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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. B_{lim}, defined as the SSB of 2007, was estimated at 14 632 t (median). Results indicate a general increase in SSB since 2005 to the highest value in 2017, decreasing since then. SSB has been above B_{lim} since 2008. Since 2013 recruitment has been at very low levels, except for 2014 and 2021. In 2023, recruitment is at its lowest level since the reopening of the fishery.

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 stocks 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 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 last fishing moratorium, yearly catches were below 1 161 tons. The results of the 2009 assessment led to a reopening of the fishery with a TAC of 5 500 tons in 2010. With the results of the following years assessments established TACs for 2010-2023 ranged between the maximum of 17 500 tons in 2019 and the minimum of 1 500 tons in 2021, being of 6 100 tons for 2023. The STACFIS estimated catches for 2010-2023 were between 17 520 tons in 2019 and 2 055 tons in 2021, being 6 027 tons in 2023 (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 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 2023.

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 fishery of the 3M cod during the first quarter of the year, as well as the mandatory use of sorting grids in this fishery.

Material and Methods

Data used

Commercial data

Total Catch

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 the use of trawl and longline, depending on the year. This causes the proportion of trawlers and longliners to be variable among the years, ranging between 16% and 53% (Table 1B).

In 2023 the WG-CESAG estimated catch data was 6 027 tons (Table 1A, Figure 1). Information on cod catches from the following countries were available for the estimation in 2023: EU-Portugal, EU-Spain, Faroe Islands (Denmark), Norway and Russia. The proportion of longline catches in 2023 was 27% (Faroe Islands catches).

Length distributions

In 2023 length sampling of catch was conducted by EU-Portugal (Vargas *et al*., 2024), EU-Spain (González-Costas *et al.*, 2024), Faroes (Ridao-Cruz, 2024a), Russia (Fomin and Pochtar, 2024) and Norway (Nedreaas, personal communication). Given the low level of sampling at the Faroese survey (Ridao-Cruz, 2024b), the samples were not considered to be representative of the total catch of the haul. For this reason, those samples were not considered when estimating the length distribution for the commercial Faroese catches, as in previous years, and consequently only the samples from the Faroese commercial vessels were considered. 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 2023 from the commercial catch by country and total and from the EU survey (González-Troncoso *et al.*, 2024) 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 2019-2020 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 2023 length distribution go back to a unimodal shape, with the mode being around 54 cm. The mean lengths (Figure 2C) in the 2019-2023 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.

Due to administrative problems, the ALK from the EU survey in 2023 is not available for the assessment. The ALK resulting from the average of the last 3 years (2020-2022) was used to derive both commercial and survey indices in 2023.

Catch-at-age

Catch-at-age in numbers for 1988 to 2023 is presented in Table 2. These numbers were obtained by applying the ALK to the total commercial catch length distribution each year.

The catch-at-age ranges 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 3A) 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 2015-2023, 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 and 2010 cohorts can be easily followed, reaching age 8+ in 2019 and 2020. Cohort from 2011 started with a good recruitment in 2012 but then disappeared until age 5, in 2016. The cohorts since 2012 were very poor. As a consequence, since 2015 all the values of the ages less than 4 are negative until 2022. The 2012 cohort show a recruitment over the average in 2013, but remains below the average for all the other ages. Since then, low recruitments have been observed as well as low abundances until age 5. It is remarkable the big catches starting at age 5 for these cohorts, except for the one from 2015, recruited in 2016, which is the first one that remains negative during all its life.

Mean weight-at-age

For 2023, there are four commercial length-weight relationships available: EU-Portugal, EU-Spain, Faroes and Norway. All of them are presented in Figure 4 besides the 2023 EU bottom survey one. This year, the length-weight relationship from the EU bottom trawl survey has proved to be the one that better characterizes the length distribution of the commercial fleet and, for this reason, was the one used to obtain the mean weight-at-age in the catch. 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 2023.

Mean weight-at-age in the catch for 1988-2023 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. Since 2020, the average weights of almost all ages have fluctuated around intermediate levels.

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 1988-2023 are presented in González-Troncoso *et al.* (2024).

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 remains at the level of the first years of the assessment, or higher, 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 until 2019, when a shift in the trend occurs. In 2023, a steep increase can be seen. 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 steep decline until 2019, when values lower than those observed in the precollapse period were reached. This low level has remained stable, although an increase is observed in the last years.

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, especially those from 2010-2012. In 2019-2021, 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. In 2023, a negative recruitment is observed again. Note that the values of the EU survey since 2020 are all positive, except for age 1 in 2023, even for those ages that correspond to the bad recruitments in 2015-2018.

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

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 the 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. 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. After that, the mean weights remained fairly stable in the last years at low or intermediate levels.

<u>Maturity at age</u>

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.

As it occurred with the 2023 ALK, the maturity ogive is not available in 2023 for the assessment due to administrative issues. The average of the last three years (2020-2022) 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. In recent years, the percentage of matures at age oscillated around low levels compared to those between 1995-2010.

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 oscillating around 5 years old.

Faroes survey

The Faroese longline survey has been carried out in NAFO Div. 3M since 2021 during a four-week period from mid-May to mid-June (NAFO, 2023; Ridao-Cruz, 2024b). The objective of the survey is to get an indication of the cod stock with an alternative gear and build a time series which can potentially be incorporated to the assessment. The 2023 survey covered 28 stations of 52 planned in 3M. The number of hooks in every longline set was set to 3600.

Cod dominated the catch and the overall catch rate of cod was extremely high, ~1000 grams per hook. Biological samples were also taken: individual length, weight, maturation and otoliths samples were collected.

Some problems were raised with regards the methodology of this survey (NAFO, 2021b, 2022). Moreover, as only three years of data are available, it was not used in the assessment as a survey input. 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 8+ and years are from 1988 to 2023. 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, considering 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, 2018b). The natural mortality, M, is estimated by the model via a prior to be constant by year but variable through the ages.

Given the very low catch numbers observed at age 1 (Table 2), the catch at age 1 data was set equal to zero in all years and it was assumed in the model that F at age 1 is equal to zero. The 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 36 years, from 1988 to 2023

Catch in tonnes in all years; years with catch-at-age: 1988-2001, 2006-2023

Tuning with EU survey from 1988 to 2023

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 for further 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-year retrospective analysis was run. Four years projections were carried out with different scenarios, as later described, in order to see the possible evolution of the stock in the medium term under different fishing mortality levels. 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 2024 was calculated using the numbers estimated by the assessment at the beginning of 2024, applying the maturity ogive and mean weight at age in stock from 2023.

Total biomass had a sharp increase from 2006 to 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 of the beginning of the series.

The results for SSB indicate that there was a substantial increase in SSB from 2007 to 2013. Between 2013 and 2017 the SSB was stable. A considerable 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 due to the strong 2009-2011 year classes.

Recruitment had an increasing trend from 2004 to 2012, being above the average recruitment of the period between 2007 and 2012. Since 2013 the recruitment has oscillated around intermediate levels. In 2021, a good recruitment was observed, while in 2023 is at a very low level.

F_{bar} (mean for ages 3-5) was estimated at very low levels in the period 2001-2009. In 2010, with the reopening of the fishery, the F_{bar} increased although it did not reach the level of the pre-collapse years and it was slightly below F_{lim}. In 2021, the minimum level of fishing mortality since the re-opening was reached, increasing since then, but remaining below F_{lim}. 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 2023, the F has increased in all ages above 3 with respect to 2022. Figure 12 shows the median PR and its confidence intervals since year 2000, 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 2023 PR and the mean of the last three years (2021-2023) PR. It is remarkable that for the period 2018-2021 and 2023 age 6 was the most caught age, especially in 2021, while in 2022 the PR follows the shape observed before that period, in which the PR increases with the age, being 7 the most caught age.

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, being higher at the beginning of the series. 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 local sharp increases in 2018 or 2023. Ages 6 and 7 show a general increasing trend since 2000, with a slight decrease in age 6 and 7 in 2022 and 2023.

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, 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, being quite low in 2023. These is probably due to the variability of the recruitment and the decrease of the older cohorts. The biomass is around the mean biomass of the series since 2020, while the abundance is below the mean abundance of the series since 2016, except in 2021.

Estimates of stock abundance at age for 1988-2023 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 2020 cohort (reaching 3 years old in 2023). Between 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.

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 placed in 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).

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+.

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 14 632 tons, and an 80% confidence interval between 13 182 and 16 686 tons (Table 7). The median value is displayed in Figure 23, showing that this value is rather consistent.

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 2021-2023 data as 0.153, not a big update from the last assessment value (0.157). The period 2021-2023 was used as a proxy of the recent productivity of the stock. SSB in 2023 is well above B_{lim}.

Figure 25 shows the Yield per Recruit and the Spawner per Recruit versus F_{bar} curve calculated with the data of years 2021-2023 as well as the value of F_{lim} and $F_{statusquo}$ (defining the latter as the mean fishing mortality over 2021-2023).

Retrospective pattern

A retrospective analysis of five years was run (Figure 26). The analysis shows revisions in the recruitment, mainly regarding the highest values of recruitment in years 2011 and 2012, which is revised downwards, and in year 2021, which is revised upwards. The downwards revision of the 2011-2012 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, although the 2018 and 2019 ones were revised to lower values.

Recruits per Spawner

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.

Projections:

To calculate projections and risk, the method presented by Fernandez *et al.* (2017) was used. Stochastic projections of the stock dynamics for three years, from 2024 to the start of 2027, 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 2024: estimated from the assessment.

Recruitments for 2024-2027: Recruits per spawner were drawn randomly from 2020-2022 (corresponding to the recruitment of 2020-2022 and number of matures of 2019-2021). The 2023 value of recruits per spawner was omitted due to uncertainty in estimating the recruitment.

Maturity ogive for 2024-2027: Mean of the last three years available (2020-2022) maturity ogive.

Natural mortality for 2024-2027: Natural mortality from the 2023 assessment results.

Weight-at-age in stock and weight-at-age in catch for 2024-2027: Mean of the last three years (2021-2023) weight-at-age.

PR at age for 2024-2027: Mean of the last three years (2021-2023) PRs.

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

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

(Scenario 2) F_{bar} =F_{sq} (median value = 0.042).

(Scenario 3) F_{bar}=1/2 F_{lim} (median value = 0.076).

(Scenario 4) F_{bar} =0.56 F_{lim} (median value = 0.086).

(Scenario 5) F_{bar}=F_{2024} (median value = 0.093).

(Scenario 6) F_{bar}=2/3 F_{lim} (median value = 0.102).

(Scenario 7) F_{bar}=3/4 F_{lim} (median value = 0.114).

(Scenario 8) F_{bar}= F_{lim} (median value = 0.153).

All scenarios assumed that the Yield for 2024 is the established TAC (11 708 t).

Results for the eight options are presented in Tables 11-26 and Figure 28. They indicate that under all scenarios with $F_{bar} \leq F_{2024}$, total biomass during the projected years will increase, whereas the SSB is projected to increase in 2027 from 2024 with a probability higher than 50% under scenarios with $F_{bar} < 0.56\ F_{lim}$. The probability of SSB being below B_{lim} is very low (≤ 4%) in all the scenarios.

Under all scenarios, the probability of F_{bar} exceeding F_{lim} is less than or equal to 10% in 2026.

To note that 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.

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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 2023 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		2211	1063		1301		185	540	9977
2012	12836	2593	745	1597		2045	868		809		172	239	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		4371			1643			1620	17381
2020	8458	4234	545	477		2263			786			204	8509
2021	2055	571	92	86		961			138			73	1921
2022	3997		241	339		1078			561			44	2263
2023	6027		377	606.9		1624.4			850.7			0	3459

[1]Recalculated from NAFO Statistical data base using the NAFO 21A Extraction Tool. In 2022-2023, STATLANT 21 information is incomplete
[2]STACFIS estimates
[3]Includes 2021 Faroese survey catches

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	2023
Total catch	9192	9794	9003	13985	14290	13785	14023	13928	6447	17520	8458	2055	3997	6027
Total trawler	9192	9794	9003	10095	12034	10125	10208	10762	4210	12968	5416	961	2338	4408
Total longliner	0	0	0	3889	2256	3659	3814	3166	3166	4552	3042	1094	1658	1619
% longliner	0	0	0	28	16	27	27	23	49	26	36	53	41	27

Table 1C. Summary of the length distributions in 2023 of each country with samples, the total commercial and the survey.

Country	EU-Portugal	EU-Spain	Faroes	Norway	Russia	Total commercial	Survey
Number of sampled individuals	4355	1479	2200	4528	4622	17184	3467
Gear	Trawl	Trawl	Longline	Trawl	Trawl		Trawl
Range (cm)	30-132	28-120	32-132	44-102	35-126	28-132	
Mean (cm)	59	56	72	63	60	62	43
Mode (cm)	54	54	84	57	57	54	34

Table 1D. Mean and mode length of the total commercial and the survey length distribution for 2010-2023.

	Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Mean	Commercial	57	59	59	51	53	54	56	64	64	61	64	68	63	62
	Survey	30	21	30	34	44	46	49	52	55	42	41	36	40	43
Mode	Commercial	54	54	54	42	51	54	39	63	63	60	63	66	51	54
	Survey	18	15	18	24	33	42	36	42	54	21	33	45	27	34

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
2023	0	3	70	651	661	371	194	523

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
2023	0.000	0.294	0.553	1.203	1.647	2.269	2.899	4.590

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
2023	260	14403	38718	34925	12952	4193	1590	1092	487	558	575	322	73	31	10	1	0	0	0	110192	100474

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
2023	0.060	0.238	0.394	0.864	1.523	2.130	2.711	4.331

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

	1	2	3	4	5	6	7	8+	a50
1988	0.053	0.097	0.172	0.286	0.438	0.599	0.742	0.878	5.38
1989	0.053	0.097	0.172	0.286	0.438	0.599	0.742	0.878	5.38
1990	0.053	0.097	0.172	0.286	0.438	0.599	0.742	0.878	5.38
1991	0.016	0.042	0.106	0.245	0.462	0.692	0.855	0.958	5.15
1992	0.002	0.011	0.046	0.181	0.499	0.818	0.953	0.993	5.00
1993	0.001	0.006	0.047	0.280	0.750	0.959	0.995	1.000	4.47
1994	0.000	0.001	0.049	0.655	0.986	1.000	1.000	1.000	3.82
1995	0.000	0.000	0.005	0.801	1.000	1.000	1.000	1.000	3.79
1996	0.000	0.000	0.028	0.666	0.993	1.000	1.000	1.000	3.84
1997	0.000	0.007	0.109	0.670	0.972	0.998	1.000	1.000	3.75
1998	0.000	0.001	0.087	0.872	0.998	1.000	1.000	1.000	3.55
1999	0.000	0.001	0.122	0.903	0.999	1.000	1.000	1.000	3.46
2000	0.000	0.001	0.156	0.975	1.000	1.000	1.000	1.000	3.36
2001	0.000	0.000	0.271	0.997	1.000	1.000	1.000	1.000	3.15
2002	0.000	0.010	0.633	0.997	1.000	1.000	1.000	1.000	2.90
2003	0.000	0.022	0.515	0.979	1.000	1.000	1.000	1.000	2.99
2004	0.000	0.000	0.092	0.966	1.000	1.000	1.000	1.000	3.41
2005	0.038	0.165	0.500	0.830	0.959	0.991	0.998	1.000	3.00
2006	0.000	0.013	0.354	0.959	0.999	1.000	1.000	1.000	3.16
2007	0.000	0.012	0.266	0.919	0.997	1.000	1.000	1.000	3.30
2008	0.000	0.012	0.232	0.883	0.995	1.000	1.000	1.000	3.37
2009	0.000	0.010	0.181	0.829	0.991	1.000	1.000	1.000	3.49
2010	0.000	0.009	0.164	0.810	0.989	1.000	1.000	1.000	3.53
2011	0.001	0.008	0.071	0.424	0.877	0.986	0.999	1.000	4.14
2012	0.000	0.000	0.016	0.572	0.991	1.000	1.000	1.000	3.94
2013	0.003	0.035	0.283	0.802	0.977	0.998	1.000	1.000	3.40
2014	0.000	0.003	0.044	0.397	0.901	0.992	0.999	1.000	4.16
2015	0.000	0.000	0.004	0.113	0.790	0.991	1.000	1.000	4.60
2016	0.000	0.000	0.004	0.046	0.388	0.892	0.991	1.000	5.18
2017	0.000	0.000	0.000	0.017	0.829	0.999	1.000	1.000	4.72
2018	0.000	0.001	0.007	0.067	0.425	0.880	0.986	0.999	5.13
2019	0.000	0.000	0.005	0.083	0.615	0.966	0.998	1.000	4.84
2020	0.000	0.000	0.003	0.041	0.402	0.908	0.993	1.000	5.15
2021	0.000	0.002	0.017	0.117	0.498	0.883	0.983	0.998	5.00
2022	0.000	0.001	0.008	0.109	0.656	0.967	0.998	1.000	4.76
2023	0.000	0.001	0.010	0.095	0.523	0.919	0.992	0.999	4.96

Table 7. Posterior results: total biomass, SSB, recruitment (tons) and F_{bar}. SSB in 2024 estimated using the biological parameters of 2023.

