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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 15 037 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. Between 2013 and 2018 recruitment was at very low levels; the 2016 and 2018 values were among the lowest of the series; as a consequence, 3-year projections indicate that total biomass will decrease during the projected years, while the SSB could increase under some scenarios in the final projected year. The probability of SSB being below Blim is low high (<10%) in all the scenarios. An increase in recruitment occurred since 2019, reaching in 2021 the 2014 level.

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. Nevertheless, recruitment was estimated above the historical average in 2005 and 2006, which in turn caused an increase of SSB that allowed the reopening of the fishery in 2009. Recruitment estimates from 2010 to 2012 (2009-2011 year-classes) have been the highest since 1992 (González-Troncoso *et al.*, 2019) and resulted in a very high stock biomass level in the following years; however, they have been followed by low recruitments and, as a consequence, a decrease in stock biomass is expected in the near future.

Since 1974, when a TAC was established for the first time, estimated catches ranged from 48 000 tons in 1989 to 5 tons in 2004. Annual catches were about 30 000 tons in the late 1980's (notwithstanding the fact that the fishery was under moratorium in 1988-1990) and diminished since then as a consequence of the stock decline. Between 1998 and 2008, almost coinciding with the fishing moratorium, yearly catches were below 1 000 tons, being lower than 100 tons from 2000 to 2005, mainly attributed to by-catches from other fisheries. Estimated commercial catches in 2006-2009 were between 339 and 1 161 tons, which represent more than a ten-fold increase over the average yearly catch during the period 2000-2005. The results of the 2009 assessment led to a reopening of the fishery with 5 500 tons of catch in 2010. With the results of the following years assessments

TACs for 2011-2021 between 9 280 and 1 500 tons were established. The STACFIS estimated catches for 2010-2021 were between 9 291 and 2 055 tons (Table 1A and Figure 1).

A VPA based assessment of the cod stock in Flemish Cap was approved by NAFO Scientific Council (SC) in 1999 for the first time and was annually updated until 2002. However, catches between 2002 and 2005 were very small undermining the VPA based assessment, as its results are quite sensitive to assumed natural mortality when catches are at low levels. Cerviño and Vázquez (2003) developed a method which combines survey abundance indices at age with catchability at age, the latter estimated from the last reliable accepted XSA. The method estimates abundances at age with their associated uncertainty and allows calculating the SSB distribution and, hence, the probability that SSB is above or below any reference value. The method was used to assess the stock in the period 2003-2007. In 2007 results from an alternative Bayesian model were also presented (Fernández *et al.*, 2007) and in 2008 this Bayesian model was further developed and approved by the NAFO SC (Fernández *et al.*, 2008), being used between 2008 and 2017 in the assessment of this stock.

In April 2018 a benchmark on the 3M cod was carried out by the NAFO Scientific Council. During that meeting it was decided to replace the Bayesian XSA with a Bayesian SCAA (statistical catch-at-age), that has been being used since then. Another important change introduced at the benchmark is the prior median value of the natural mortality, which the benchmark agreed to base on biological and multi-species considerations; this has resulted in considerably higher values of M than estimated in previous assessments. The results of the Bayesian SCAA model are presented here, including the updated input data until 2021.

Material and Methods

<u>Data used</u>

<u>Commercial data</u>

<u>Total Catch</u>

In 2021 catch data were available from EU-Estonia, EU-Portugal, EU-Spain, Faroe Islands (Denmark), Japan, Norway and Russia with a total amount of 2 055 tons (Table 1A, Figure 1). The Scientific Council agreed these numbers coming from the WG-CESAG estimates in all the cases but Faroes, for which the total catch of the longliner 3M survey carried out in 2021 was added (630.55 tons), given a total amount of 956 tons for that country.

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 2021 length sampling of catch was conducted by EU-Estonia (SCS 22/07), EU-Portugal (SCS 22/13), EU-Spain (SCS 22/06) and Norway (Nedreaas, personal communication). In the case of Faroes, there were no samples took from the commercial vessels, but a comparative analysis between Norwegian commercial and Faroese 3M survey length distributions (both carried out by longliners) resulted in a similar figure of them (Figure 2A). Given that for the Norwegian vessel only two samples were taken, it was decided to apply the Faroese survey length distribution to the Faroes commercial catches to derive the total commercial length distribution. Length frequency distributions from the commercial catch, from the EU survey (González-Troncoso *et al.*, 2022) and for the Faroese survey (Steingrund and Ridao-Cruz, 2022) are shown in Figure 2B.

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.

There is a noteworthy difference in the length distributions from the recent 2017 to 2021 period and the previous 2010-2016 period (Figure 2C). In the earlier period, following the reopening of the fishery, the bulk of the fish caught was between 40 and 60 cm, while since 2017 most of the lengths are between 55 and 75 cm. The mean lengths in the years 2010-2016 was between 47 and 59 cm, whereas in 2017, 2018 and 2020 was 64 cm, and 69 in 2021. While during the period 2010-2012 the mode of the commercial length distribution was around 54 cm, in 2013 that mode was decreased substantially, being around 42 cm. In 2014 and 2015 the first mode is about 51 and 54 cm respectively, but in both years there is a second mode around 39-42 cm. In 2016 the mode is at 39 cm, whereas in 2017, 2018 and 2020 is at 63 cm, which represents a big change (Table 1D and Figure 2D).

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 length distribution to derive the total age distribution of the commercial catches. In 2012 otoliths were not collected by the Portuguese fleet, and although a commercial ALK from the Spanish fleet was available, it was not used because it was no validated, so the commercial 2011 ALK was applied to the total commercial length distribution. In 2013-2016 there were two available ALKs for commercial length distribution, one from Portugal and the other from Spain, but as they have not been validated yet, the 2013-2016 survey ALKs were used respectively. Much progress in understanding where the differences between the commercial and survey ALKs come from were made but still need more research to completely know the problem. In 2017, ALKs from the survey and from the Spanish commercial fleet were available, but the survey one was used for the same reason stated above. Between 2018 and 2020 only the EU survey ALK was available, and it has been used for both commercial and survey indices. An ALK from the Faroese survey is available for 2021 (Steingrund and Ridao-Cruz, 2022), but as it is not still validated, the EU ALK was used to derive both commercial and survey indices.

Catch-at-age

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

The range of ages in the catch goes from 1 to 8+. No catch-at-age was available for 2002-2005 due to the lack of length distribution information because of low catches. 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 2015-2021, ages 5 to 8+ were the most dominant.

Figure 3B shows standardised catch proportions at age (each age standardised independently to have zero mean and standard deviation 1 over the range of years considered). Assuming that the selection pattern at age is not too variable over time, it should be possible to follow cohorts from such figure. Some strong and weak cohorts can be followed, although the pattern is not too evident. It is remarkable the catch over the recruitment in 2010-2012. We can follow easily the 2009-2011 cohorts, reaching age 8+ in 2019. The cohorts from 2012 were very poor. As a consequence, since 2015 all the values of the ages less than 4 are negative. It is remarkable the big catch at age 6 in 2019 and 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.

Mean weight-at-age

For 2021, mean weight-at-age has been computed using length-weight relationships from the commercial sampling. For this year, there are three commercial length-weight relationships available: EU-Estonia, EU-Portugal and EU-Spain. All of them are presenting in Figure 4 besides the 2021 EU and Faroese surveys ones. The EU-Estonia relationship gives the highest weight for the higher lengths. The surveys (EU and Faroese) give a very similar pattern. As Portugal had the biggest sample size, 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 1988-2021 is showed in Table 3 and Figure 5. In the period 2007-2017 there is a general decrease in the trend of the mean-weight for the ages older than 2, especially since 2010. In 2018 and 2019 a slight increase with regards 2017 can be seen in all ages until 6 years old (included). It is remarkable the decrease of the mean weight in ages 7 and 8 in those years. Since 2020, a quite high increase can be seen in the ages 4+, decreasing for ages 2 and 3.

The SoP (sum over ages of the product of catch weight-at-age and numbers at age) for the commercial catch differs around 5% from the estimated total catch in 2021.

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. 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 1988-2021 are presented in González-Troncoso *et al.* (2022).

The survey abundance indices besides the total biomass are presented in Table 4. Figure 6 displays the estimated survey biomass and abundance indices over time. Biomass and abundance showed a high increase since 2005, higher in biomass than in abundance except for 2011, following an extremely low period starting in the mid 1990's. The large number in 2011 is due to a big presence of individuals of age 1. From 2009 biomass is higher than the level of the first years of the assessment (is approximately twice the mean of the EU series), but it must be noted that abundance in these years is roughly the same as the pre-collapse years (it is below the mean abundance of the EU entire series). In 2010 the biomass has suffered a slight decrease, probably due to the opening of the fishery, increasing since then until the maximum of the series in 2014. The abundances in 2011-2012 are, by far, the highest of the time series of this survey. The abundance increased too but much less, being well below the maximum observed during years 2011-2012. The increase in biomass is due to a big increase in the number of individuals of 3 and 4 years old, those from the 2010-2011 cohorts, and the decrease in abundance to a less presence of individuals of ages 1 and 2 (González-Troncoso *et al.*, 2021). Since 2012 both biomass and abundance have had a decreasing trend, due mainly to the failure of the recruitment, with the exception of 2020, mainly due to an increase in the numbers of almost all the ages (except ages 1, 5 and 8+) with respect to year 2019. It is remarkable the increase in ages 3 and 4, that implies that the cohorts of 2016 and 2017 could be better than estimated in the past.

Figure 7 shows a bubble plot of the abundances at age, in logarithmic scale, with each age standardised separately (each age to have mean 0 and standard deviation 1 over the range of survey years). Grey and black bubbles indicate values above and below average, respectively, with larger sized bubbles corresponding to larger magnitudes. The plot indicates that the survey is able to detect strength of recruitment and to track cohorts through time very well. It clearly shows a series of consecutive recruitment failures from 1996 to 2004, leading to very weak cohorts. Cohorts recruited from 2005 to 2014 appear to be above average. In 2010-2012 a good recruitment can be seen, especially in 2011, lead to two reasonably good cohorts. 2013 and 2014 recruitment were not as good as in those years, but it is still at the level of the beginning of the recovery of the stock. 2015-2018, especially 2016 recruitments, have failed. The 2015 cohort is the worst since the 2003 one.

Age 8+ in 2014-2021 presented a high value, which indicates the strength of the 2006-2011 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. To point out that the values of the EU survey in 2020 and 2021 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, being much higher than at the beginning of the series. Since 2008 to 2017 a deceasing trend was observed for all age groups, being very steep in some cases. In those years the mean weights in stock for ages 1-7 decreased among 38% and 75% and all of them are among the minimum of the entire series. The biggest difference is from 2011 to 2012, when the weight-at-age for ages 1-2 increased, but decreased substantially for ages 3-8+. It is remarkable the low value of weight at age 3 (0.35 kg) in 2014, which is the lowest since 1990. In 2018 and 2019 an increase with regards 2017 can be seen in all ages until 6 years old (included), being quite important in some of the ages, as age 3 (from 385 grams in 2017 to 776 gram in 2019). For age 8, a rather decrease occurs, being in 2019 the lowest of the time series. In 2020 and 2021, a decrease in the mean weight of the youngest ages (1-5), and a quite high increase in the rest of the ages can be observed.

Maturity at age

Maturity ogives are available from the EU survey for years 1990-1998, 2001-2006 and 2008-2021. For those years a Bayesian logistic regression models for proportion mature at age with 1000 iterations have been fitted independently for each year. For 1988 and 1989 the 1990 maturity ogive was applied. For 1999 and 2000 maturity ogive was computed as a mixture of 1998 and 2001 data, and for 2007 as a mixed of 2006 and 2008 maturity ogive. Maturity data for 1991 were of poor quality and did not allow a good fit, so a mixture of the ogives for 1990 and 1992 was used.

The median of the maturity ogives for the whole period are presented in Table 6 and Figure 9A. It can be seen that the percentage of matures in all ages decreased since 2006 to 2011, especially in 2011. This fact, along with the decreasing mean weight at age, is consistent with a stock in a recovery process, with a slower growth and maturing. In 2012 the percentage in ages 4 and 5 increased, as in all ages in 2013 (especially for ages 3 and 4). This is not consistent with the decrease in the mean weight for all ages. Maturity for all age groups declined sharply from 2013 to 2016, being since then quite irregular for ages 5-6 and increasing for age 4 until 2019 and decreasing for 2020 for all ages.

Figure 9B displays the evolution of the a50 (age at which 50% of fish are mature) through the years (estimate and 90% uncertainty limits) and the median value is presented in Table 6. The figure shows a continuous decline of the a50 through time, from above 5 years old in the late 1980's to below 3 years old in 2002 and 2003. An upward trend is present in a50 since 2005. From 2005 to 2011 a50 increased monotonously from 3 to 4.13 years respectively and it declined in 2012 and again in 2013 to 3.39 years due to the increase in the percentage of maturation on all the ages. In 2014-2016 it increased substantially to 5.17 years old in 2016, around the maximum in the time series, being since then quite stable around 5 years old with ups and downs.

Faroes survey data

Faroes carried out in June 2021 a survey in a commercial vessel with a longline gear with approximately 6000 hooks (Steingrund and Ridao-Cruz, 2022). The objective of the survey was to cover as much as possible of area 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. The area covered mainly the shallow area (< 600 m) on Flemish Cap with 101 longline sets.

Cod dominated the catch and the overall catch rate of cod was extremely high, 1049 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 2 to 11-years old.

Some problems were raised with regards the methodology of this survey (NAFO, 2021). Nevertheless those problems, as only one year of data is available, it was not used in the assessment as an 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 A+=8+ and years are from 1988 to 2021. 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), 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 34 years, from 1988 to 2021

Catch in tonnes in all years; Years with catch-at-age: 1988-2001, 2006-2021

Tuning with EU survey for 1988 to 2021

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

Catchability analysis

Survey catchability dependent on stock size for age 1

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

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

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

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

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

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

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

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

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

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

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

The CV of the prior distribution of M (0.15) was set during the benchmark to have a small variability in the posterior distribution of this parameter. To test if this CV of the prior distribution of M would affect the assessment results, the assessment model was run as the base case (CV=0.15) and doubling the value of the CV (CV=0.3). The results of this analysis are in Annex II. No significant differences can be seen in the analysis so the CV of the base case was used in the assessment of this stock.

F_{bar} for this stock is calculated as mean F of ages 3-5, that were the most abundant ages in the catch in the past. But in last years ages 5 to 8+ have been the most dominant in the catch (see Catch-at-age section above), so the appropriateness of the base case range of ages for calculating F_{bar} was explored. Two different additional runs were made, with F_{bar} the mean of F of ages 6+, and with F_{bar} the mean of F from ages 3 to 7. Although some differences in the value of F_{bar} can be seen in the results, the trend is the same for all the cases except in year 1994, so no reason for changing the base case was encountered (Annex III).

A five year retrospective plot was made. Four years projections were made with three different scenarios, as later described, in order to see the possible evolution of the stock in the medium term. The settings and the results are explained above.

Results

Assessment results regarding total biomass, SSB, recruitment and F_{bar} (ages 3-5) are presented in Table 7 and Figure 10. SSB in 2022 was calculated using the numbers estimated by the assessment at the beginning of 2022, applying the maturity ogive and mean weight at age in stock from 2021.

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 has been below the level of the beginning of the series.

The results for SSB indicate that there was a substantial increase in SSB from 2007. After a small decrease in 2011 and 2012, the SSB between 2013 and 2017 was stable. A substantial decrease since 2018 is displayed, being in 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 incorporation of the strong 2009-2011 year classes which leads in a higher number of individuals.

Recruitment had an increasing trend from 2005 to 2012, being above the mean recruitment of the period between 2007 and 2012. The 2010-2012 values are the highest of the series. Since 2012 the recruitment has been decreased substantially and in 2016 is among the lowest of the series. Since 2019 an increase can be seen, specially in 2021, reaching the level of 2014 recruitment.

F_{bar} (mean for ages 3-5) was estimated at very low levels in the period 2001-2009. In 2010, when the fishery was reopened, the F_{bar} increased although it did not reach the level of the pre-collapse years and it was below F_{lim}. Since then until 2018, fishing mortalities slightly decreased. A considerable increase occurred in 2019, reaching the level of the pre-collapse period and being just below F_{lim}, decreasing after. 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 2020 and 2021, the F has decreased in all ages with respect to 2019, with highest F values at ages 5-6. Figure 12 shows the PR along the years, calculated as the ratio of fishing mortalities to F_{bar}. Figure 13A shows the median PR for the years since the reopening of the fishery (2010-2021) and Figure 13B the mean of the three last years (2019-2021) PR *versus* the 2021 PR. Until 2017, all the years have a similar and increasing PR by age. Since 2018, age 6 was the most caught age, especially in 2021.. Mean PRs of the last three years is quite similar to the 2021 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. 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 decreasing trend between 2014 and 2018, sharply increasing after that. Age 6 shows a steep increase since 2015, and age 7 in 2021. The selectiviy isare quite different to those estimated in the last approved assessment (González-Troncoso *et al.*, 2021).

Figure 15 shows total biomass and abundance by year. In general, there is a good concordance between biomass and abundance until 2018, although between 2012 and 2018 abundance decreased in a more extent than biomass. Since 2019, the decrease in biomass continues, but an increase in the abundance can be seen, especially in 2021. These is probably due to the increase in recruitment and the decrease of the older cohorts. The biomass is slightly below the mean value of the series and the abundance is slightly above.

Estimates of stock abundance at age for 1988-2021 are presented in Table 9 and Figure 16. It can be seen a general increasing trend in the total number of matures until 2013, due probably to the decreasing in the age of maturity. Since then it has decreased. The maximum numbers-at-age since 2005 in all the ages correspond to the 2010 cohort (reaching 7 years old in 2017 and being incorporated to the 8+ group since 2018), followed by the 2011 cohort (reaching 8 years old in 2019). Since those cohorts, all the numbers at age have decreased (ages 1 to 6) except age 5 in 2021. 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. The failure in recruitment since 2013 gave low numbers in ages 2-5 in the most years, which led to the decrease in the SSB.

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

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

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

Figure 20 shows the prior and the posterior distributions of the natural mortality, M, by age. The prior and posterior medians can be seen in Table 10. For ages 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, but big positive residuals at age 3 in 2020 and age 4 in 2021 in the EU survey can be observed. In general, the residuals are quite high both in the catch numbers at age and in the EU survey indices. In the case of the EU survey indices, in 2016 all the residuals are negative, i.e. survey catchabilities are below average.

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

Biological Referent Points

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

In this way, for the present assessment 1000 values of B_{lim}, one for each iteration, are considered, with a median value of 15 037 tons, and an 80% confidence interval between 13 388 and 17 402 tons (Table 7). This value is displayed in Figure 23, showing that this value is rather consistent. SSB is well 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 2019-2021 data as 0.167, which is a big update from the last assessment value (0.196). The period 2019-2021 was chosen due to the rapid change in biological parameters in the stock.

Figure 26 shows the Yield per Recruit versus F_{bar} curve calculated with the data of years 2019-2021 as well as the value of F_{lim} and $F_{statusquo}$ (defining the latter as the mean fishing mortality over 2019-2021).

Retrospective pattern

A retrospective analysis of five years was made (Figure 25). The analysis shows revisions in the recruitment, mainly regarding the highest values of recruitment in years 2011 and 2012, and in year 2019. The 2019 recruitment has been revised to a lowest value. But no clear patterns are evident in recent years. 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 2019 one was revised to a lowest value.

Recruits per Spawner

Figure 27 displays the Recruits per Spawner. The variability over the years of the assessment is very high. Between 2007 and 2018 a decreasing trend can be seen, reaching since 2013 very low values. The 2021 value is quite high and it is at the 2012 level.

Projections:

The same method as last year was used to calculate the projections and the risk. To know more details about the projection method, see Fernández *et al.* (2017). Stochastic projections of the stock dynamics for two years, from 2022 to the start of 2025, 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 2022: estimated from the assessment.

Recruitments for 2022-2025: Recruits per spawner were drawn randomly from 2018-2020 (corresponding to the recruitment of 2018-2020 and number of matures of 2017-2019). The 2021 value of recruits per spawner was omitted due to uncertainty in estimating the recruitment.

Maturity ogive for 2022-2025: Mean of the last three years (2019-2021) maturity ogive.

Natural mortality for 2022-2025: Natural mortality from the 2021 assessment results.

Weight-at-age in stock and weight-at-age in catch for 2022-2025: Mean of the last three years (20198-2021) weight-at-age.

PR at age for 2022-2025: Mean of the last three years (2019-2021) PRs.

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

(*Scenario 1*) $F_{bar} = F_{sq}$ (median value = 0.089).

(*Scenario 2*) F_{bar}=0 (no catch).

(*Scenario 3*) $F_{bar} = F_{2021}$ (median value = 0.022).

