:

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

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

- *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:

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

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

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

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*

Prior on *phi.EU[a]*:

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

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

Prior on*gama.EU[a]*:

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