# Golden redfish
# *Sebastes norvegicus*

## STOCK DESCRIPTION AND MANAGEMENT UNITS

Golden redfish (*Sebastes norvegicus*) in ICES division 5.a (Iceland), 5.b (Faroe Islands) and Subarea 14 (East Greenland) have been considered as one management unit.

## SURVEYS

This section describes results from various surveys conducted annually on the continental shelves and slopes of ICES Subareas 5 and 14.

### DIVISION 5.A (ICELANDIC WATERS ECOREGION)

Information on abundance and biological parameters from golden redfish in 5.a is available from two surveys, the Icelandic groundfish survey in the spring (IS-SMB) and the Icelandic autumn survey (IS-SMH). The spring survey has been conducted annually in March since 1985 and the autumn survey has been conducted annually in October since 1996. The autumn survey was not conducted in 2011.

The total biomass of golden redfish as observed in the spring survey decreased from 1988 to a record low in 1995 (Figure 1). From 2000 to 2016 the biomass increased to the highest value in the time-series and has, since then, with some fluctuation, been at that level. The total biomass index from the autumn survey shows a similar trend as in the spring survey until 2019 but decreased sharply in 2020–2022 (Figure 1).

Length disaggregated indices from the spring survey shows that the peaks in length 4–11 cm, which can be seen first in 1987 (the 1985 cohort) and then in 1991–1992 (the 1990 cohort) (Figure 1), reached the fishable stock approximately 10 years later (Figure 2). The increase in the survey index between 1995 and 2005 is reflected in the recruitment of these two strong year classes. During the 1999–2008 period the abundance of small redfish was lower than in 1986–1990 and was highest in 2000–2003 (Figure 1). In 2009–2020, very little of small redfish (4-11 cm) was observed in the spring survey but in 2021–2023 the index has increased to a similar level as it was at the turn of the century (Figure 1).

The modes of the length distribution in both surveys have shifted to the right and are narrower. The abundance of golden redfish smaller than 30 cm has decreased since 2006 in both surveys and is now at the lowest level in the time-series (Figures 1–3).

The sharp increase in the survey indices since 2005 reflects the recruitment of the year-classes from 1996–2007 (Figure 4). The year classes 1996–2002 are gradually disappearing from the stock and the 2003–2008 cohorts are now the most abundant year classes in the stock. The age disaggregated abundance indices indicate that the 2009–2019 cohorts are small.

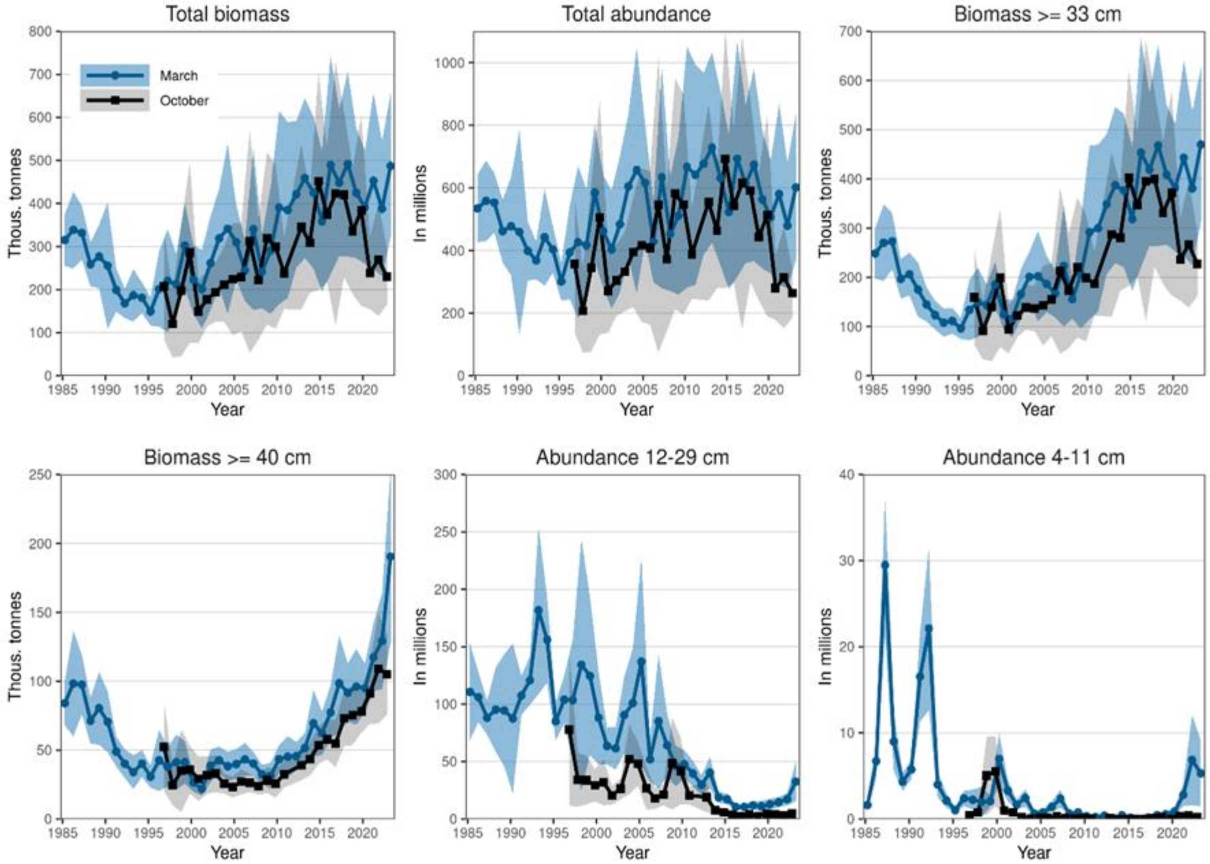


**Figure 1. Indices of golden redfish in ICES Division 5.a (Icelandic waters) from the groundfish surveys in March 1985–2023 (blue lines and shaded area) and October 1996–2022 (black lines and shaded areas). The shaded areas represent 95% CI.**

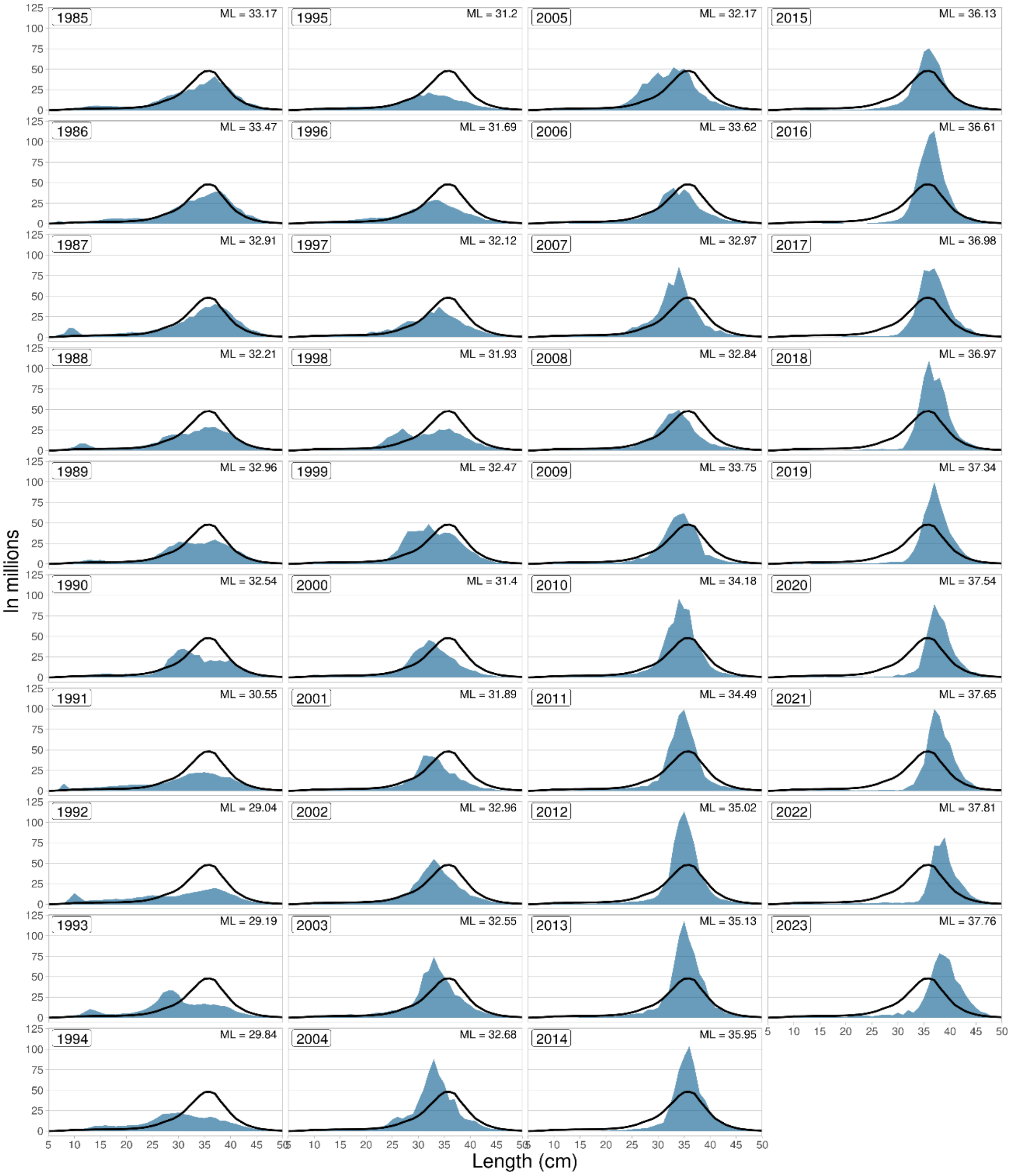


**Figure 2. Length disaggregated abundance indices (blue area) of golden redfish from the groundfish survey in March 1985–2023 conducted in Icelandic waters. The black line is the mean of total indices 1985–2023.**

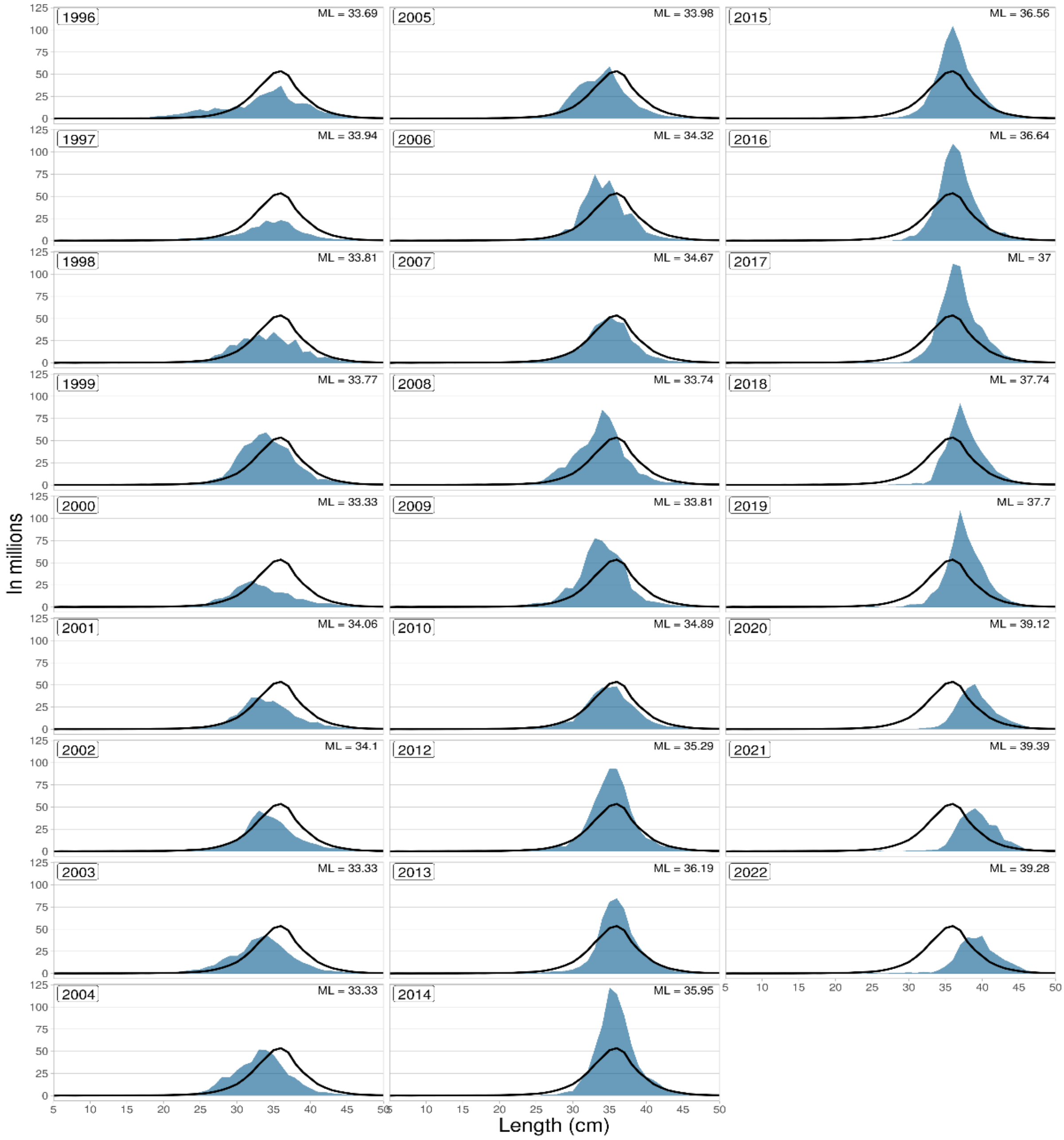


**Figure 3. Length disaggregated abundance indices (blue area) of golden redfish from the groundfish survey in October 1996–2022 conducted in Icelandic waters. The black line is the mean of total indices 1996–2022. The survey was not conducted in 2011.**