(*Scenario 4*) F_{bar}=1/2 F_{lim} (median value = 0.083).

(*Scenario 5*) F_{bar}=2/3 F_{lim} (median value = 0.111).

(*Scenario 6*) F_{bar}=3/4 F_{lim} (median value = 0.125).

(*Scenario 7*) F_{bar}= F_{lim} (median value = 0.166).

(*Scenario 8*) Catch in 2023-2024=4000 tons.

(*Scenario 9*) Catch in 2023-2024=5000 tons.

Results for the nine options are presented in Tables 11-28 and Figure 28.

The results indicate that under all scenarios with Fbar>0, total biomass during the projected years will decrease, whereas the SSB is projected to increase slightly in 2025 except in all scenarios with F≥2/3 F_{lim}. The probability of SSB being below B_{lim} in 2024 is low (≤3%) in all the scenarios. The probability of SSB in 2025 being above that in 2022 ranges between 9% and 100%, depending on the scenario.

Under all scenarios, the probability of F_{bar} exceeding F_{lim} is less than or equal to 3% in 2023 and 2024 except for F_{lim} as expected.

To note that projections of risk, in particular more than one year ahead (even Tables between 11 and 28), will inherently include more uncertainty than projected median stock sizes (odd Tables between 11 and 28). 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 2021 in tons.

Year	Estimated[2]	Portugal	Russia	Spain	France	Faroes	UK	Poland	Norway	Germany	Cuba	Others	Total[1]
1960		9	11595	607					46	86		10	12353
1961		2155	12379	851	2626		600	336		1394		0	20341
1962		2032	11282	1234			93	888	25	4		349	15907
1963		7028	8528	4005	9501		2476	1875				0	33413
1964		3668	26643	862	3966		2185	718	660	83		12	38797
1965		1480	37047	1530	2039		6104	5073	11	313		458	54055
1966		7336	5138	4268	4603		7259	93		259		0	28956
1967		10728	5886	3012	6757		5732	4152		756		46	37069
1968		10917	3872	4045	13321		1466	71				458	34150
1969		7276	283	2681	11831					20		52	22143
1970		9847	494	1324	6239		3	53				35	17995
1971		7272	5536	1063	9006			19		1628		25	24549
1972		32052	5030	5020	2693	6902	4126	35	261	506		187	56812
1973		11129	1145	620	132	7754	1183	481	417	21		18	22900
1974		10015	5998	2619		1872	3093	700	383	195		63	24938
1975		10430	5446	2022		3288	265	677	111	28		108	22375
1976		10120	4831	2502	229	2139		898	1188	225		134	22266
1977		6652	2982	1315	5827	5664	1269	843	867	45	1002	553	27019
1978		10157	3779	2510	5096	7922	207	615	1584	410	562	289	33131
1979		9636	4743	4907	1525	7484		5	1310		24	76	29710
1980		3615	1056	706	301	3248		33	1080	355	1	62	10457
1981		3727	927	4100	79	3874			1154			12	13873
1982		3316	1262	4513	119	3121	33		375			14	12753
1983		2930	1264	4407		1489			111	3		1	10205
1984		3474	910	4745		3058			47	454	5	9	12702
1985		4376	1271	4914		2266			405	429	9	5	13675
1986		6350	1231	4384		2192				345	3	13	14518
1987		2802	706	3639	2300	916						269	10632
1988	28899	421	39	141		1100					3	14	1718
1989	48373	170	10	378								359	917
1990	40827	551	22	87		1262						840	2762
1991	16229	2838	1	1416		2472	26		897		5	1334	8989
1992	25089	2201	1	4215		747	5				6	51	7226
1993	15958	3132	0	2249		2931						4	8316
1994	29916	2590	0	1952		2249			1			93	6885
1995	10372	1641	0	564		1016						0	3221
1996	2601	1284	0	176		700	129			16		0	2305
1997	2933	1433	0	1			23					0	1457
1998	705	456	0									0	456
1999	353	2	0									0	2
2000	55	30	6									0	36
2001	37	56	0									0	56
2002	33	32	1									0	33
2003	16	7	0									9	16
2004	5	18	2									3	23
2005	19	16	0			7						3	26
2006	339	51	1	16								55	123
2007	345	58	6	33								28	125
2008	889	219	74	42	3	0						63	401
2009	1161	856	87	85		22						122	1172
2010	9291	1345	374	921		1183	761		514			147	5245
2011	12836	2412	655	1610	200	2211	1063		1301		185	340	9977
2012	12836	2593	745	1597	131	2045	868		809		172	108	9068
2013	13985	4427	896	2380		2723	1328		1322			445	13521
2014	14290	5345	950	2099		3370		393	1344			855	14356
2015	13785	4680	893	1999		3319			1296			641	12828
2016	14023	5484	893			3124	1198		1336			72	12107
2017	13928	5245	900	900		3165	1148		1240			1322	13920
2018	11481	4690	705	726		2972			1043			1040	11176
2019	17520	6319	1132	2296	13	4371			1643			1607	17381
2020	8458	4234	545	477		2263			786			204	8509
2021	2055	718	92	82		956[3]			138			69	

[1] Recalculated from NAFO Statistical data base using the NAFO 21A Extraction Tool
[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
Total catch	9192	9794	9003	13985	14290	13785	14023	13928	6447	17520	8458	2055
Total trawler	9192	9794	9003	10095	12034	10125	10208	10762	4210	12968	5416	961
Total longliner	0	0	0	3889	2256	3659	3814	3166	3166	4552	3042	1094
% longliner	0	0	0	28	16	27	27	23	49	26	36	53

Table 1C. Summary of the length distributions in 2021 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	324	4106	897	3016	597	8940	2920
Gear	Trawl	Trawl	Trawl	Longline	Longline		Trawl
Range (cm)	49-107	18-123	35-96	25-130	30-115	18-130	6-132
Mean (cm)	67	69	67	69	70	69	37
Mode (cm)	64	66	74	69	75	66	17

Table 1D. Mean and mode length of the total commercial and the survey length distribution for 2010-2021.

	Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Mean	Commercial	57	58	59	47	52	53	56	64	64	61	64	69
	Survey	30	21	31	34	44	46	49	52	55	43	41	37
Mode	Commercial	54	54	54	42	51	54	39	63	63	60	63	66
	Survey	18	15	18	24	33	42	36	42	54	21	33	17

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

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

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	406	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

201										3	1										
6		448	143	223	145	123	48	11	52	0	4	2	2								805
	56	5	56	0	40	75	14	57	2	3	5	8	0	0	0	0	0	0	0	55032	83
201										3	1										
7	201		651	166	326	158	85	27	78	4	3	5	2								894
	0	314	6	45	7	42	19	65	9	5	7	3	7	6	7	0	0	0	0	57241	14
201										3	1										
8		430		608	129	344	70	39	10	0	6	5	1			1					757
	366	8	309	2	96	7	90	33	46	6	5	9	0	0		1	8	0	0	40139	95
201										8	1										
9	118	173	521		325	573	41	14	19	2	2	3	1								424
	96	7	3	295	2	3	7	95	56	2	2	3	4	7	0	0	0	0	8	33002	60
202			2520	1349																	671
0	7137	4733	3	5	5678	4109	3336	687	631	938	566	126	54	14	29	0	0	8	0	66744	30
202				1907																	515
1	19195	8871	9272	4	3913	960	1061	1035	289	558	636	195	31	37	0	7	0	0	0	65149	01

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	2.47	2.982	4.703
2021	0.045	0.188	0.665	0.842	1.604	2.428	3.134	5.021

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	0.020	0.048	0.112	0.246	0.458	0.667	0.818	0.936	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	0.118	0.903	0.999	1.000	1.000	1.000	3.47
2000	0.000	0.001	0.147	0.961	1.000	1.000	1.000	1.000	3.34
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	0.917	0.997	1.000	1.000	1.000	3.31
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

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	84311	79602	89041	22970	19382	27265	61128	47227	83482	0.527	0.486	0.576
1989	95153	90392	100385	28986	24303	33505	121779	93556	163502	0.633	0.588	0.686
1990	87452	82967	92271	32033	28282	36324	110300	85064	145439	0.746	0.693	0.800
1991	73714	68448	81265	24565	21459	27957	371244	288497	487751	0.445	0.407	0.486
1992	86751	81110	95329	25234	22702	28047	300897	234221	403336	1.440	1.340	1.534
1993	61150	57366	65582	10250	9084	11598	20165	15661	26642	0.983	0.905	1.056
1994	53993	50682	57604	21010	18491	23668	37219	29312	48941	1.382	1.309	1.469
1995	19561	18303	20707	13352	12341	14451	15455	11891	20439	1.323	1.238	1.408
1996	7171	6770	7573	3530	3226	3856	960	740	1291	0.485	0.443	0.530
1997	6100	5759	6480	3933	3630	4252	830	642	1122	0.943	0.867	1.024
1998	2973	2748	3248	2579	2371	2834	1381	1073	1888	0.338	0.298	0.379
1999	2390	2153	2684	2137	1894	2423	211	160	287	0.218	0.187	0.254
2000	2663	2361	3035	2062	1803	2391	3878	2943	5257	0.067	0.055	0.079
2001	3354	2990	3810	2048	1808	2332	9098	6854	12323	0.078	0.063	0.096
2002	3624	3299	4040	2318	2080	2583	861	655	1186	0.021	0.018	0.024
2003	4809	4309	5448	2745	2491	3032	23789	18374	32014	0.006	0.005	0.007
2004	8284	7525	9260	4195	3822	4604	726	554	970	0.002	0.002	0.002
2005	12987	11568	14763	6380	5736	7092	52780	41122	70728	0.002	0.002	0.002
2006	28752	25747	32879	10510	9621	11531	85181	66449	115367	0.054	0.047	0.062
2007	43088	39231	47791	15037	13388	17402	114187	88232	154148	0.015	0.013	0.016
2008	58340	53733	63715	26093	24145	28383	100723	78395	135624	0.028	0.025	0.032
2009	78790	73145	85831	40876	37923	44028	143530	111861	189997	0.021	0.019	0.023
2010	105827	98476	114727	59716	55203	64462	242041	190669	330879	0.131	0.118	0.146
2011	108526	100709	117690	52249	48203	56336	387269	300972	520278	0.142	0.127	0.161
2012	145710	134086	160714	54385	50133	59169	306523	239194	410931	0.099	0.087	0.112
2013	134928	126099	145054	85856	79241	93242	44859	35084	60538	0.102	0.090	0.115
2014	132668	123303	141902	83500	76452	90331	141155	108799	186620	0.079	0.070	0.089
2015	114965	107102	123327	77249	70348	83829	58036	44811	77306	0.088	0.078	0.099
2016	118261	109939	127709	83171	75653	90716	11477	8830	15551	0.092	0.080	0.105
2017	99675	92421	107838	82589	75783	89943	78311	60214	104832	0.051	0.045	0.059
2018	93866	87115	101721	71392	65098	78439	23989	18039	32595	0.073	0.064	0.082
2019	79232	73303	85755	59116	54371	65081	64298	47045	88697	0.145	0.128	0.163
2020	54143	49161	59222	37188	32988	41450	62961	46236	88499	0.101	0.088	0.117
2021	51858	46255	57779	28827	25275	32706	165193	111822	249781	0.022	0.019	0.026

Table 8. F at age (posterior median).

	F at age							
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**
1988	0.000	0.018	0.345	0.592	0.639	0.646	0.782	0.782
1989	0.000	0.011	0.366	0.807	0.726	0.779	0.858	0.858
1990	0.000	0.018	0.391	0.925	0.914	1.214	1.044	1.044
1991	0.000	0.023	0.301	0.487	0.545	0.557	0.671	0.671
1992	0.000	0.145	1.019	1.513	1.787	1.419	1.966	1.966
1993	0.000	0.087	0.688	1.165	1.089	1.511	0.858	0.858
1994	0.000	0.195	1.004	1.753	1.377	1.318	0.983	0.983
1995	0.000	0.190	0.564	1.520	1.885	2.302	2.172	2.172
1996	0.000	0.049	0.254	0.505	0.695	0.908	0.818	0.818
1997	0.000	0.116	0.588	0.870	1.377	2.022	1.819	1.819
1998	0.000	0.046	0.205	0.333	0.469	0.549	0.405	0.405
1999	0.000	0.026	0.238	0.185	0.227	0.230	0.084	0.084
2000	0.000	0.005	0.131	0.027	0.042	0.032	0.010	0.010
2001	0.000	0.008	0.142	0.037	0.054	0.040	0.013	0.013
2002	0.000	0.002	0.036	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	0.076	0.039	0.046	0.032	0.028	0.028
2007	0.000	0.000	0.010	0.015	0.018	0.017	0.023	0.023
2008	0.000	0.002	0.014	0.030	0.039	0.036	0.030	0.030
2009	0.000	0.001	0.008	0.025	0.030	0.029	0.033	0.033
2010	0.000	0.011	0.072	0.133	0.187	0.189	0.213	0.213
2011	0.000	0.011	0.092	0.113	0.222	0.273	0.373	0.373
2012	0.000	0.006	0.062	0.079	0.154	0.199	0.288	0.288
2013	0.000	0.006	0.069	0.079	0.156	0.214	0.282	0.282
2014	0.000	0.003	0.036	0.091	0.110	0.172	0.230	0.230
2015	0.000	0.003	0.049	0.088	0.126	0.203	0.236	0.236
2016	0.000	0.003	0.040	0.106	0.128	0.155	0.234	0.234
2017	0.000	0.001	0.017	0.046	0.090	0.161	0.205	0.205
2018	0.000	0.002	0.024	0.057	0.138	0.280	0.219	0.219
2019	0.000	0.001	0.044	0.126	0.263	0.542	0.373	0.373
2020	0.000	0.001	0.018	0.097	0.187	0.419	0.263	0.263
2021	0.000	0.000	0.003	0.024	0.040	0.122	0.074	0.074

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	61128	140190	94739	29862	4288	954	705	276	334153	45683
1989	121779	15690	75133	47421	12872	1749	343	315	277715	42133
1990	110300	31216	8476	36987	16637	4796	550	193	209677	31700
1991	371244	28209	16737	4045	11463	5117	973	184	438511	21032
1992	300897	94738	15047	8749	1947	5120	2001	416	430934	11646
1993	20165	77702	44961	3868	1507	253	846	236	149901	6222
1994	37219	5191	39054	15980	942	393	38	324	99508	14289
1995	15455	9558	2317	10055	2147	184	71	90	39969	10546
1996	960	3942	4304	932	1718	250	13	12	12185	2742
1997	830	248	2061	2371	439	661	69	8	6701	2985
1998	1381	214	119	807	772	86	60	9	3458	1642
1999	211	355	111	68	451	373	34	33	1647	979
2000	3878	54	189	62	44	277	204	42	4764	670
2001	9098	1003	29	118	47	33	184	171	10680	565
2002	861	2323	542	18	88	35	22	241	4159	780
2003	23789	221	1272	371	14	67	24	175	25914	1337
2004	726	6139	120	893	290	11	46	132	8346	1363
2005	52780	185	3348	85	698	224	7	120	57502	4875
2006	85181	13517	101	2371	66	539	153	85	102012	3383
2007	114187	21860	7338	67	1783	49	358	162	145815	4752
2008	100723	29507	11903	5161	51	1352	33	354	149210	9521
2009	143530	25866	15994	8326	3904	38	893	251	199708	15246
2010	242041	36679	14128	11258	6327	2935	25	780	315904	22055
2011	387269	62858	19856	9338	7682	4043	1662	431	492873	19157
2012	306523	99119	33913	12914	6504	4776	2117	1011	467160	22516
2013	44859	78825	53984	22625	9327	4295	2676	1629	219105	54319
2014	141155	11611	42657	35828	16351	6136	2389	2252	258581	41875
2015	58036	35975	6315	29182	25486	11268	3545	2543	173428	40986
2016	11477	14830	19670	4271	20886	17348	6294	3330	98806	33506
2017	78311	2950	8075	13434	3004	14160	10184	5303	135419	32446
2018	23989	20151	1606	5639	10003	2109	8279	8779	81065	23508
2019	64298	6098	11056	1117	4160	6729	1095	9400	104244	19820
2020	62961	16440	3367	7497	768	2465	2685	4837	101675	10404
2021	165193	16303	8991	2338	5318	490	1117	3938	203339	8700

Table 10. Prior and posterior median for M

	1	2	3	4	5	6	7	8+
Prior	1.26	0.65	0.44	0.35	0.30	0.27	0.24	0.24
Posterior	1.35	0.60	0.34	0.24	0.26	0.37	0.33	0.41

Table 11. N-at-age in prediction years (medians) with $F_{bar}=F_{sq}=0.089$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2022	21837	42001	8876	6354	1778	3937	296	3166	87193	8672
2023	21205	5759	23067	6197	4711	1257	2145	1992	65088	8450
2024	20315	5648	3161	16138	4444	3091	574	2206	53517	9315
2025	22184	5321	3121	2193	11555	2916	1425	1454	47961	11596

Table 12. Projections results (median and 80% CI) with $F_{bar}=F_{sq}=0.089$.

Year	Total Biomass		SSB		P(SSB<B_{lim})	P(SSB_{25} >SSB_{22})	Yield	P(F>F_{lim})
2022	50511	(45475 - 56297)	25994	(23085 - 28992)	<1%	60%	4000	<1%
2023	48942	(43410 - 55808)	22651	(19983 - 25601)	<1%		5791	<1%
2024	47441	(41115 - 55572)	23797	(20536 - 27170)	<1%		6987	<1%
2025	43101	(35439 - 52003)	27046	(22345 - 32507)	<1%			

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

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2022	21837	42001	8876	6354	1778	3937	296	3166	87193	8672
2023	21205	5759	23067	6197	4711	1257	2145	1992	65088	8450
2024	20315	5648	3162	16433	4851	3637	860	2859	55710	10983
2025	26302	5321	3122	2233	12892	3740	2506	2506	56377	15172

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

Year	Total Biomass		SSB		P(SSB<B_{lim})	P(SSB_{25} >SSB_{22})	Yield	P(F>F_{lim})
2022	50511	(45475 - 56297)	25994	(23085 - 28992)	<1%	100%	4000	<1%
2023	48942	(43410 - 55808)	22651	(19983 - 25601)	<1%		0	<1%
2024	53489	(47131 - 61613)	29062	(25841 - 32474)	<1%		0	<1%
2025	55443	(47659 - 64531)	37876	(33038 - 43336)	<1%			

Table 15. N-at-age in prediction years (medians) with $F_{bar}=F_{2021}=0.022$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2022	21837	42001	8876	6354	1778	3937	296	3166	87193	8672
2023	21205	5759	23067	6197	4711	1257	2145	1992	65088	8450
2024	20315	5648	3161	16260	4618	3315	683	2472	54408	9988
2025	23801	5321	3121	2210	12128	3252	1824	1844	51458	13003

Table 16. Projections results (median and 80% CI) with $F_{bar}=F_{2021}=0.022$.

Year	Total Biomass		SSB		P(SSB<B_{lim})	P(SSB_{25} >SSB_{22})	Yield	P(F>F_{lim})
2022	50511	(45475 - 56297)	25994	(23085 - 28992)	<1%	95%	4000	<1%
2023	48942	(43410 - 55808)	22651	(19983 - 25601)	<1%		3425	<1%
2024	49900	(43564 - 58037)	25929	(22708 - 29370)	<1%		4429	<1%
2025	47858	(40184 - 56840)	31201	(26375 - 36582)	<1%			

Table 17. N-at-age in prediction years (medians) with $F_{bar}=1/2F_{lim}=0.083$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2022	21837	42001	8876	6354	1778	3937	296	3166	87193	8672
2023	21205	5759	23067	6197	4711	1257	2145	1992	65088	8450
2024	20315	5648	3161	16158	4471	3124	589	2244	53647	9402
2025	22410	5321	3121	2196	11646	2967	1482	1512	48520	11773

Table 18. Projections results (median and 80% CI) with $F_{bar}=1/2F_{lim}=0.083$.

Year	Total Biomass	SSB	$P(SSB<B_{lim})$	$P(SSB_{25}>SSB_{22})$	Yield	$P(F>F_{lim})$
2022	50511 (45475 - 56297)	25994 (23085 - 28992)	<1%	67%	4000	<1%
2023	48942 (43410 - 55808)	22651 (19983 - 25601)	<1%		5446	<1%
2024	47801 (41467 - 55931)	24123 (20900 - 27453)	<1%		6610	<1%
2025	43807 (36133 - 52710)	27667 (22940 - 33046)	<1%			

Table 19. N-at-age in prediction years (medians) with $F_{bar}=2/3F_{lim}=0.111$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2022	21837	42001	8876	6354	1778	3937	296	3166	87193	8672
2023	21205	5759	23067	6197	4711	1257	2145	1992	65088	8450
2024	20315	5648	3160	16064	4344	2973	520	2068	53044	8960
2025	21397	5321	3120	2182	11256	2742	1238	1279	46349	10924

Table 20. Projections results (median and 80% CI) with $F_{bar}=2/3F_{lim}=0.111$.