	B quantiles			SSB quantiles			R quantiles			F_{bar} quantiles		
Year	**50%**	**10%**	**90%**	**50%**	**10%**	**90%**	**50%**	**10%**	**90%**	**50%**	**10%**	**90%**
1988	82912	78922	87396	22464	19189	26795	60398	46754	81178	0.533	0.492	0.577
1989	93870	89139	99196	28457	24205	33486	120835	93200	162226	0.64	0.592	0.688
1990	86730	82059	91446	31728	28019	35868	110334	84227	148891	0.753	0.702	0.807
1991	73150	67680	80551	24453	21452	27400	368478	284407	484975	0.451	0.411	0.494
1992	86575	80679	93878	24916	22503	27601	301276	237776	400899	1.458	1.369	1.556
1993	60830	57133	64935	10066	8862	11420	19686	15437	26325	0.993	0.922	1.06
1994	53628	50350	56905	20620	18232	23247	36433	28338	48716	1.394	1.313	1.475
1995	19264	18193	20539	13248	12231	14286	14894	11661	20074	1.335	1.25	1.415
1996	7025	6669	7470	3488	3192	3821	912	706	1225	0.489	0.449	0.535
1997	5973	5662	6368	3880	3593	4179	796	605	1078	0.98	0.905	1.053
1998	2831	2626	3072	2450	2259	2679	1328	1014	1824	0.362	0.317	0.403
1999	2236	2016	2502	1985	1784	2245	202	150	278	0.232	0.201	0.267
2000	2463	2201	2782	1892	1669	2163	3704	2803	4964	0.069	0.059	0.083
2001	3133	2797	3518	1891	1689	2129	8574	6661	11557	0.081	0.065	0.1
2002	3430	3120	3772	2168	1953	2408	814	622	1121	0.022	0.019	0.025
2003	4594	4136	5183	2620	2392	2888	22701	17485	30847	0.006	0.006	0.008
2004	7973	7273	8856	4060	3723	4431	692	536	938	0.002	0.002	0.002
2005	12501	11263	14281	6165	5580	6898	50007	38645	67655	0.002	0.002	0.003
2006	27780	24876	31358	10266	9428	11213	81010	62464	107773	0.056	0.048	0.064
2007	41588	37923	45683	14630	13182	16686	110028	84564	146202	0.015	0.013	0.017
2008	56376	52189	61303	25432	23522	27526	97449	75719	130832	0.029	0.025	0.032
2009	76506	70971	82998	39957	37100	42922	138510	106124	184150	0.021	0.019	0.024
2010	102984	96094	111375	58483	54277	62945	235932	183040	314622	0.134	0.122	0.15
2011	105800	98529	114075	51270	47338	55075	372767	290738	502070	0.147	0.13	0.164
2012	142141	130648	155572	53053	49077	57511	299568	233465	394822	0.102	0.09	0.115
2013	131549	122610	141192	83608	77362	90888	44018	34175	59849	0.105	0.093	0.119
2014	129757	120882	139167	81279	74693	88539	140198	108433	187603	0.081	0.072	0.092
2015	113149	105547	121295	75603	69410	82451	57927	45410	77753	0.091	0.08	0.103
2016	116647	108558	125516	81582	74544	89033	13303	10354	17731	0.093	0.082	0.106
2017	98834	91290	106630	81295	74503	88660	70949	55197	94869	0.051	0.045	0.059
2018	94102	86865	101321	70799	64314	77125	37840	29526	51716	0.074	0.065	0.085
2019	83856	77497	90496	59711	54740	65224	108032	81983	144714	0.139	0.124	0.156
2020	58975	53846	63866	38637	34722	42848	71706	54524	98480	0.097	0.085	0.112
2021	62345	56567	68269	30771	27333	34476	231922	172030	320006	0.02	0.017	0.023
2022	60064	55244	64901	32350	29295	35570	69177	49759	95559	0.035	0.03	0.041
2023	57256	52041	62460	27464	24720	30122	6581	4537	9858	0.07	0.059	0.082
2024				31227	28003	34653						

Table 8. F at age (posterior median).

	F at age							
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**
1988	0.000	0.019	0.350	0.596	0.641	0.648	0.800	0.800
1989	0.000	0.011	0.370	0.809	0.727	0.782	0.883	0.883
1990	0.000	0.018	0.398	0.940	0.918	1.200	1.067	1.067
1991	0.000	0.023	0.307	0.494	0.548	0.562	0.688	0.688
1992	0.000	0.146	1.041	1.535	1.787	1.425	1.994	1.994
1993	0.000	0.086	0.702	1.170	1.090	1.533	0.868	0.868
1994	0.000	0.199	1.028	1.770	1.378	1.338	1.004	1.004
1995	0.000	0.196	0.583	1.535	1.887	2.336	2.210	2.210
1996	0.000	0.050	0.263	0.511	0.695	0.913	0.826	0.826
1997	0.000	0.121	0.623	0.903	1.405	2.081	1.888	1.888
1998	0.000	0.050	0.220	0.356	0.503	0.589	0.452	0.452
1999	0.000	0.028	0.252	0.198	0.246	0.252	0.094	0.094
2000	0.000	0.006	0.136	0.028	0.044	0.035	0.011	0.011
2001	0.000	0.008	0.147	0.038	0.056	0.042	0.015	0.015
2002	0.000	0.002	0.037	0.011	0.016	0.012	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	0.079	0.040	0.047	0.033	0.029	0.029
2007	0.000	0.000	0.011	0.016	0.018	0.018	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	0.012	0.074	0.136	0.192	0.195	0.215	0.215
2011	0.000	0.012	0.095	0.116	0.228	0.282	0.379	0.379
2012	0.000	0.007	0.065	0.080	0.159	0.205	0.299	0.299
2013	0.000	0.007	0.071	0.081	0.162	0.218	0.288	0.288
2014	0.000	0.003	0.037	0.093	0.113	0.175	0.238	0.238
2015	0.000	0.003	0.050	0.090	0.131	0.211	0.242	0.242
2016	0.000	0.003	0.039	0.107	0.133	0.157	0.238	0.238
2017	0.000	0.001	0.015	0.045	0.093	0.161	0.208	0.208
2018	0.000	0.002	0.021	0.055	0.145	0.278	0.220	0.220
2019	0.000	0.001	0.036	0.116	0.265	0.510	0.365	0.365
2020	0.000	0.000	0.010	0.091	0.188	0.378	0.251	0.251
2021	0.000	0.000	0.001	0.020	0.038	0.097	0.071	0.071
2022	0.000	0.000	0.001	0.041	0.064	0.150	0.147	0.147
2023	0.000	0.000	0.002	0.089	0.118	0.252	0.221	0.221

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	60398	137807	93454	29570	4260	946	694	270	327399	44360
1989	120835	15575	74058	47373	12773	1729	337	303	272982	41303
1990	110334	30983	8391	36431	16547	4733	537	184	208139	31594
1991	368478	28439	16726	4029	11237	5105	970	175	435159	19737
1992	301276	94590	15150	8786	1937	5034	1976	404	429152	11409
1993	19686	77807	44651	3838	1477	249	828	228	148762	6060
1994	36433	5131	39071	15793	934	383	37	311	98092	13889
1995	14894	9386	2289	9943	2124	181	69	88	38974	10449
1996	912	3879	4189	913	1707	249	12	12	11872	2682
1997	796	236	2010	2308	430	659	68	7	6514	2914
1998	1328	206	114	773	735	82	56	8	3302	1560
1999	202	344	107	65	426	345	31	29	1548	902
2000	3704	52	183	59	42	257	182	38	4517	603
2001	8574	950	28	114	45	31	170	154	10066	520
2002	814	2215	515	17	87	33	20	223	3924	723
2003	22701	211	1214	356	14	66	23	167	24752	1251
2004	692	5853	115	864	280	10	45	131	7989	1307
2005	50007	180	3198	82	680	216	7	122	54493	4627
2006	81010	13052	98	2290	65	527	148	89	97279	3241
2007	110028	20889	7086	65	1736	48	349	161	140362	4563
2008	97449	28334	11367	5042	50	1319	32	348	143941	9217
2009	138510	25219	15457	8043	3849	38	868	255	192238	14717
2010	235932	35656	13693	11044	6192	2894	25	764	306200	21265
2011	372767	60577	19226	9137	7593	3959	1631	437	475326	18546
2012	299568	96322	32805	12543	6378	4680	2038	995	455328	21750
2013	44018	77345	52420	22006	9126	4215	2600	1572	213301	52523
2014	140198	11410	41945	34984	15992	6005	2321	2183	255039	40591
2015	57927	36267	6213	28994	25092	11104	3455	2476	171529	39966
2016	13303	15000	19721	4226	20844	17050	6147	3238	99529	32784
2017	70949	3439	8173	13573	2986	14178	9971	5190	128459	31996
2018	37840	18243	1879	5781	10247	2115	8217	8610	92933	23285
2019	108032	9809	9976	1317	4303	6854	1093	9417	150800	19910
2020	71706	27781	5364	6920	924	2549	2807	5044	123094	10801
2021	231922	18639	15163	3809	4983	596	1194	4241	280547	9212
2022	69177	59837	10163	10861	2948	3713	367	3508	160573	10680
2023	6581	17773	32844	7261	8230	2147	2185	2309	79330	11771

Table 10. Prior and posterior median for M

Age	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	1.34	0.60	0.33	0.24	0.25	0.38	0.35	0.37

Table 11. 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
2024	84756	1675	9704	23377	5261	5669	1139	2508	136186	13859
2025	102040	22067	916	6919	16679	3435	2612	1799	166147	16928
2026	123191	25893	12096	658	5425	12861	2348	3100	211632	20499
2027	149304	30946	14132	8649	518	4206	8770	3791	255737	18113
2028	143299	38191	16774	10088	6790	401	2877	8817	281246	18057
2029	132795	35903	20950	12174	7940	5259	273	8139	281220	22765

Table 12. Projections results (median and 80% CI) with F_{bar}=0.

Year	Total Biomass		SSB		P(SSB<Blim)	P(SSB27> SSB24)	Yield	P(F>Flim)
2024	69964	(61172 - 80992)	34191	(30581 - 37965)	<1%		11708	<1%
2025	71077	(58334 - 87704)	38180	(32789 - 44159)	<1%		0	<1%
2026	85529	(70215 - 108862)	54962	(47380 - 63261)	<1%	100%	0	<1%
2027	97470	(75277 - 128007)	56346	(49099 - 64824)	<1%		0	<1%
2028	112632	(84394 - 154854)	61036	(51011 - 75698)	<1%			

Table 13. N-at-age in prediction years (medians) with F_{bar}=F_{sq} =0.042 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2024	84756	1675	9704	23377	5261	5669	1139	2508	136186	13859
2025	102040	22067	916	6919	16679	3435	2612	1799	166147	16928
2026	123191	25893	12094	658	5175	11933	1958	2656	209644	18671
2027	136051	30946	14130	8640	491	3716	6816	2768	240984	14692
2028	116443	34497	16771	10073	6463	354	2133	5761	243495	13903
2029	103538	28913	19120	12156	7550	4610	201	4733	233177	18216

Table 14. Projections results (median and 80% CI) with F_{bar}=F_{sq}=0.042.

Year	Total Biomass		SSB		P(SSB<Blim)	P(SSB27> SSB24)	Yield	P(F>Flim)
2024	69964	(61172 - 80992)	34191	(30581 - 37965)	<1%		11708	<1%
2025	71077	(58334 - 87704)	38180	(32789 - 44159)	<1%		5580	<1%
2026	79679	(64255 - 102904)	49425	(42014 - 57552)	<1%	100%	7112	<1%
2027	84088	(62475 - 114436)	44197	(36922 - 52632)	<1%		6224	<1%
2028	92067	(64603 - 132496)	43517	(33401 - 58227)	<1%			

Table 15. N-at-age in prediction years (medians) with F_{bar}=1/2F_{lim} =0.076 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2024	84756	1675	9704	23377	5261	5669	1139	2508	136186	13859
2025	102040	22067	916	6919	16679	3435	2612	1799	166147	16928
2026	123191	25893	12093	657	4963	11200	1682	2342	208135	17330
2027	125218	30946	14129	8632	471	3350	5508	2124	229774	12376
2028	98044	31793	16769	10061	6168	317	1642	4020	215848	11481
2029	86323	24234	17580	12143	7151	4080	153	2982	201537	15517

Table 16. Projections results (median and 80% CI) with F_{bar}=1/2F_{lim} =0.076.

Year	Total Biomass		SSB		P(SSB<Blim)	P(SSB27> SSB24)	Yield	P(F>Flim)
2024	69964	(61172 - 80992)	34191	(30581 - 37965)	<1%		11708	<1%
2025	71077	(58334 - 87704)	38180	(32789 - 44159)	<1%		9786	<1%
2026	75187	(59830 - 98431)	45287	(37898 - 53368)	<1%	66%	11351	<1%
2027	74899	(53930 - 104982)	36282	(28988 - 44515)	<1%		9057	<1%
2028	79494	(52952 - 118721)	33179	(23210 - 48173)	<1%			

Table 17. N-at-age in prediction years (medians) with F_{bar}=0.56F_{lim} =0.086 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2024	84756	1675	9704	23377	5261	5669	1139	2508	136186	13859
2025	102040	22067	916	6919	16679	3435	2612	1799	166147	16928
2026	123191	25893	12092	656	4906	11002	1614	2256	207729	16939
2027	122863	30946	14128	8629	464	3257	5179	1969	227043	11801
2028	93581	31021	16768	10058	6091	306	1521	3624	208734	10895
2029	82792	23075	17151	12139	7062	3950	142	2621	194040	14935

Table 18. Projections results (median and 80% CI) with F_{bar}=0.56F_{lim} =0.086.

Year	Total Biomass		SSB		P(SSB<Blim)	P(SSB27> SSB24)	Yield	P(F>Flim)
2024	69964	(61172 - 80992)	34191	(30581 - 37965)	<1%		11708	<1%
2025	71077	(58334 - 87704)	38180	(32789 - 44159)	<1%		10913	<1%
2026	73981	(58650 - 97233)	44158	(36816 - 52286)	<1%	50%	12310	<1%
2027	72678	(51812 - 102907)	34312	(27034 - 42517)	<1%		9602	1%
2028	76721	(50313 - 115621)	30813	(20886 - 45778)	1%			

Table 19. N-at-age in prediction years (medians) with $F_{bar}=F_{2024}=0.093$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2024	84756	1675	9704	23377	5261	5669	1139	2508	136186	13859
2025	102040	22067	916	6919	16679	3435	2612	1799	166147	16928
2026	123191	25893	12092	656	4872	10883	1572	2203	207476	16718
2027	121365	30946	14128	8628	461	3200	4995	1883	224881	11487
2028	90771	30622	16768	10056	6035	301	1462	3420	204196	10608
2029	80645	22337	16876	12138	7004	3867	136	2436	189323	14666

Table 20. Projections results (median and 80% CI) with $F_{bar}=F_{2024}=0.093$.

Year	Total Biomass		SSB		P(SSB<Blim)	P(SSB27> SSB24)	Yield	P(F>Flim)
2024	69964	(61172 - 80992)	34191	(30581 - 37965)	<1%		11708	<1%
2025	71077	(58334 - 87704)	38180	(32789 - 44159)	<1%		11613	<1%
2026	73231	(57914 - 96493)	43491	(36115 - 51656)	<1%	41%	12820	<1%
2027	71372	(50559 - 101399)	33209	(25935 - 41462)	<1%		9900	3%
2028	75016	(48824 - 113857)	29468	(19637 - 44547)	2%			

Table 21. N-at-age in prediction years (medians) with $F_{bar}=2/3F_{lim}=0.102$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2024	84756	1675	9704	23377	5261	5669	1139	2508	136186	13859
2025	102040	22067	916	6919	16679	3435	2612	1799	166147	16928
2026	123191	25893	12092	656	4822	10696	1509	2133	207114	16377
2027	118602	30946	14127	8626	456	3110	4714	1753	222149	10975
2028	86951	29977	16767	10053	5953	292	1363	3097	197493	10119
2029	77473	21346	16562	12134	6895	3721	126	2150	182420	14126

Table 22. Projections results (median and 80% CI) with $F_{bar}=2/3F_{lim}=0.102$.

Year	Total Biomass		SSB		P(SSB<Blim)	P(SSB27> SSB24)	Yield	P(F>Flim)
2024	69964	(61172 - 80992)	34191	(30581 - 37965)	<1%		11708	<1%
2025	71077	(58334 - 87704)	38180	(32789 - 44159)	<1%		12613	<1%
2026	72160	(56868 - 95434)	42483	(35219 - 50627)	<1%	29%	13622	2%
2027	69541	(48765 - 99338)	31548	(24214 - 39695)	<1%		10286	8%
2028	72736	(46403 - 111060)	27614	(17703 - 42656)	4%			

Table 23. N-at-age in prediction years (medians) with F_{bar}=3/4F_{lim} =0.114 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2024	84756	1675	9704	23377	5261	5669	1139	2508	136186	13859
2025	102040	22067	916	6919	16679	3435	2612	1799	166147	16928
2026	123191	25893	12091	656	4749	10450	1428	2031	206608	15963
2027	115280	30946	14127	8623	448	2997	4371	1587	218680	10360
2028	81990	29079	16766	10049	5857	280	1242	2729	190266	9563
2029	72862	20269	16099	12127	6733	3550	114	1829	173070	13479

Table 24. Projections results (median and 80% CI) with F_{bar}=3/4F_{lim}=0.114.

Year	Total Biomass		SSB		P(SSB<Blim)	P(SSB27> SSB24)	Yield	P(F>Flim)
2024	69964	(61172 - 80992)	34191	(30581 - 37965)	<1%		11708	<1%
2025	71077	(58334 - 87704)	38180	(32789 - 44159)	<1%		13949	2%
2026	70731	(55473 - 94021)	41172	(33870 - 49383)	<1%	18%	14558	10%
2027	67180	(46452 - 96710)	29424	(22151 - 37537)	1%		10674	18%
2028	69817	(43326 - 107655)	25302	(15500 - 40371)	9%			

Table 25. N-at-age in prediction years (medians) with F_{bar}=F_{lim} =0.153 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2024	84756	1675	9704	23377	5261	5669	1139	2508	136186	13859
2025	102040	22067	916	6919	16679	3435	2612	1799	166147	16928
2026	123191	25893	12090	655	4543	9714	1213	1766	205165	14708
2027	106006	30946	14125	8614	427	2672	3466	1185	207723	8744
2028	68783	26794	16764	10037	5540	248	934	1850	170790	8143
2029	61382	17288	14772	12103	6282	3098	86	1106	151742	11953

Table 26. Projections results (median and 80% CI) with F_{bar}=F_{lim}=0.153.