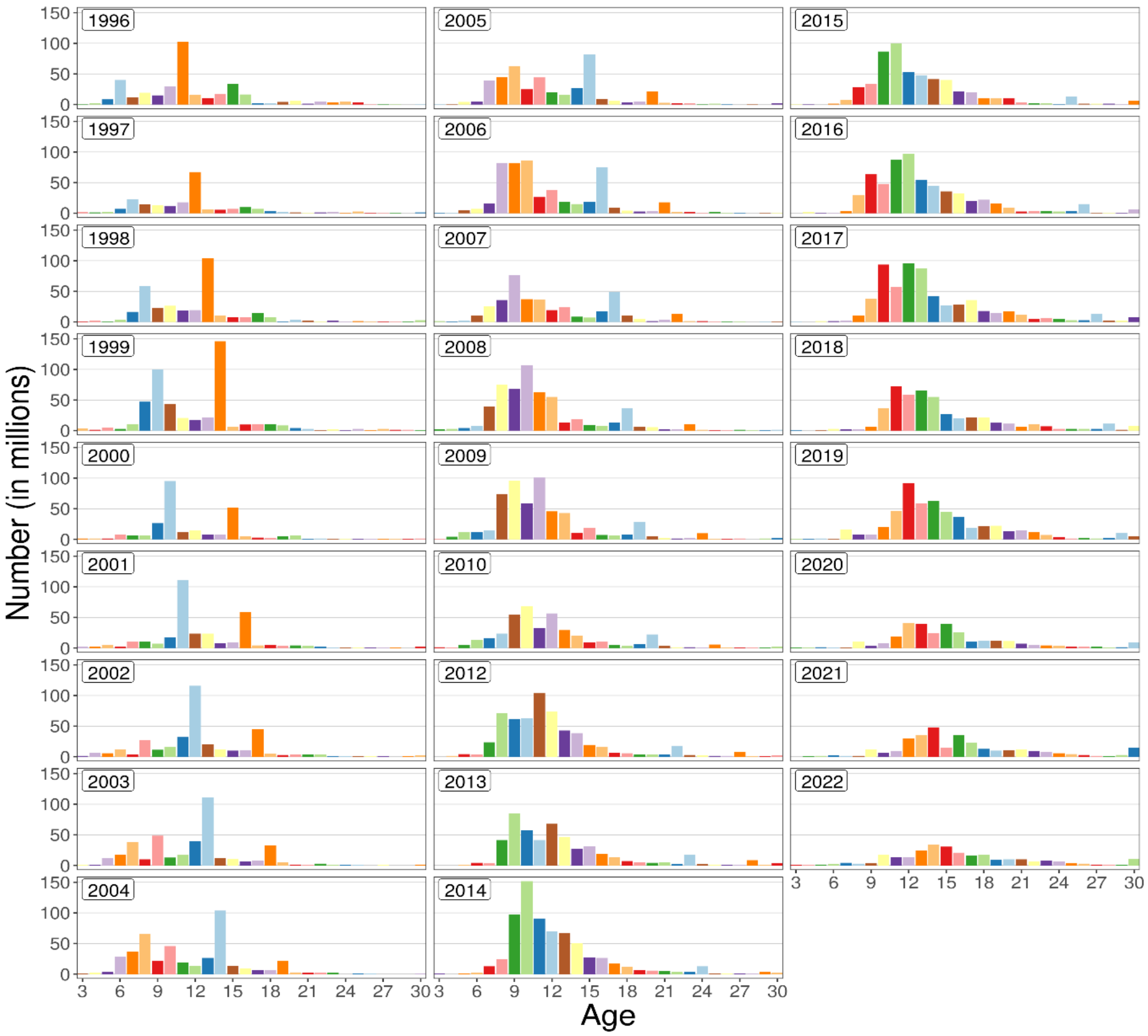


**Figure 4. Age disaggregated abundance indices of golden redfish in the groundfish survey in October conducted in Icelandic waters 1996–2022. The survey was not conducted in 2011.**

## DIVISION 5.B (FAROES ECOREGION)

In Division 5.b, the biomass indices of golden redfish are available from the Faroes spring groundfish survey 1994–2023 and the summer groundfish survey 1996–2022. Both survey indices show a declining trend between 1996 and 2000 and relatively low levels since then (Figure 5). The modes of the length distribution are between 40–45 cm and fish smaller the 35 cm is rarely seen (Figures 6 and 7). The fish caught in these surveys are on the average larger than the fish caught in the Icelandic surveys and the surveys conducted in East Greenland waters.

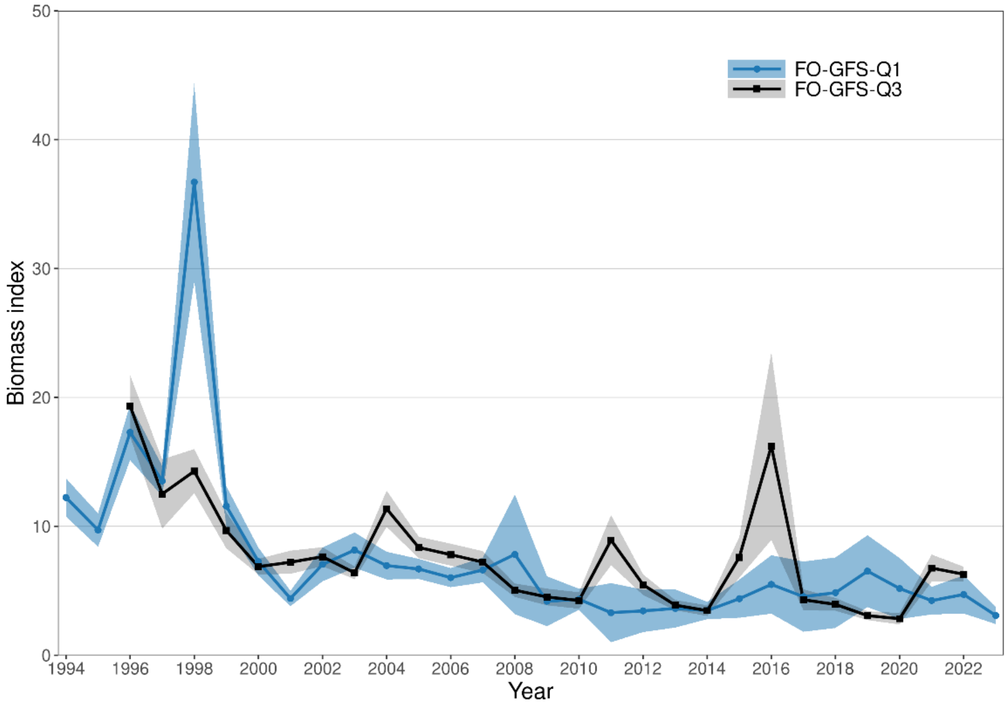


**Figure 5. Survey biomass index of golden redfish in the Faeroes spring groundfish survey 1994–2023 (blue line and shaded area) and the summer groundfish survey 1996–2022 (black line and shaded area) in ICES Division 5.b.**