Year	Total Biomass	SSB	$P(SSB<B_{lim})$	$P(SSB_{25}>SSB_{22})$	Yield	$P(F>F_{lim})$
2022	50511 (45475 - 56297)	25994 (23085 - 28992)	<1%	39%	4000	<1%
2023	48942 (43410 - 55808)	22651 (19983 - 25601)	<1%		7032	<1%
2024	46140 (39833 - 54302)	22661 (19467 - 26010)	1%		8128	<1%
2025	40803 (33146 - 49719)	25127 (20387 - 30497)	1%			

Table 21. N-at-age in prediction years (medians) with $F_{bar}=3/4F_{lim}=0.125$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2022	21837	42001	8876	6354	1778	3937	296	3166	87193	8672
2023	21205	5759	23067	6197	4711	1257	2145	1992	65088	8450
2024	20315	5648	3160	16022	4285	2901	490	1989	52755	8735
2025	20838	5321	3120	2175	11072	2633	1134	1169	45206	10547

Table 22. Projections results (median and 80% CI) with $F_{bar}=3/4F_{lim}=0.125$.

Year	Total Biomass	SSB	$P(SSB<B_{lim})$	$P(SSB_{25}>SSB_{22})$	Yield	$P(F>F_{lim})$
2022	50511 (45475 - 56297)	25994 (23085 - 28992)	<1%	27%	4000	<1%
2023	48942 (43410 - 55808)	22651 (19983 - 25601)	<1%		7787	<1%
2024	45350 (39053 - 53527)	21986 (18790 - 25344)	1%		8790	3%
2025	39437 (31811 - 48396)	23977 (19350 - 29304)	1%			

Table 23. N-at-age in prediction years (medians) with $F_{bar}=F_{lim}=0.166$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2022	21837	42001	8876	6354	1778	3937	296	3166	87193	8672
2023	21205	5759	23067	6197	4711	1257	2145	1992	65088	8450
2024	20315	5648	3159	15884	4125	2692	404	1763	51945	8153
2025	19259	5321	3119	2157	10516	2346	869	908	42404	9475

Table 24. Projections results (median and 80% CI) with $F_{bar}=F_{lim}=0.166$.

Year	Total Biomass		SSB		$P(SSB<B_{lim})$	$P(SSB_{25}>SSB_{22})$	Yield	$P(F>F_{lim})$
2022	50511	(45475 - 56297)	25994	(23085 - 28992)	<1%		4000	<1%
2023	48942	(43410 - 55808)	22651	(19983 - 25601)	<1%	9%	9915	50%
2024	43154	(36866 - 51292)	20065	(16900 - 23469)	3%		10431	50%
2025	35770	(28221 - 44759)	20928	(16358 - 26280)	6%			

Table 25. N-at-age in prediction years (medians) with Catch=4000 tons including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2022	21837	42001	8876	6354	1778	3937	296	3166	87193	8672
2023	21205	5759	23067	6197	4711	1257	2145	1992	65088	8450
2024	20315	5648	3161	16234	4579	3262	656	2408	54192	9834
2025	23475	5321	3122	2212	12156	3246	1834	1813	51104	12943

Table 26. Projections results (median and 80% CI) with Catch=4000 tons.

Year	Total Biomass		SSB		$P(SSB<B_{lim})$	$P(SSB_{25}>SSB_{22})$	Yield	$P(F>F_{lim})$
2022	50511	(45475 - 56297)	25994	(23085 - 28992)	<1%		4000	<1%
2023	48942	(43410 - 55808)	22651	(19983 - 25601)	<1%	94%	4000	<1%
2024	49306	(42971 - 57441)	25399	(22161 - 28803)	<1%		4000	<1%
2025	47760	(40074 - 56713)	31052	(26294 - 36499)	<1%			

Table 27. N-at-age in prediction years (medians) with Catch=5000 tons including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2022	21837	42001	8876	6354	1778	3937	296	3166	87193	8672
2023	21205	5759	23067	6197	4711	1257	2145	1992	65088	8450
2024	20315	5648	3161	16183	4504	3165	610	2295	53816	9553
2025	22694	5321	3121	2205	11948	3108	1672	1652	49624	12418

Table 28. Projections results (median and 80% CI) with Catch=5000 tons.

Year	Total Biomass		SSB		$P(SSB<B_{lim})$	$P(SSB_{25}>SSB_{22})$	Yield	$P(F>F_{lim})$
2022	50511	(45475 - 56297)	25994	(23085 - 28992)	<1%		4000	<1%
2023	48942	(43410 - 55808)	22651	(19983 - 25601)	<1%	86%	5000	<1%
2024	48274	(41931 - 56397)	24492	(21285 - 27869)	<1%		5000	<1%
2025	45838	(38143 - 54765)	29349	(24623 - 34867)	<1%			

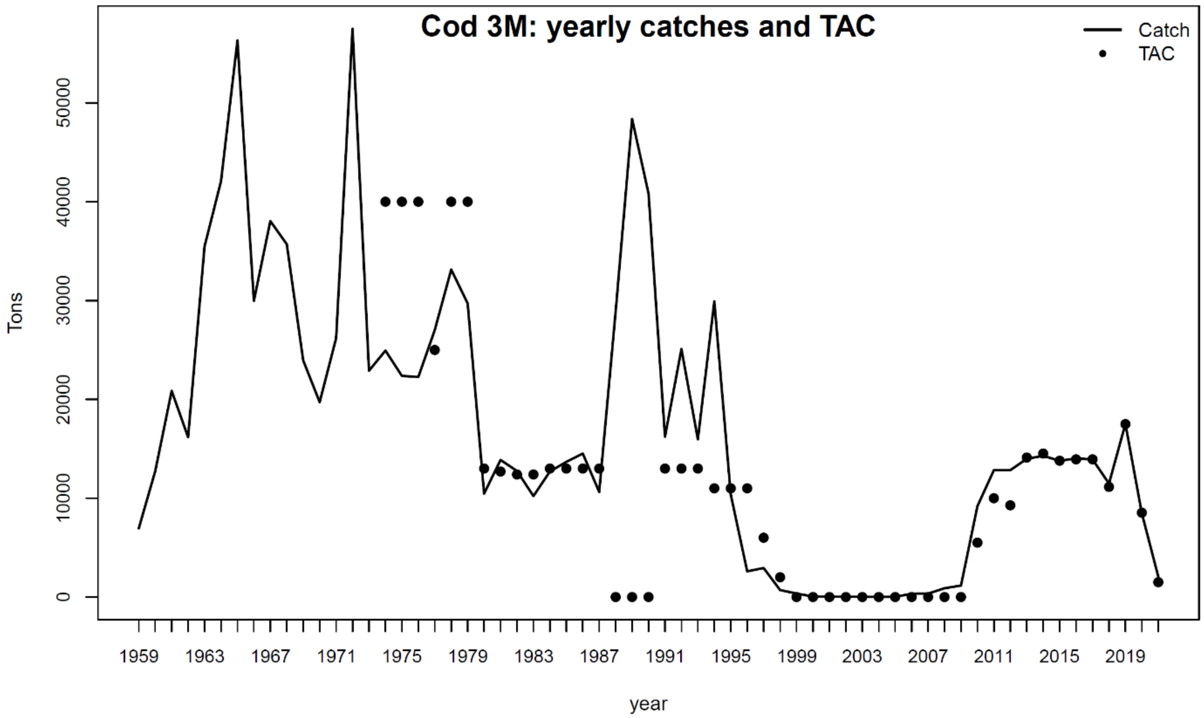


Figure 1. Catch and TAC of the 3M cod for the period 1959-2021.

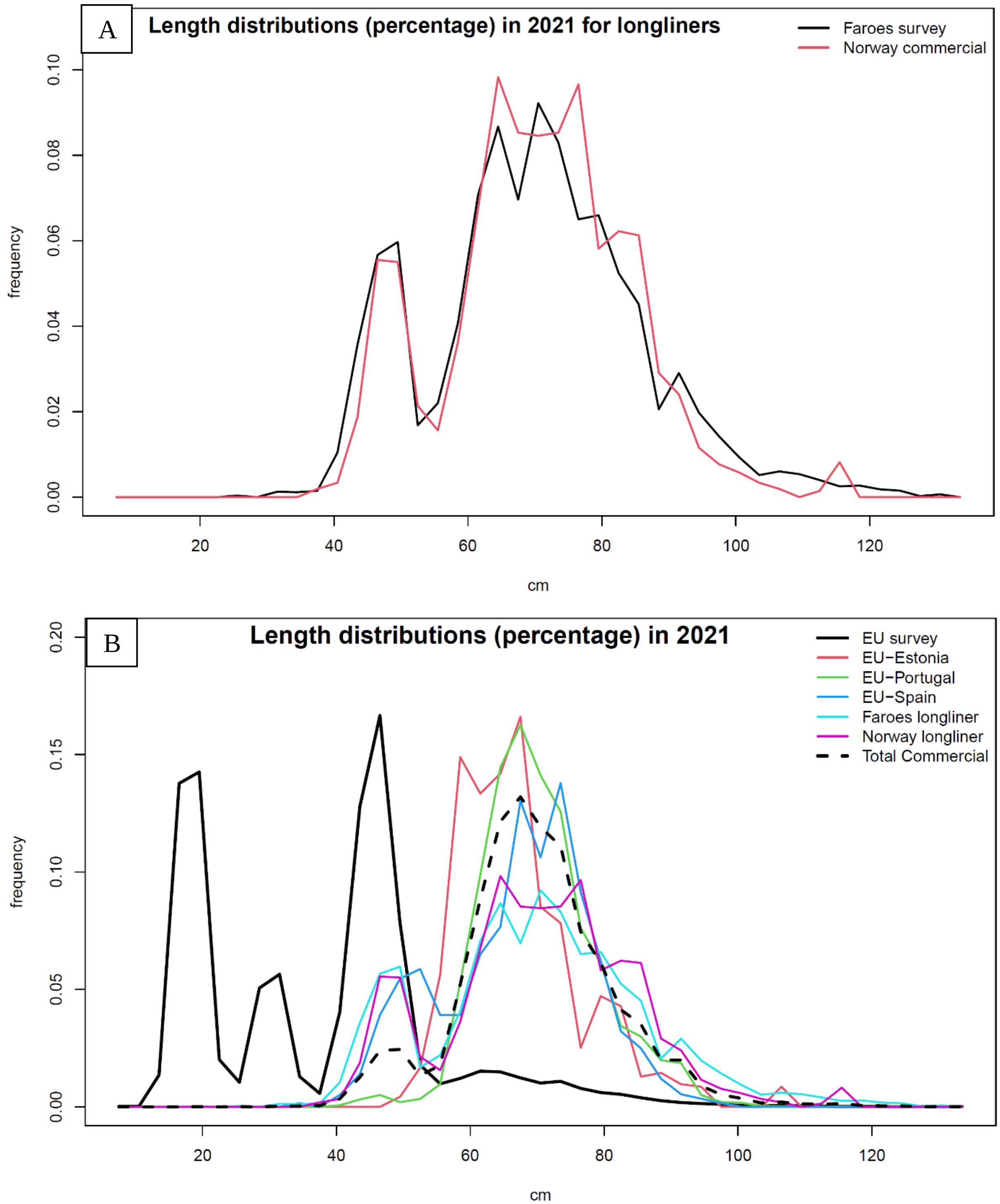
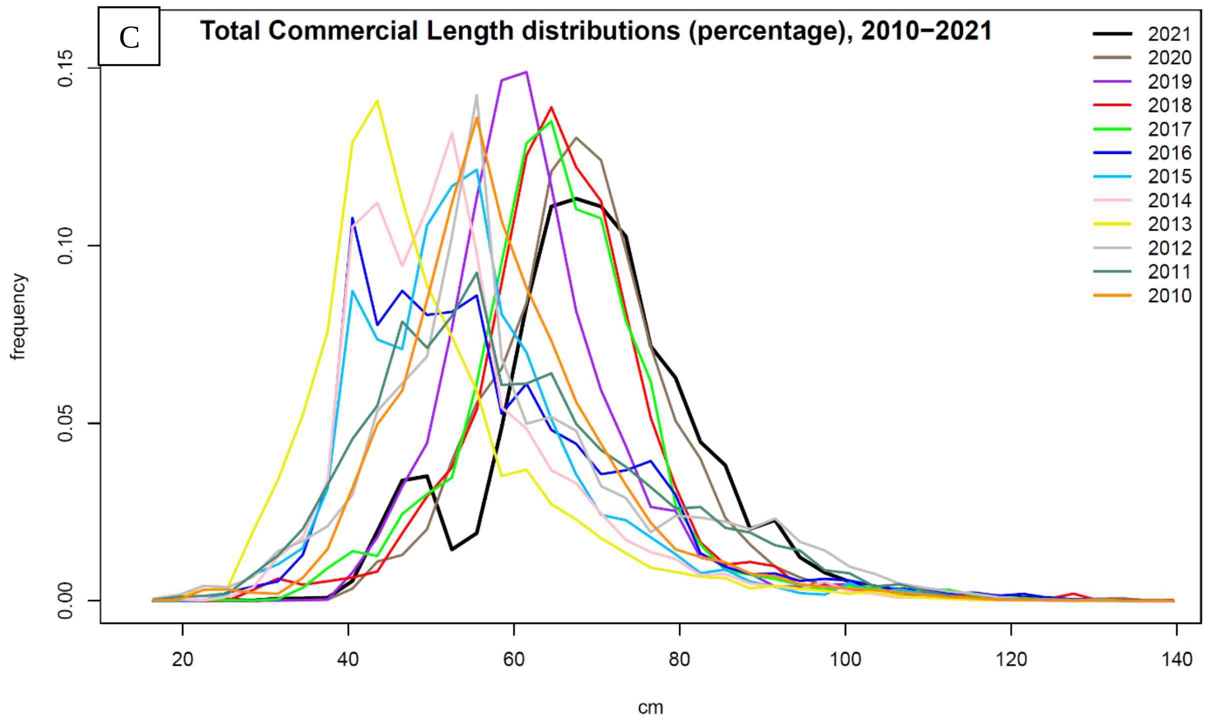


Figure 2. Length frequencies: comparative length distribution between the Faroese survey and the Norwegian commercial (A); in commercial catches (total includes the length distribution of the Faroese survey), EU survey and Faroese survey (Faroese longliner) in 2021 (B), and the total commercial for the last fishery period (2010-2021) (C). In (D), the mean and the mode length of the commercial length distribution is shown (2010-2021).



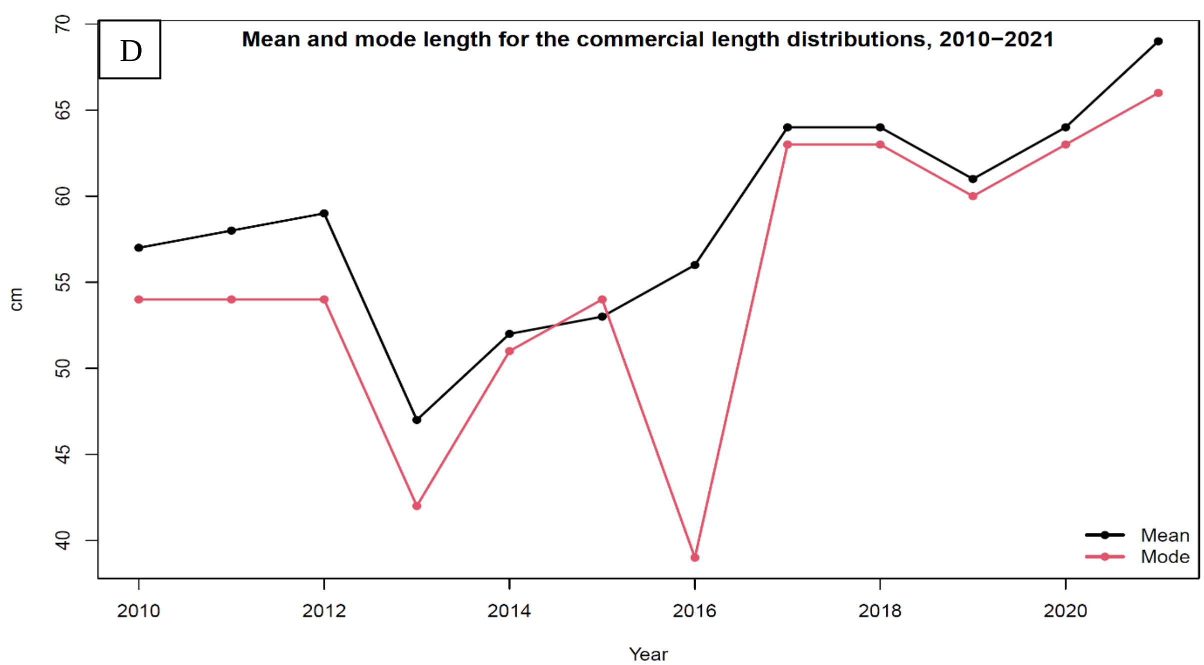


Figure 2 (cont.). Length frequencies: comparative length distribution between the Faroese survey and the Norwegian commercial (A); in commercial catches and EU survey in 2020 (B), and the total commercial for the last fishery period (2010-2021) (C). In (D), the mean and the mode length of the commercial length distribution is shown (2010-2021).

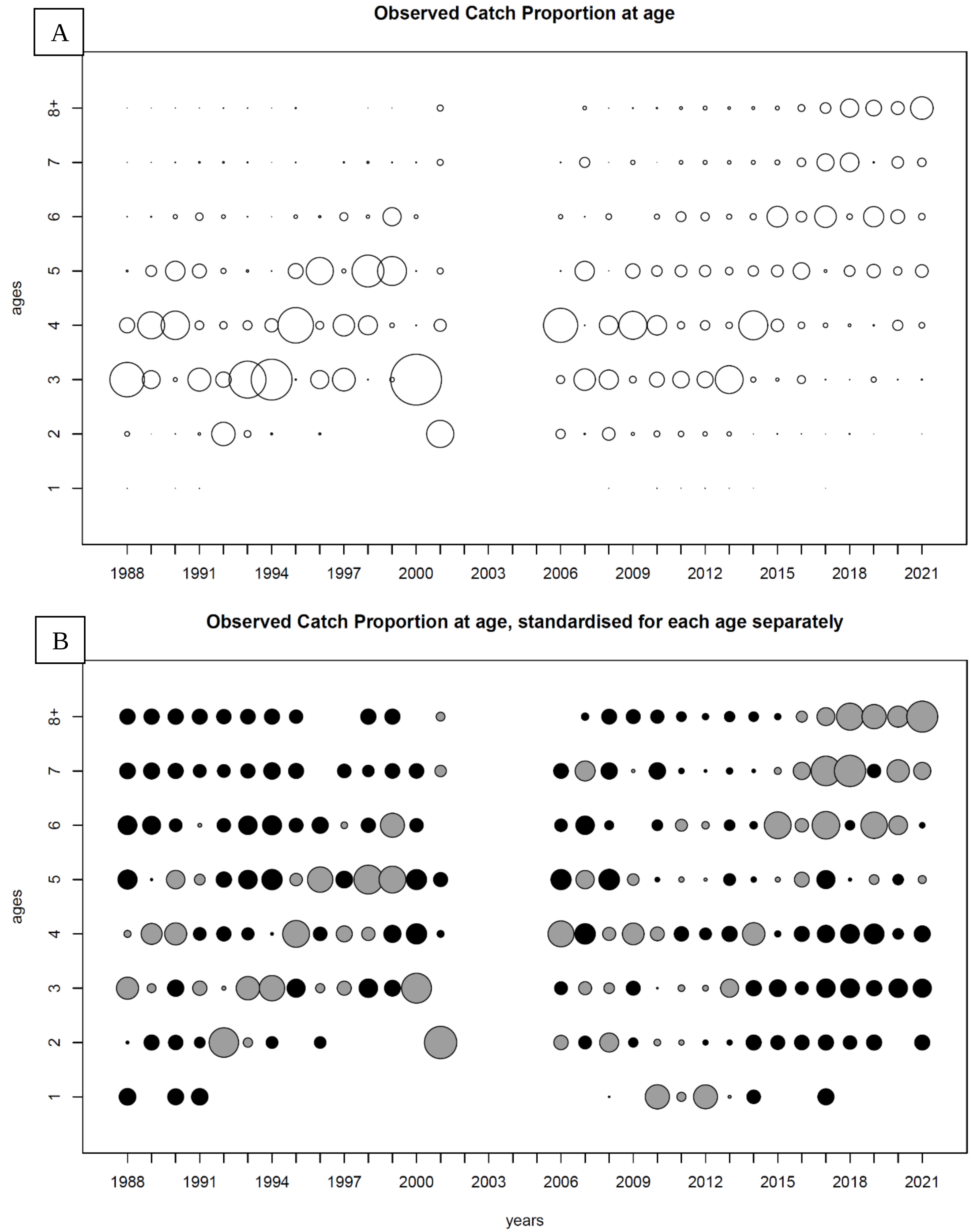


Figure 3. Commercial catch proportions at age (A) and standardised proportions at age (B). In B, grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

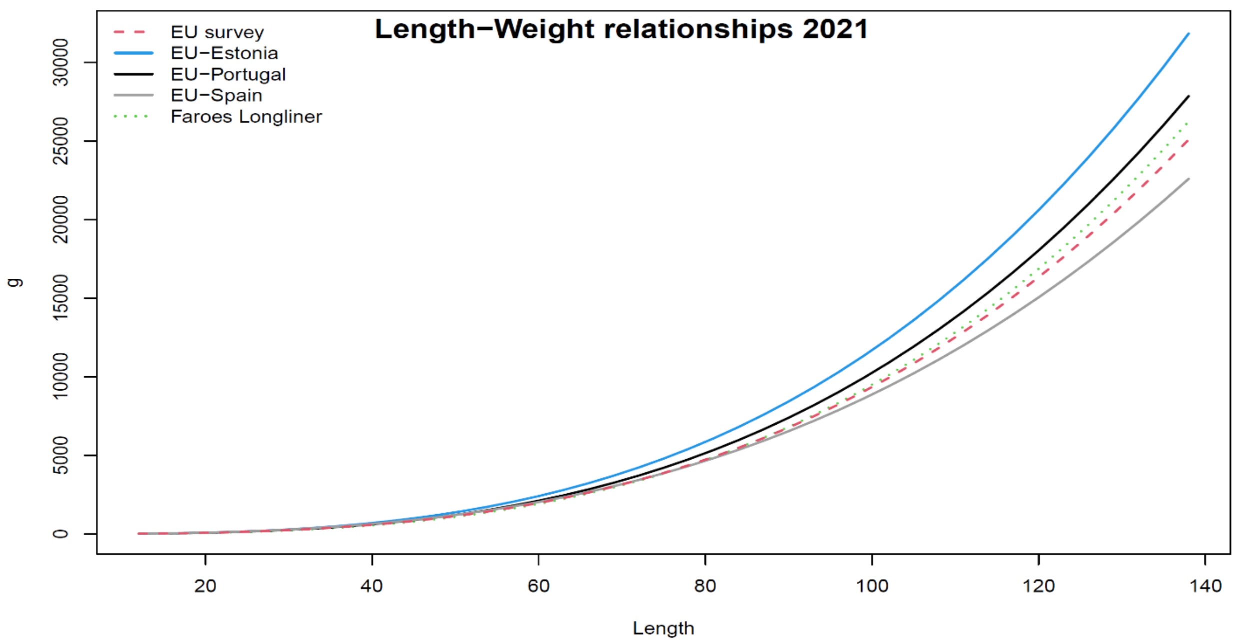


Figure 4. Length-weight relationships for commercial catches and EU survey in 2021.