Year	Total Biomass		SSB		P(SSB<Blim)	P(SSB27> SSB24)	Yield	P(F>Flim)
2024	69964	(61172 - 80992)	34191	(30581 - 37965)	<1%		11708	<1%
2025	71077	(58334 - 87704)	38180	(32789 - 44159)	<1%		17711	50%
2026	66783	(51499 - 90043)	37545	(30323 - 45626)	<1%	3%	16719	50%
2027	60872	(40592 - 90361)	23935	(16734 - 32123)	4%		11323	50%
2028	62288	(36377 - 99719)	19741	(9858 - 34712)	27%			

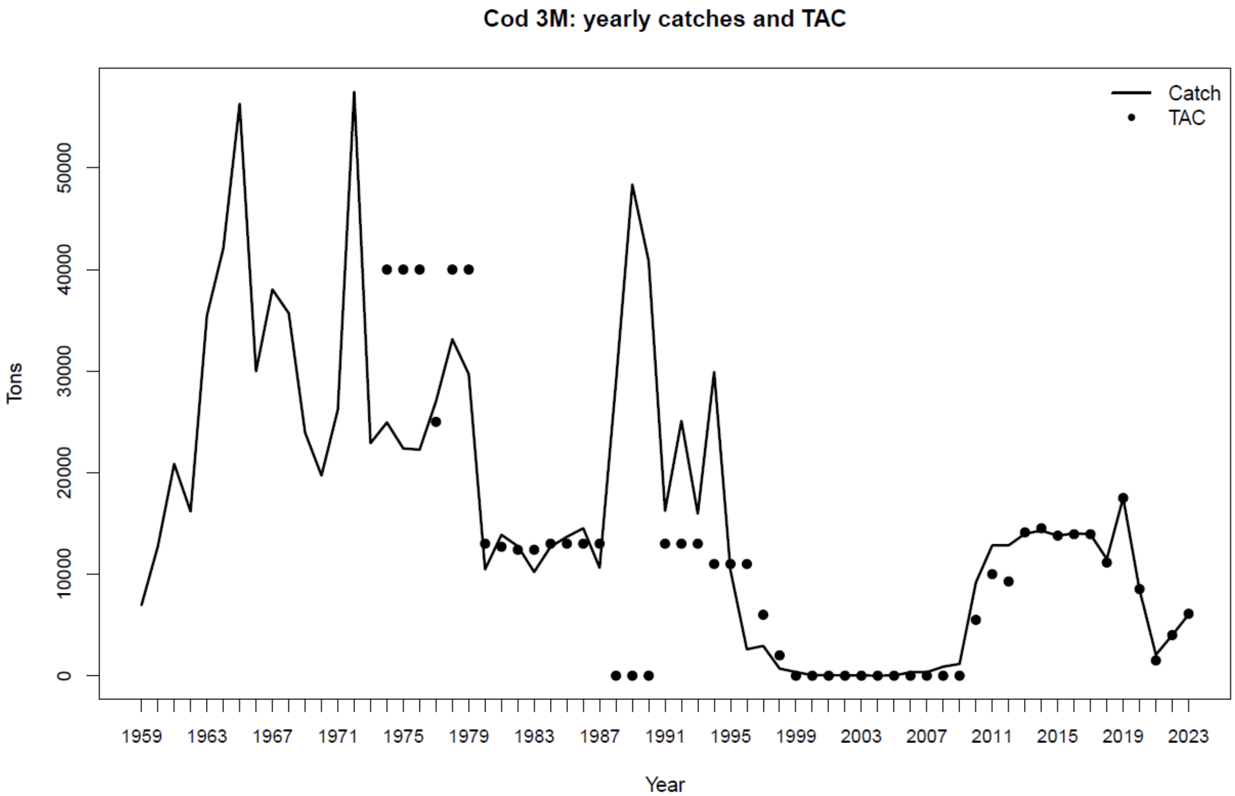


Figure 1. Catch and TAC of the 3M cod for the period 1959-2023.

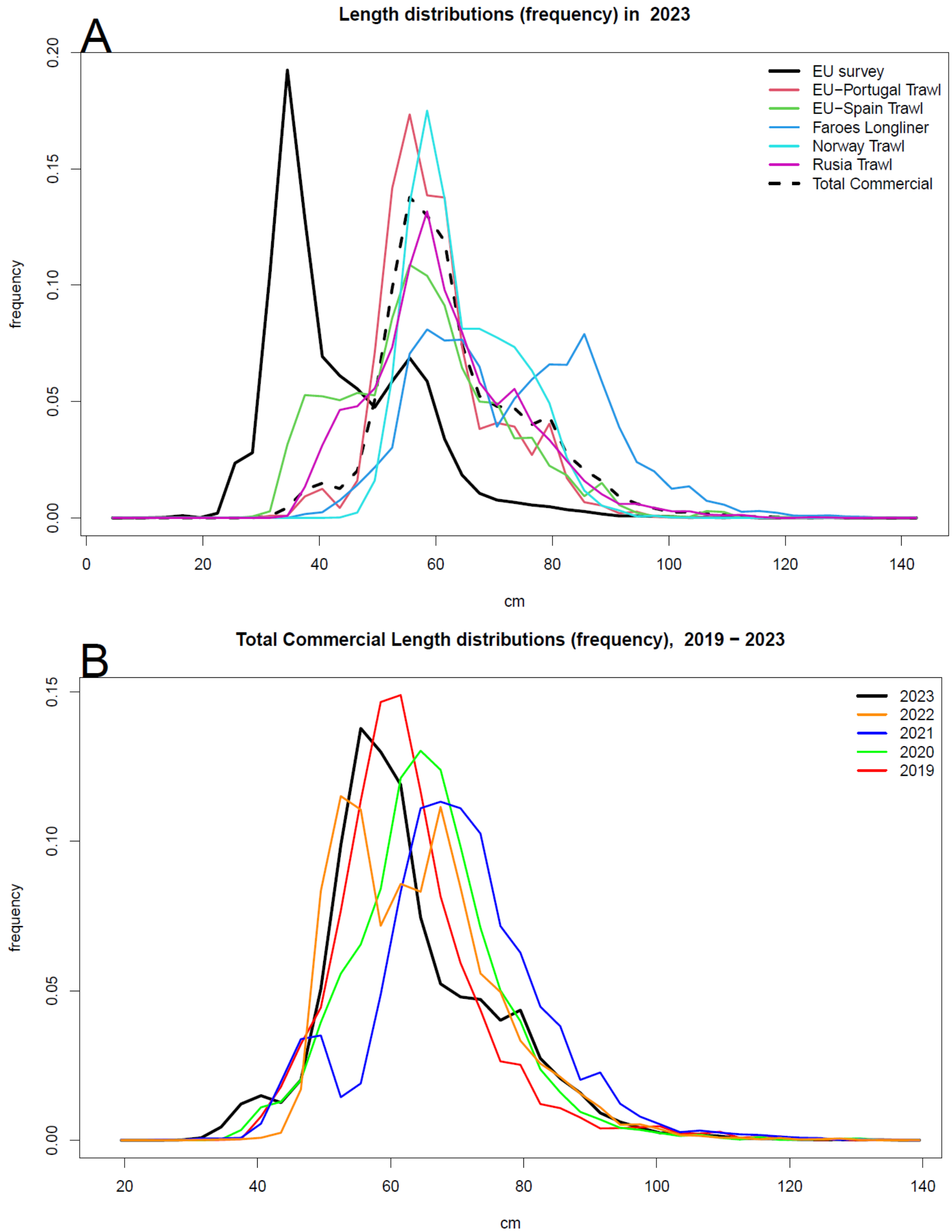


Figure 2. Length distributions in commercial catches and EU survey in 2023 (A), and the total commercial for the last five years (2019-2023) (B). In (C), the mean and the mode length of the commercial length distribution is shown (2010-2023).

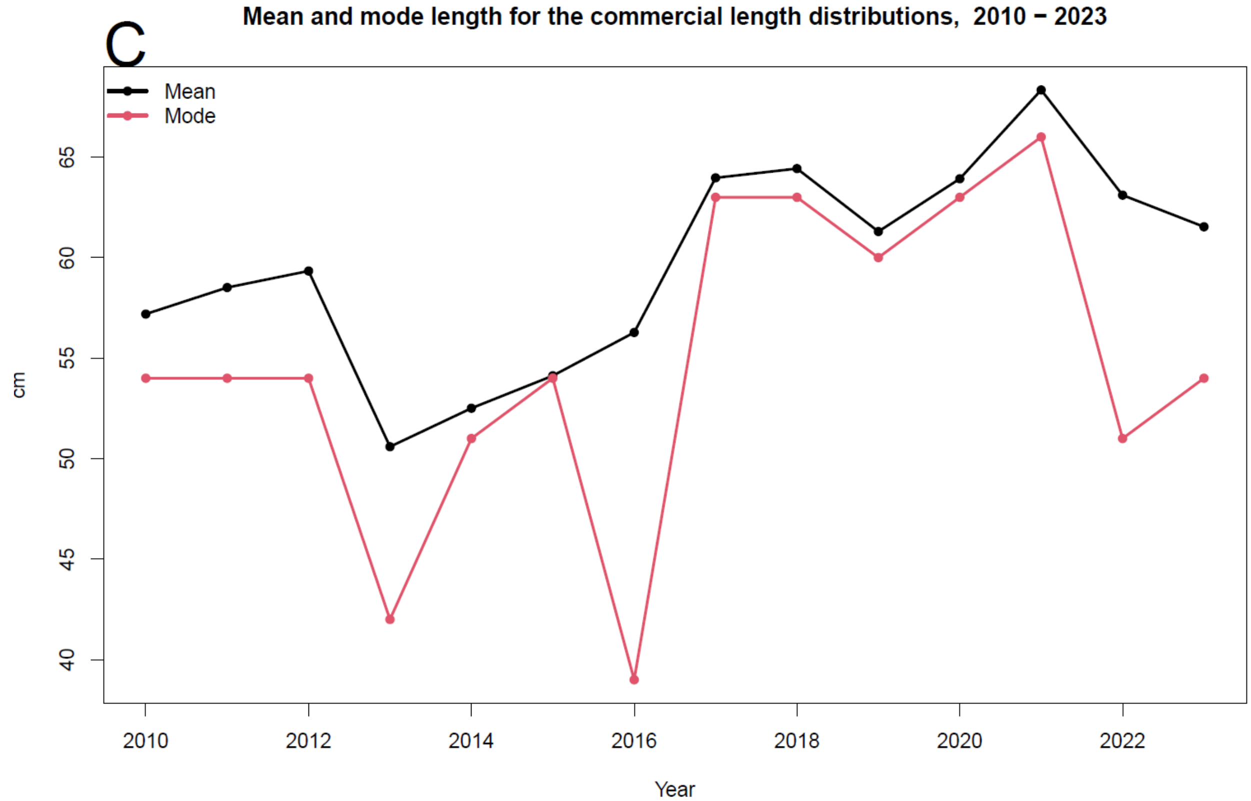


Figure 2 (cont.). Length distributions in commercial catches and EU survey in 2023 (A), and the total commercial for the last five years (2019-2023) (B). In (C), the mean and the mode length of the commercial length distribution is shown (2010-2023).

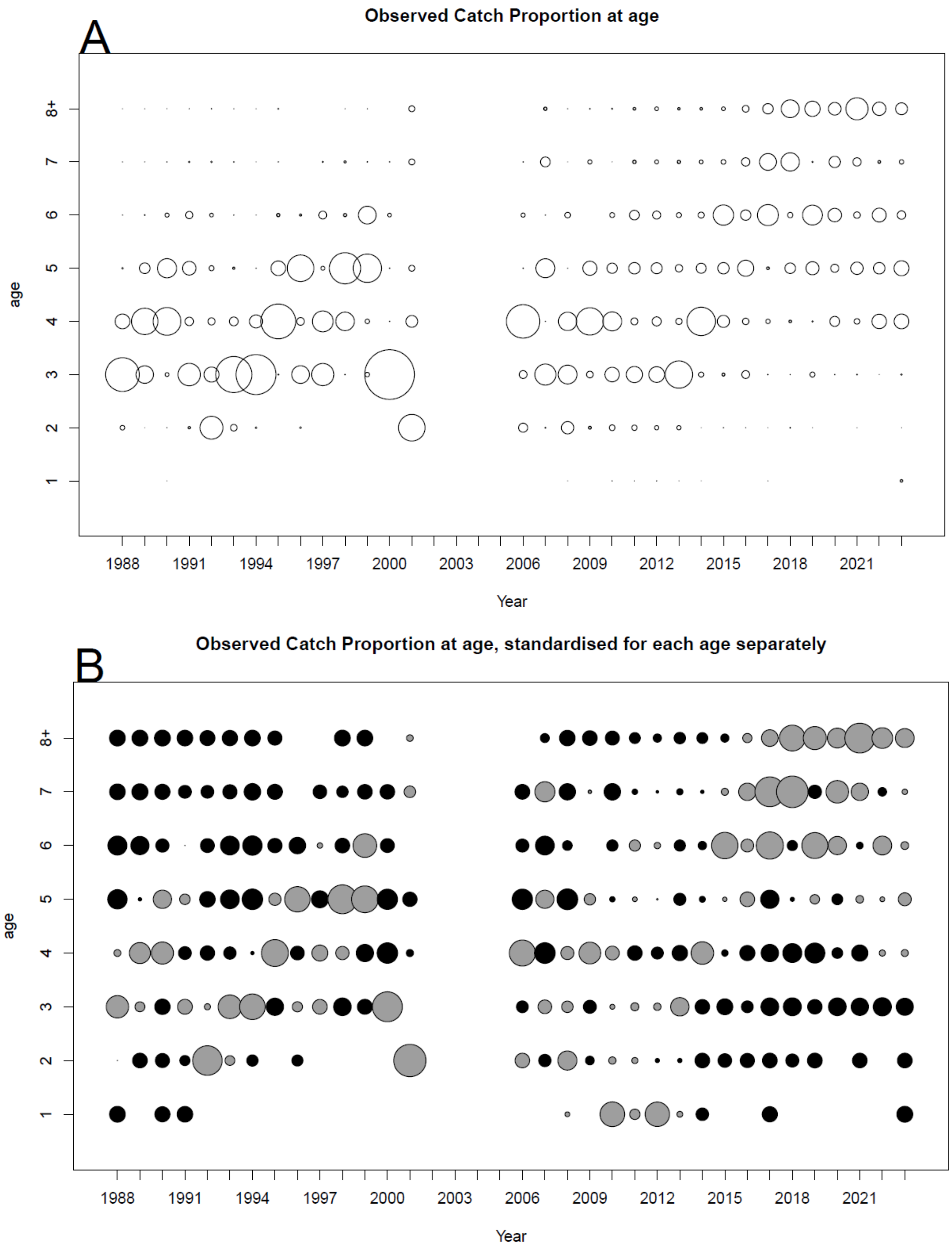


Figure 3. Commercial catch proportions at age (A) and standardised proportions at age (B). In B, grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

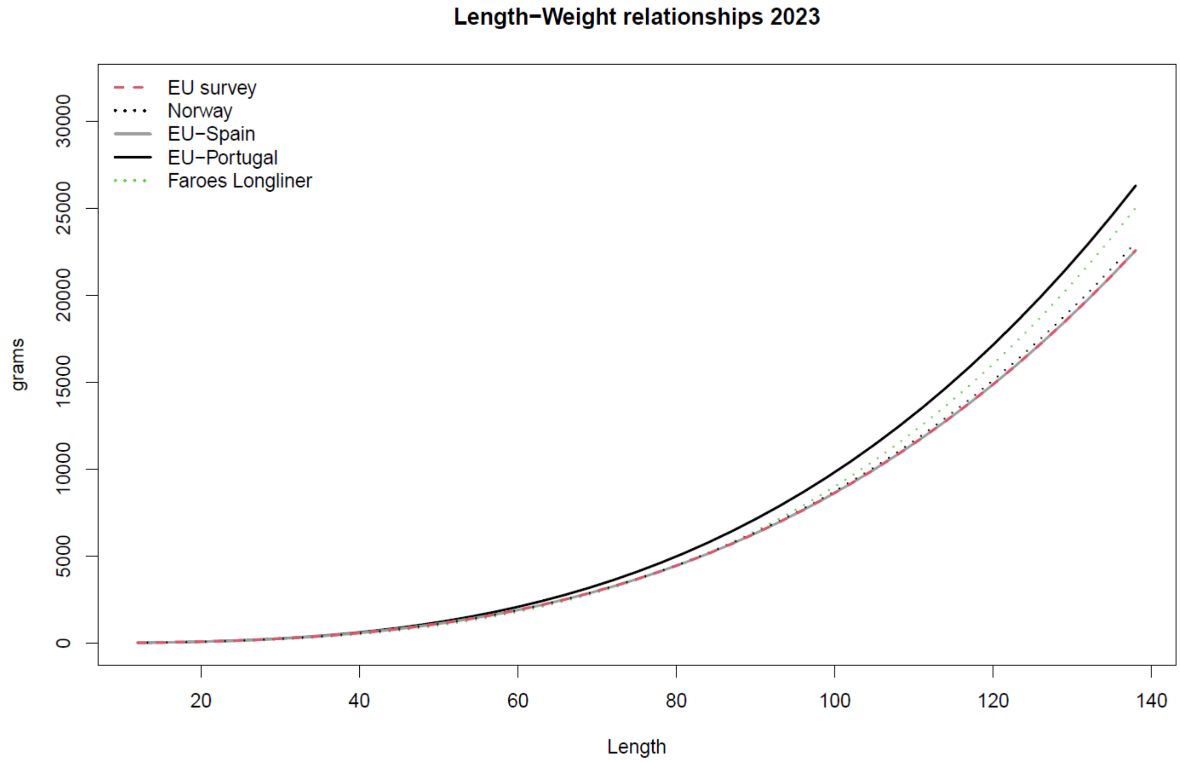


Figure 4. Length-weight relationships for commercial catches and EU survey.