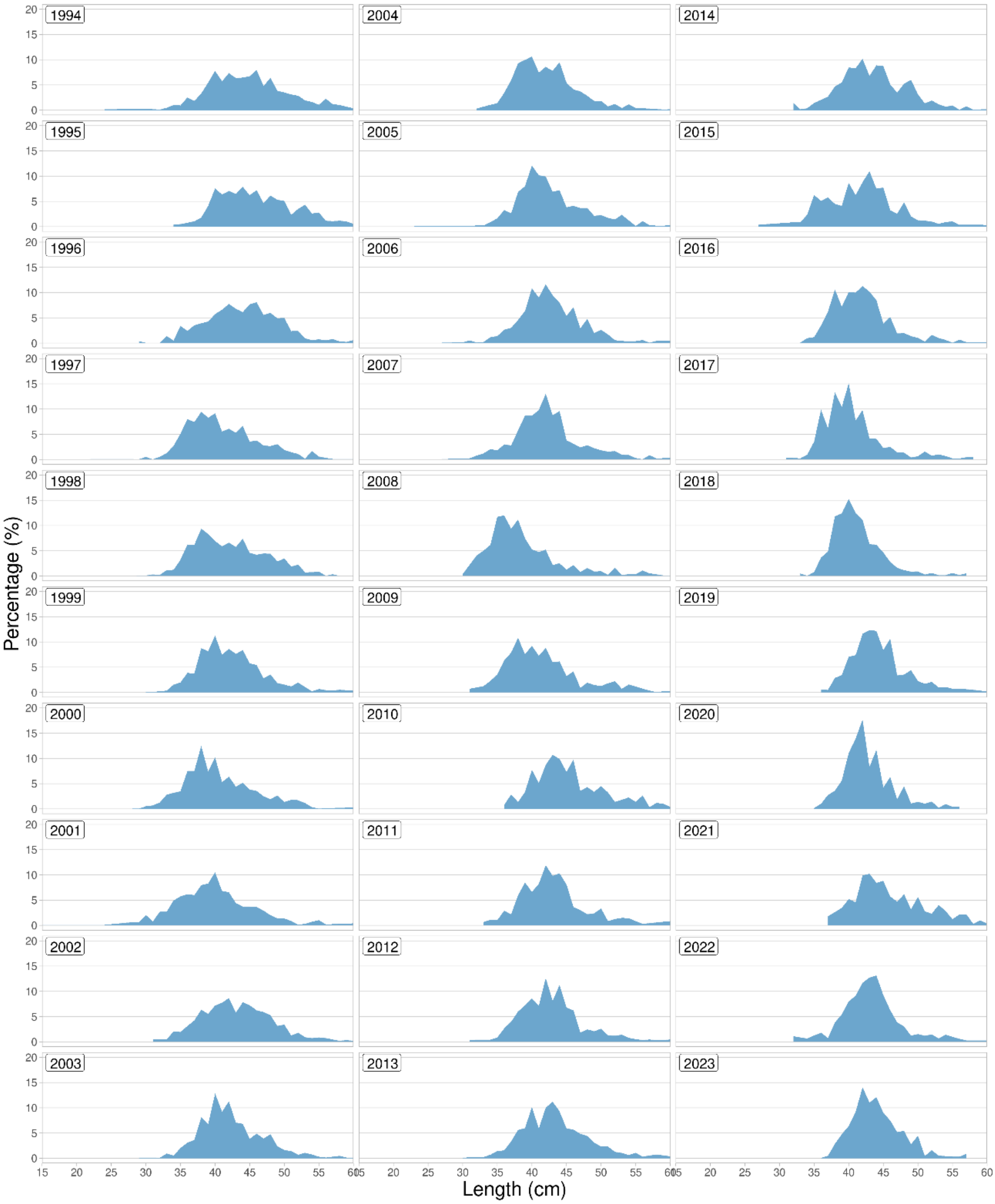


**Figure 6. Golden redfish. Length distribution in the Faroes spring groundfish survey 1994–2023.**

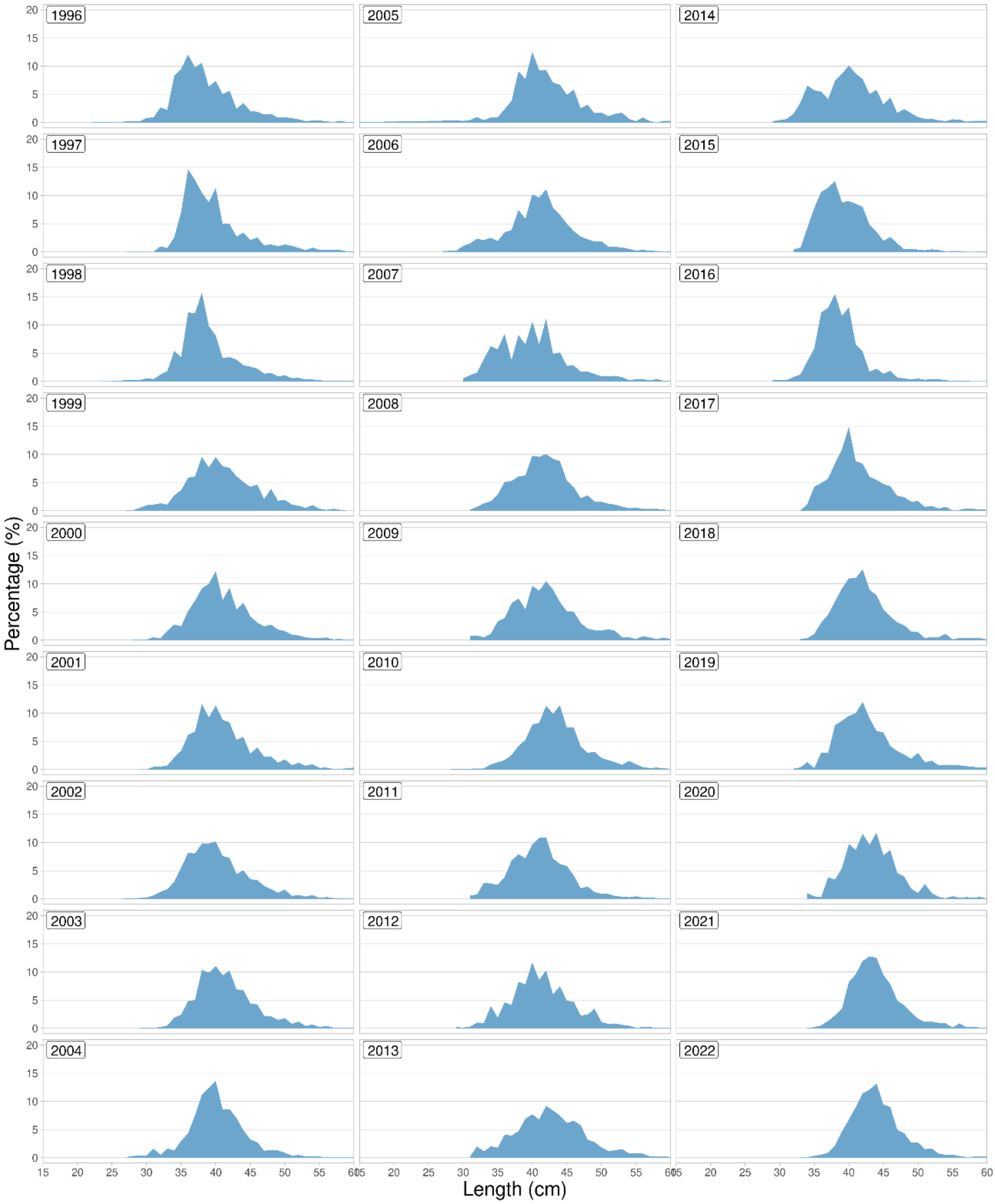


**Figure 7. Golden redfish. Length distribution in the Faroes summer groundfish survey 1996–2022.**

## SUBAREA 14 (GREENLAND SEA ECOREGION)

Information on abundance and biological parameters from golden redfish in Subarea 14 is available from two surveys, the German Groundfish Survey and the Greenland Shallow Water Survey. Only information from the German survey is used in the assessment.

The German Groundfish Survey has been conducted annually in the autumn from 1982 to 2017 and in 2019–2020 covering shelf areas and the continental slopes off East Greenland. The survey was not conducted in 2018, 2021 and 2022. Abundance and biomass indices for golden redfish (fish >17 cm) are illustrated in Figure 8. After a severe depletion of the stock in the early 1990s, the survey estimates significantly increased from 2003 to 2016, both in biomass and abundance. In the years 2014–2016 the biomass index was at the highest level in the time-series but dropped from 2017 to 2020 to a similar level as in 2006 (Figure 8). It should be noted that the CV for the indices is high, and the increase is driven by a few very large hauls. In 2010–2020, the biomass of pre-fishery recruits (17–30 cm) has decreased compared to previous five years and in 2017-2020 very little of 17–30 cm fish was observed (Figure 8).

The Greenland Shallow Water Survey 2008-2022 (the survey was not conducted in 2017–2019 and in 2021) covers the shelf area off East Greenland down to 600 m. Throughout the time series, index values have been highly variable (Figure 10). The indices increased from a very low level in the years 2008–2010 to the highest level in the 2011–2016 period. This increase was driven by the income of small fish (<30 cm) which can be followed until 2016 where the fish ranged from 25–40 cm with a mode around 30 cm (Figure 11). Both abundance and biomass indices decreased in 2020 to a similarly low levels as in the years 2008–2010 but increased slightly in the 2022 survey. This increase is driven by the income of small redfish <25 cm).

Abundance indices of redfish smaller than 18 cm (not classified to species) from the German annual groundfish survey show that juveniles were abundant in 1993 and 1995–1998 (Figure 12). The juvenile index was very low in the years 2008–2020. The Greenland Shallow Water Survey also shows low abundance of juvenile redfish (<18 cm, not classified to species) in 2013–2016 (Figure 12). Juveniles were more abundant in the Greenland survey in 2022 than they have been for more than a decade (Figure 12). Juvenile redfish in these two surveys were only classified to the genus *Sebastes* spp. as species identification of small specimens is difficult due to very similar morphological features. This increasing trend of juveniles in the Greenland Shallow Water Survey indicates potentially better recruitment of either *S. mentella* or *S. norvegicus* (or both) in the future.

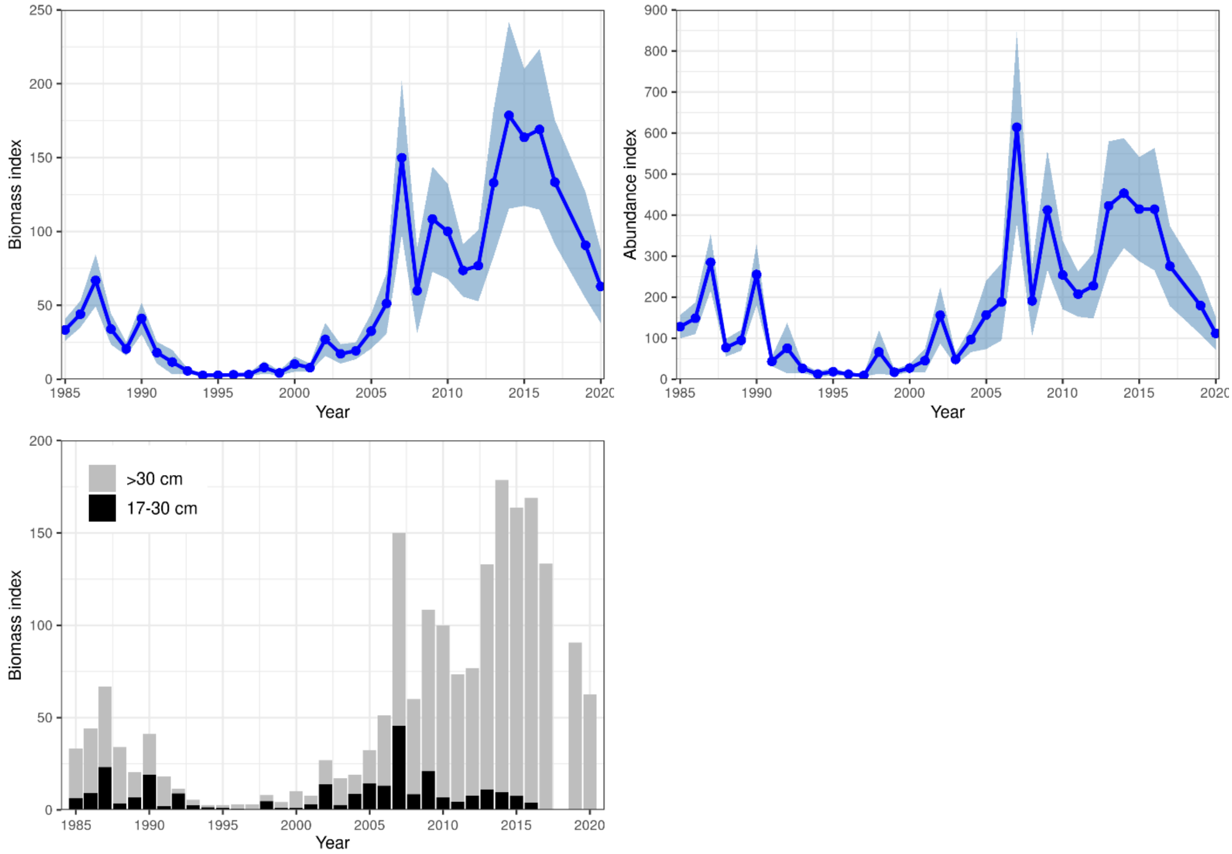


**Figure 8. Golden redfish (>17 cm). Survey indices for East Greenland (ICES Subarea 14) from the German groundfish survey 1985–2020. a) Total biomass index, b) total abundance index, c) biomass index divided by size classes (17–30 cm and >30 cm). The survey was not conducted in 2018 and 2021.**

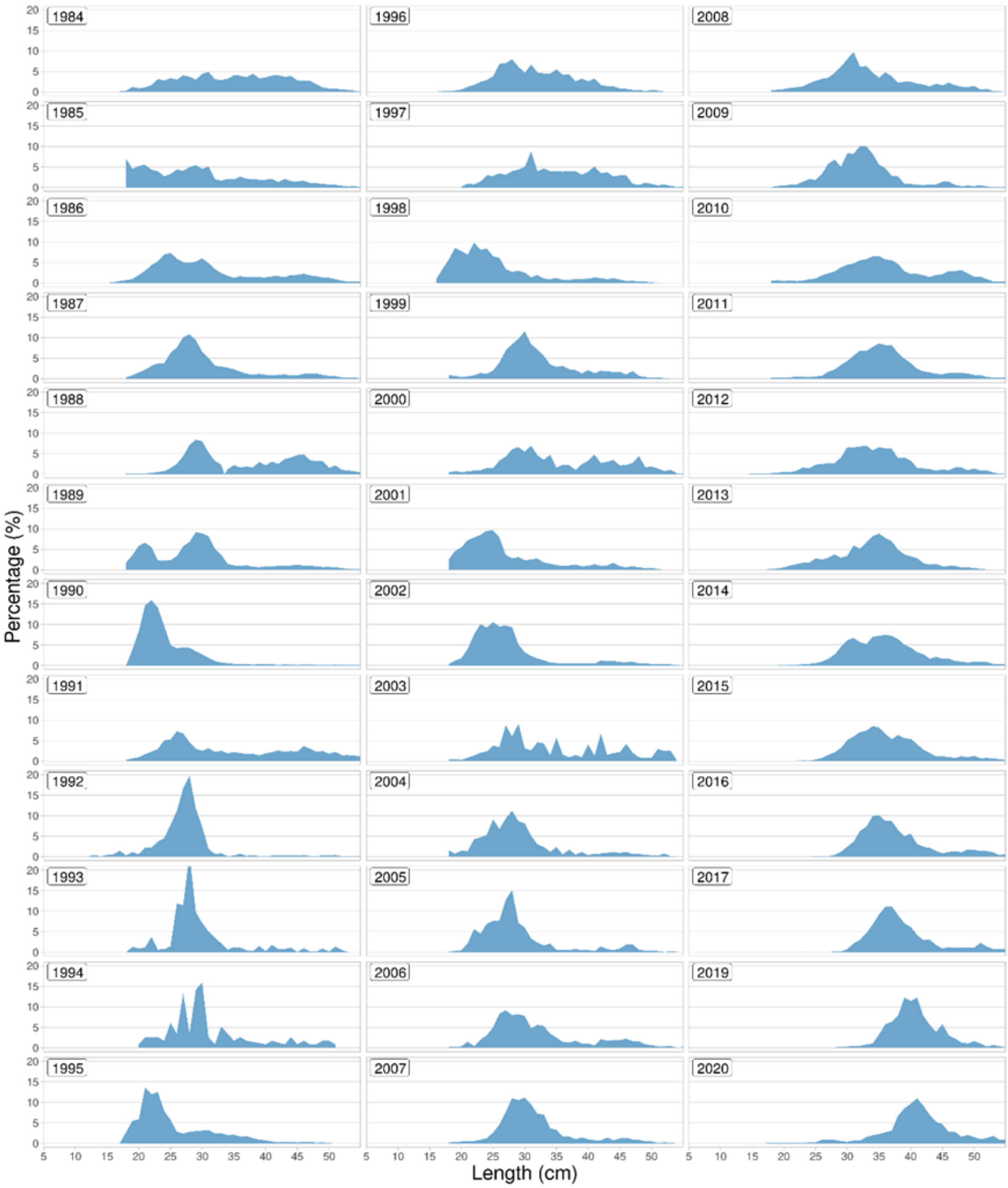


**Figure 9. Golden redfish (>17 cm). Length frequencies for East Greenland (ICES Subarea 14) 1982–2020. The survey was not conducted in 2018 and 2021–2022.**