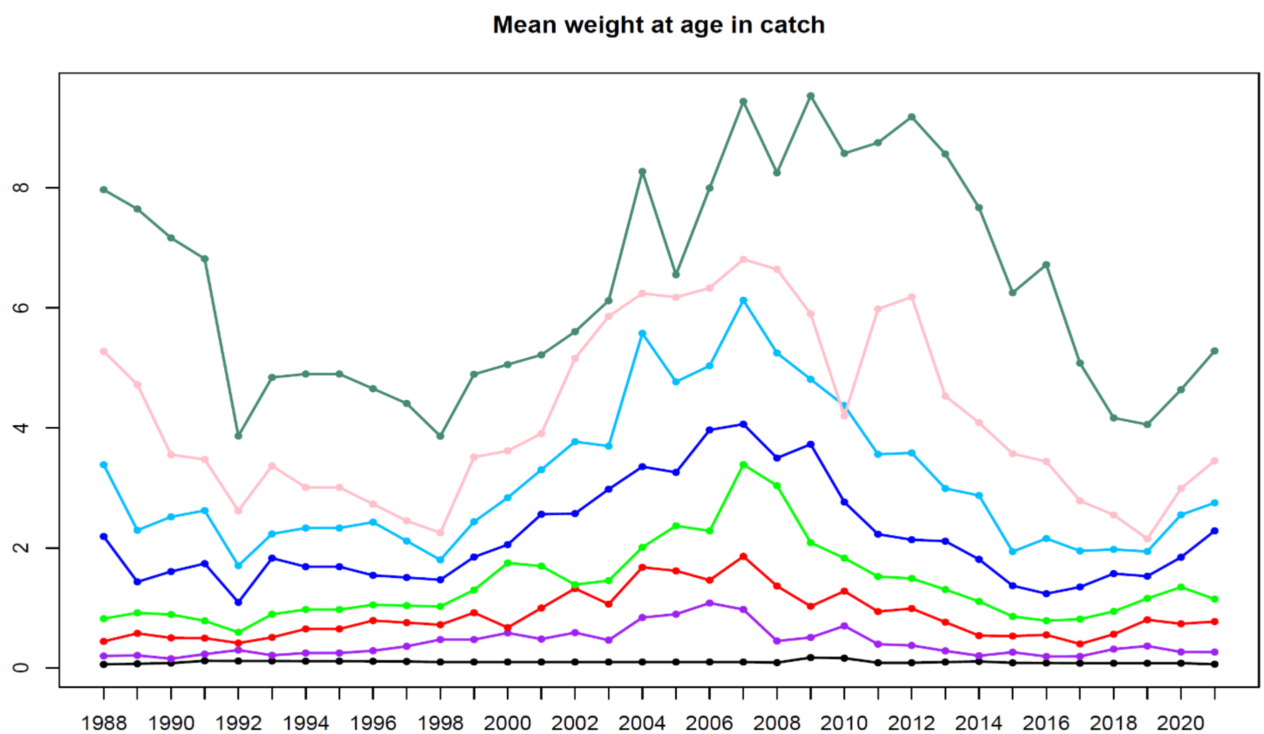


Figure 5. Catch mean weight at age.

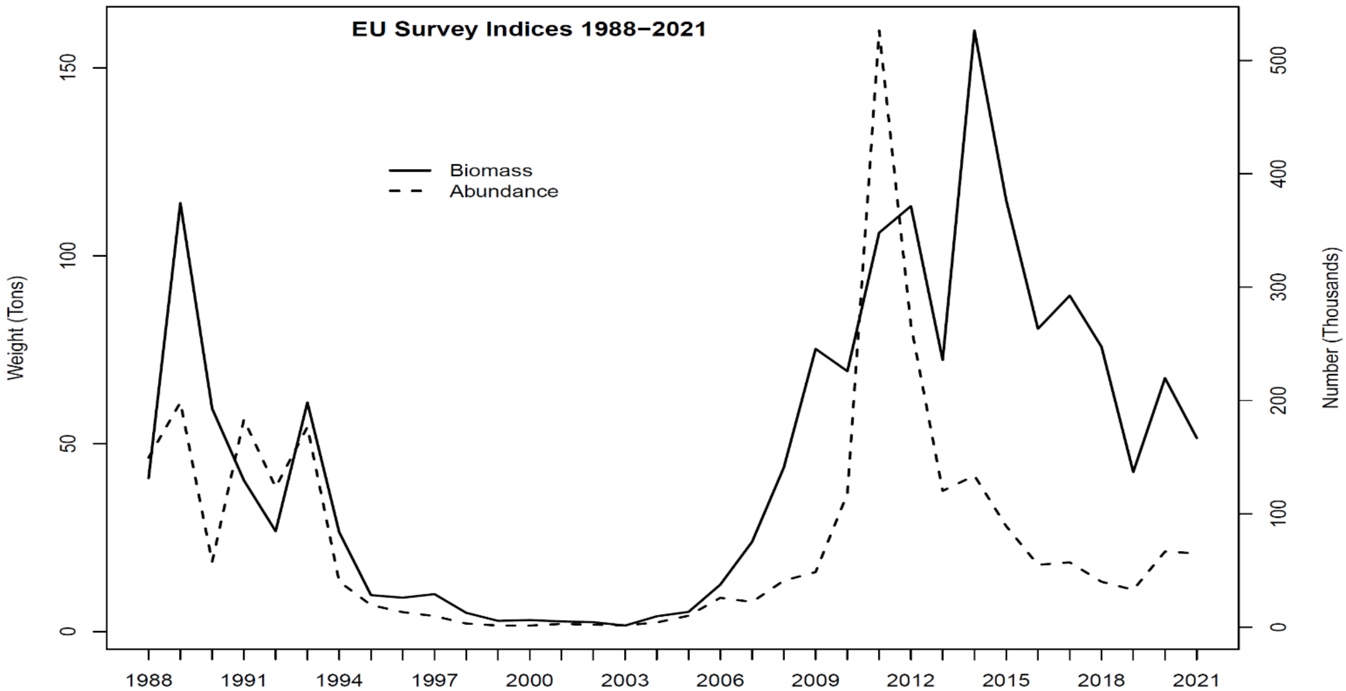


Figure 6. Biomass and abundance from EU surveys.

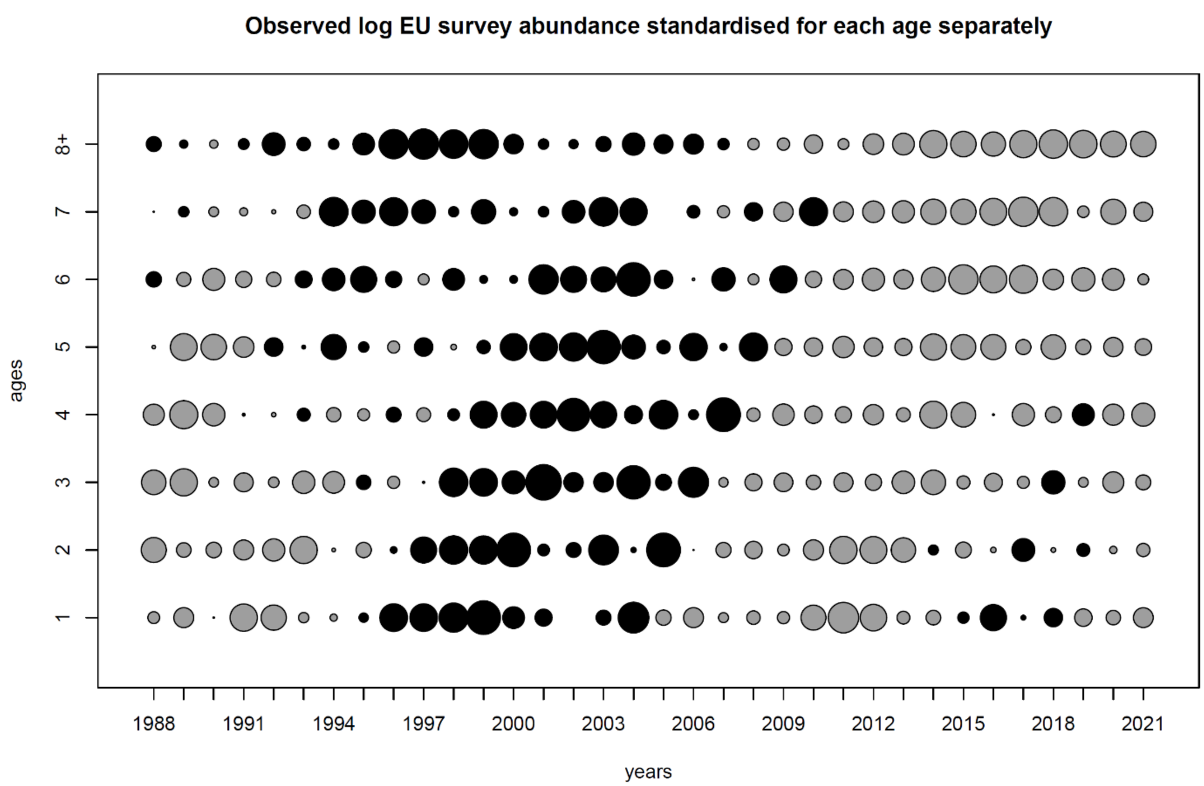


Figure 7. Standardised log(Abundance at age) indices from EU survey. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

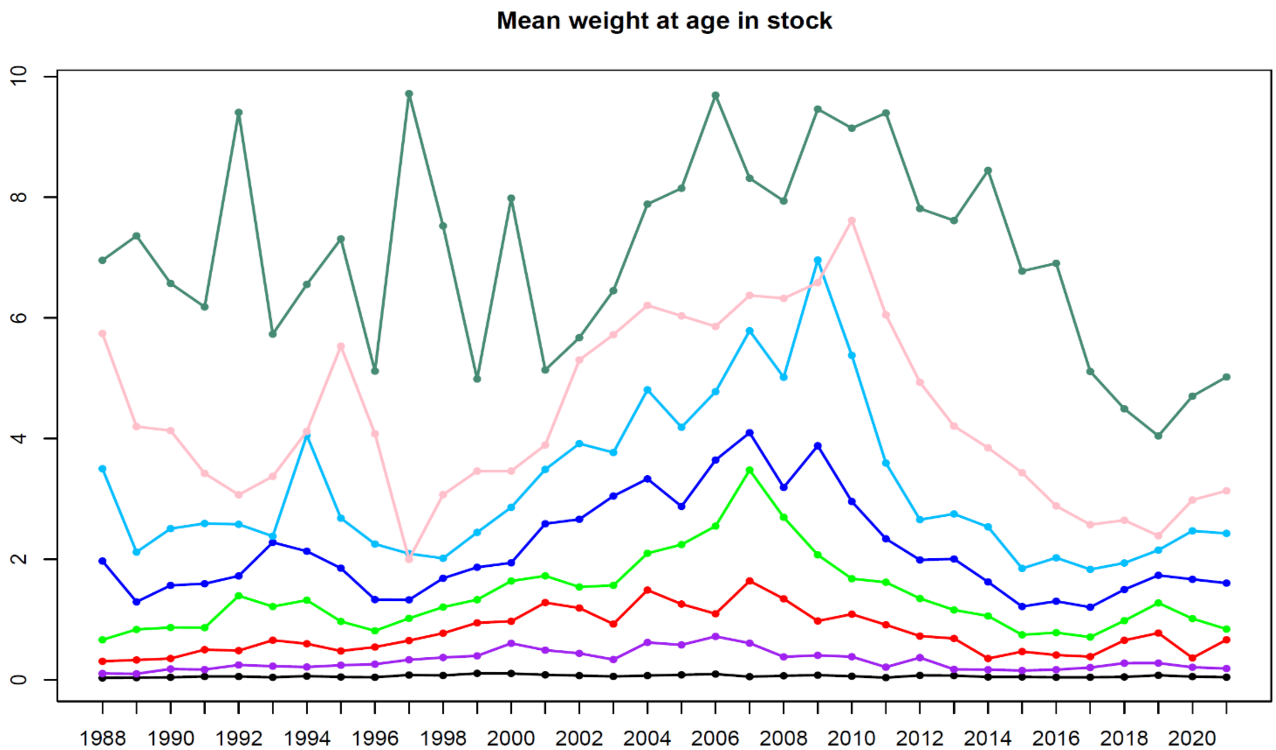
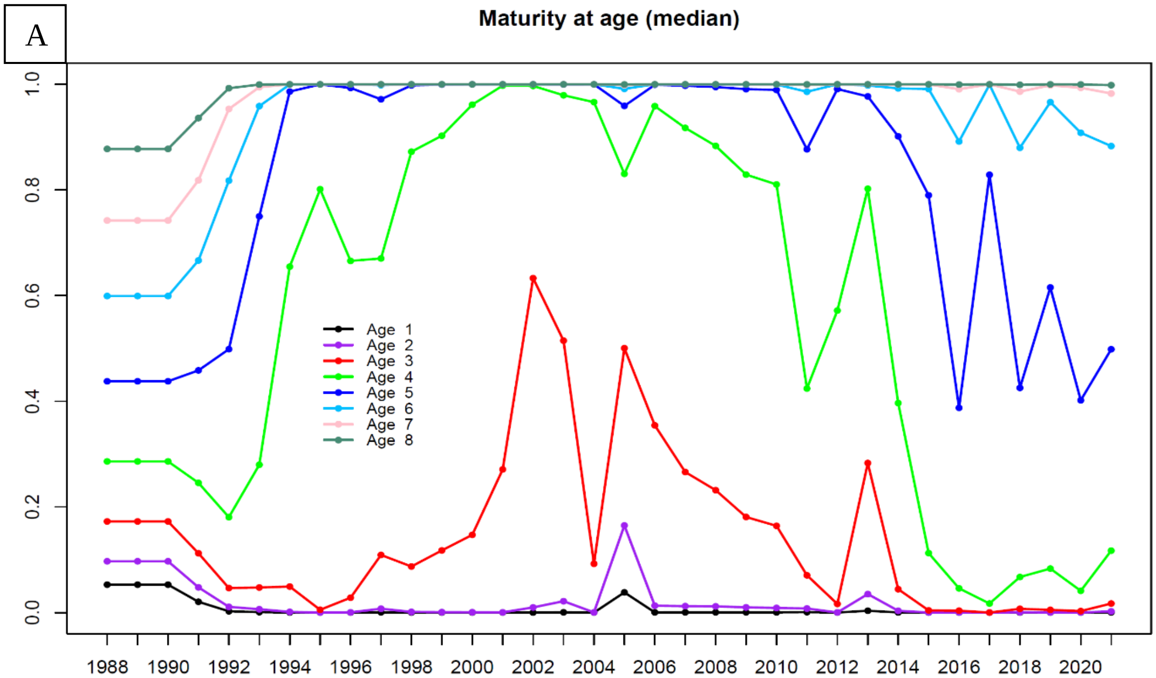


Figure 8. Stock mean weight at age.



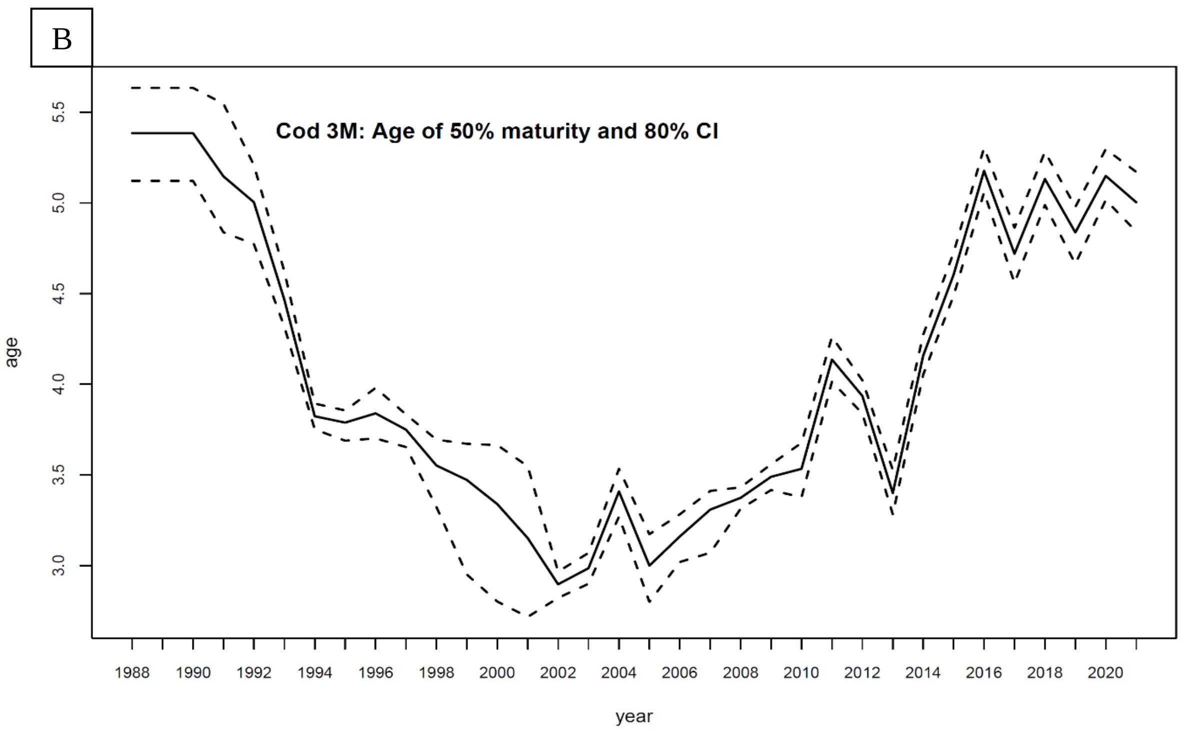


Figure 9. Maturity ogive by age (A) and age at which 50% of fish are mature (B).