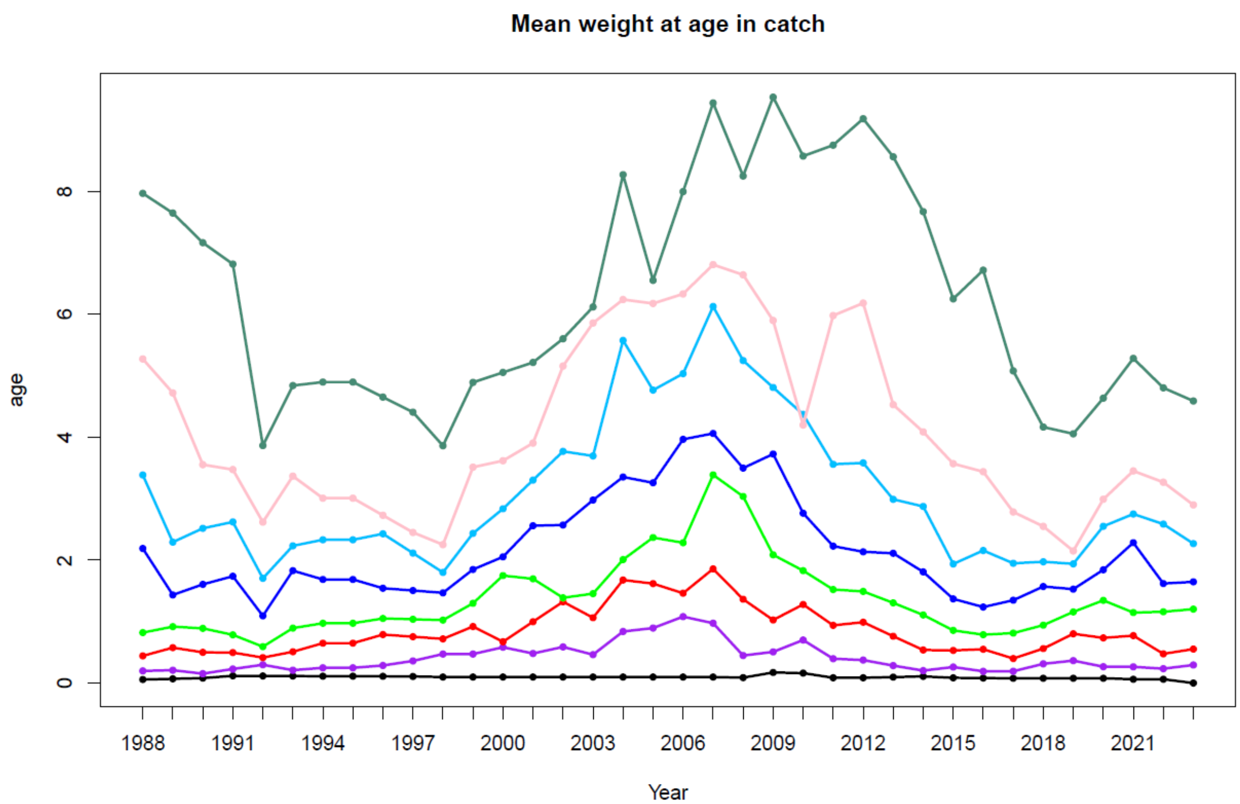


Figure 5. Mean weight at age in catch.

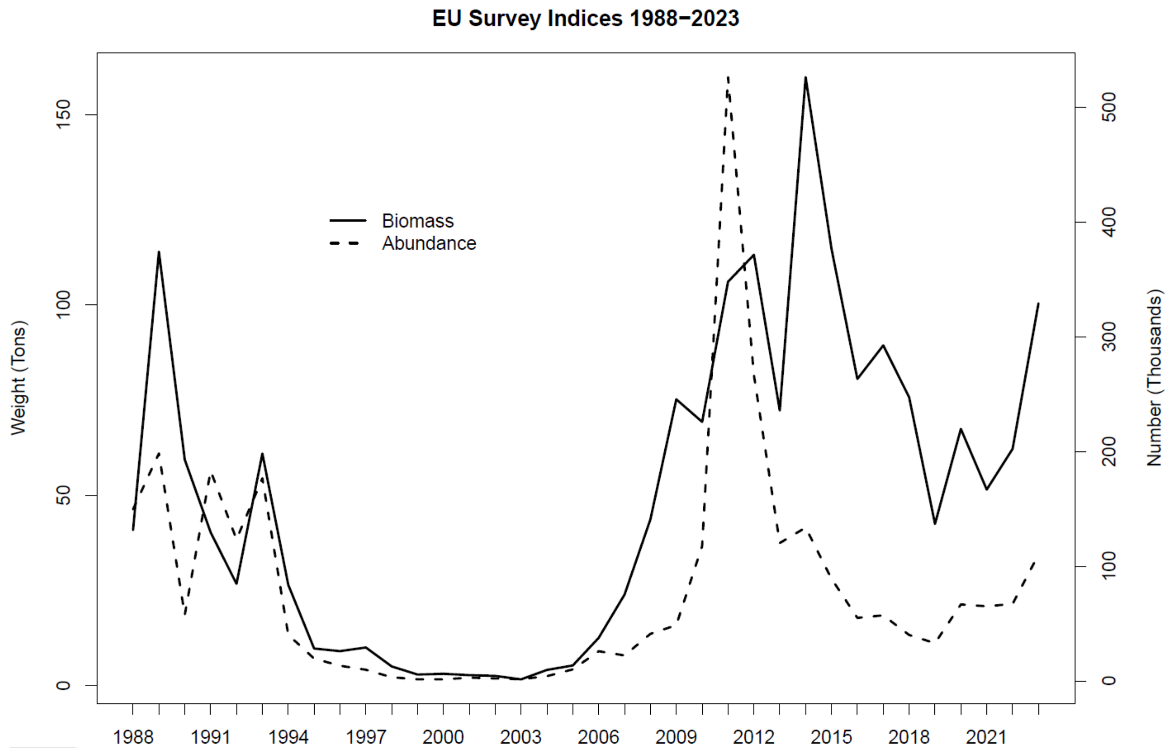


Figure 6. Biomass and abundance from EU surveys.

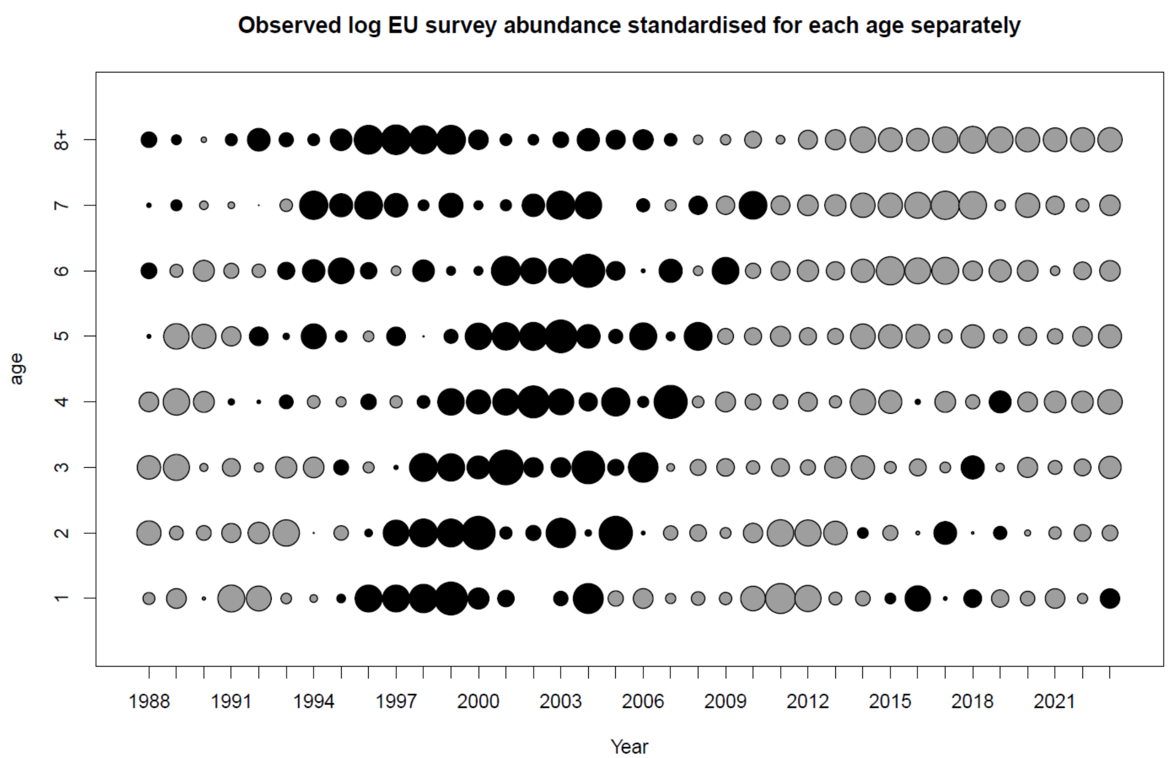


Figure 7. Standardised log(Abundance at age) indices from EU survey. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

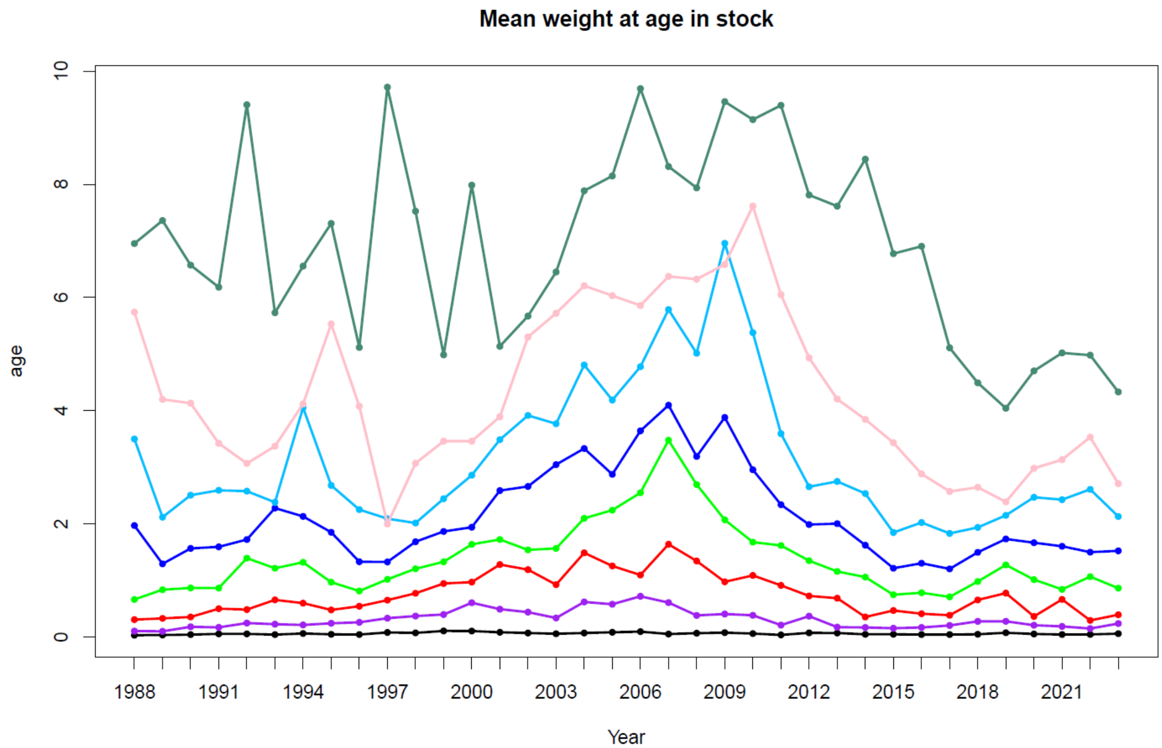
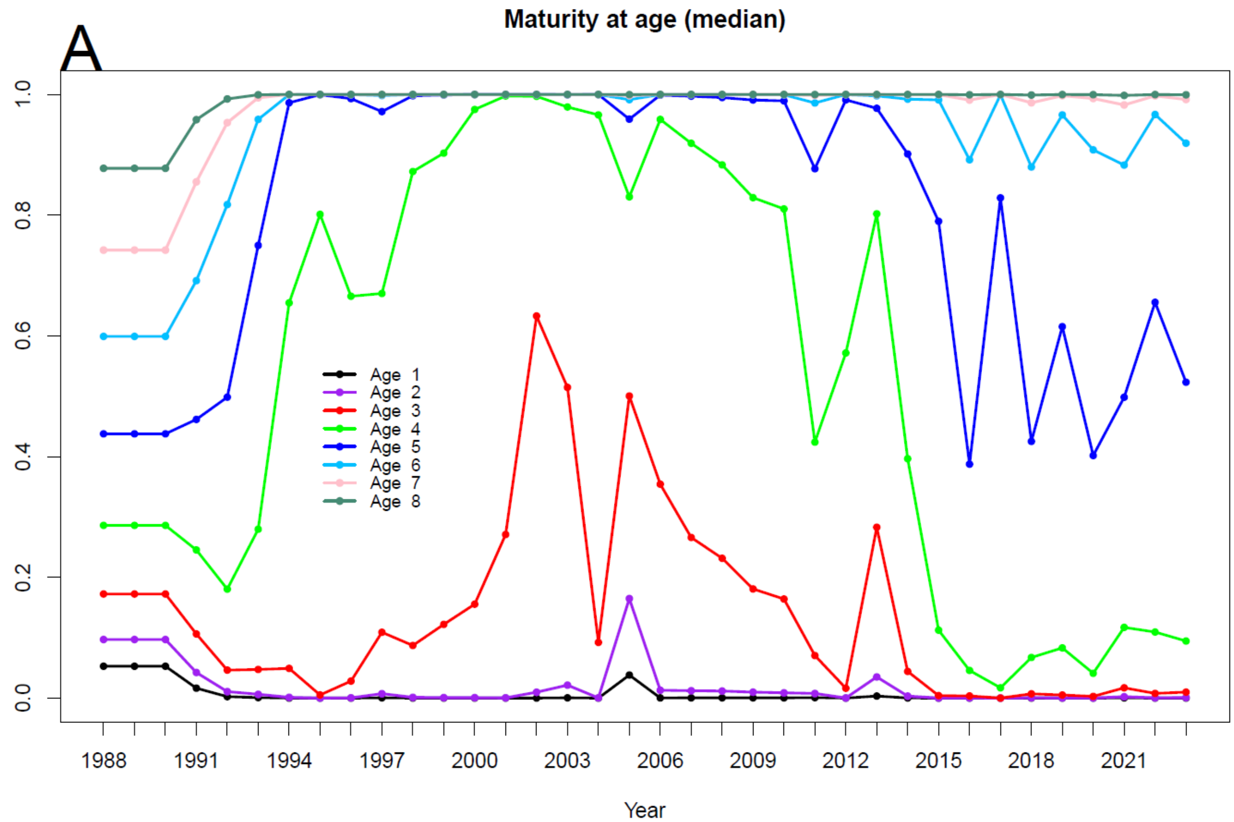


Figure 8. Mean weight at age in stock.



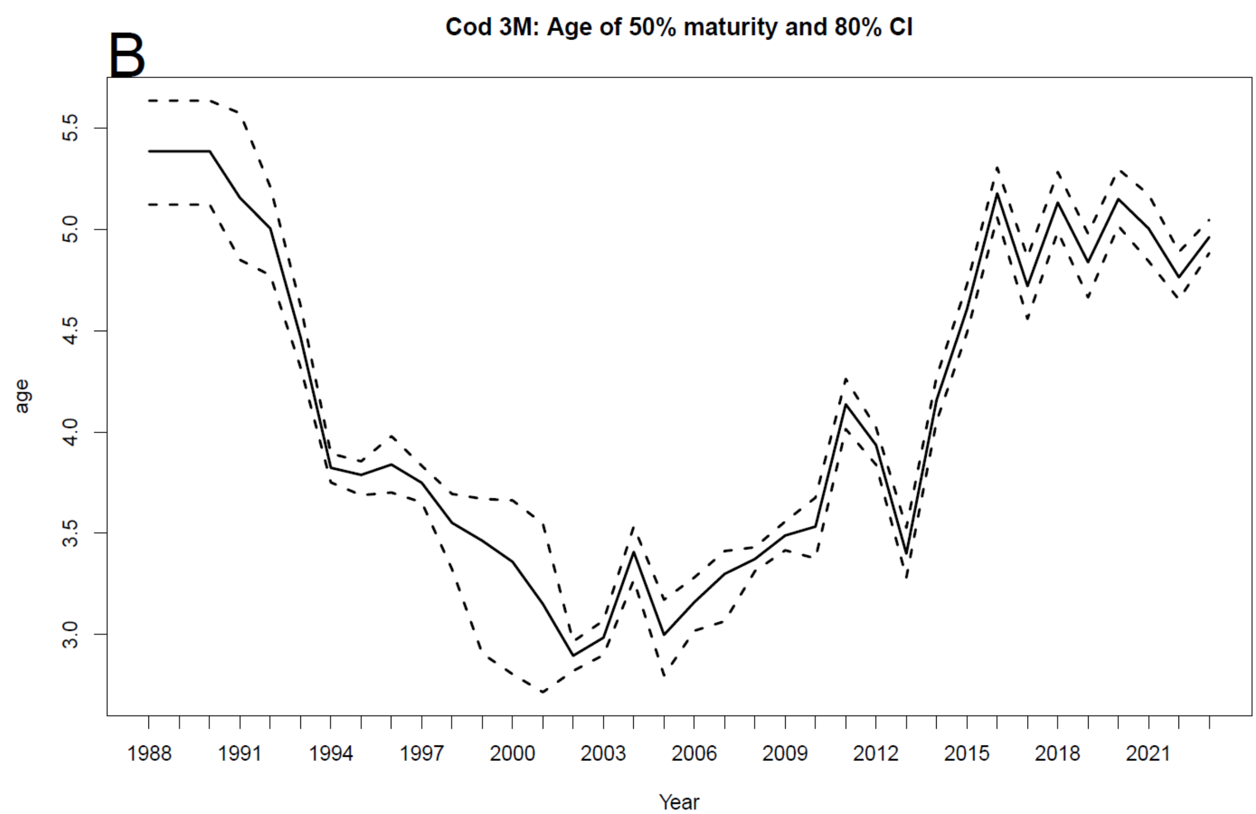


Figure 9. Maturity ogive by age (A) and age at which 50% of fish are mature (B).