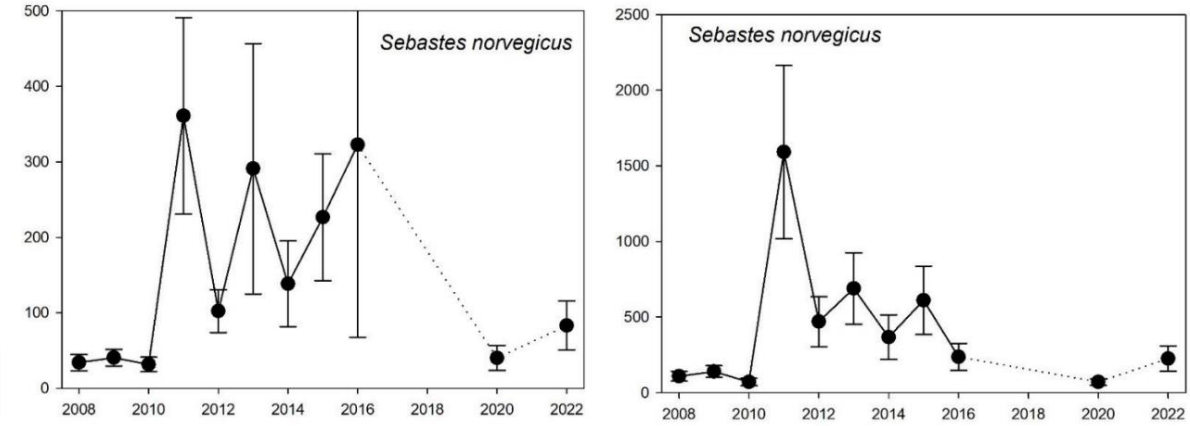


**Figure 10. Golden redfish. Survey biomass (left) and abundance (right) indices for East Greenland (ICES Subarea 14) from the Greenland Shallow Water Groundfish Survey 2008–2022. The survey was not conducted in 2017‒2019 and in 2021.**

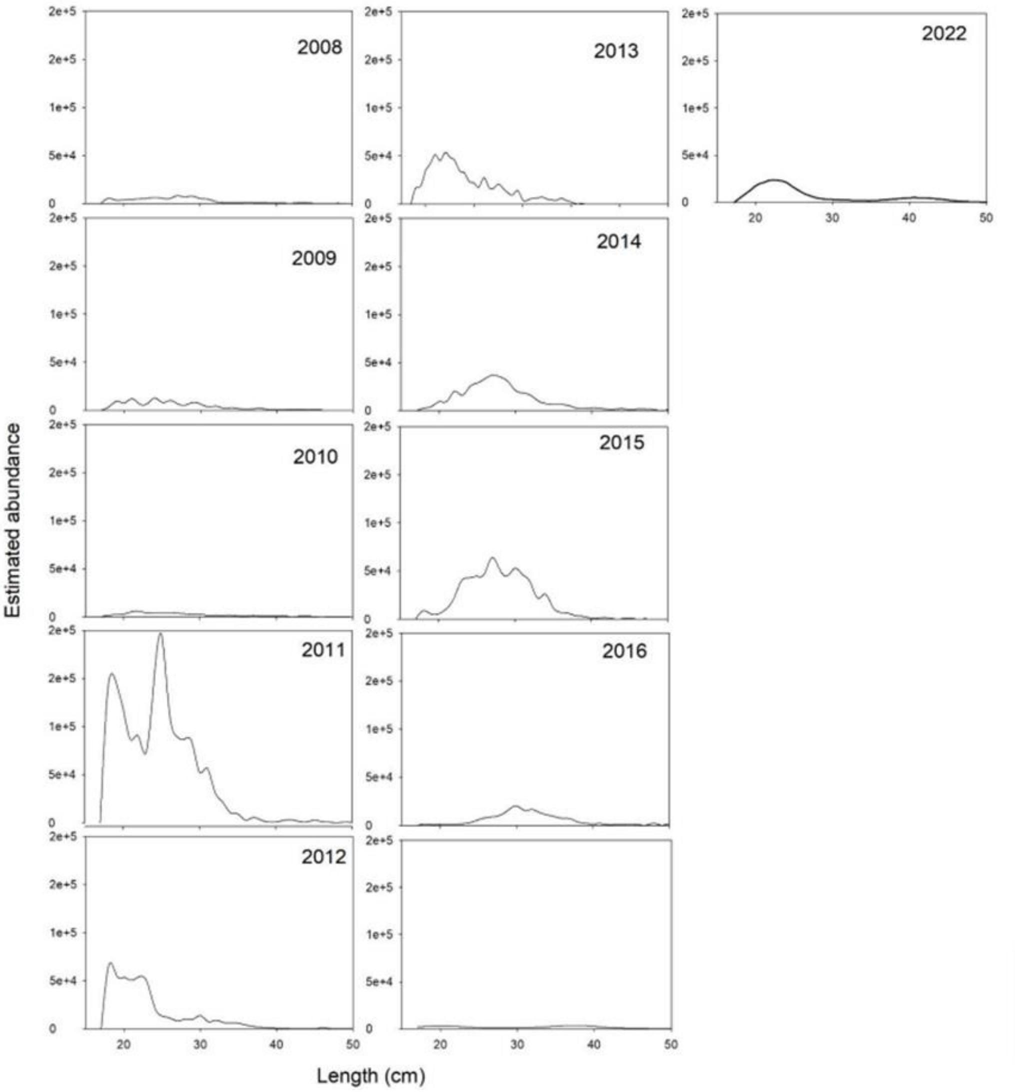


**Figure 11. Golden redfish. Length distributions from the Greenland Shallow Water Groundfish Survey 2008–2022 off East Greenland. The survey was not conducted in 2017‒2019 and in 2021.**

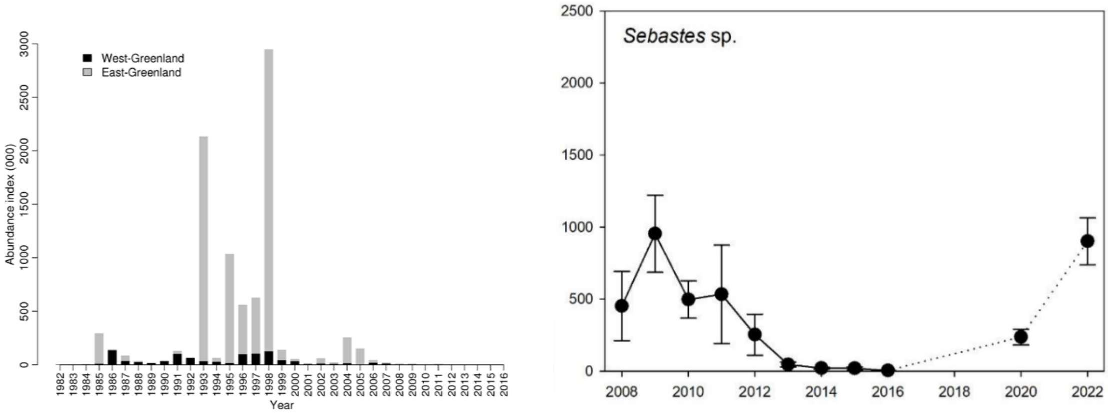


**Figure 12. Survey abundance index of small unidentified redfish species (*Sebastes* spp. <18 cm) in East Greenland (ICES Subarea 14) from the German Groundfish Survey 1982–2018 (left) and the Greenland Shallow Water Groundfish Survey 2008–2022 (left).**

# FISHERY

## LANDINGS

Total landings of golden redfish decreased gradually by more than 70% in 1982–1994 or from 130 429 t in 1982 to 43 515 t in 1994 (Figure 13). In the years 1995–2016, the annual landings varied between 33 451 t and 59 698 t, the highest in 2016. Since then, landings have decreased and in 2022 were 32 895 t, which is 10 531 t less than in 2021. This recent decrease in annual landings is directly related to decreased golden redfish TAC in East Greenland and Iceland. About 90–95% of the golden redfish catch has been taken in Icelandic Waters (ICES Division 5.a).

Landings of golden redfish in Icelandic waters declined from 97 899 t in 1982 to 38 669 t in 1994 (Figure 13). Since then, landings have varied between 31 686 t and 54 041 t, the highest in 2016. The annual landings since 2016 have decreased and were 30 037 t in 2022, 9579 t less than in 2021. The landings for the 2021/2022 fishing year were 16% higher than allocated quota of 28 554 t. The this can be related to the management system that allows for transfers of quota share between fishing years and conversion of TAC from one species to another.

Between 90–95% of the golden redfish catch in in Icelandic waters is taken by bottom trawlers targeting the species. The remaining catches are bycatch in the gillnet, long-line, and lobster fisheries. In 2022, as in previous years, most of the catches were taken along the shelf southwest, west, and northwest of Iceland (Figure 14). Higher proportion of the catches is now taken along the shelf northwest of Iceland and less south and southwest.

In Faroes waters, annual landings decreased from 9 194 t in 1985 to less than 200 t in 2016 (Figure 13). After an increase of landings in 2017-2020 landings to an annual average of 1250 t, the landings decreased substantially in 2021 and 2022 and were 178 t and 128 t respectively. Most of the golden redfish caught in Faroes waters are taken by pair and single trawlers (vessels larger than 1000 HP).

In East Greenland waters, the landings of golden redfish reached a record high of 30 962 t in 1982 but decreased rapidly to 2 117 t in 1985 (Figure 13). During the period 1985–1994, the annual landings varied between 687 and 4 255 t. There was little or no direct fishery for golden redfish in the years 1995–2009 and annual landings were 200 t or less, mainly taken as bycatch in the shrimp fishery. In 2010, landings of golden redfish increased considerably and were 1 650 t. This increase was mainly due to increased *S. mentella* fishery in the area. Annual landings in 2010–2022 have been between 1 000 t and 5 442 t. The landings in 2022 were 2 210 t, 1 322 t less than in 2021.