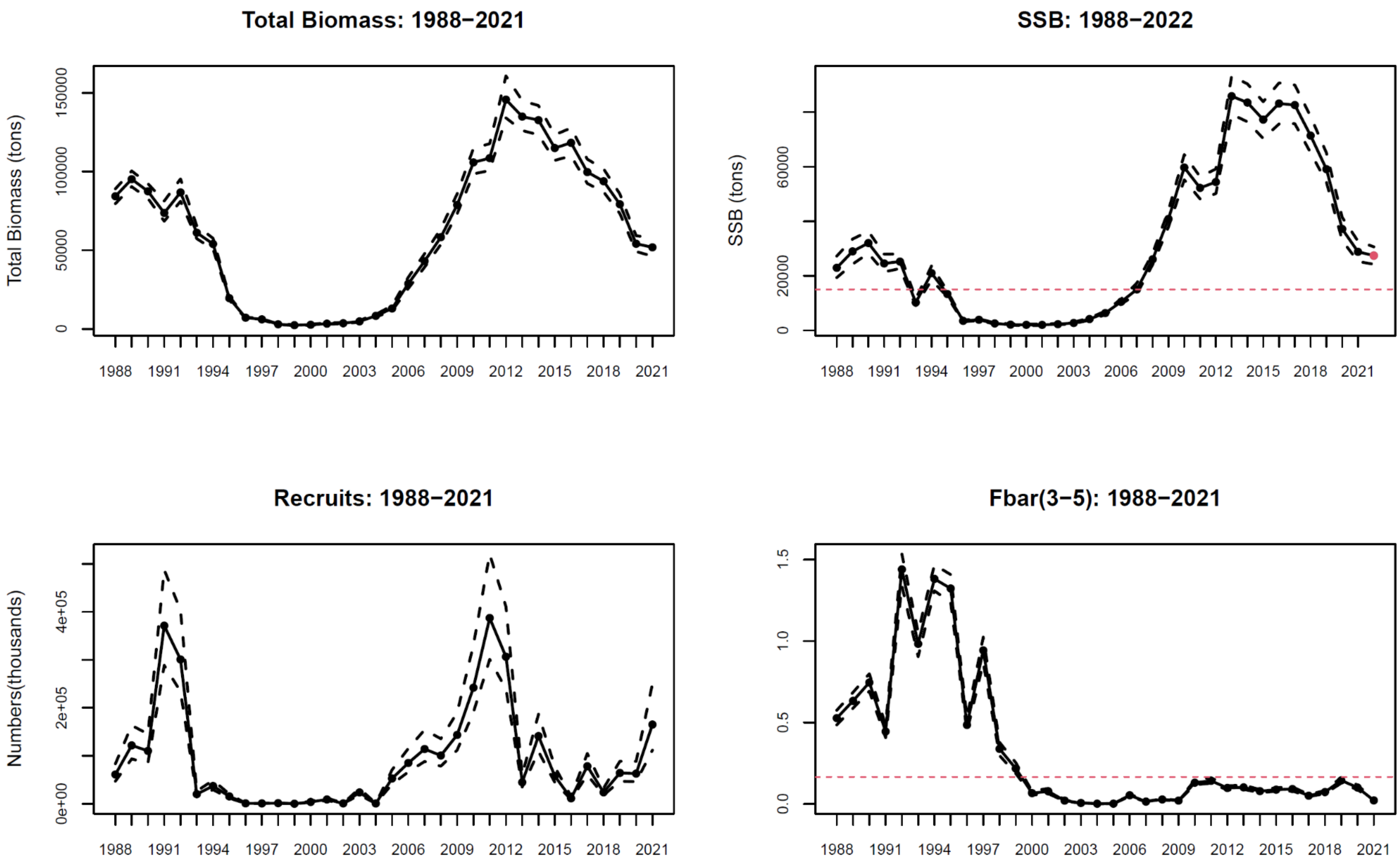


Figure 10. Estimated trends in biomass, SSB, recruitment and F_{bar}. The solid lines are the posterior medians and the dashed lines show the limits of 80% posterior credible intervals. Red point in the SSB plot indicates the SSB in 2022. Red horizontal line in the SSB graph represents median B_{lim} = medianSSB$_{2007}$ = 15 037 tons. Red horizontal line in the F_{bar} graph represents median F_{lim} = 0.166 (with the last three years parameters).

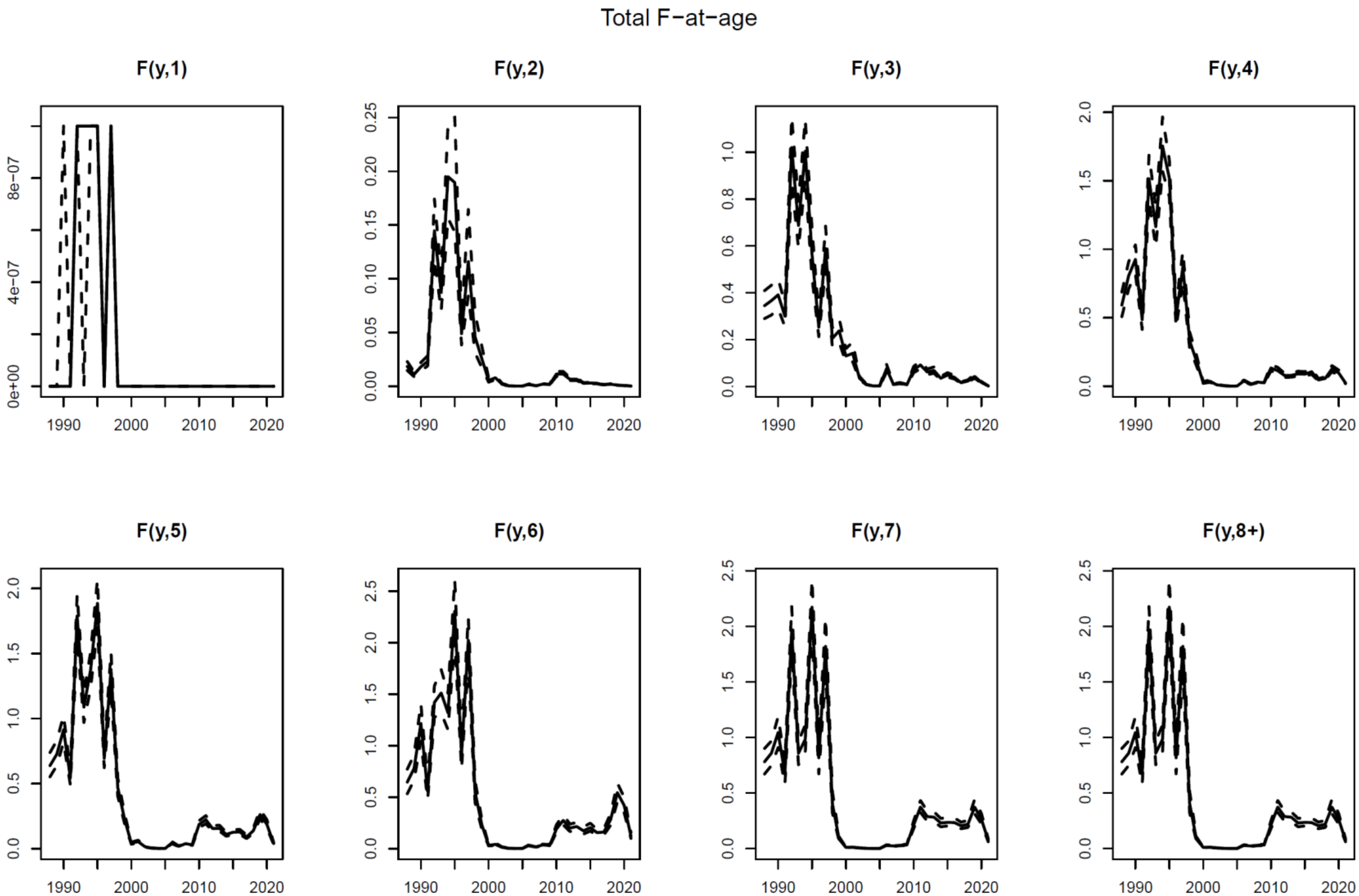


Figure 11. Estimated fishing mortality at age. The y-axis scale is different in all the graphs.

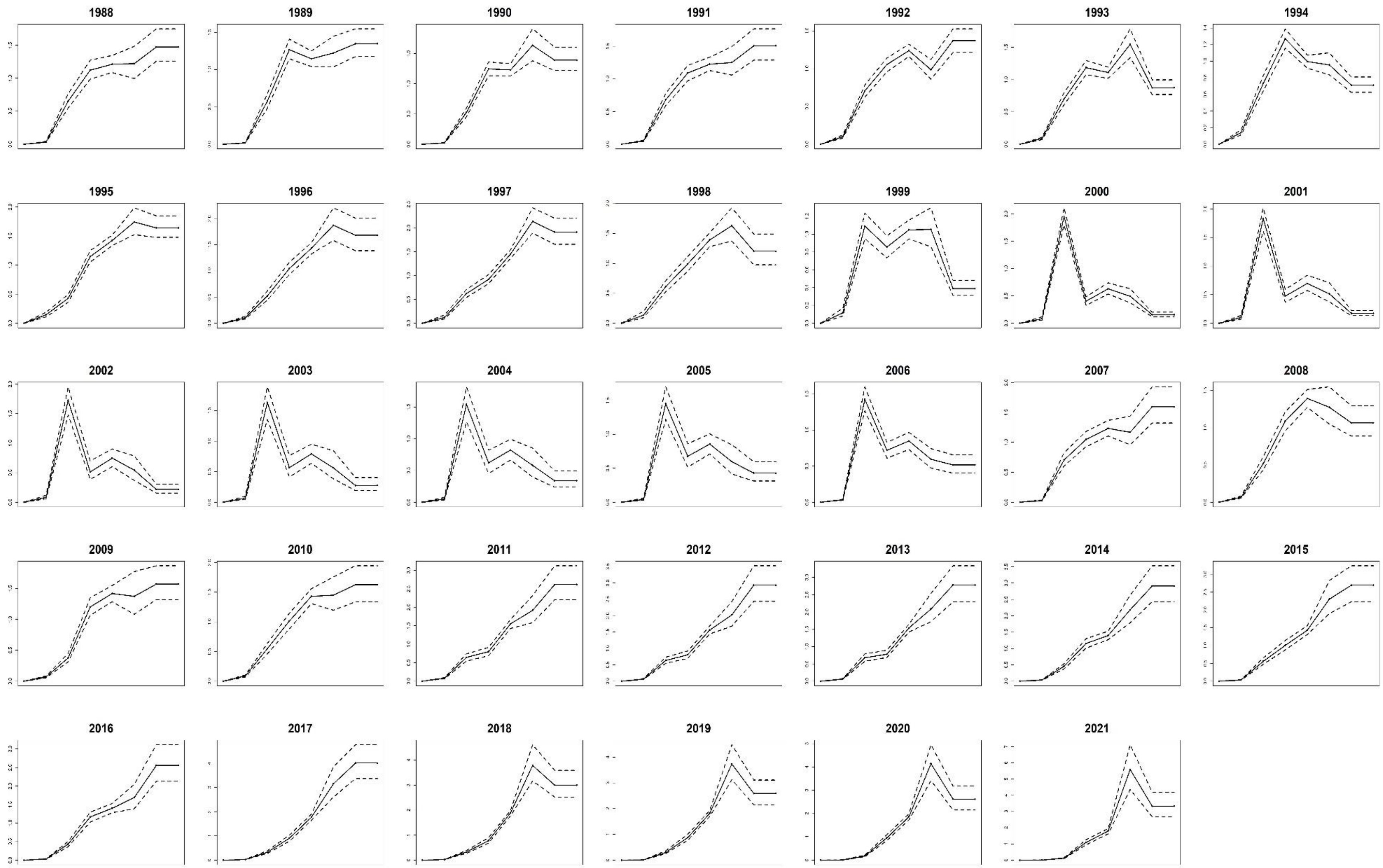


Figure 12. Estimated PR (F/F_{bar}) per age and year. The y-axis scale is different in all the graphs.

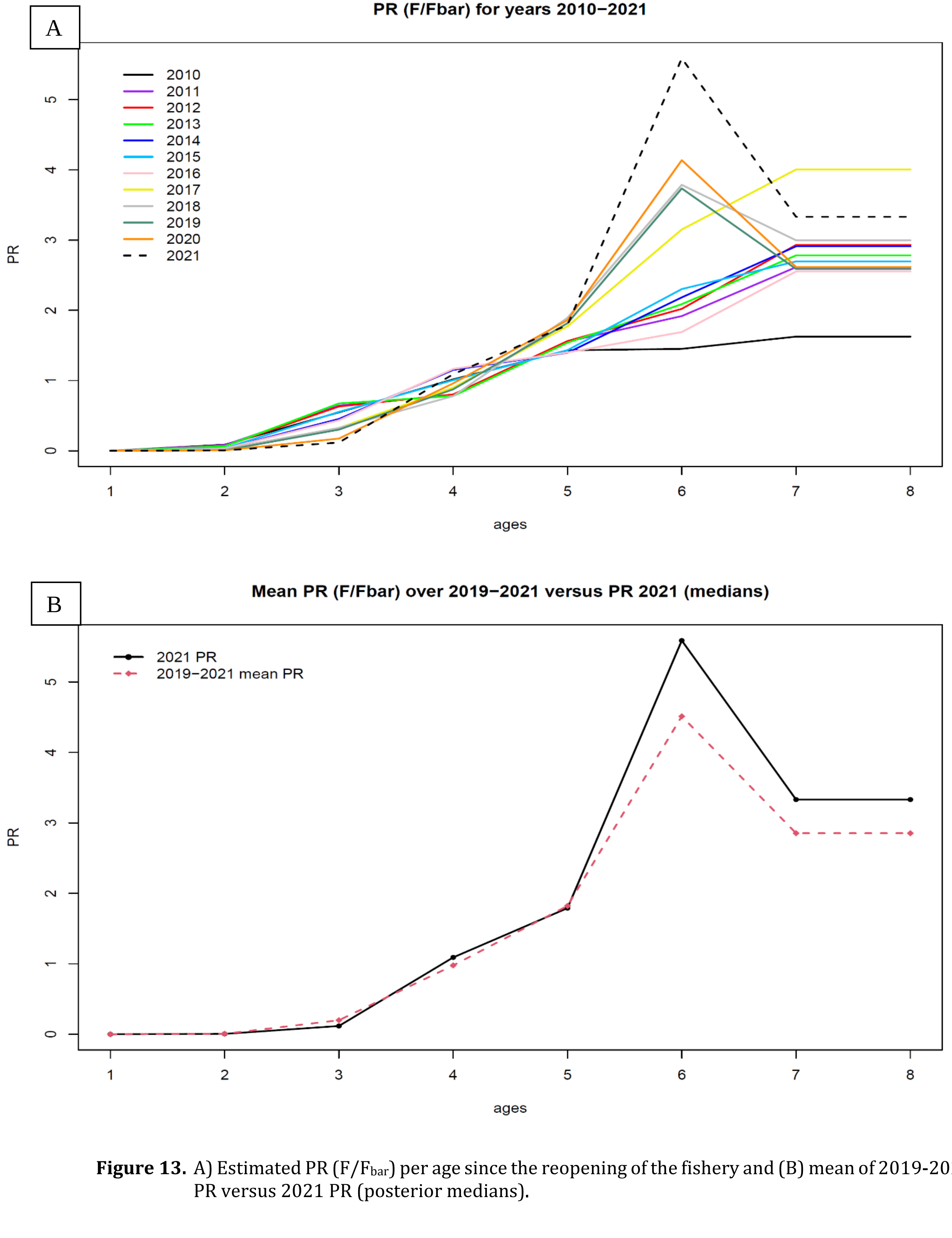


Figure 13. A) Estimated PR (F/F_{bar}) per age since the reopening of the fishery and (B) mean of 2019-2021 PR versus 2021 PR (posterior medians).

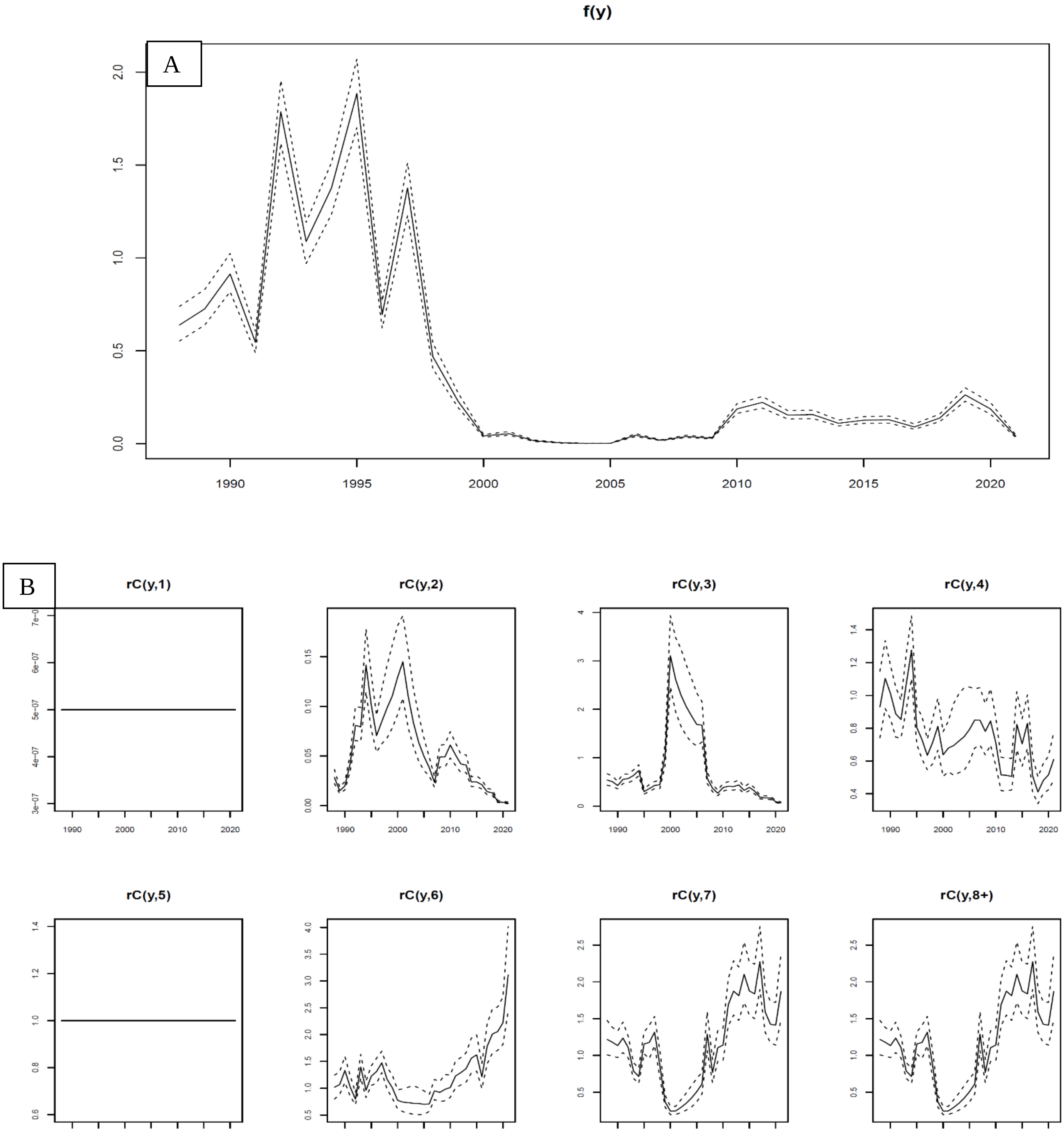


Figure 14. Components of the semi-separable model for Fishing Mortality: F[y,a]=*f*[y]***rC*[y,a].