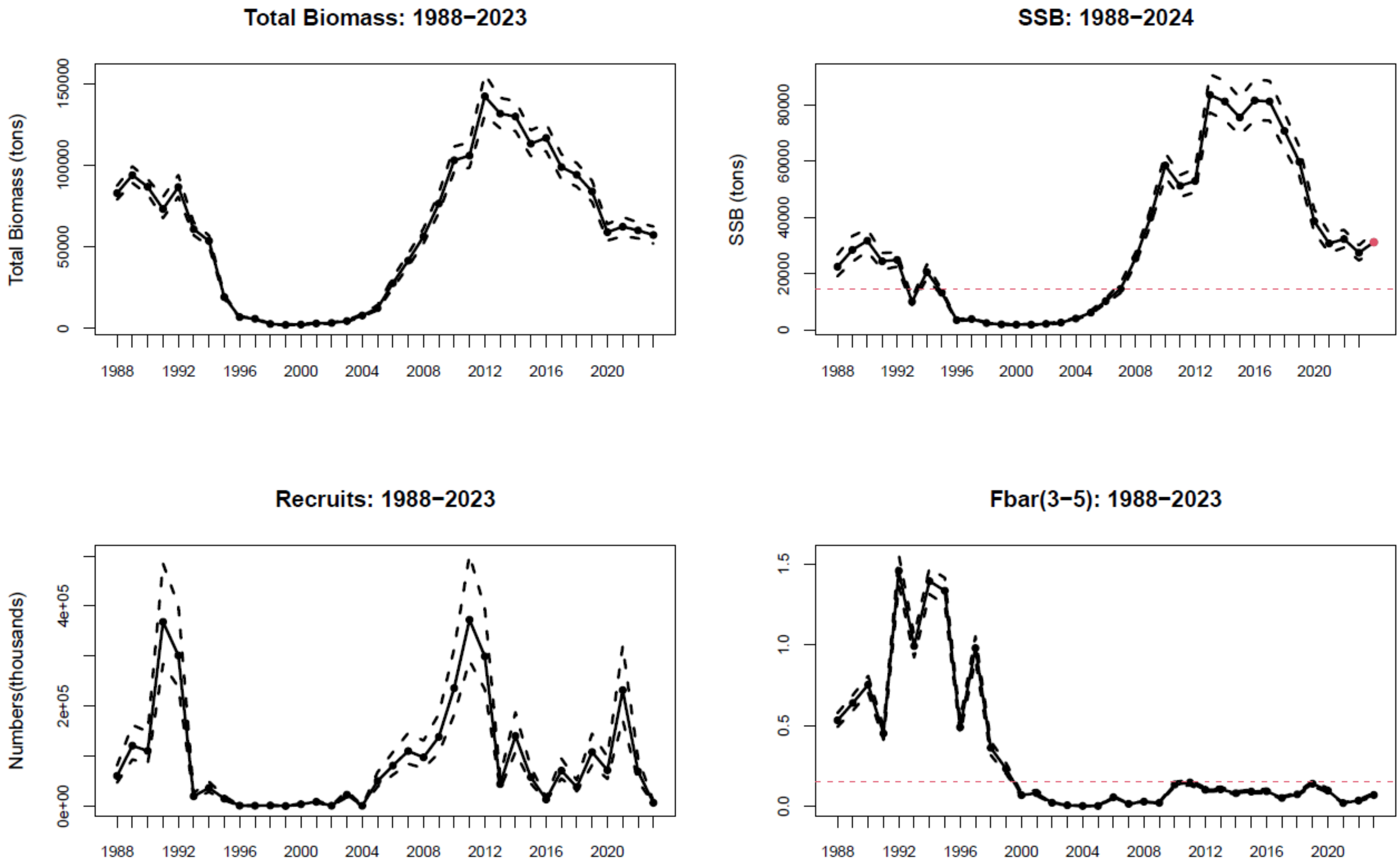


Figure 10. Estimated trends in biomass, SSB, recruitment and F_{bar}. The solid lines are the posterior medians and the dashed lines show the limits of 80% posterior confidence intervals. Red point in the SSB plot indicates the SSB in 2024. Red horizontal line in the SSB graph represents median B_{lim} = medianSSB_{2007} = 14 632 tons. Red horizontal line in the F_{bar} graph represents median F_{lim} = 0.153 (with the last three years parameters).

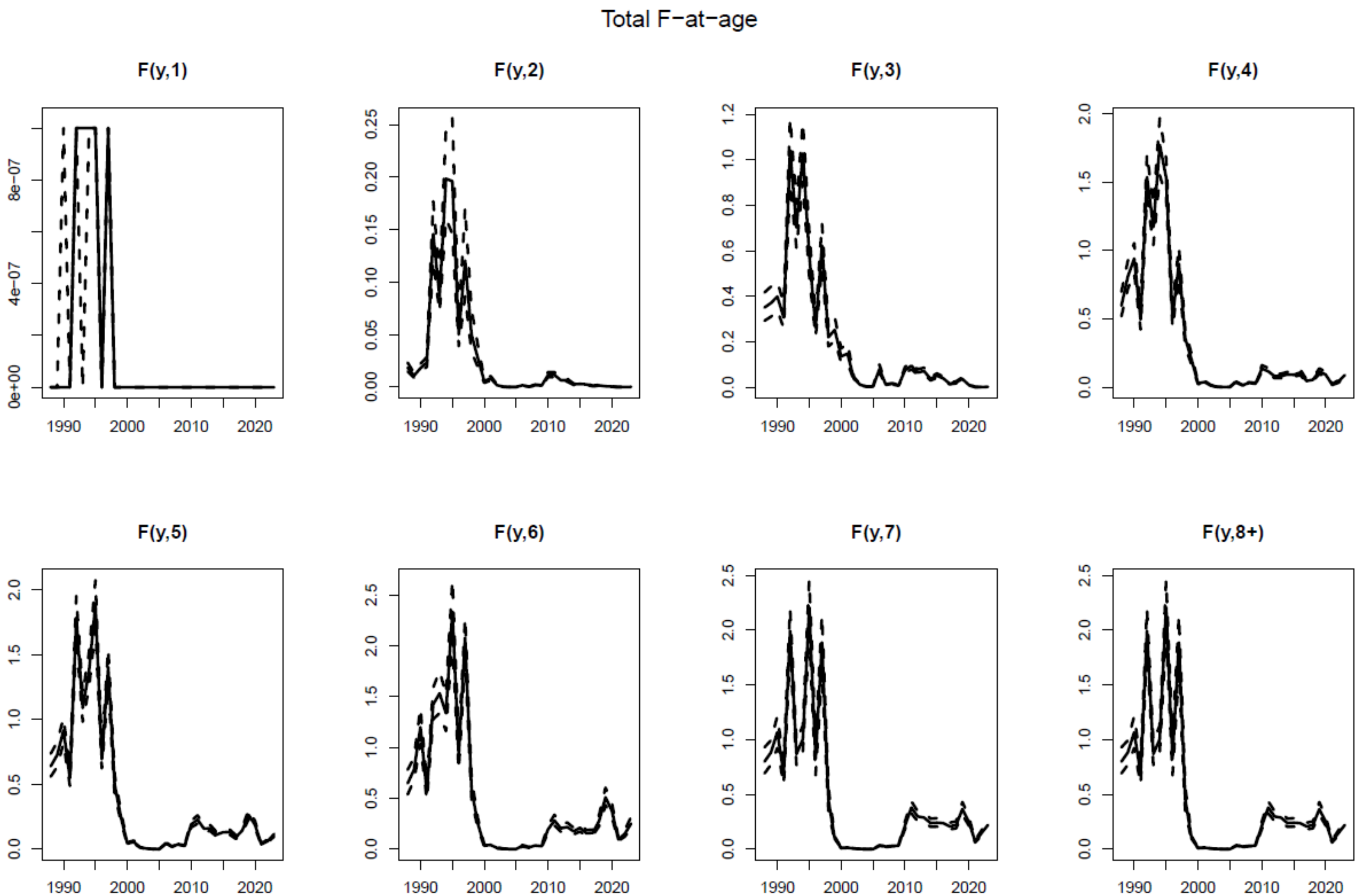


Figure 11. Estimated fishing mortality at age. The y-axis scale is different in all the graphs.

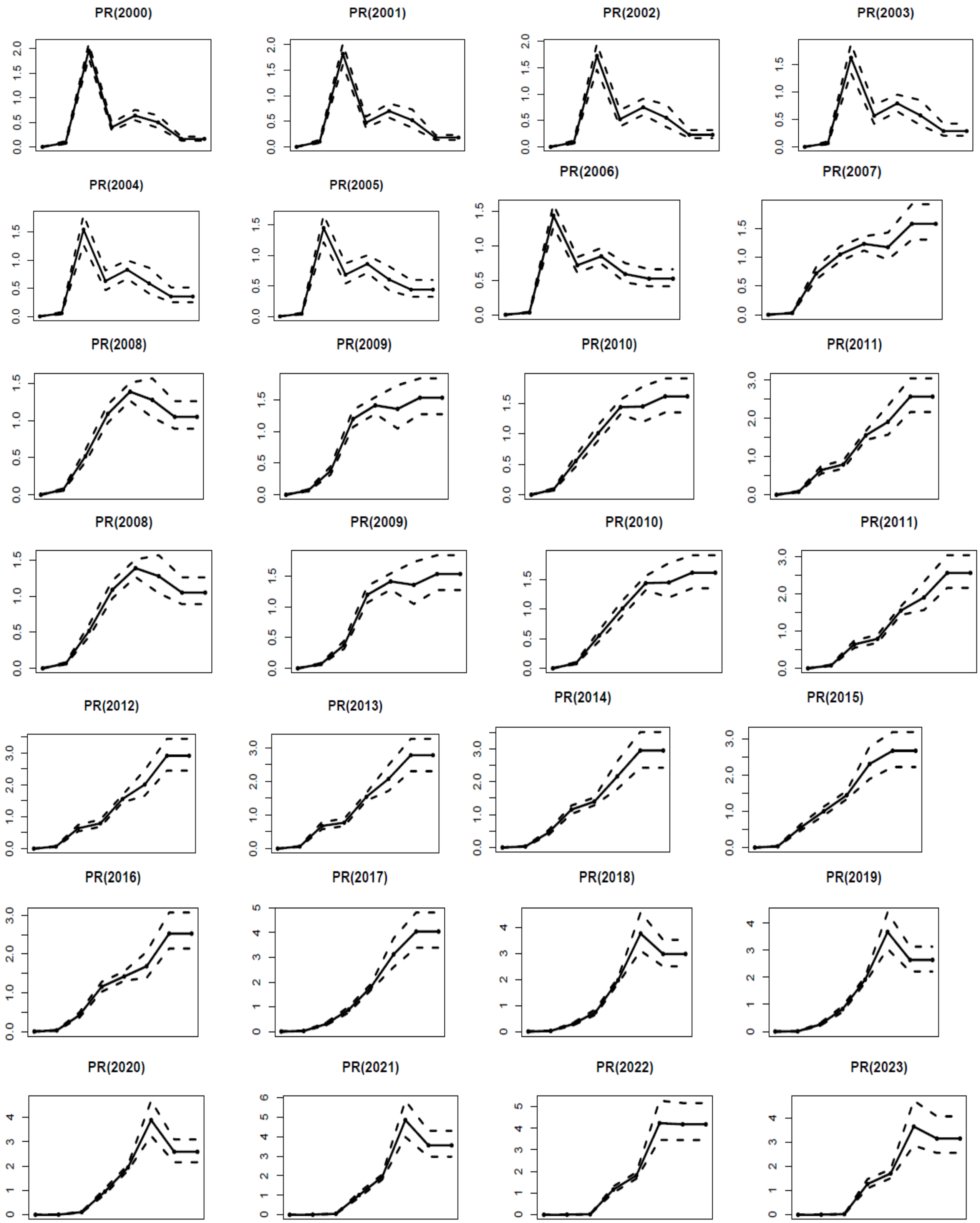


Figure 12. Estimated PR (F/F_{bar}) per age and year.

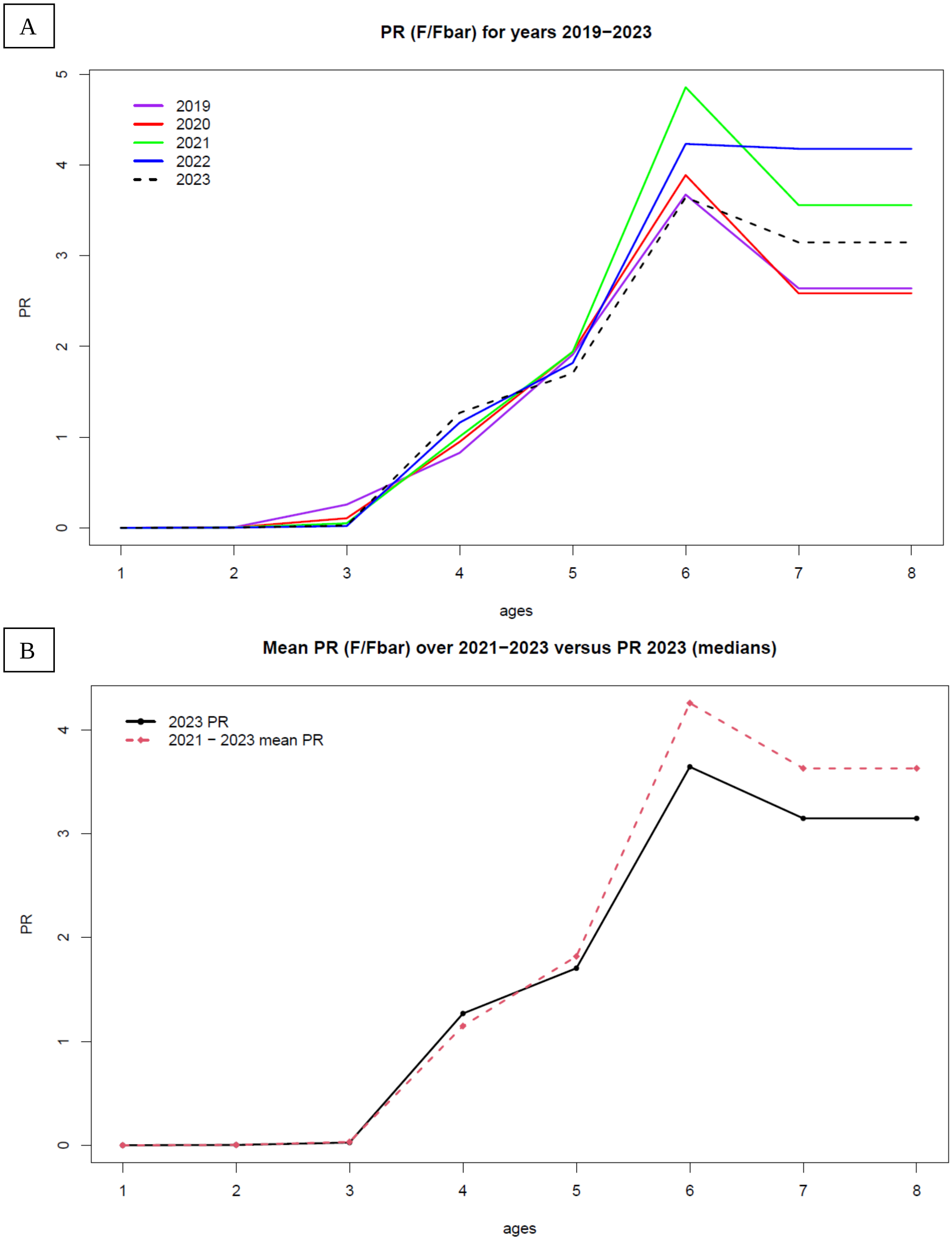


Figure 13. A) Estimated PR (F/F_{bar}) per age for the last five years and (B) mean of 2021-2023 PR (after the implementation of the technical measures) versus 2023 PR (posterior medians).