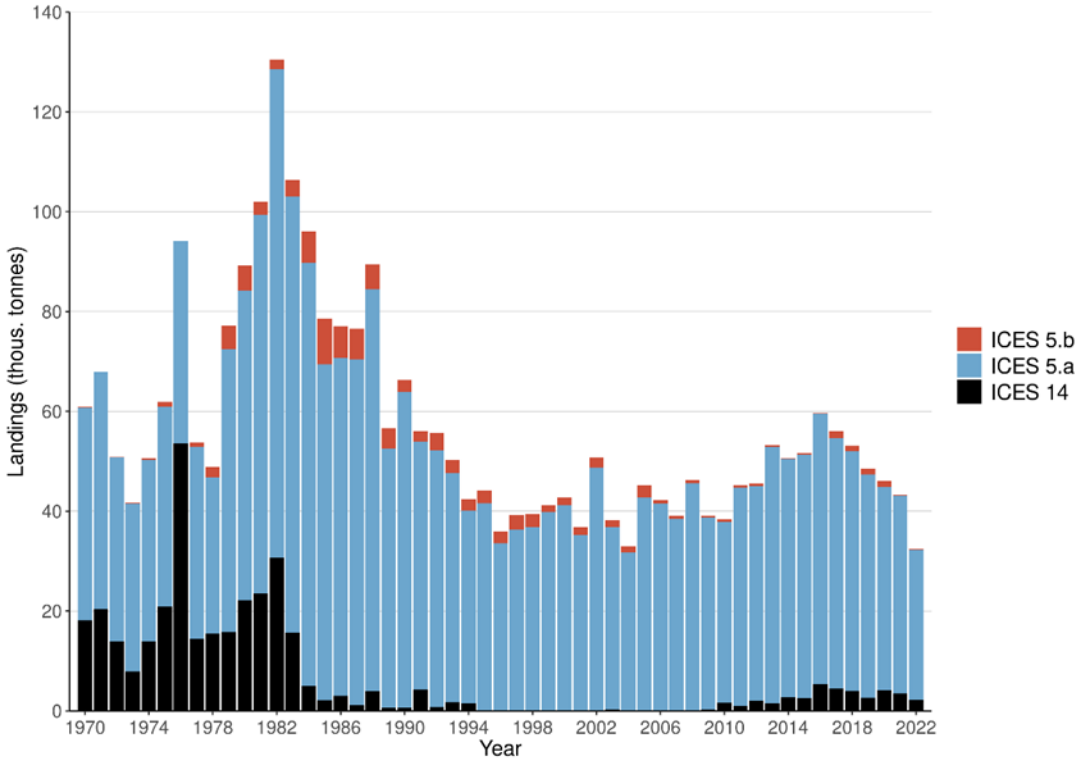


**Figure 13. Golden redfish. Nominal landings in tonnes by ICES Subareas and Divisions 1978–2022.**

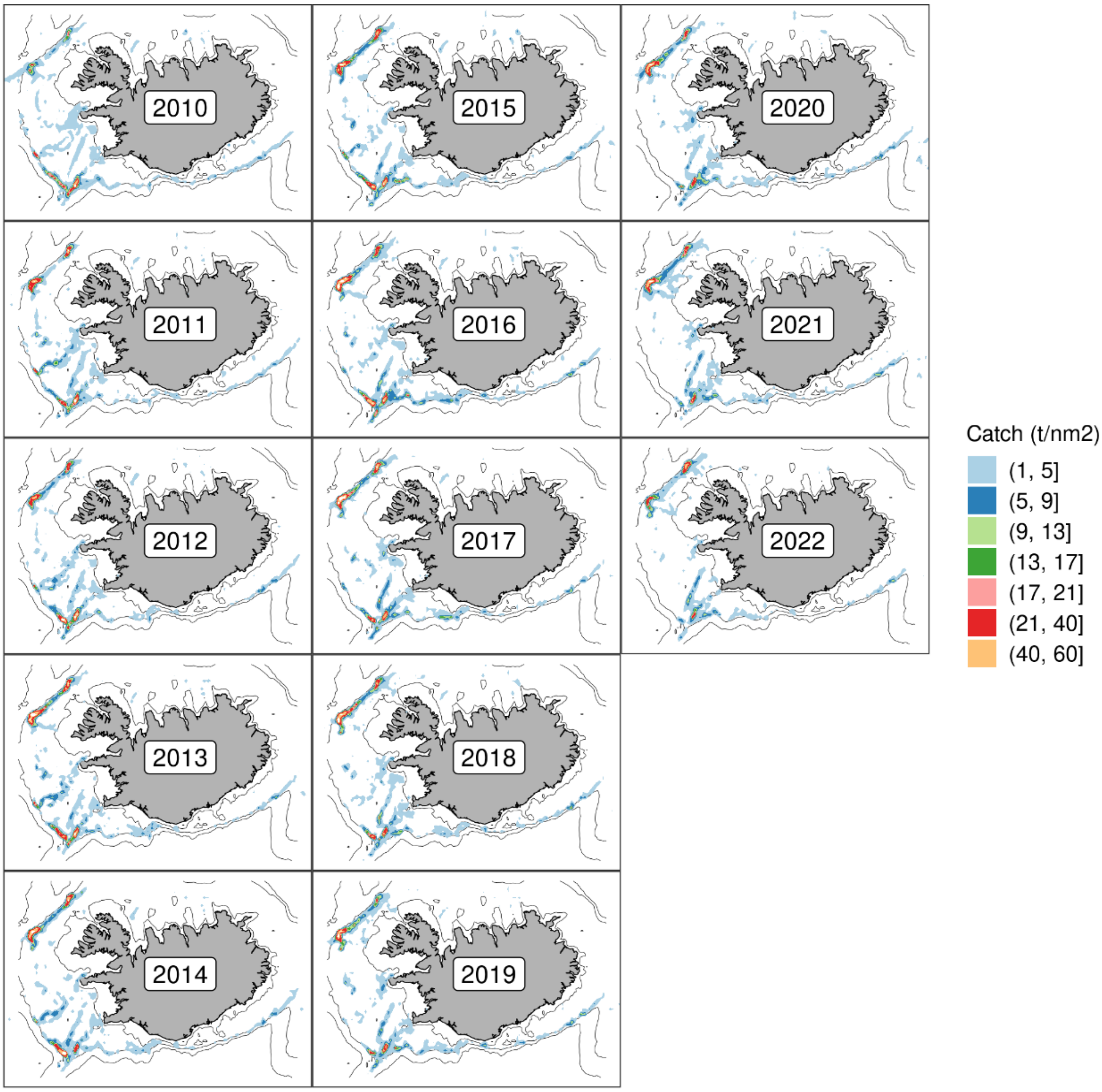


**Figure 14. Golden redfish. Geographical distribution of bottom trawl catches in ICES Division 5.a 2010–2022.**

## DISCARD

Comparison of sea and port samples from the Icelandic discard sampling program does not indicate significant discarding due to high grading (Pálsson et al. 2010). Substantial discard of small redfish took place in the deep-water shrimp fishery from 1986–1992, before sorting grids became mandatory. Since then, the discard has been insignificant both due to the sorting grid and much less abundance of small redfish in the region.

Discard of redfish species in the shrimp fishery in ICES Division 14.b is currently considered insignificant.

## BIOLOGICAL DATA FROM THE COMMERCIAL FISHERY

The table below shows sampling of golden redfish from the bottom trawl catches by ICES divisions in 2022.

| Area | Nation | Gear | Landings (t) | Samples | No. length measured | No. Age read |
|---|---|---|---|---|---|---|
| 5.a | Iceland | Bottom trawl | 30 037 | 59 | 8 688 | 674 |
| 5.b | Faroe Islands | Bottom trawl | 128 | | | |
| 14 | Greenland | Bottom trawl | 2 210 | | 1 506 | |

In general sampling is considered good from commercial catches in Icelandic waters. The sampling does seem to cover the spatial and seasonal distribution of catches (Figures 15 and 16). In 2020 sampling effort was reduced substantially, especially the on-board sampling, due to the COVID-19 pandemic. This reduction in sampling is, however, considered to be sufficiently representative of the fishing operations and thus not considered to substantially affect the assessment of the stock.

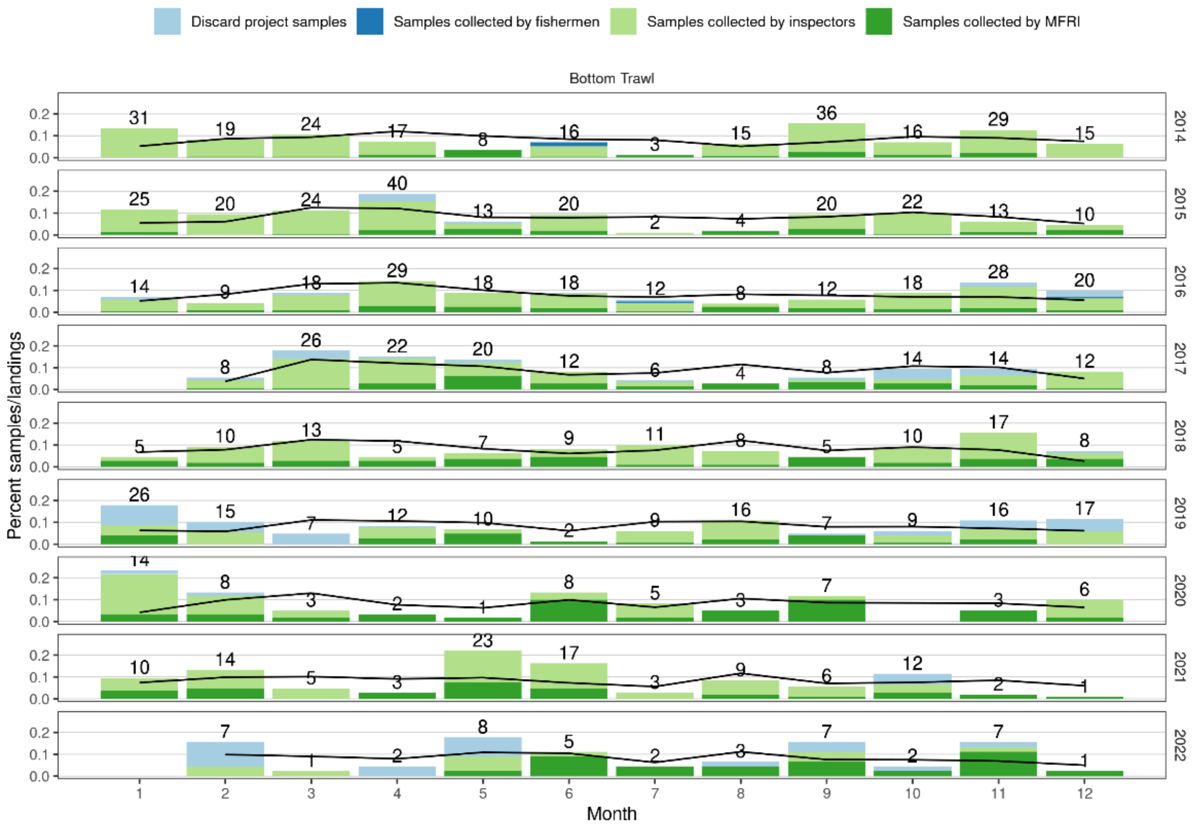


**Figure 15. Golden redfish. Ratio of samples by month (blue bars) compared with landings by month (solid black line) split by year in Icelandic waters. Numbers of above the bars indicate number of samples by year and month.**

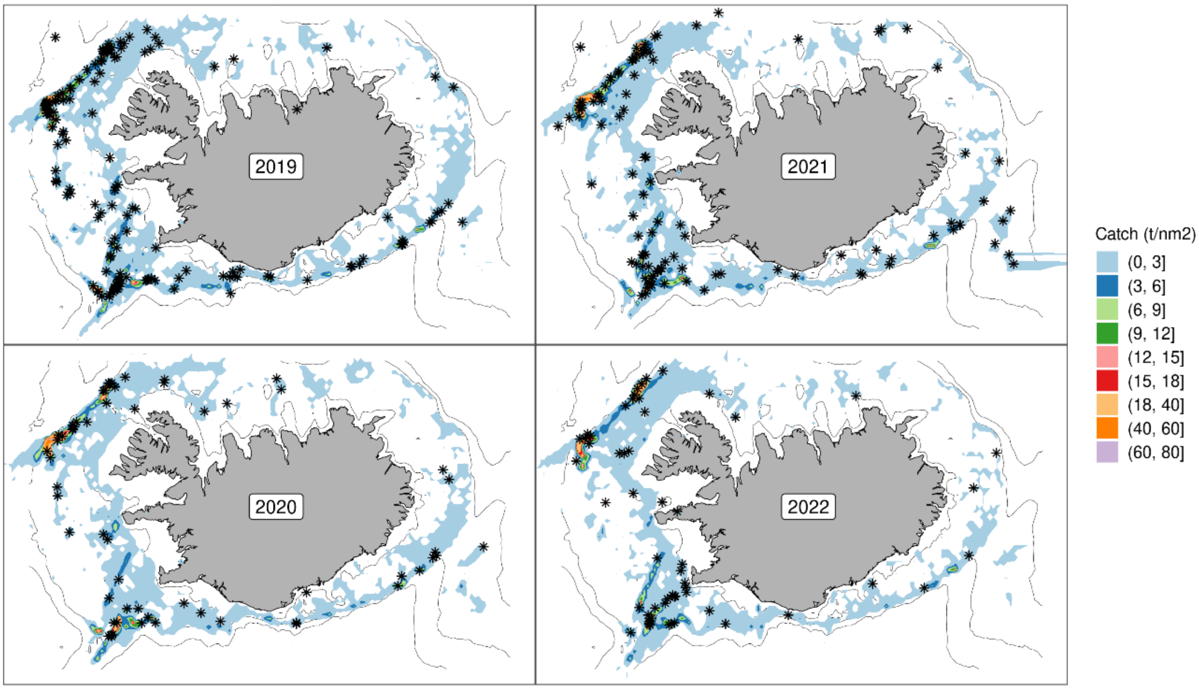


**Figure 16. Golden redfish. Fishing grounds in Icelandic waters in 2019–2022 as reported in logbooks (contours) and positions of samples taken from landings (asterisks) by year.**

## LANDINGS BY LENGTH AND AGE

Length distributions from the Icelandic commercial trawler fleet in 1976–2022 show that most of the fish caught are between 30 and 45 cm (Figure 17). The modes of the length distributions range between 35 and 40 cm and have over the past decade shifted to the right. The length distributions in 2012–2022 are narrower than previously, with less than average of small fish (<35 cm) caught, and the mean length has increased by almost 5 cm.

Catch-at-age data from the Icelandic fishery in Division 5.a show that the 1985-year class dominated the catches from 1995–2002 (Figure 18). The strong 1990 cohort dominated the catch in 2003–2007 contributing between 25–30% of the total catch in weight. In 2007–2010 the 1996–1999 cohorts dominated in the catches but are now gradually decreasing. The 2004–2009 cohorts (ages 13–18) were the most dominant year classes in the fishery in 2022. There is a substantial decrease of 7–10-year-old fish in the catch, compared to recent previous years, an additional indicator of low recruitment in recent year observed in all surveys conducted in East Greenland and Icelandic waters.

Length distribution from the German commercial fleet in East Greenland indicates similar trend as observed in Icelandic waters (Figure 19).

Length distribution from the Faroese commercial catches 2001–2020 shows that the fish are on average larger than 40 cm with modes between 45 cm and 50 cm (Figure 20).