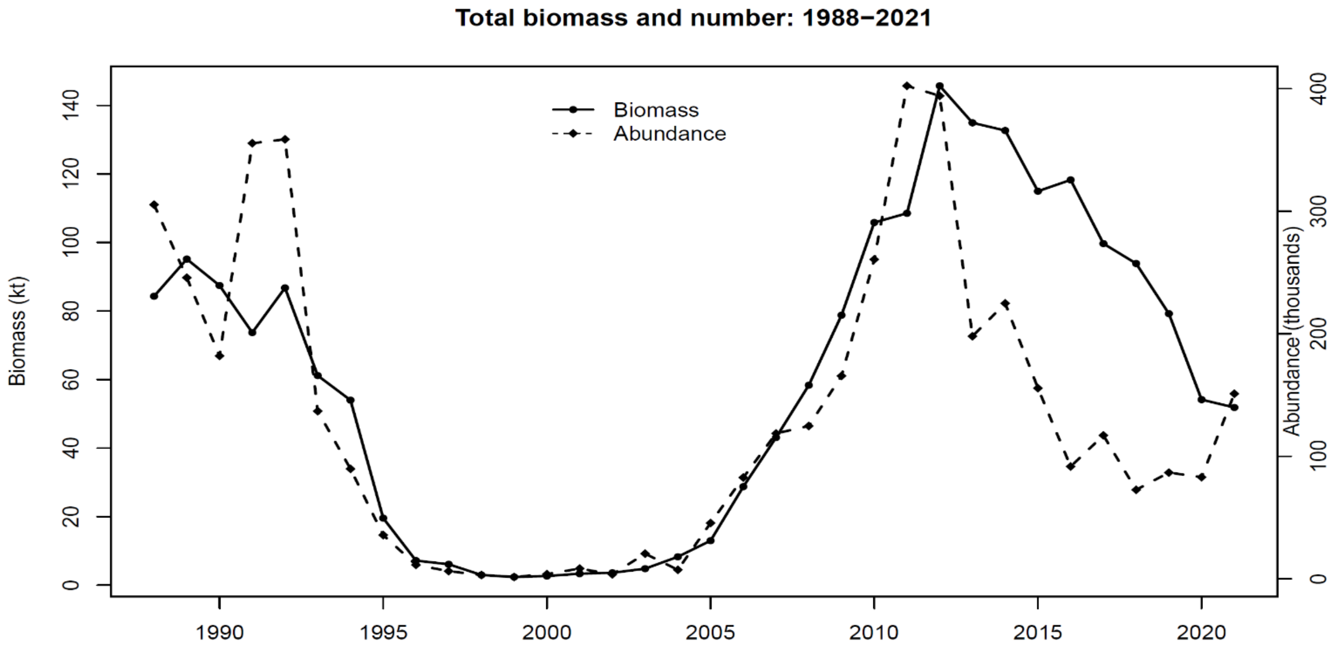


Figure 15. Estimated trends in biomass and abundance.

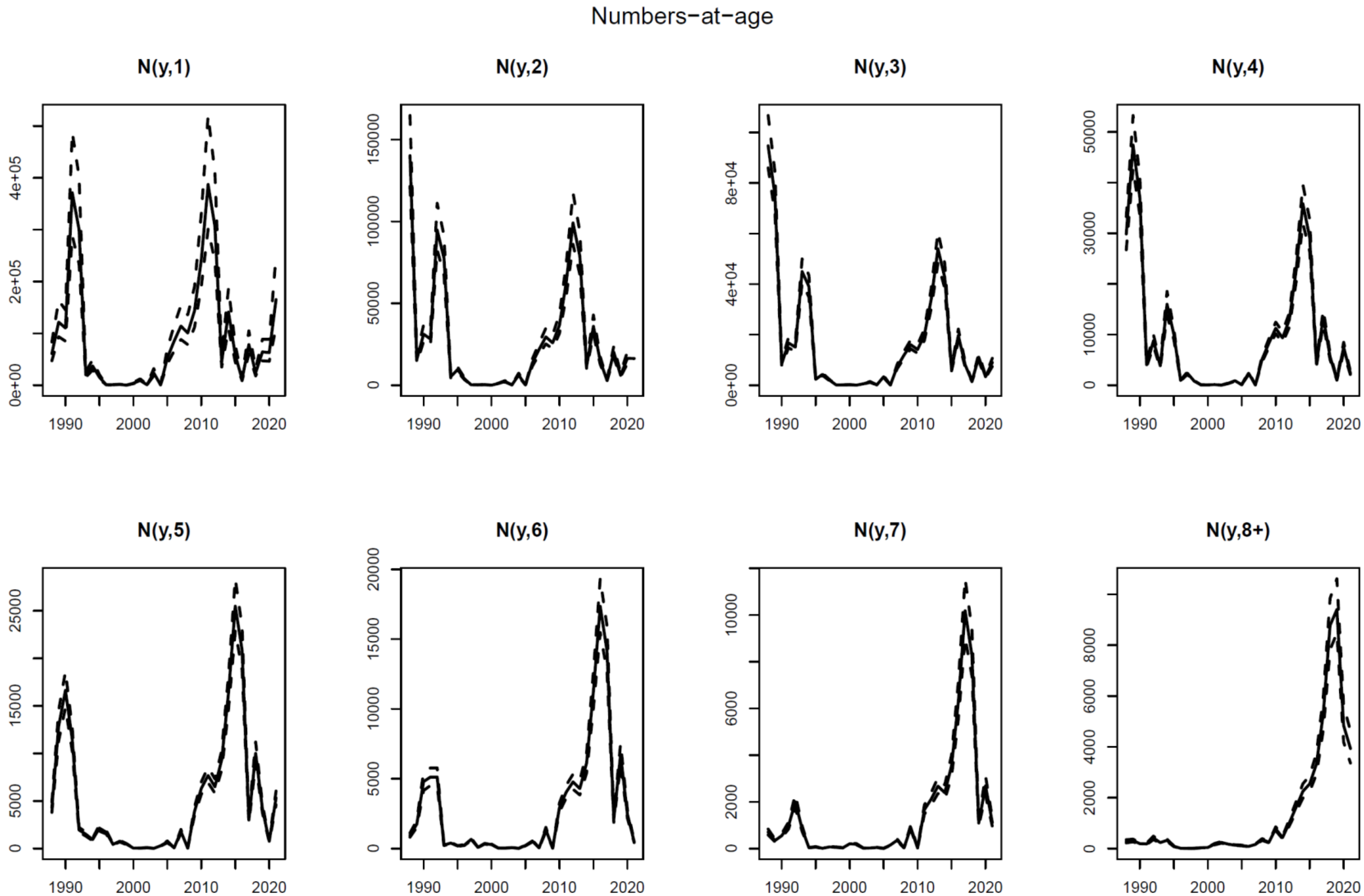


Figure 16. Estimated numbers at age. The y-axis scale is different in all the graphs.

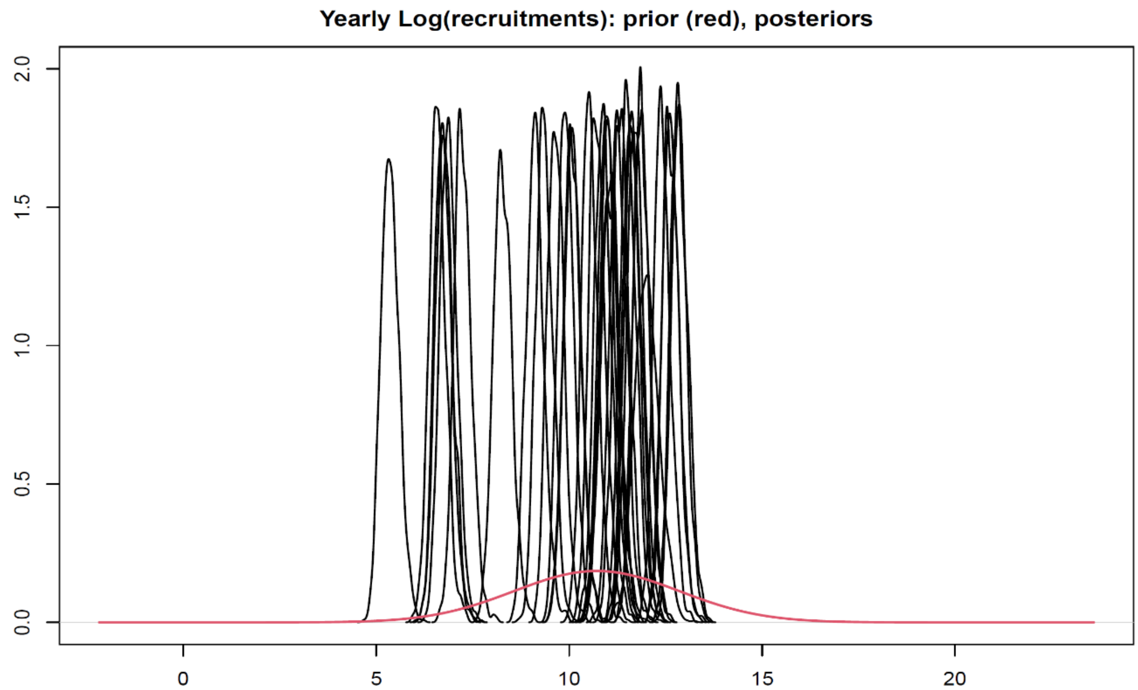


Figure 17. Prior and posterior of recruitment by year.

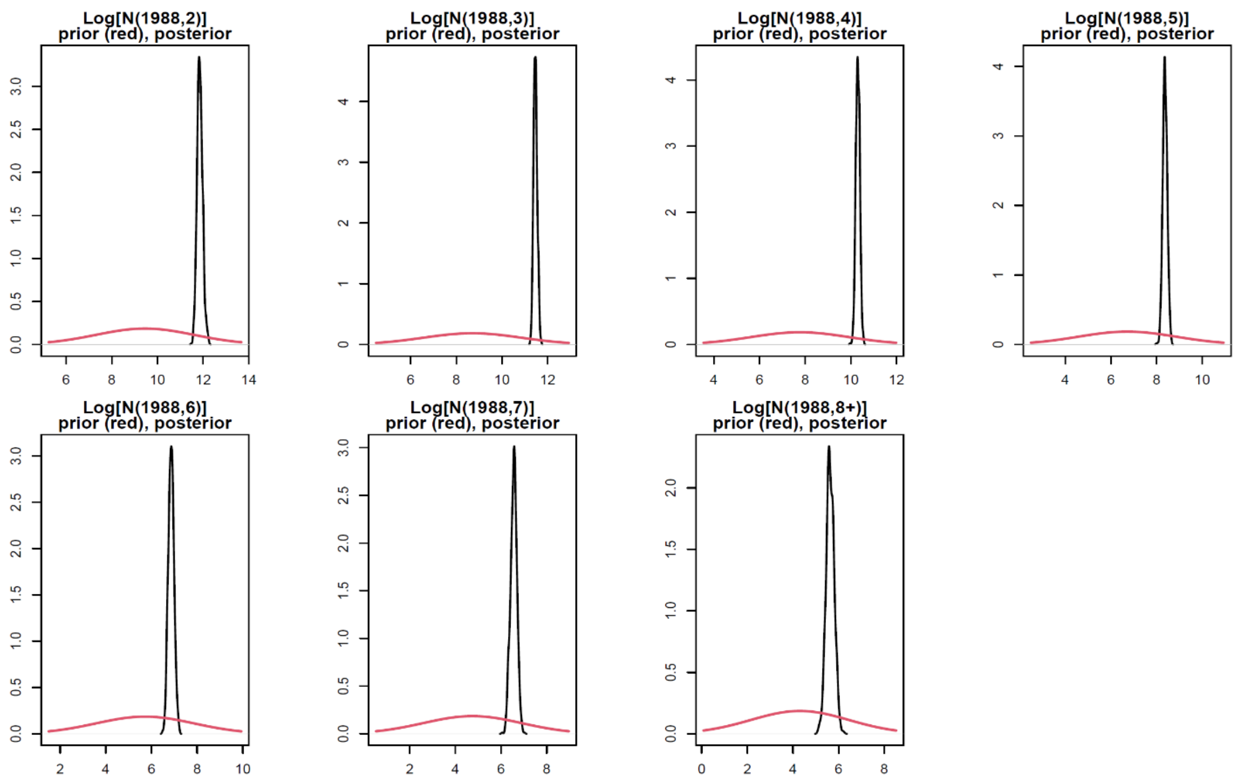


Figure 18. Prior and posterior of the numbers in the first year (1988) from age 2 to 8+.The x- and y-axis scales are different in all the graphs.

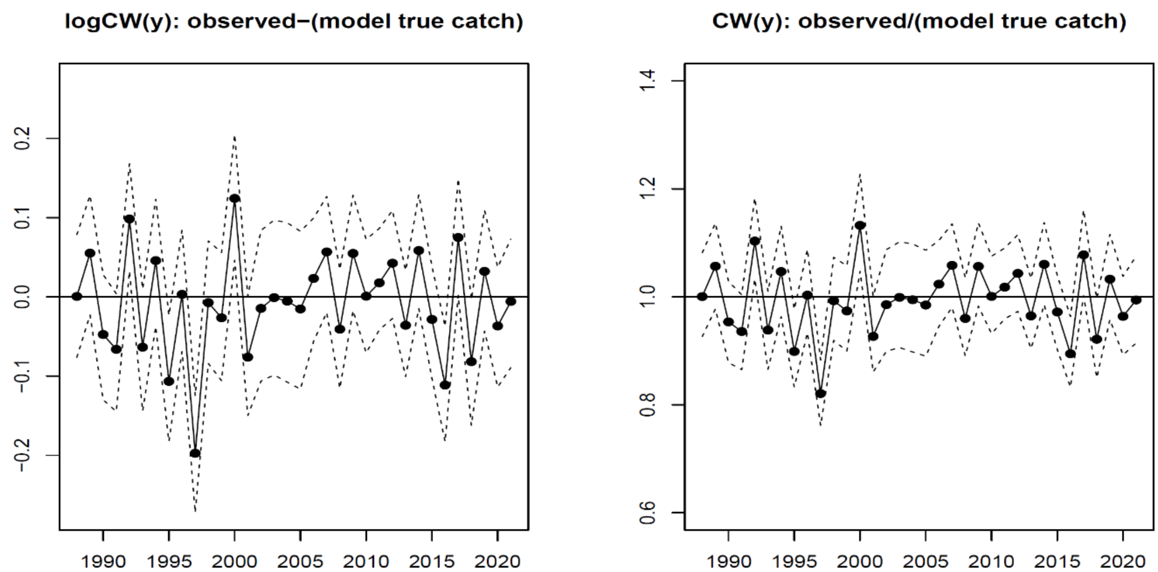


Figure 19. Observed versus estimated total catches by year.

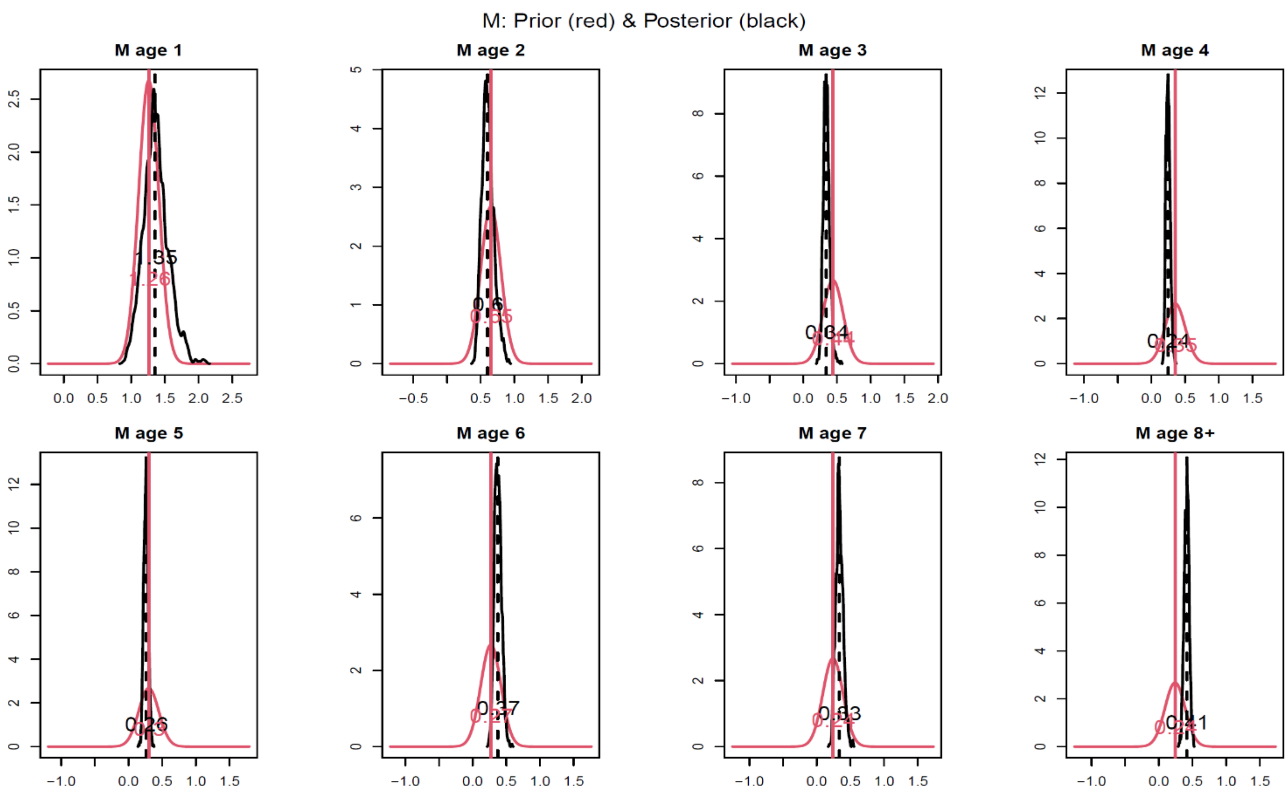


Figure 20. Estimated natural mortality by age in 2021.

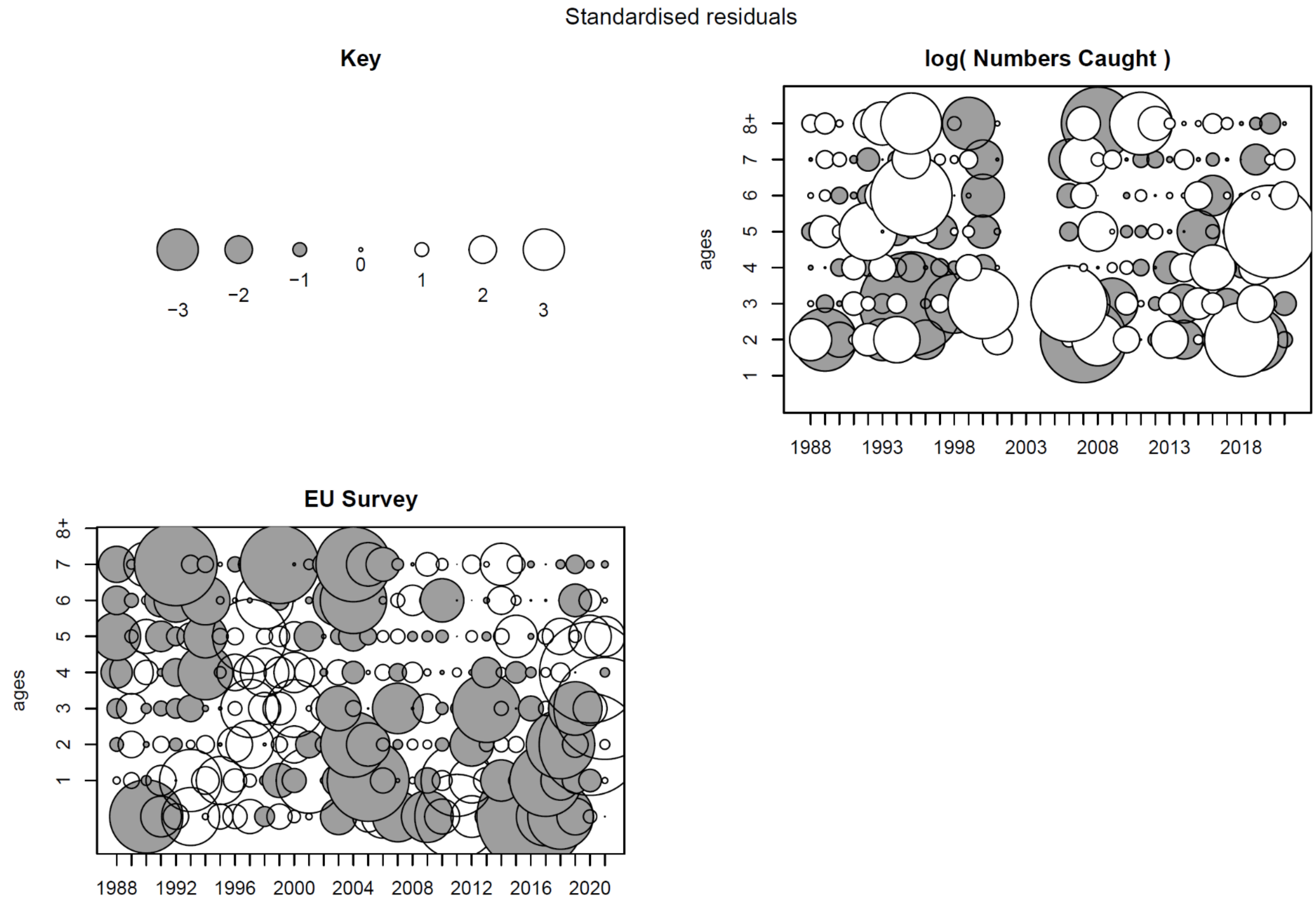


Figure 21. Standardised residuals (observed minus fitted value) in logarithmic scale of catch numbers at age and EU survey abundance indices at age. Grey and black values indicate values above and below the average. The larger the bubble size the larger the magnitude of the value.