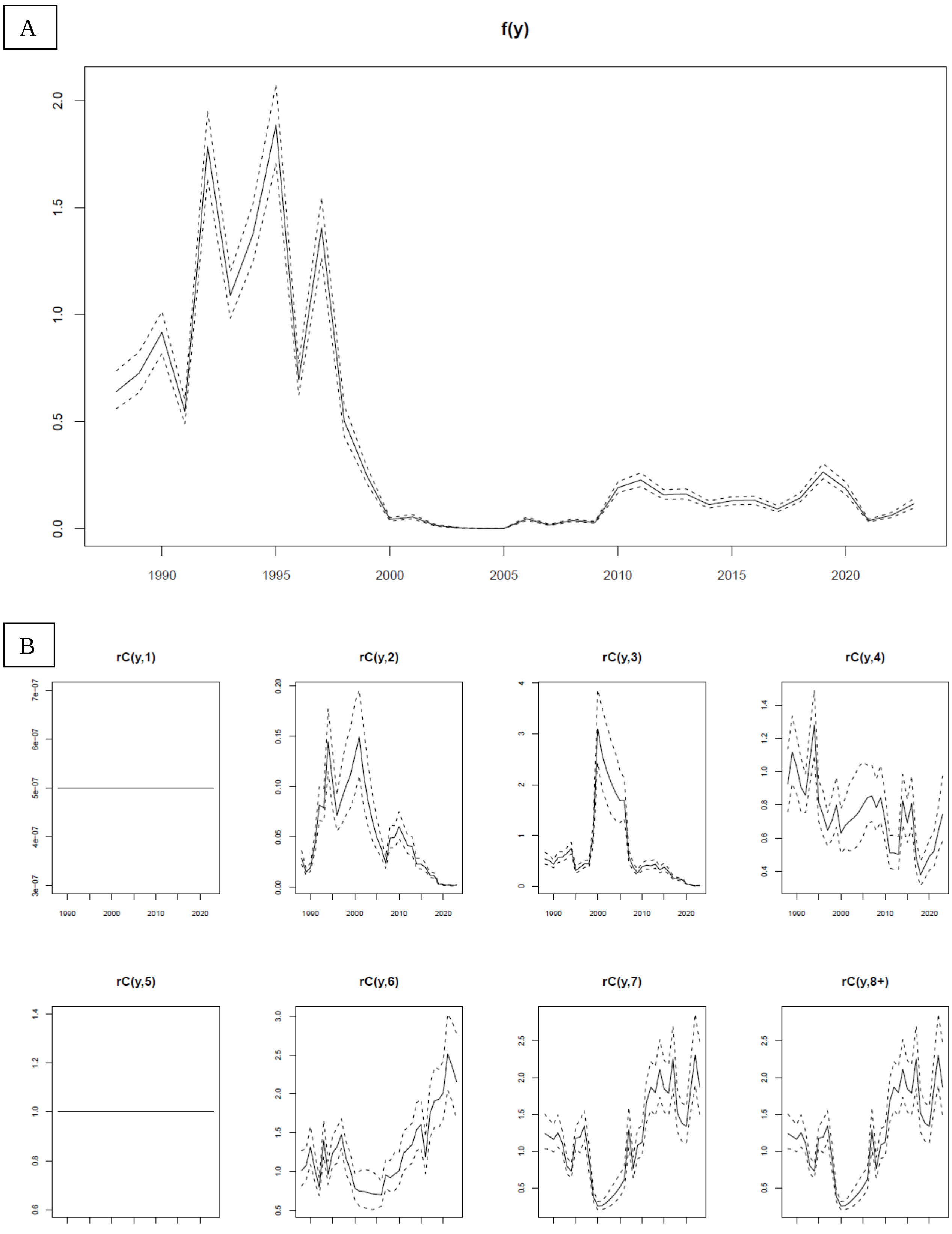


Figure 14. Components of the semi-separable model for Fishing Mortality: F[y,a]=*f*[y]**rC*[y,a].

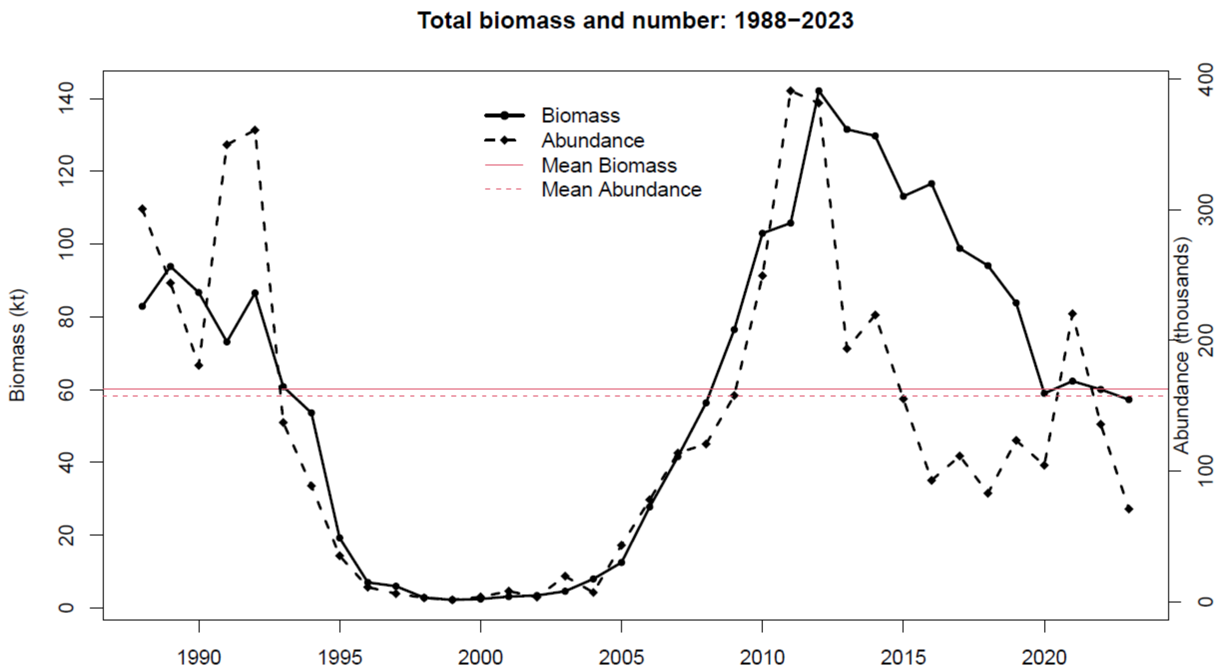


Figure 15. Estimated trends in biomass and abundance. The red lines indicate the means over the whole period.

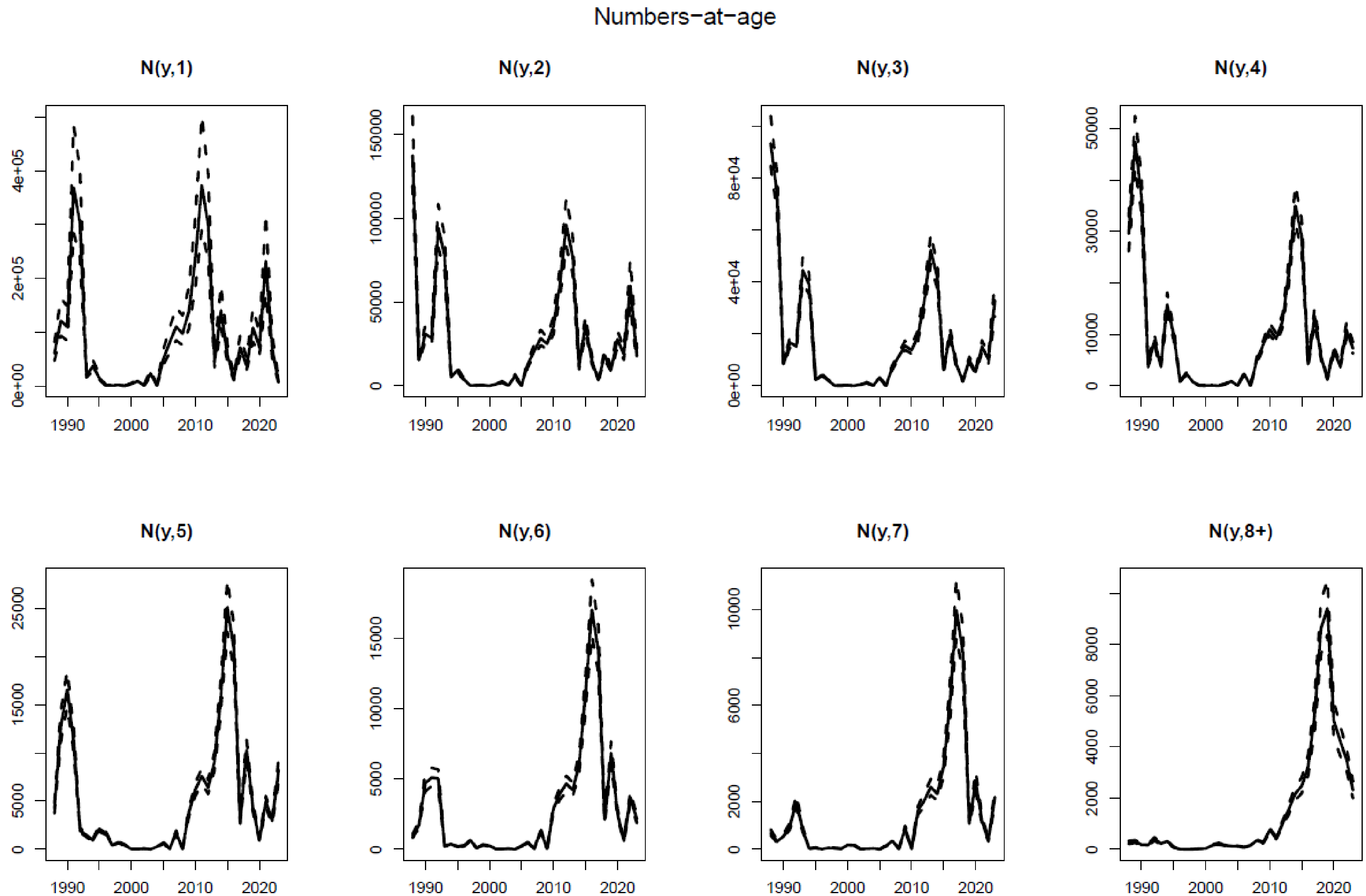


Figure 16. Estimated numbers at age. The y-axis scale is different in all the graphs.

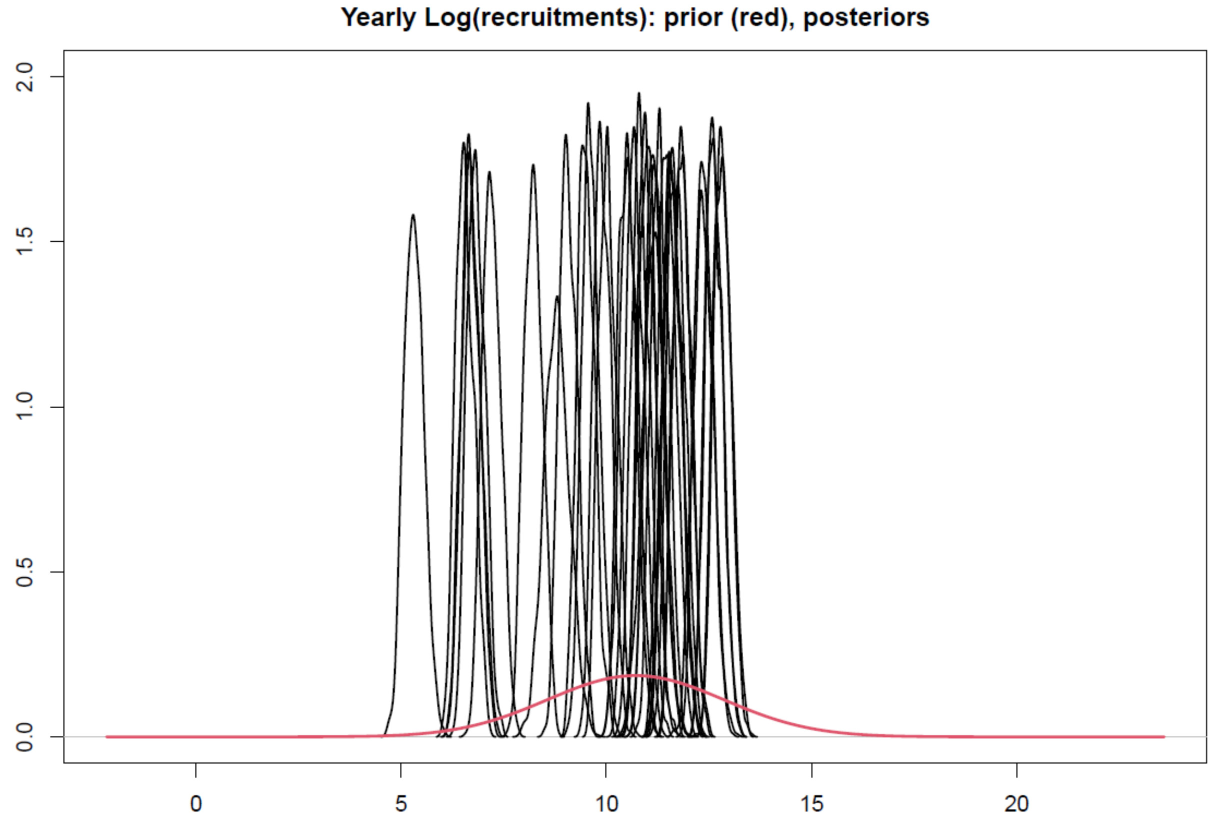


Figure 17. Prior and posterior of recruitment by year.

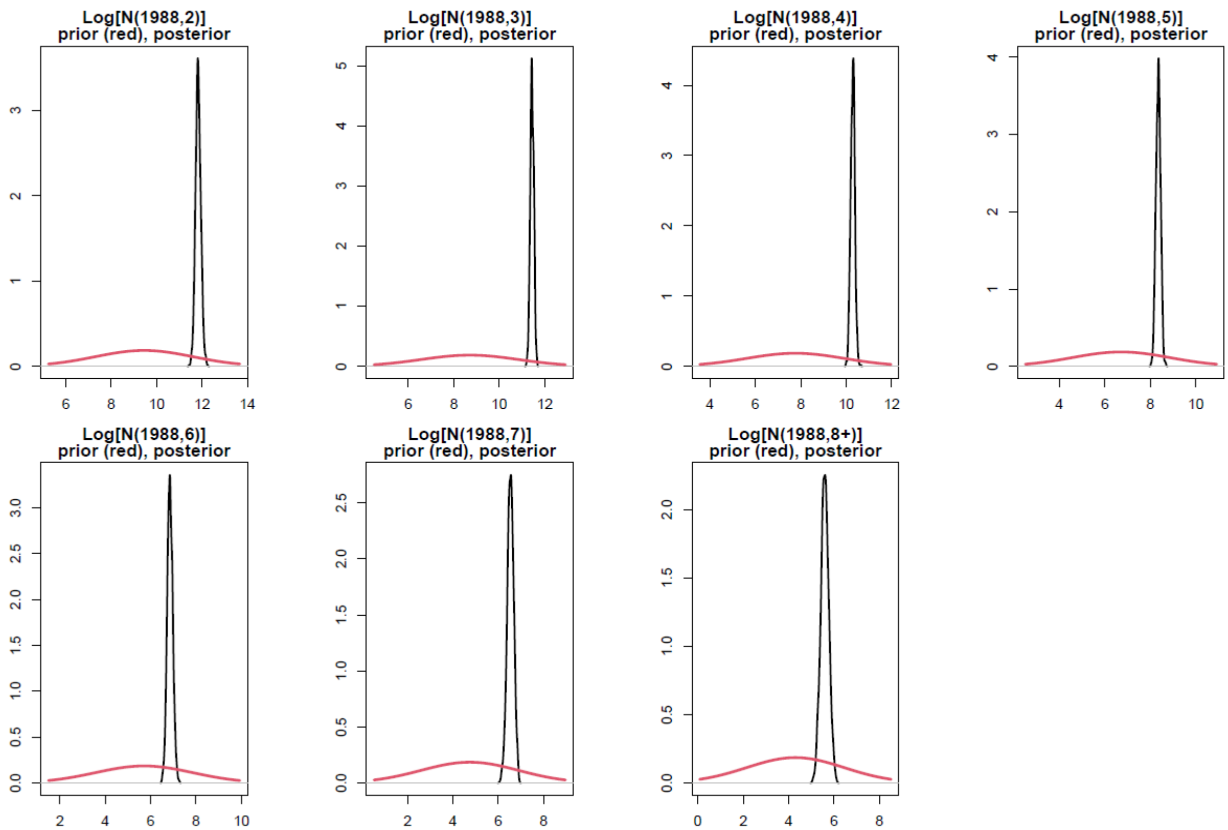


Figure 18. Prior and posterior of the numbers in the first year (1988) from age 2 to 8+.The x- and y-axis scales are different in all the graphs.