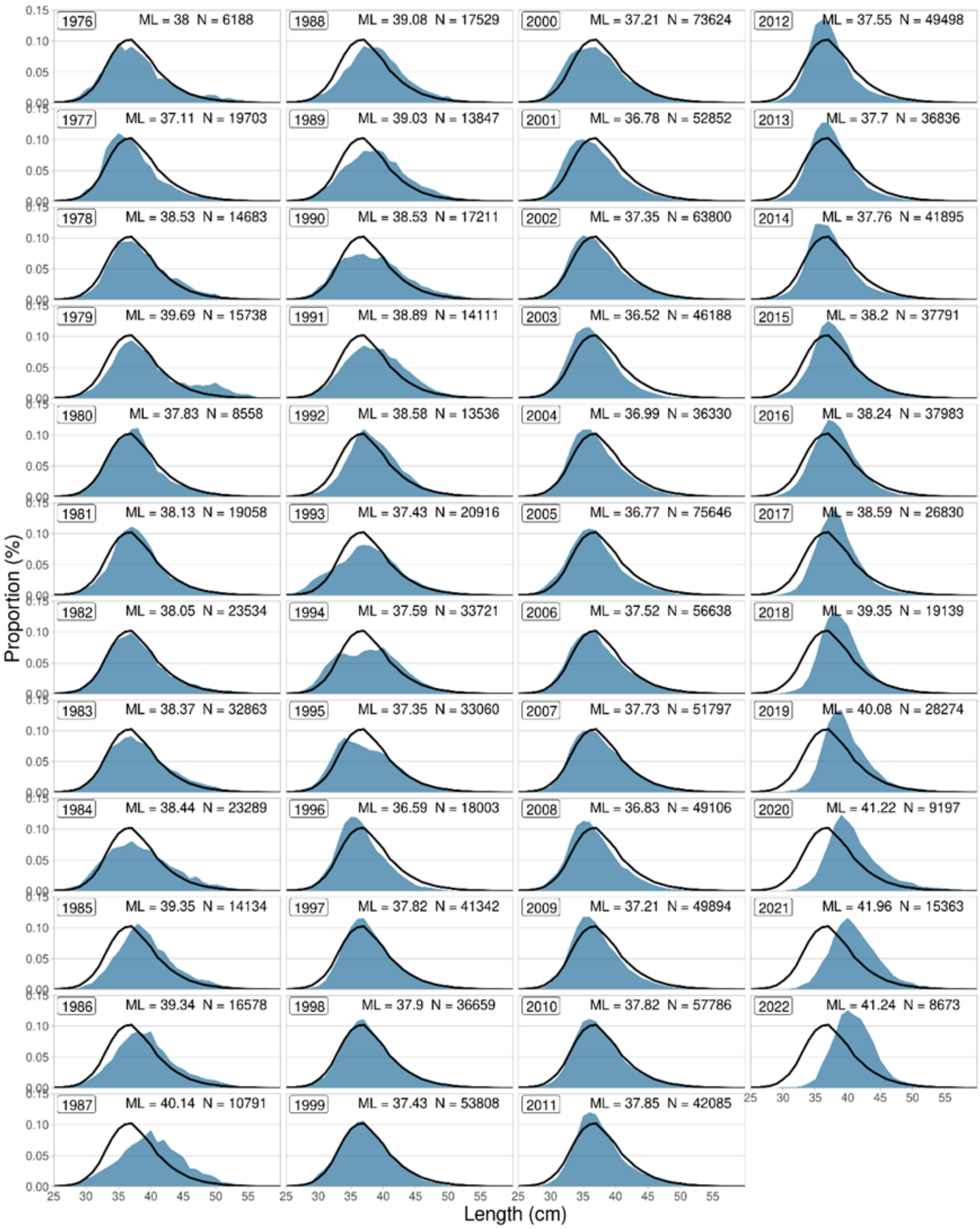


**Figure 17. Golden redfish. Length distribution (blue shaded area) in Icelandic waters (ICES Division 5.a) in the commercial landings of the Icelandic bottom trawl fleet 1976–2022. The black line is the mean of the years 1976–2022.**


**Figure 18. Golden redfish. Catch-at-age in numbers in ICES Division 5.a 1995–2022. Bar size is indicative of the catch in numbers and bars are colored by cohort.**

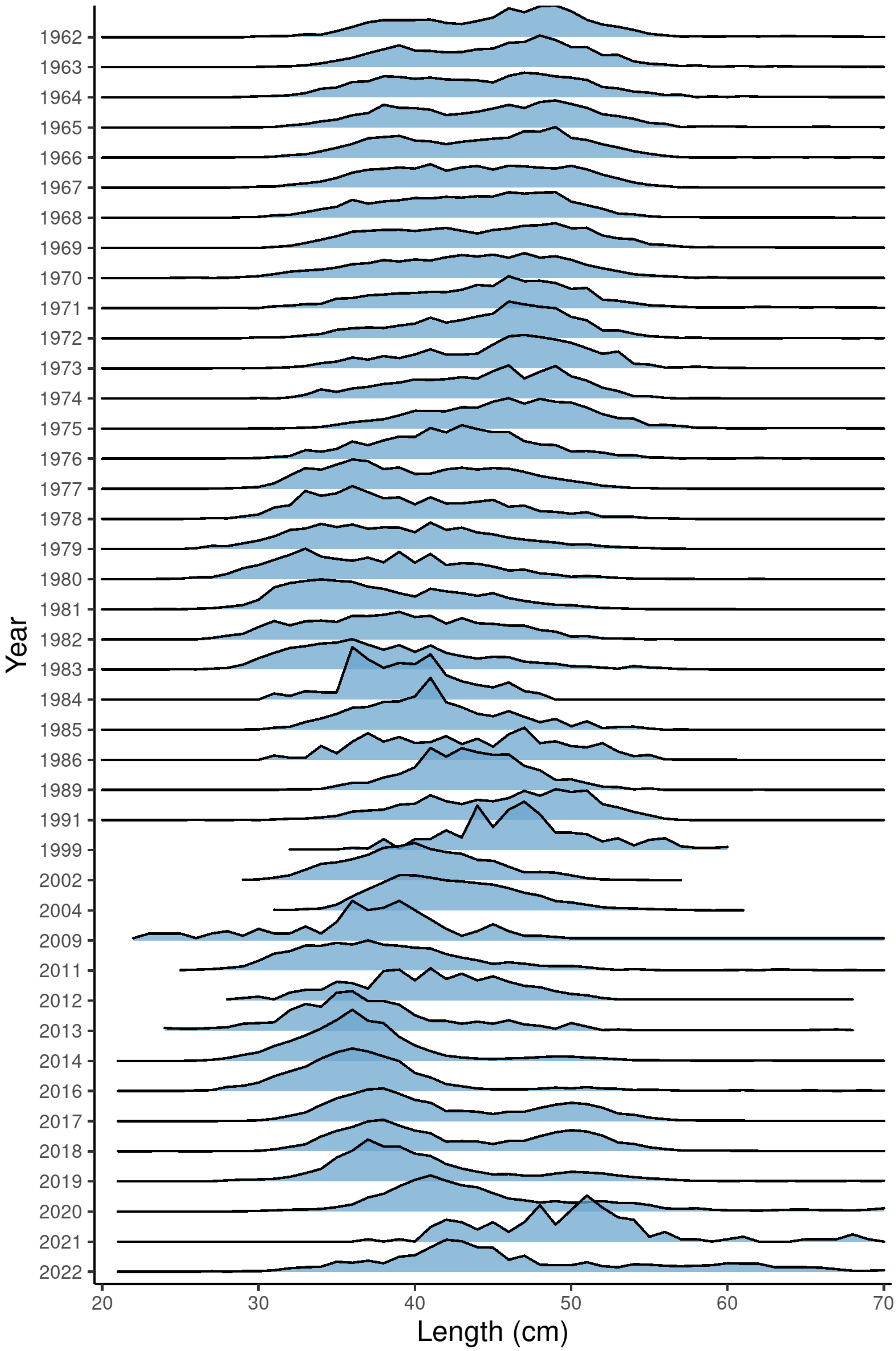


**Figure 19. Golden redfish. Length distribution from German catches in ICES Division 14.b (East Greenland) in 1962–2022.**

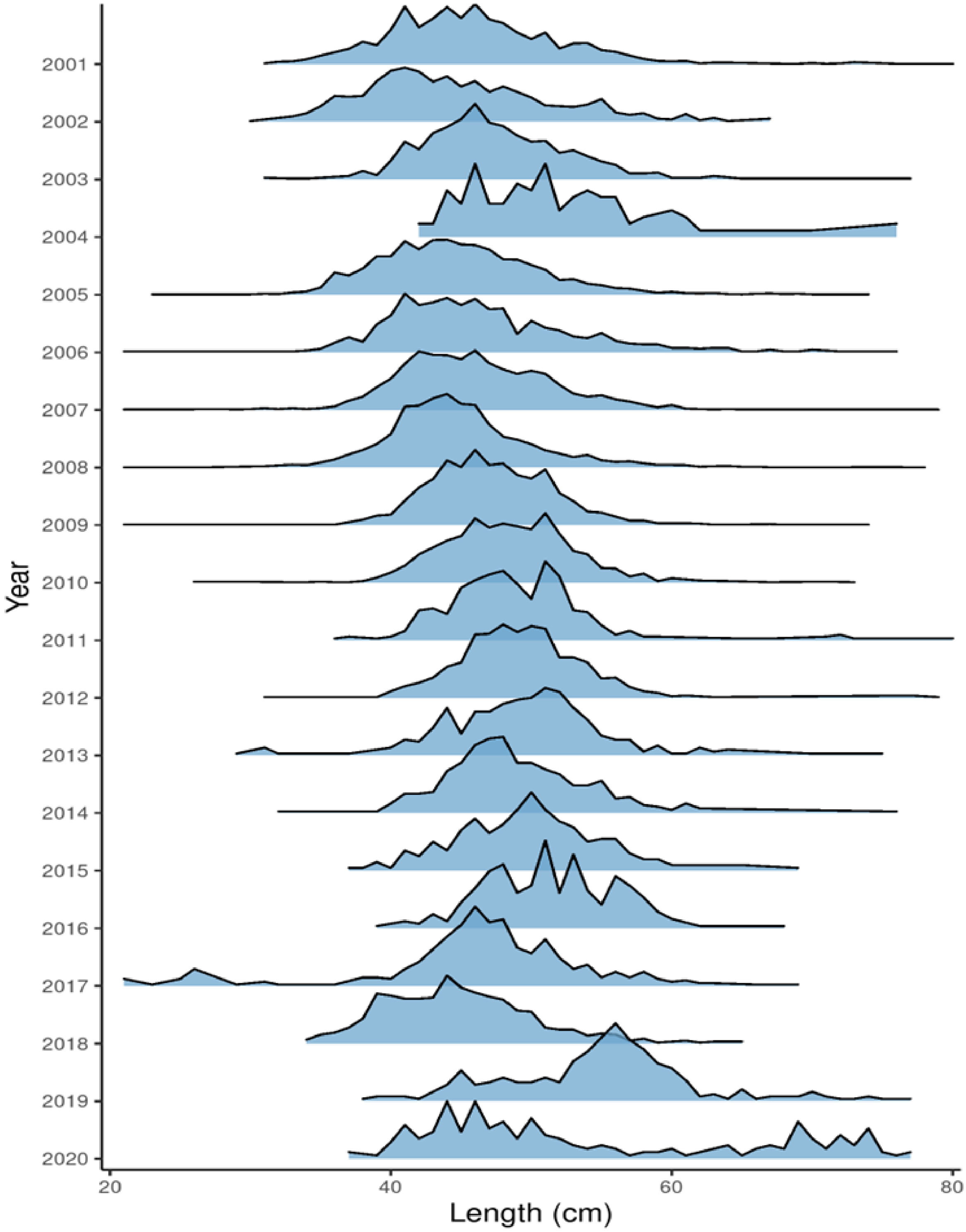


**Figure 20. Golden redfish. Length distribution from Faroese catches in ICES Division 5.b in 2001-2020.**

## CATCH PER UNIT EFFORT

The unstandardized CPUE index from the Icelandic bottom trawl fleet operating in Division 5.a has increased sharply from 2006 to the highest level in the time series in 2017-2019 (Figure 21). CPUE has since then decreased although it remains high. Data was not available for 2022.

Effort towards golden redfish has since 1986 gradually decreased and is at the lowest level recorded (Figure 21). CPUE derived from logbooks is not considered indicative of stock trends, however the information contained in the logbooks on effort, spatial and temporal distribution of the fishery is of value.

CPUE from other areas are not available. This is because no separation of *S. norvegicus* / *S. mentella* is made in the catches.