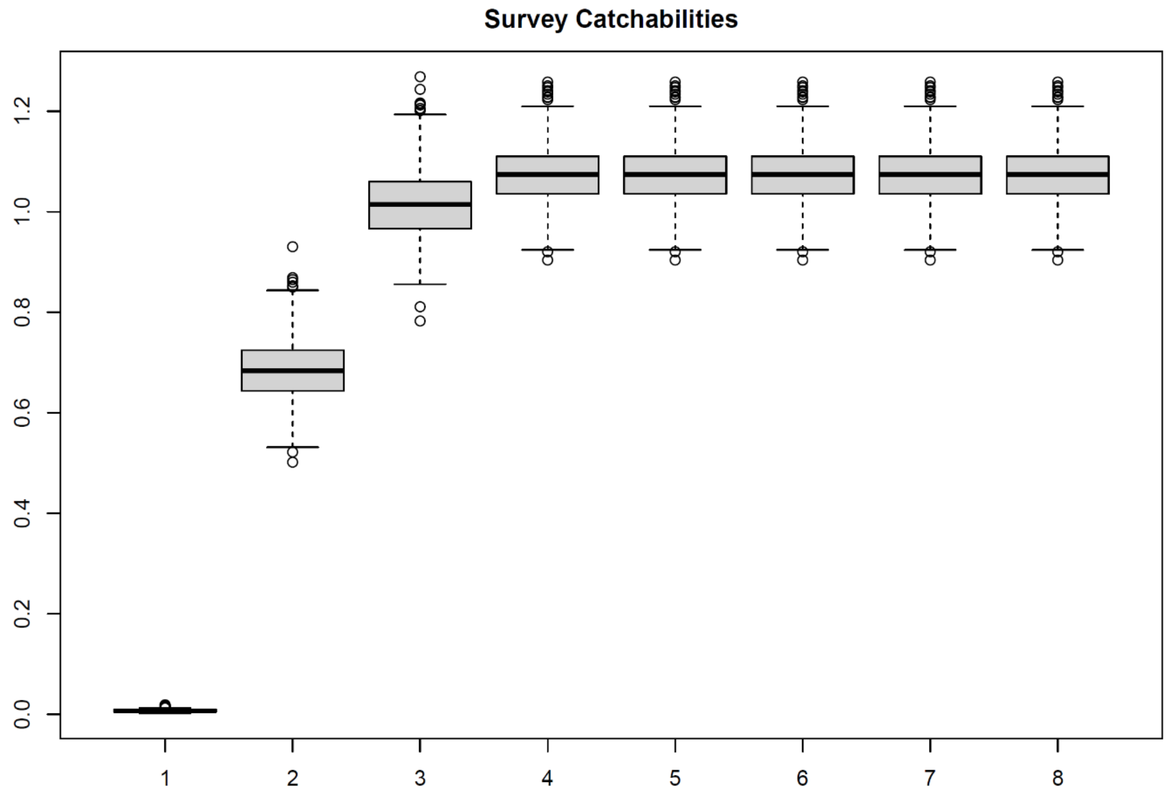


Figure 22. EU survey catchabilities distribution

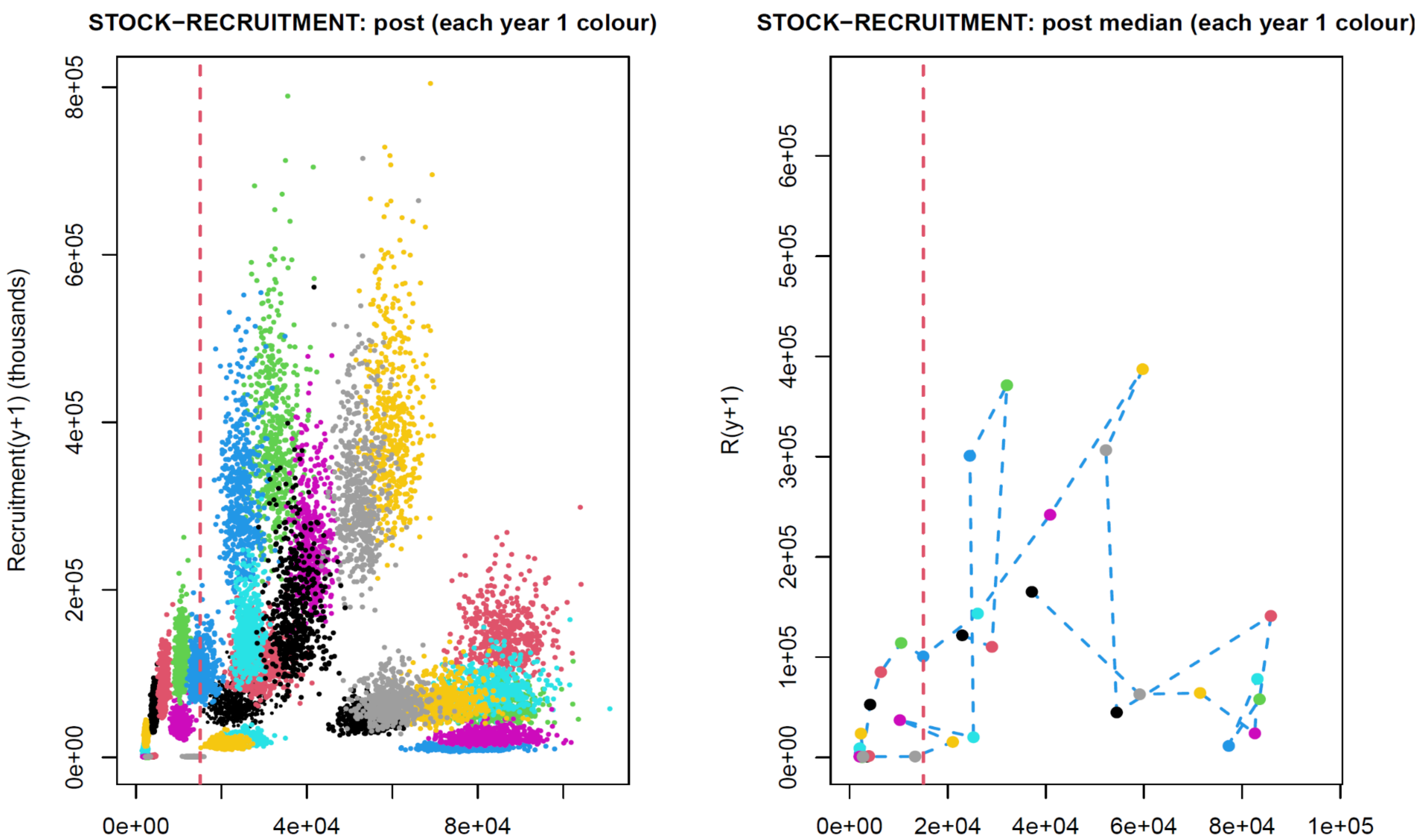


Figure 23. Stock-Recruitment plots. The value of median B_{lim}=medianSSB_{2007}=15 037 tons is shown as the red vertical line.

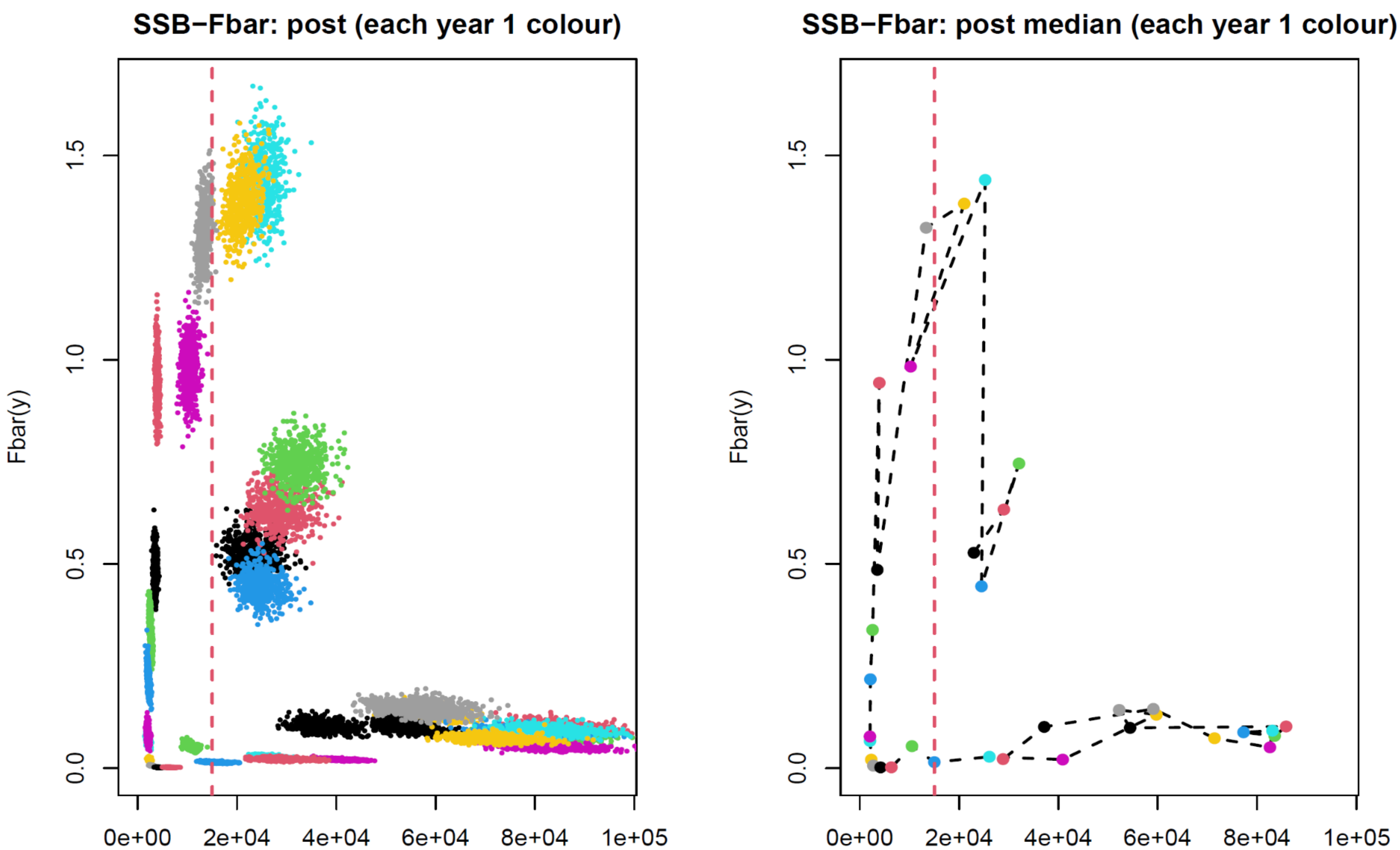


Figure 24. F_{bar} versus SSB plots. The value of median B_{lim}=medianSSB_{2007}=15 037 tons is shown as the red vertical line.

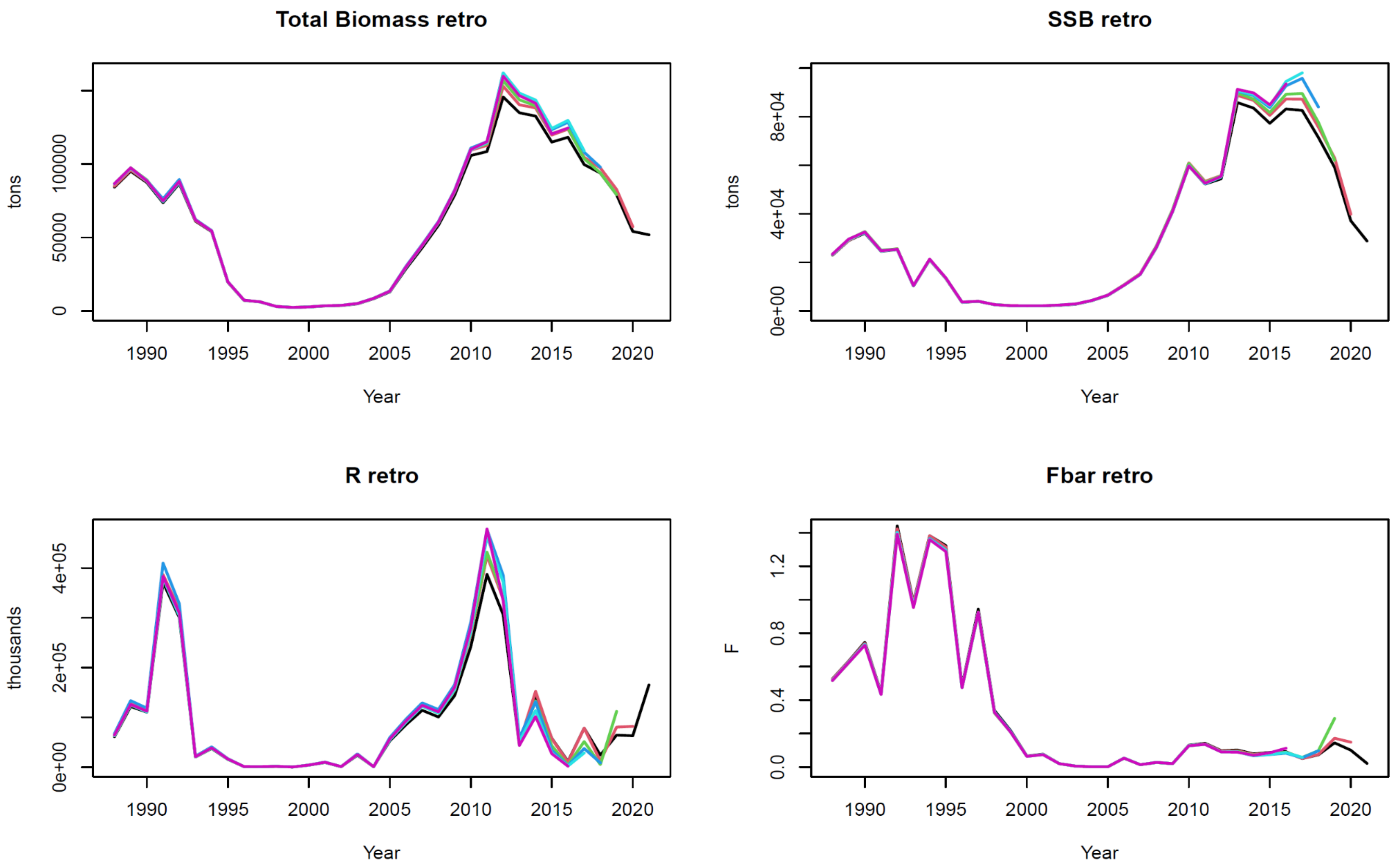


Figure 25. Retrospective patterns.

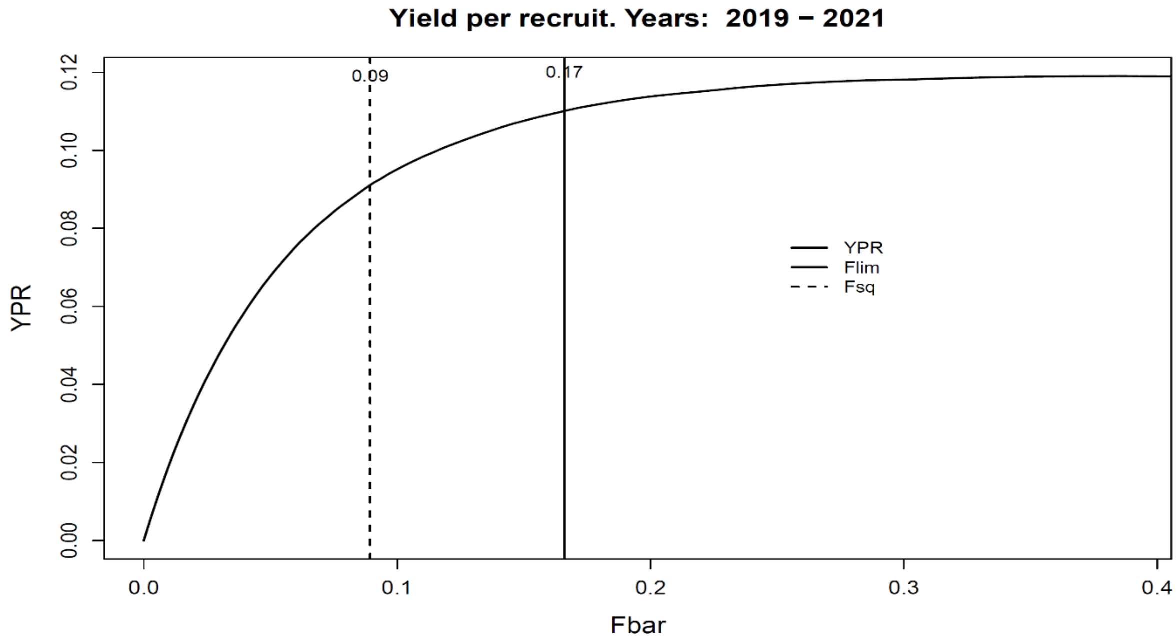


Figure 27. Yield per Recruit (2019-2021) versus F_{bar}. The values of F_{lim} ($F_{30\%SPR}$) and $F_{statusquo}$ (mean F over 2019-2021) are indicated.

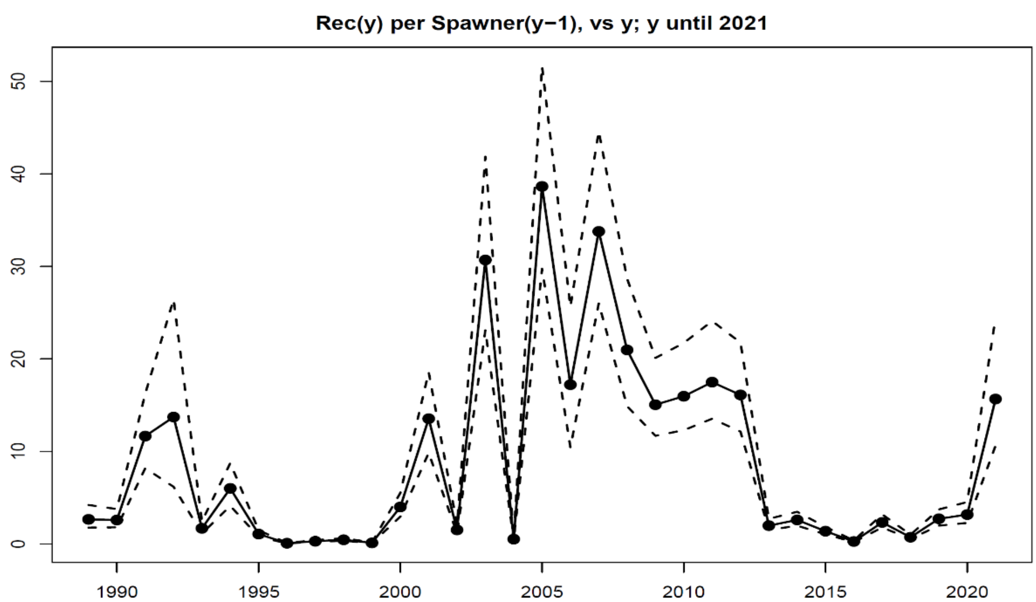


Figure 26. Estimated recruits (age 1) per spawner. First point: R_{1989}/SSB_{1988}.