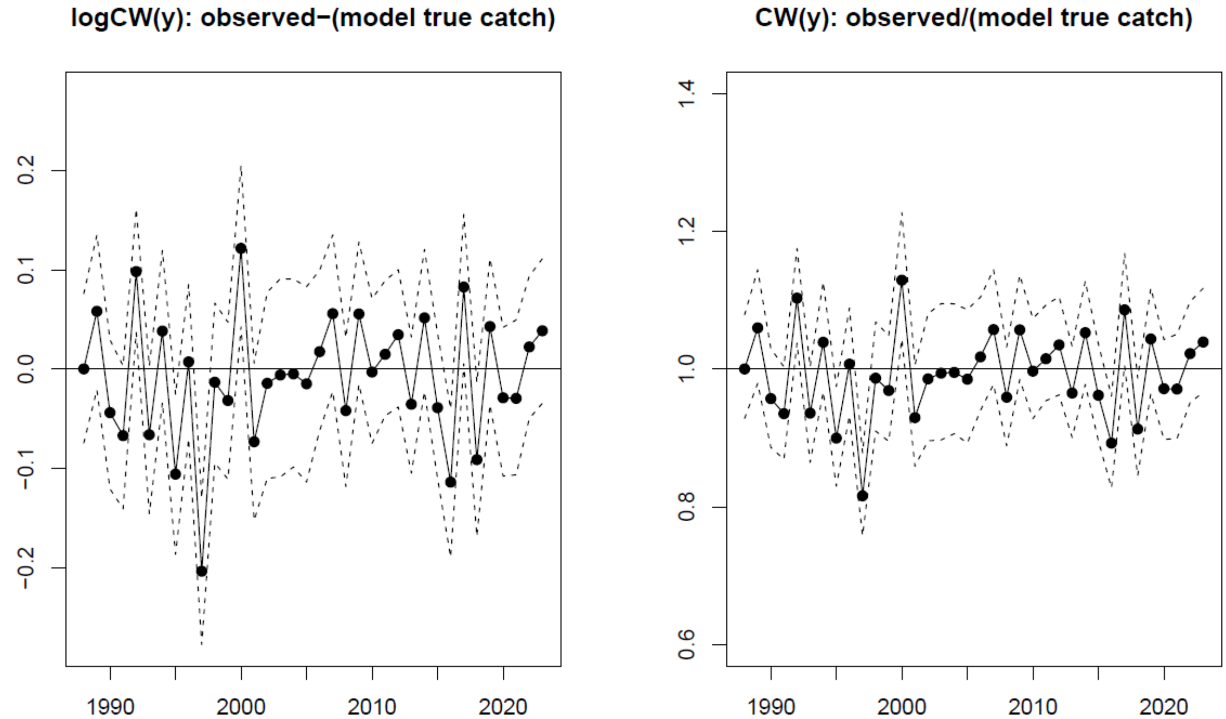


Figure 19. Observed versus estimated total catches by year.

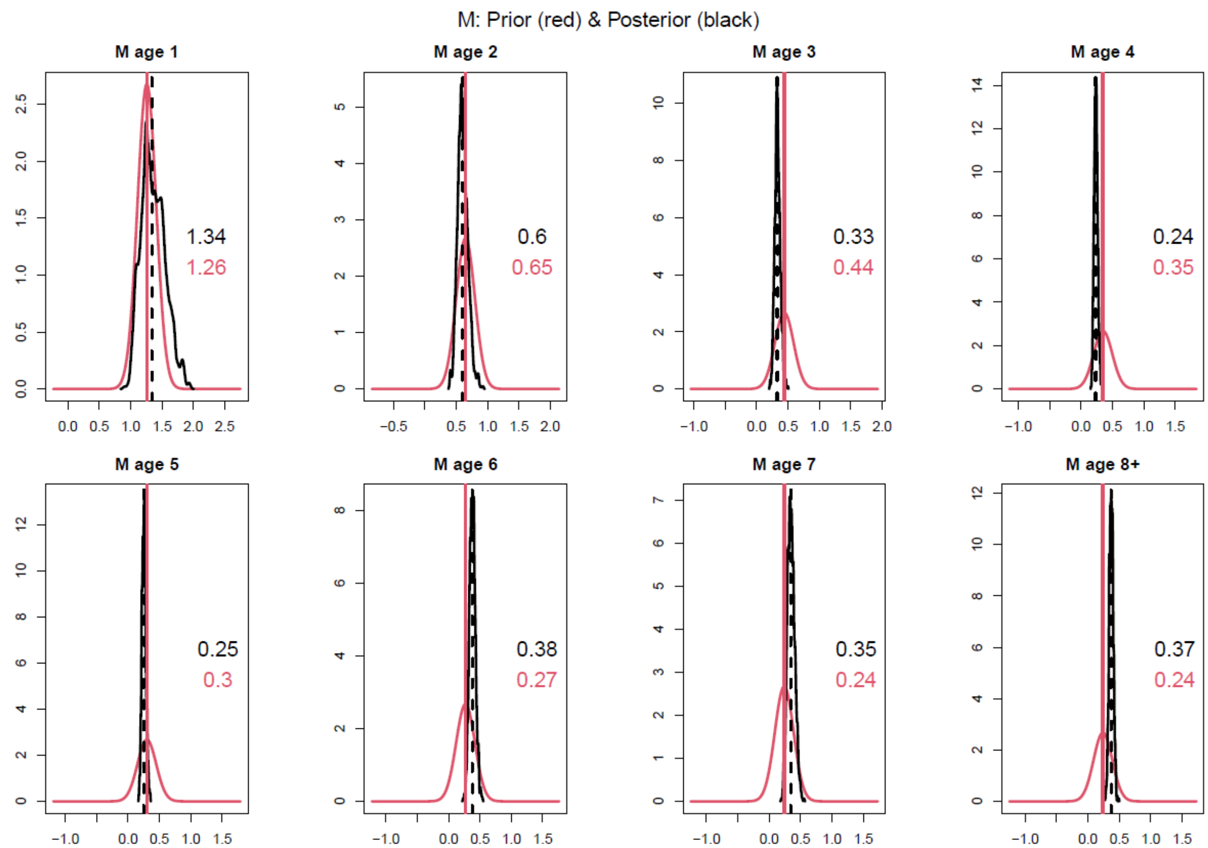


Figure 20. Estimated natural mortality by age in 2023. In black, the prior distribution; in red, the posterior distribution. The numbers inside the graph represent the median value of the distribution in each case.

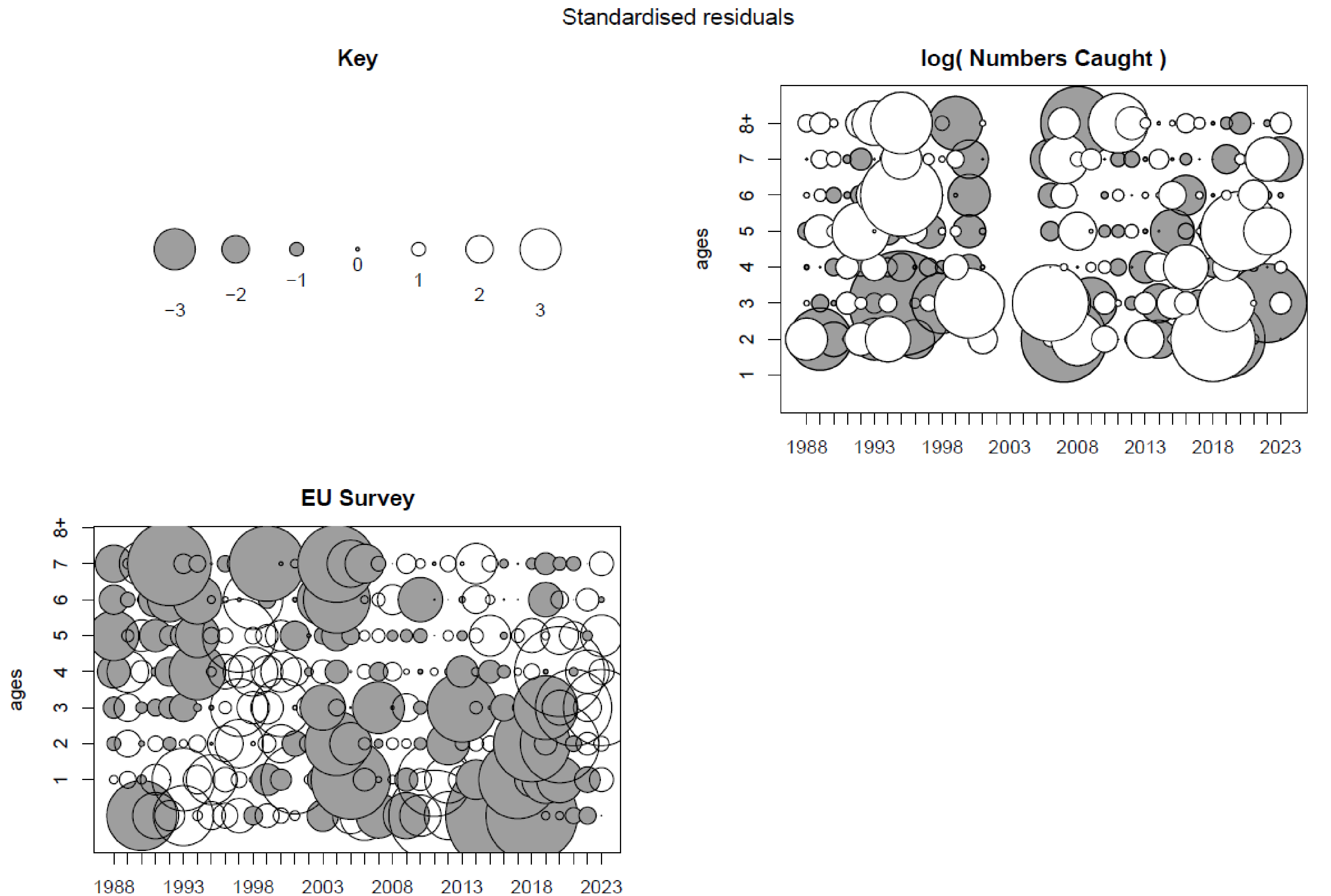


Figure 21. Standardised residuals (observed minus fitted value) in logarithmic scale of catch numbers at age and EU survey abundance indices at age. White and grey values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

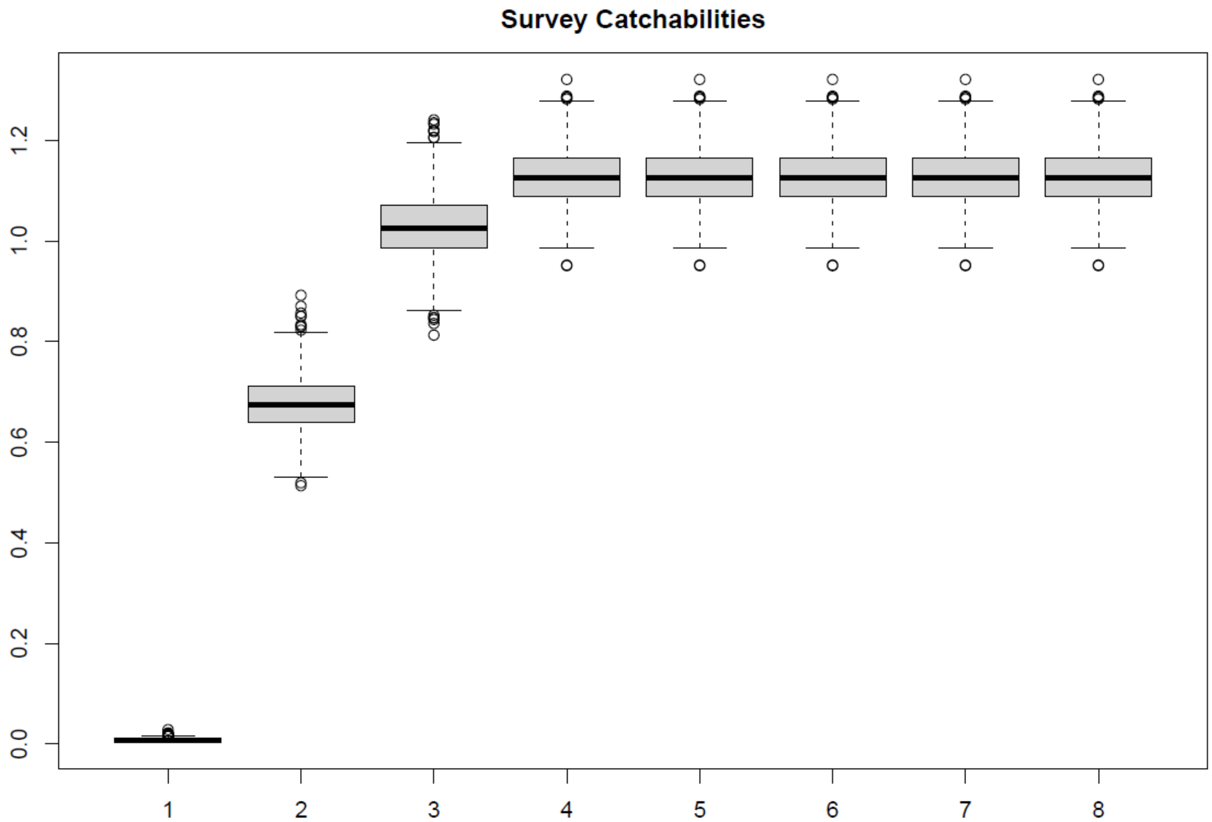


Figure 22. EU survey catchabilities distribution.

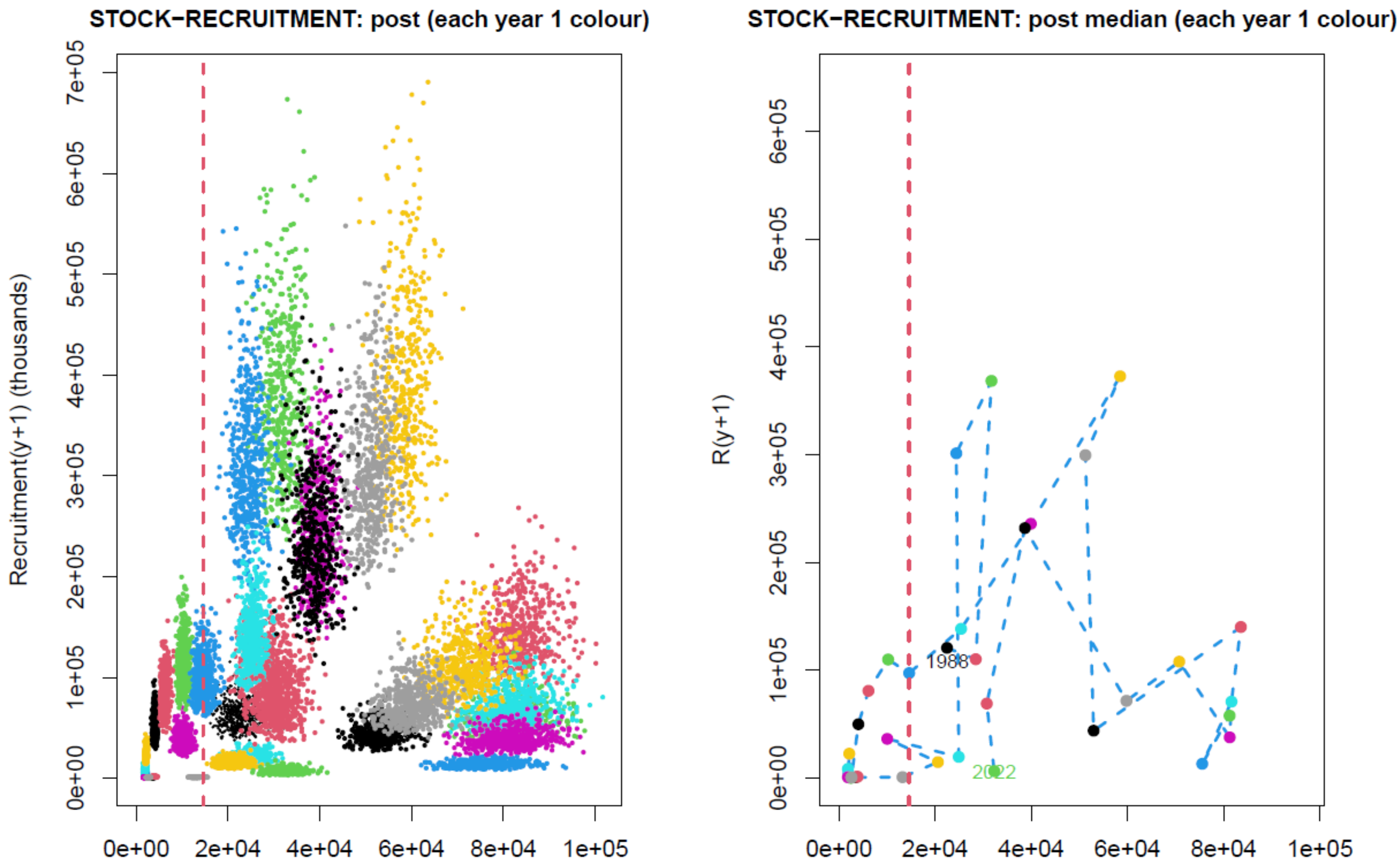


Figure 23. Stock-Recruitment plots. The value of median B_{lim}=medianSSB_{2007}=14 632 tons is shown as the red vertical line.