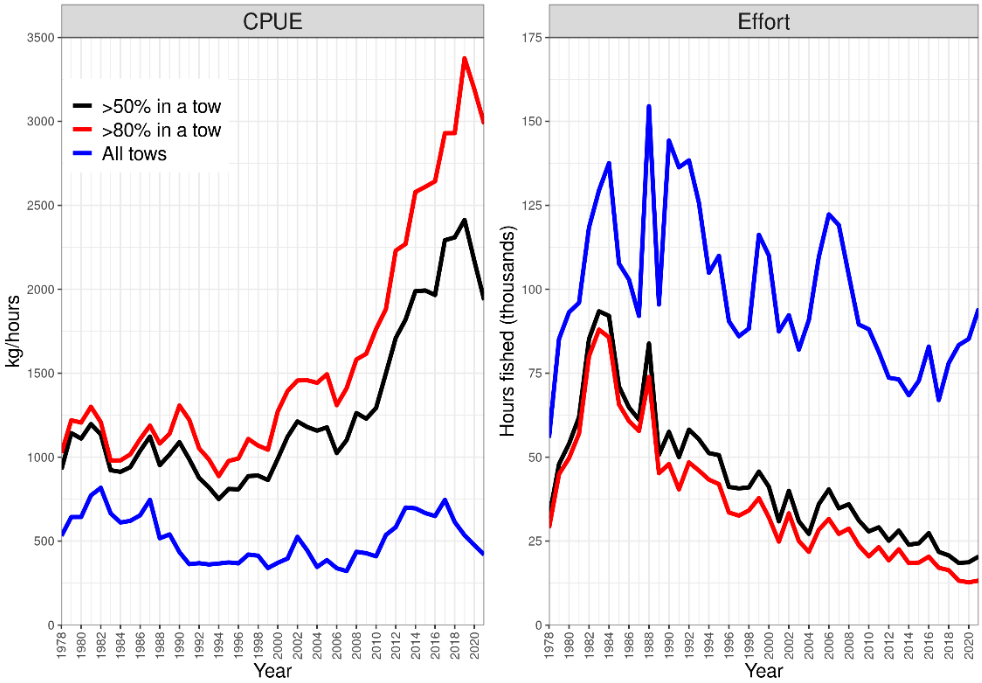


**Figure 21. Golden redfish. CPUE from Icelandic trawlers 1978–2021 where golden redfish catch composed at least 50% of the total catch in each haul (black line), 80% of the total catch (red line), and in all tows where golden redfish was caught (blue line). Data was not available for 2022.**

## ANALYTICAL ASSESSMENT

The stock was benchmarked in February 2023 (WKBNORTH 2023; ICES 2023) which resulted in changes in the assessment method (SAM model; Nielsen and Berg 2017) and updated reference points. The Gadget model development was discontinued as it was apparent that there was a long enough time series of age data to run an age-based assessment.

### SURVEY INDICES

A designed method (Cochran, 1977) is used to calculate the survey indices for golden redfish for each of five surveys conducted in the Greenland Waters, Icelandic Waters, and the Faroes Ecoregions. In the SAM model input data, two length disaggregated survey indices were made to cover the full range of the stock:

1. Spring survey index
   - Icelandic spring survey 1985–2023.
   - German autumn survey index 1984–2020, which the year was shifted by one year ($y$ + 1). For 2018 (missing) the average of 2017 and 2019 was used, and for 2021 and 2022 (missing) the index for 2020 was applied.
   - Faroese spring survey 1994–2023. The indices for 1985–1993 were the averages of 1994–1999.
2. Autumn survey index:
   - Icelandic autumn survey 1996–2022. For 2011 (missing) the average of 2010 and 2012 was used.
   - German autumn survey 1996–2020 from East Greenland. For 2018 (missing) the average of 2017 and 2019 was used, and for 2021 and 2022 (missing) the index for 2020 was applied.
   - Faroese summer survey 1996–2022.

Figure 22 shows the two combined survey indices divided by area. The survey index is mainly driven by the Icelandic survey indices.

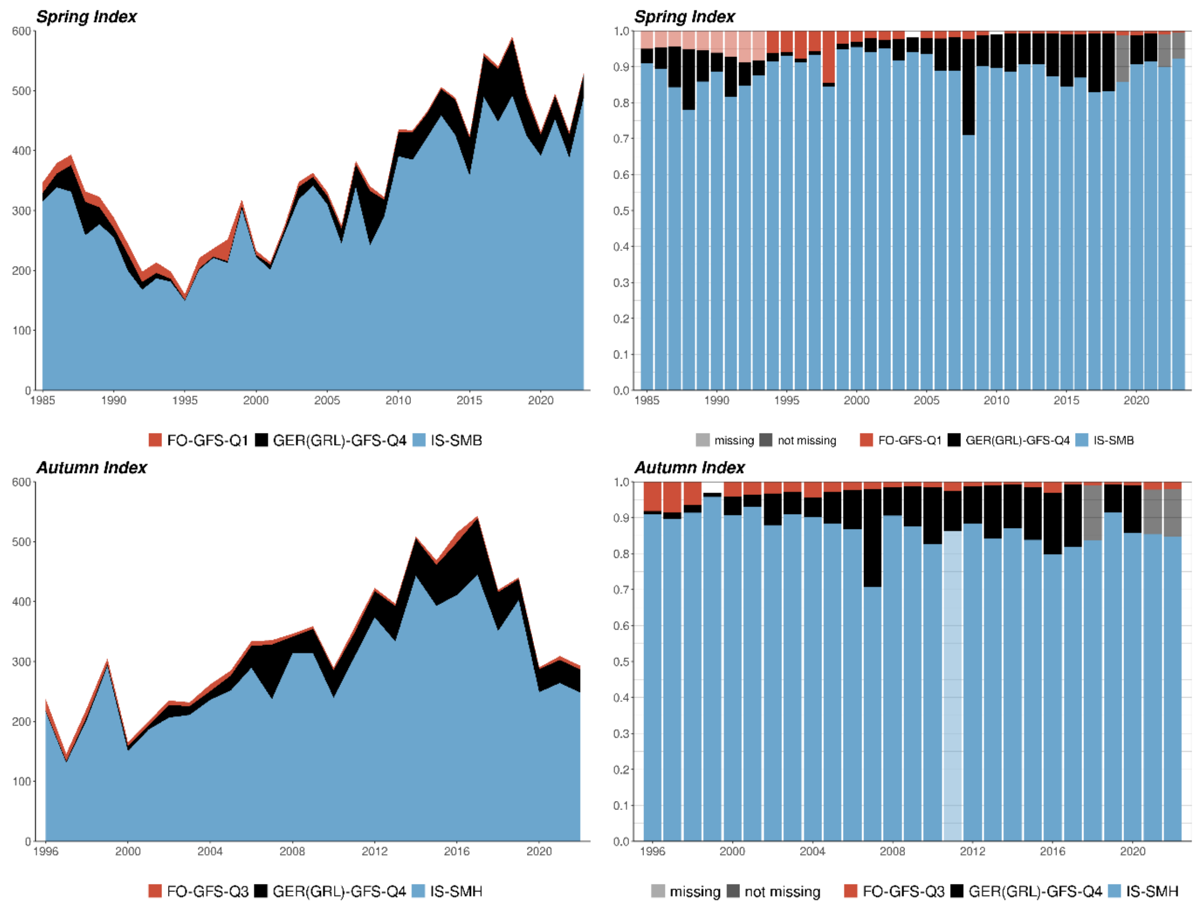


**Figure 22. Golden redfish. Combined survey indices.**

## GROWTH

Although golden redfish rarely attain sizes over 60 cm and 2 kg in the surveys and commercial catches, their growth is highly variable from year to year, leading to a wide range of ages possible from roughly 30 cm. Age-length keys are therefore highly variable, and this is thought to be the result of variable growth rather than ageing error, as ageing consistency is anecdotally good. Despite temporal differences in growth, the length-weight relationship is highly stable, so there is likely little variation in condition.

Fish weights at length are available from both surveys and commercial data. Stock weights were calculated as the mean weight at age taken from the combined spring survey, after converting lengths to weights using an estimated power relationship from fish with both length and weight data collected in both survey and commercial samples (Figure 23). Weights are calculated as the mean weight expected from the length distribution observed for that year. Before 1985, survey data were replaced with catch weight data, which are available from 1966. Where weights at a certain age were missing, which occurred only in very rare cases, data from the other data sources were used to fill the gap. To reduce variation among years, stock weights were calculated as a moving average of the current and previous year.

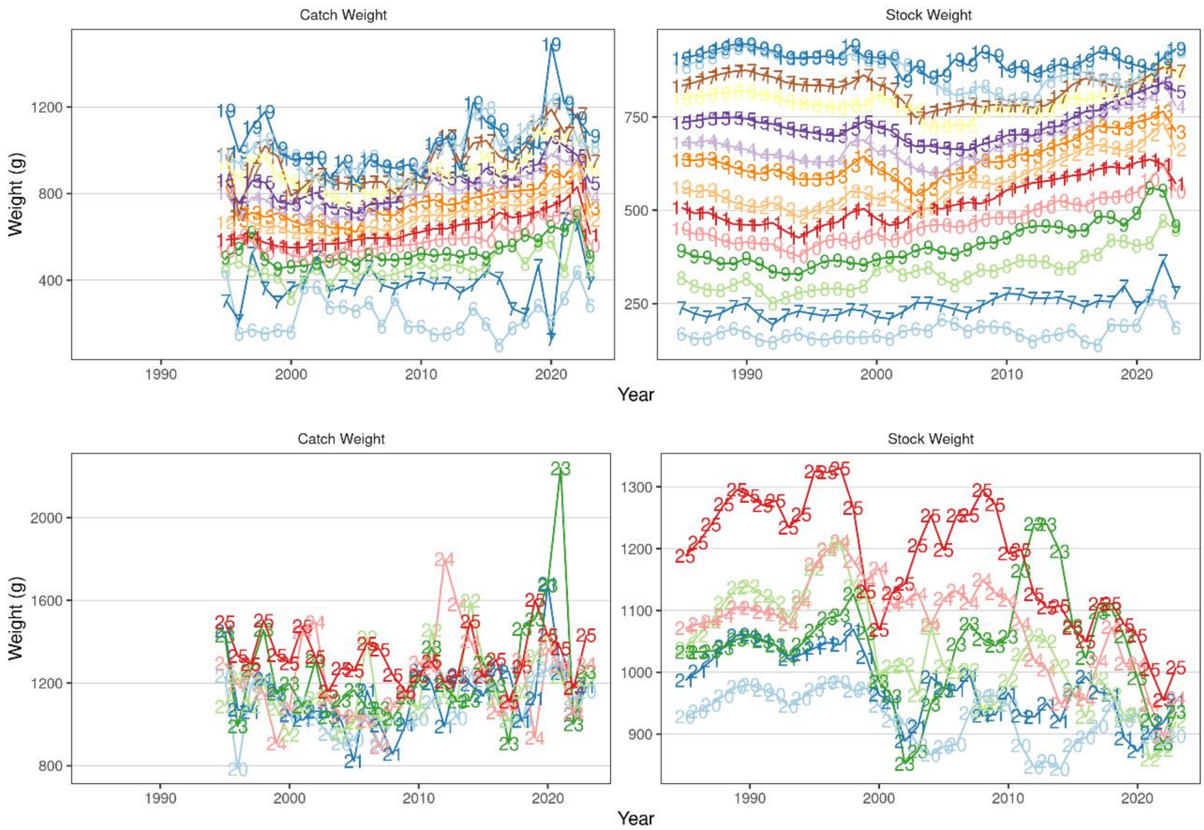


**Figure 23. Golden redfish. Weight at age observed in the commercial catches (left) and the spring survey (right).**

## MATURITY

Maturity at length is rather stable among years and regions, so a fixed maturity ogive is applied to length distributions and then averaged within ages after the ALK is applied. In the past Gadget model, a fixed ogive has been used: P = 1/(1+exp(-0.3122*(length + 1.5 - 33.54))). To help compare between modelling frameworks, this ogive was maintained. The updated ogive was based on fitting a maturity-at-length ogive to length data pooled across all years, using maturity data taken from the spring survey. The updated ogive is the one proposed to be used here: although changing the maturity ogive has no impact on model estimation, it does have an impact on calculation of spawning stock biomass and therefore reference point generation. All reference points calculated are based on using the updated maturity ogive. To reduce variation among years, maturity at age was taken as the average between this and the previous year for ages less than 15 and the average over this and the three years prior for ages 15 and greater. Maturity at age is shown in Figure 14.

## NATURAL MORTALITY

In the previous Gadget model, natural mortality, M, was set to 0.05 with the plus age group set to 0.1. The same procedure is done in this model, so that all profile likelihoods include a plus group with a natural mortality value set to 0.1.