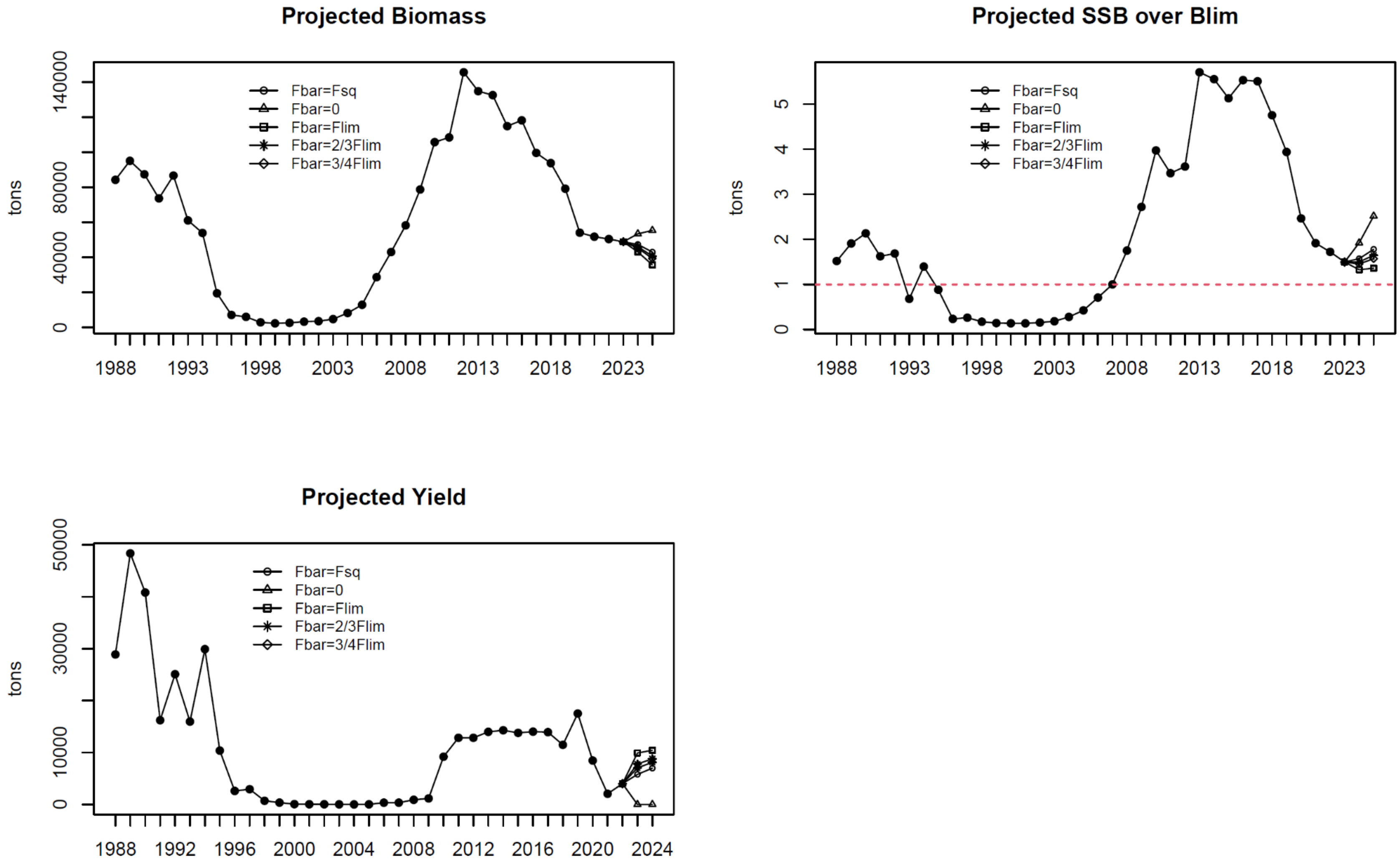


Figure 28. Projections for total Biomass, SSB/B_{lim} and Yield with different scenarios.

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. 2021) 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*

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

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

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

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

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

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

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

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

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

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

ANNEX II

Results of changing the CV of the M to 0.3:

M: *medM*[a]= c(1.26,0.65,0.44,0.35,0.30,0.27,0.24,0.24), *cvM* = 0.3.

F_{lim} (CV_M=0.15) = 0.166
F_{lim} (CV_M=0.30) = 0.182

B_{lim} (CV_M=0.15) = 15,037
B_{lim} (CV_M=0.30) = 15,852

Table II.1.- Posterior results: total biomass, SSB, recruitment (tons) and F_{bar} WITH CV_M = 0.30 (to compare with Table 7, WITH CV_M = 0.15).

	B quantiles			SSB quantiles			R quantiles			F_{bar} quantiles		
Year	**50%**	**10%**	**90%**	**50%**	**10%**	**90%**	**50%**	**10%**	**90%**	**50%**	**10%**	**90%**
1988	77643	73241	82243	22310	19095	26104	61487	43327	101395	0.539	0.497	0.586
1989	91138	86135	95893	28240	24008	32838	124328	87417	203054	0.646	0.6	0.697
1990	86648	82088	92068	32526	28614	36807	114998	80405	190327	0.756	0.701	0.811
1991	75512	68065	89622	25924	22760	29706	389785	276256	642884	0.453	0.411	0.494
1992	85725	77944	98451	26790	24120	29573	319506	228528	537806	1.476	1.389	1.576
1993	55487	51826	59914	10219	9172	11657	21330	15217	34968	1.002	0.93	1.076
1994	51327	48226	54992	20446	18210	23043	39475	28393	65710	1.421	1.34	1.502
1995	18555	17443	19957	12911	11986	13993	16410	11782	27317	1.346	1.269	1.432
1996	6739	6356	7175	3518	3238	3829	1007	720	1640	0.488	0.443	0.536
1997	6062	5698	6464	4012	3696	4360	874	609	1435	0.918	0.843	1
1998	3146	2889	3459	2766	2514	3036	1477	1016	2409	0.309	0.271	0.349
1999	2740	2440	3083	2506	2217	2836	222	152	362	0.206	0.177	0.241
2000	3022	2656	3479	2390	2085	2716	4159	2906	6815	0.066	0.056	0.078
2001	3504	3086	4113	2216	1957	2479	9631	6920	15995	0.079	0.062	0.099
2002	3550	3193	3945	2406	2127	2656	888	632	1474	0.02	0.017	0.024
2003	4929	4318	5899	2811	2526	3086	25549	17666	41300	0.006	0.005	0.007
2004	7845	7025	8771	4393	4006	4857	751	531	1248	0.002	0.002	0.002
2005	13296	11587	16318	6673	5954	7544	54159	38835	89664	0.002	0.002	0.002
2006	28191	24350	34344	11296	10264	12331	87043	61813	144319	0.053	0.045	0.061
2007	40813	36369	46450	15852	14222	18010	116109	83420	192289	0.014	0.012	0.016
2008	56567	51176	63158	27349	24994	29902	104000	73753	170618	0.026	0.023	0.029
2009	77798	71112	86902	42449	39173	46012	146412	105511	246306	0.019	0.017	0.022
2010	107593	98241	119905	64345	58950	69770	254039	181965	414743	0.123	0.109	0.137
2011	110779	101714	123304	57088	52271	62050	404371	288955	680835	0.133	0.119	0.151
2012	144188	129959	163380	59442	54194	64331	317455	224343	527612	0.091	0.081	0.105
2013	135387	125311	145935	90725	82825	98612	46181	33233	76207	0.094	0.083	0.106
2014	139477	128692	150794	90662	82311	98927	141414	101212	234867	0.073	0.064	0.082
2015	123271	113927	133245	85983	77967	94169	57964	41622	95538	0.082	0.072	0.093
2016	129592	119409	140483	93325	84104	102678	11663	8214	19168	0.085	0.074	0.098
2017	108533	99509	117839	91416	83161	99992	79652	56347	134006	0.047	0.041	0.055
2018	97622	89807	106114	75269	68376	83482	24411	17239	41341	0.068	0.059	0.079
2019	82360	75861	90890	63106	57540	69864	66741	45110	111071	0.137	0.12	0.154
2020	55643	50497	61843	39181	34874	44002	66512	44116	112291	0.096	0.083	0.111
2021	52719	46715	60094	29830	26238	33966	172726	109967	294828	0.021	0.018	0.024

Table II.2.- Posterior results: EU survey catchability and Natural Mortality (posterior medians) with CV_M = 0.15 and CV_M=0.30.

	50% q			M 50%		
Age	CV15	CV30	Age	Prior	CV15	CV30
1	0.007	0.007	1	1.26	1.35	1.59
2	0.684	0.796	2	0.65	0.60	0.50
3	1.015	1.067	3	0.44	0.34	0.23
4	1.074	1.006	4	0.35	0.24	0.15
5	1.074	1.006	5	0.30	0.26	0.18
6	1.074	1.006	6	0.27	0.37	0.53
7	1.074	1.006	7	0.24	0.33	0.38
8	1.074	1.006	8	0.24	0.41	0.43

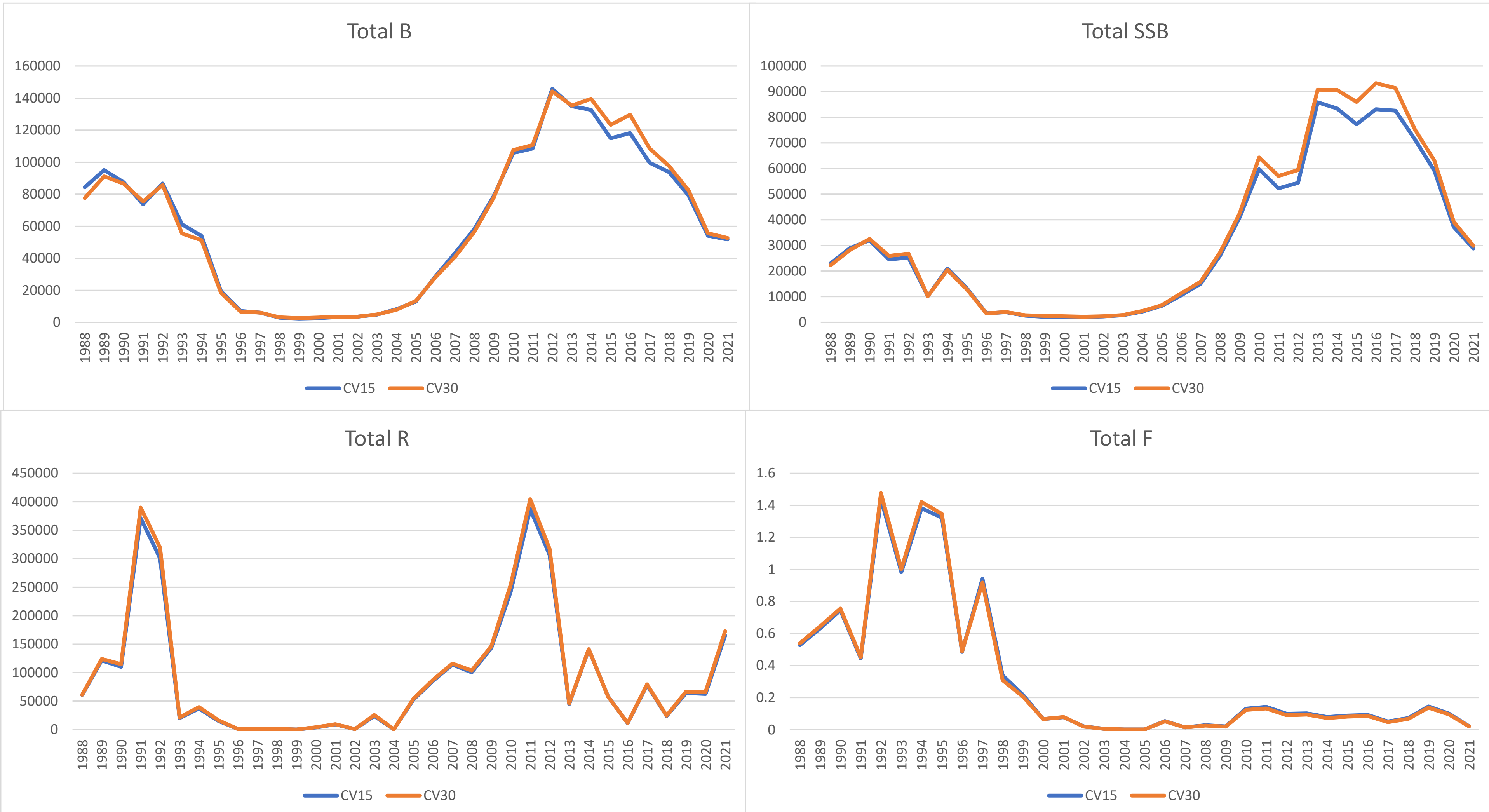


Figure II.1.- Results of the 3M cod assessment with CV of M equal to 0.15 and equal to 0.3.

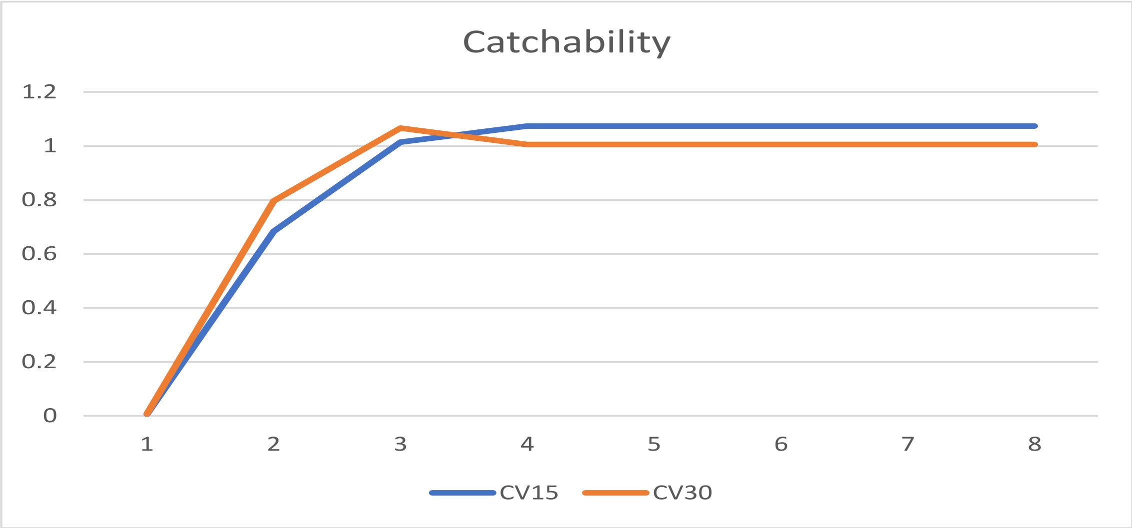


Figure II.2.- EU survey catchabilities from the 3M cod assessment with CV of M equal to 0.15 and equal to 0.3.

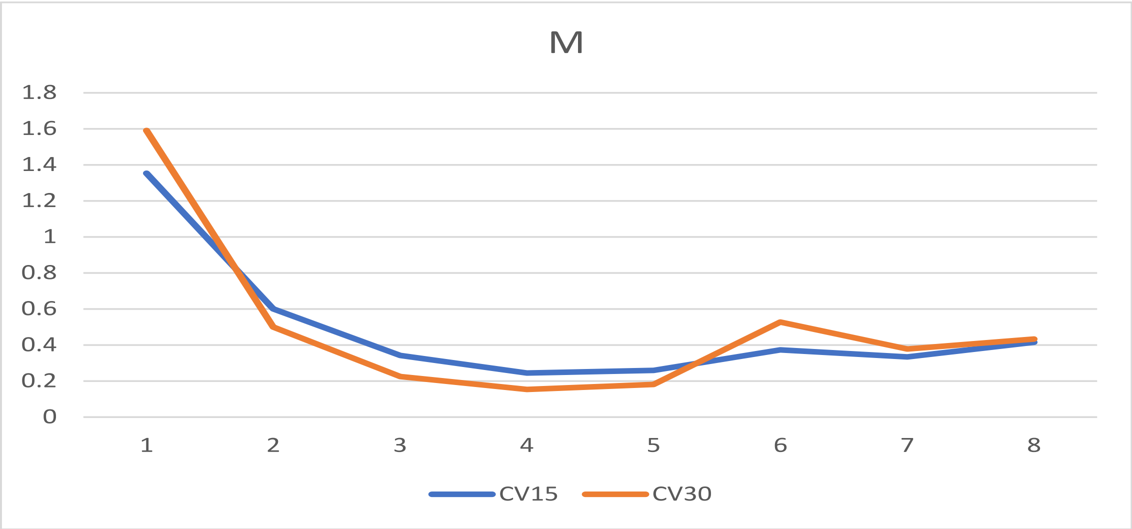


Figure II.3.- M from the 3M cod assessment with CV of M equal to 0.15 and equal to 0.3.

ANNEX III

Results of changing the range of ages to calculate F_{bar}:

Table III.1.- 3M cod F_{bar} taking different age ranges for the mean.

Year	Fbar 3-5	Fbar6+	Fbar3-7	Year	Fbar 3-5	Fbar6+	Fbar3-7
1988	0.525	0.736	0.601	2005	0.002	0.001	0.002
1989	0.633	0.831	0.707	2006	0.054	0.029	0.044
1990	0.743	1.101	0.898	2007	0.015	0.021	0.017
1991	0.444	0.633	0.512	2008	0.028	0.032	0.030
1992	1.440	1.784	1.541	2009	0.021	0.032	0.025
1993	0.980	1.075	1.062	2010	0.131	0.205	0.159
1994	1.378	1.095	1.287	2011	0.142	0.340	0.215
1995	1.323	2.215	1.689	2012	0.098	0.258	0.156
1996	0.485	0.848	0.636	2013	0.101	0.259	0.160
1997	0.945	1.887	1.335	2014	0.079	0.211	0.128
1998	0.336	0.453	0.392	2015	0.088	0.225	0.141
1999	0.217	0.133	0.193	2016	0.091	0.207	0.132
2000	0.066	0.018	0.048	2017	0.051	0.191	0.104
2001	0.077	0.022	0.057	2018	0.073	0.239	0.144
2002	0.021	0.007	0.015	2019	0.144	0.429	0.270
2003	0.006	0.002	0.005	2020	0.100	0.315	0.197
2004	0.002	0.001	0.002	2021	0.022	0.090	0.052

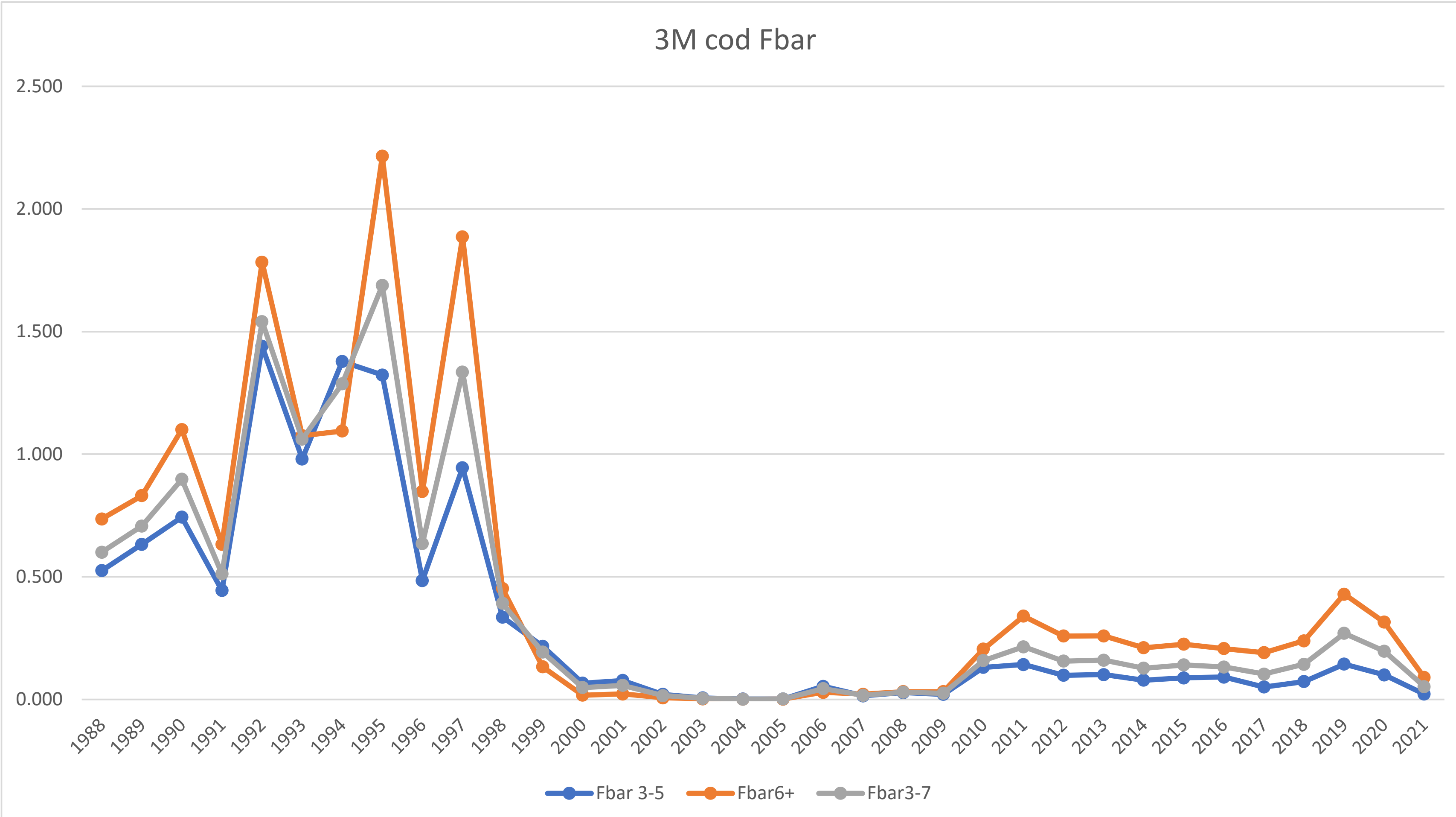


Figure III.1.- 3M cod F_{bar} taking different age ranges for the mean.