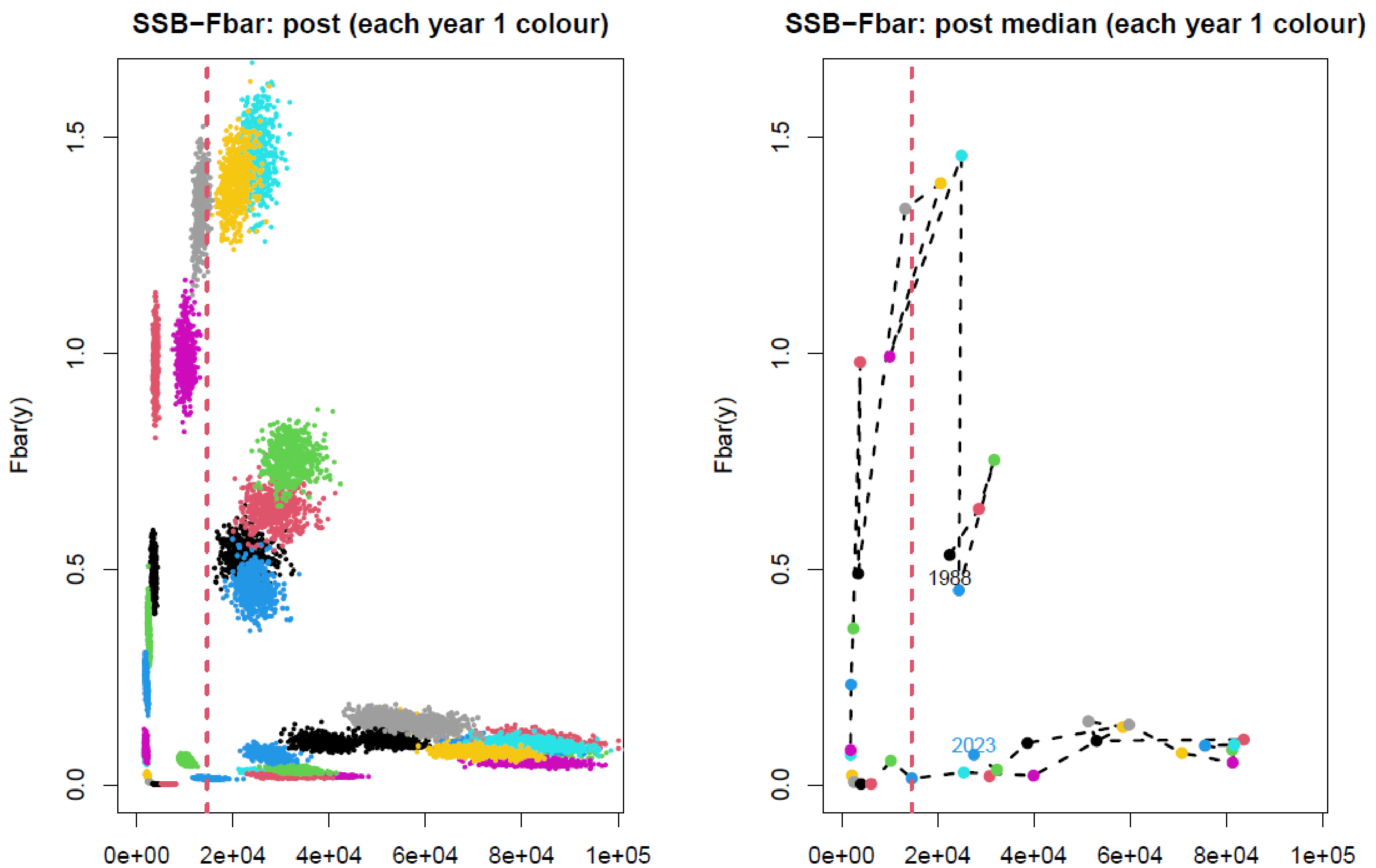


Figure 24. F_{bar} versus SSB plots. The value of median B_{lim}=medianSSB_{2007}=14 632 tons is shown as the red vertical line.

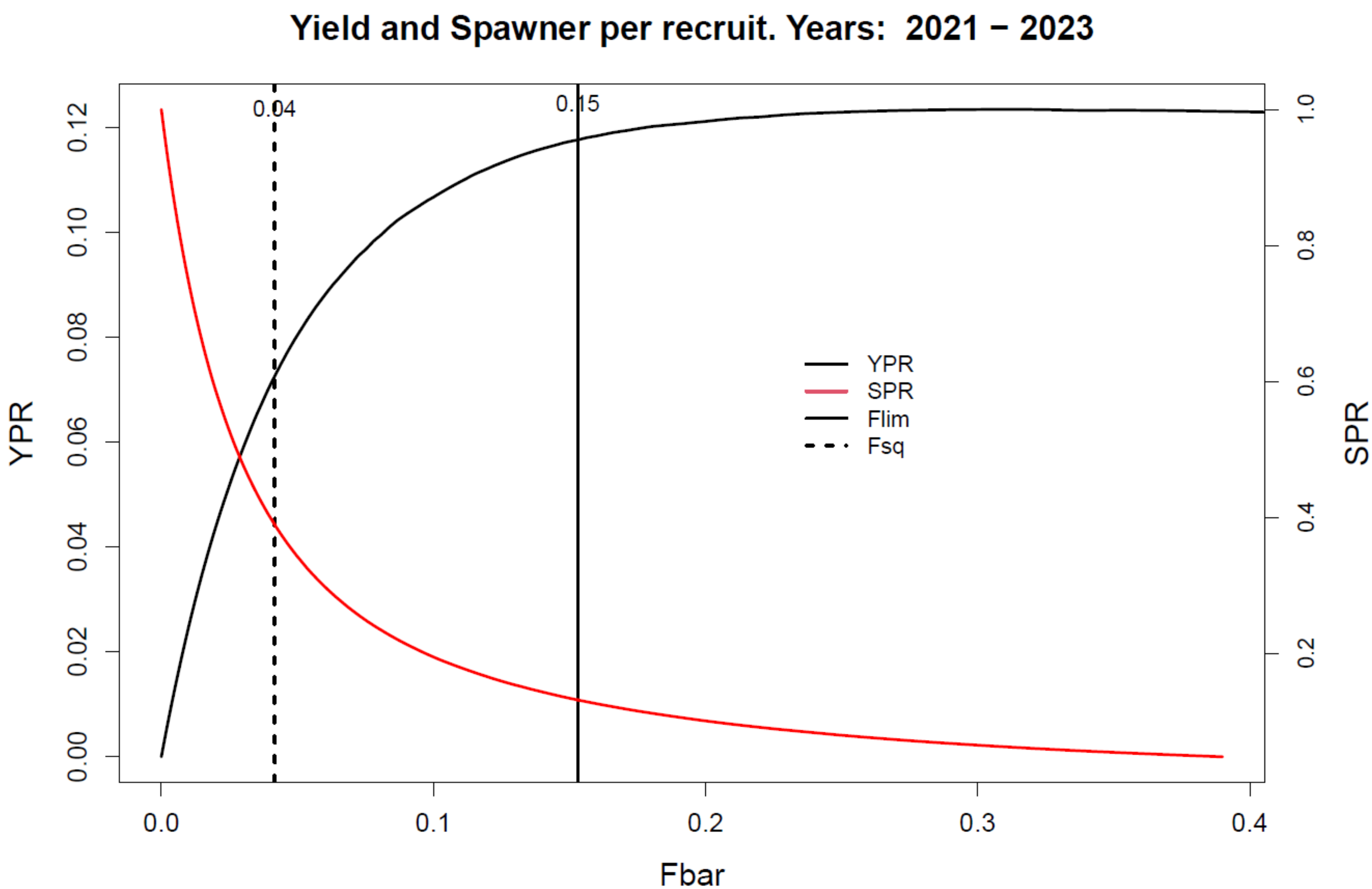


Figure 25. Yield per Recruit (2021-2023) versus F_{bar}. The values of F_{lim} ($F_{30\%SPR}$) and $F_{statusquo}$ (mean F over 2021-2023) are indicated.

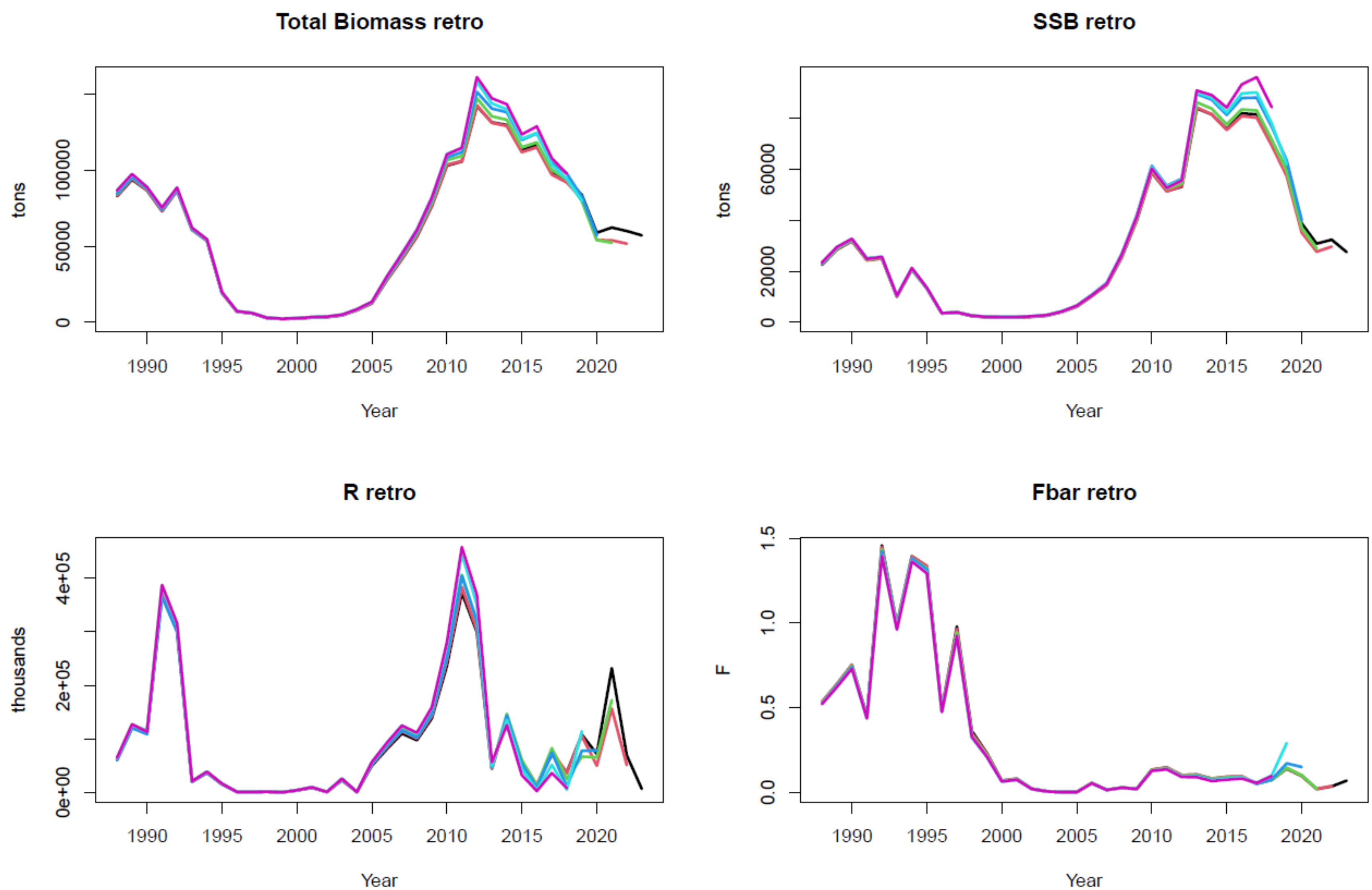


Figure 26. Retrospective patterns.

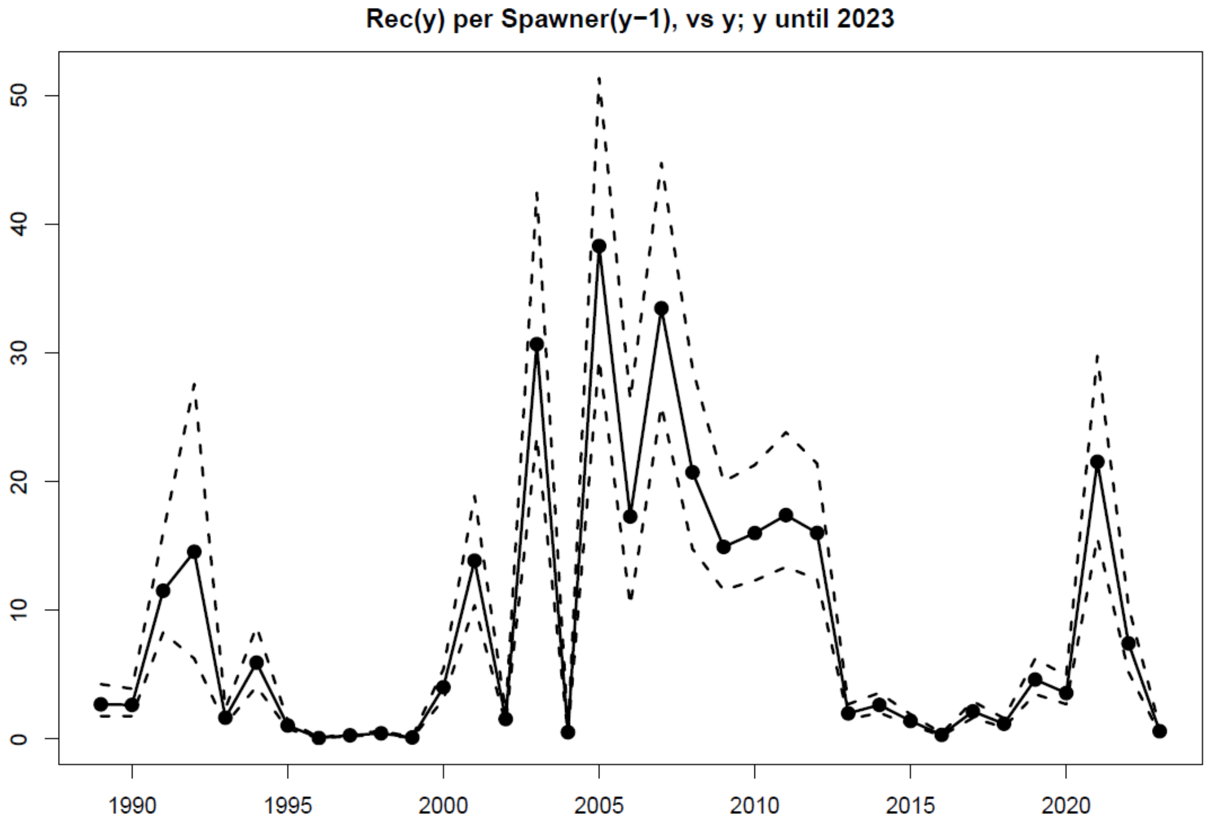


Figure 27. Estimated recruits (age 1) per spawner. First point: R_{1989}/SSB_{1988}.

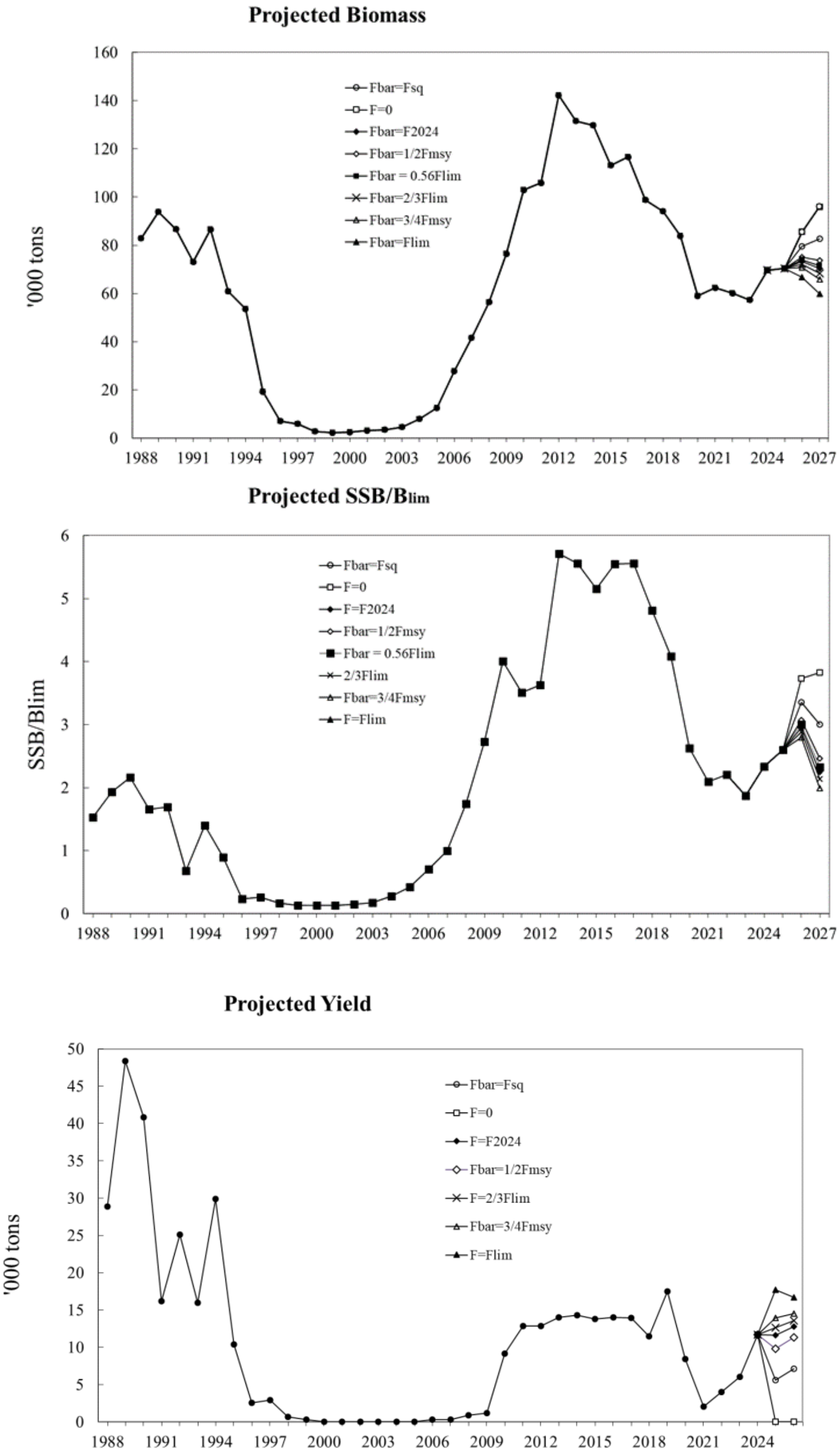


Figure 28. Projections for total Biomass, SSB/B_{lim} and Yield with different scenarios.

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. 2023) 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:

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

$$mu.C[y,a]\ =\ N[y,a]\ \left(1 - e^{-Z[y,a]}\right) \frac{F[y,a]}{Z[y,a]}$$ 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>

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

- *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*:

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

- *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