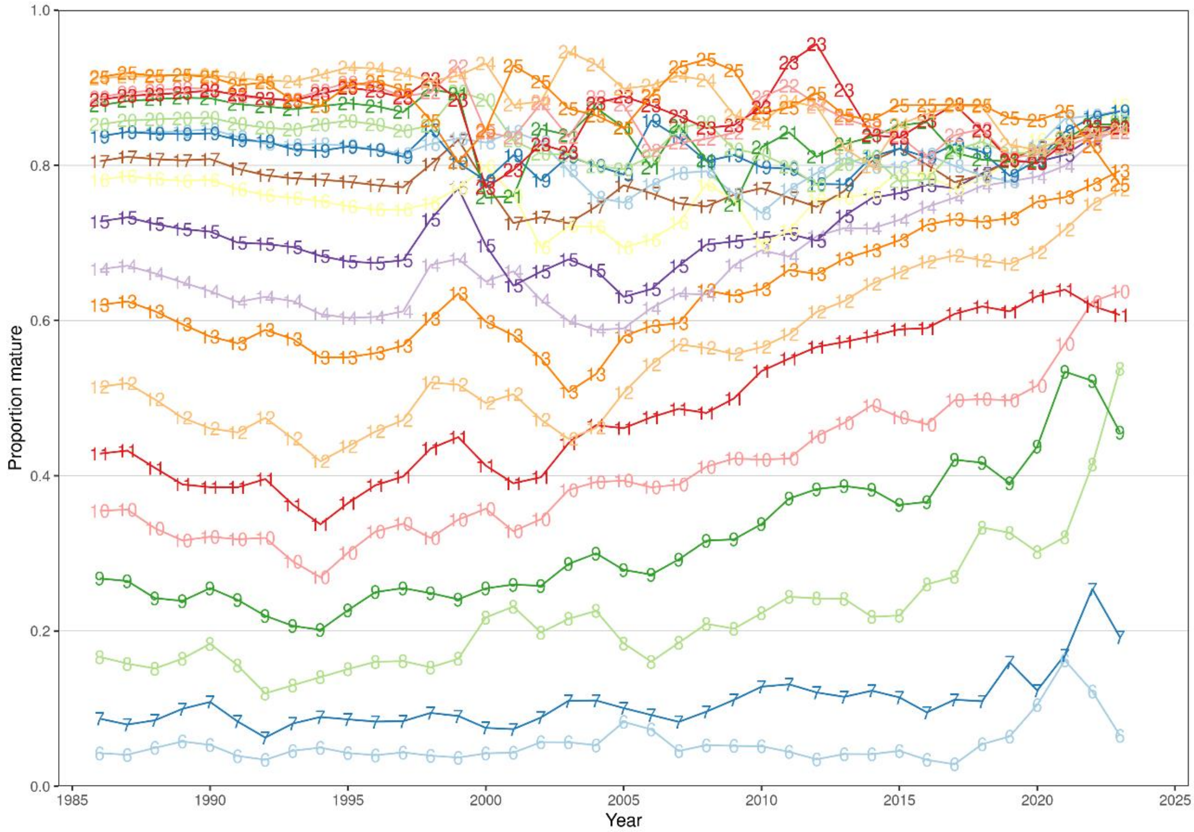


**Figure 24. Golden redfish. The proportion mature at age applied on ALKs from the autumn survey and commercial data.**

## ASSESSMENT

The SAM model runs from 1966 onwards and ages 6 to 25+ are tracked by the model, treating age 25 as a plus group. Observations in SAM are assumed to arise from a multivariate normal process with an expected value derived from the model. SAM allows for the investigation of how to treat patterns in the residuals by defining different parameters by age for observation residual variances and correlations for all data sets. Furthermore, the user can define age groups for sur-vey catchabilities, and related power relationships, and process variances for the $\log(N)$ and $\log(F)$ residuals.

SAM model development began with ALK refinement and choice of model age structure that emphasized correlations among consecutive cohort observations within catch-at-age and survey index data. The youngest ages observed in the catches were discarded due to high noise (ages 5 and 6), and the model begins at the earliest age that golden redfish start appearing in the surveys consistently (age 6).

## DATA AND MODEL SETTINGS

Below is a brief description of the data used in the model and the model settings is given.

- The simulation period is from 1966 to 2023.
- Two survey indices for the whole area used.
  - Spring survey length data from 1985–2023. As little age data are available for the spring survey, it was inputted as a single total biomass series.
  - Autumn survey length and age data from 1996–2022.
- Age ranges in the model spanned ages 6–25+.

  - Although age data range to 60, individual ages detected can be sparse by year in the range 25–60.
- Age-length keys (ALKs) for the surveys were created and applied within regions (east versus west) to account for regional growth differences from autumn survey data.
  - The east ALK was applied to length data from Faroese surveys and the west ALK was applied to length data from Greenlandic surveys.
- ALKs generated from commercial samples were applied within biannual time periods (January-June and July-December, but not by region) to catch length distributions.
- All ALKs were created using 2 cm length bins from 6–60 cm, with longer bins at lengths 0–6, 61–70, and 70+.
- Catch at age and total landings are available from 1966, but only those from 1995 on-wards are used due to available age data.
- An ALK generated by pooling data from the years 1995–2003 was applied to length distribution data in 1966 and 1972.
- Annual ALKs were created from 1995 onwards to account for time-variable growth. These ALKs are time-specific (biannual, January-June and July-December) and applied to the approximate amount of catch from the corresponding period. This was done to account for differences in growth patterns between sampling times.
- Total catch-at-age over sectors is used in the tuning.
- Only Icelandic commercial length distribution data was used.
  - These total catches at ages were scaled according to total landings across all countries and areas fished within the stock.
- Recruitment was set at age 6.
- Natural mortality (M) was set to 0.05, except for the oldest age (25+) which was set to 0.1.

## RESULTS OF THE ASSESSMENT MODEL

The summary of the assessment is shown in Figure 25.

Population dynamics of the golden redfish estimated in this model show a clear trend of dynamic recruitment period from 1990–2013. Relatively high recruitment during 2000–2013 corresponds with increased spawning stock biomass (SSB) and catches after 2010. However, recruitment has decreased greatly since 2014 and shows a prolonged period of low recruitment. It is difficult to suggest whether this indicates a productivity shift or a long low period in a highly autocorrelated recruitment series. Fishing mortality has declined since 1990 but has been rather steady in recent years. The spawning stock biomass observed over the past decade in this model is higher than that observed in the previous Gadget model, largely because of variable growth: a high number of relatively old fish in the stock are better accounted for in this model, increasing the numbers of old spawners. Faster growth of smaller fish indicates a greater contribution of smaller fish to the spawning biomass as well. Any trends prior to the onset of age data (1996) should be taken with caution due to a lack of data supporting the model during this period.

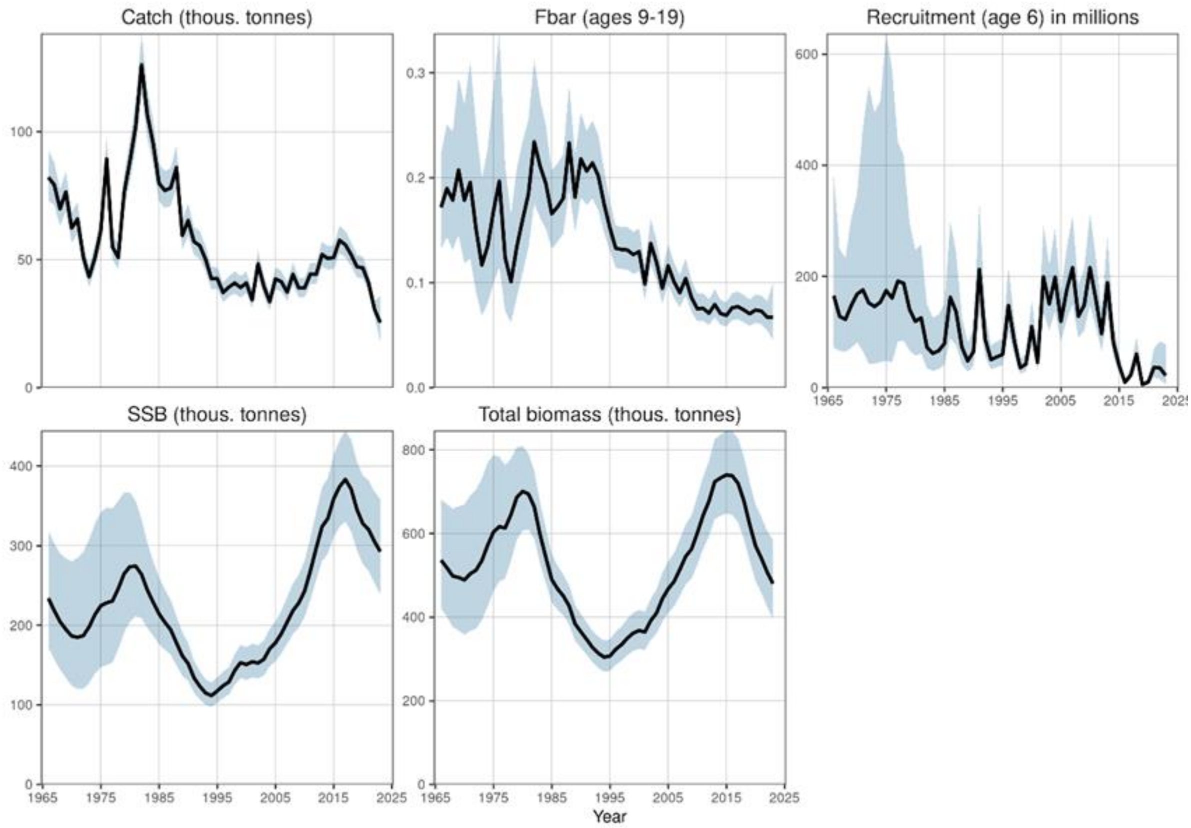


**Figure 25. Golden redfish. Summary from the assessment 2023. The figure shows total catch, recruitment (age 6), spawning stock biomass (SSB), total biomass, and fishing mortality for ages 9-19.**

## RETROSPECTIVE ANALYSIS

The analytical retrospective pattern (five-year peel) of the assessment is presented in Figure 26. The table below shows the Mohn's rho values for SSB, F and recruitment for this five-year peel:

| Variable | Value |
|---|---|
| $F_{bar}$ | 0.067 |
| SSB | -0.024 |
| Rec. | -0.259 |

The Mohn's rho values for $F_{bar}$ and the spawning stock biomass are relatively low or 6.7% and 2.4% respectively. Mohn's rho for recruitment is on the other hand higher (-26%) and is likely a result of high uncertainty due to low selectivity at the smallest age (6) detectable by the surveys. Mohn's $\rho$ values are within the range recommended by Carvalho et al. [2] (< 0.2).

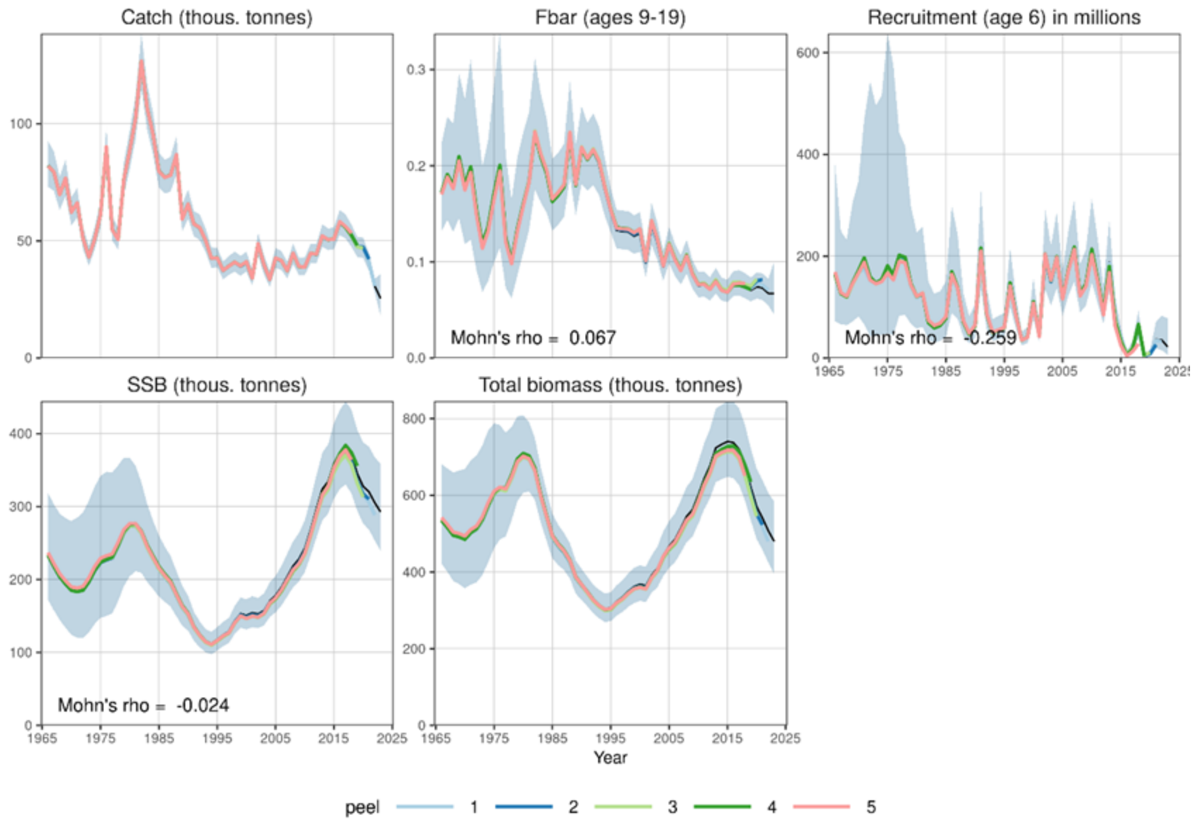


**Figure 26. Golden redfish. Analytical retrospective pattern of the base run. Recruitment is at age 6 and F shows the development of ages 9–19.**

## DIAGNOSTICS

Fits to the survey numbers-at-age indices and the catch-at-age data can be found in Figures 27 and 28 and to the spring survey index in Figure 29. The fit to total catch and landings data is shown in Figure 30. Catch and spring survey data are followed the closest by the model, whereas fits to the autumn survey series are slightly noisier but follow a similar pattern. Fits to landings data are quite variable, but more recent fits catch at age data are better.

Neither observation nor process residuals show obvious trends (Figures 31 and 32).

An overview of model parameter estimates is shown in Figure 33. Parameters with similar values were joined across ages within data sources if estimates overlapped substantially; therefore, those left show appreciable differentiation.

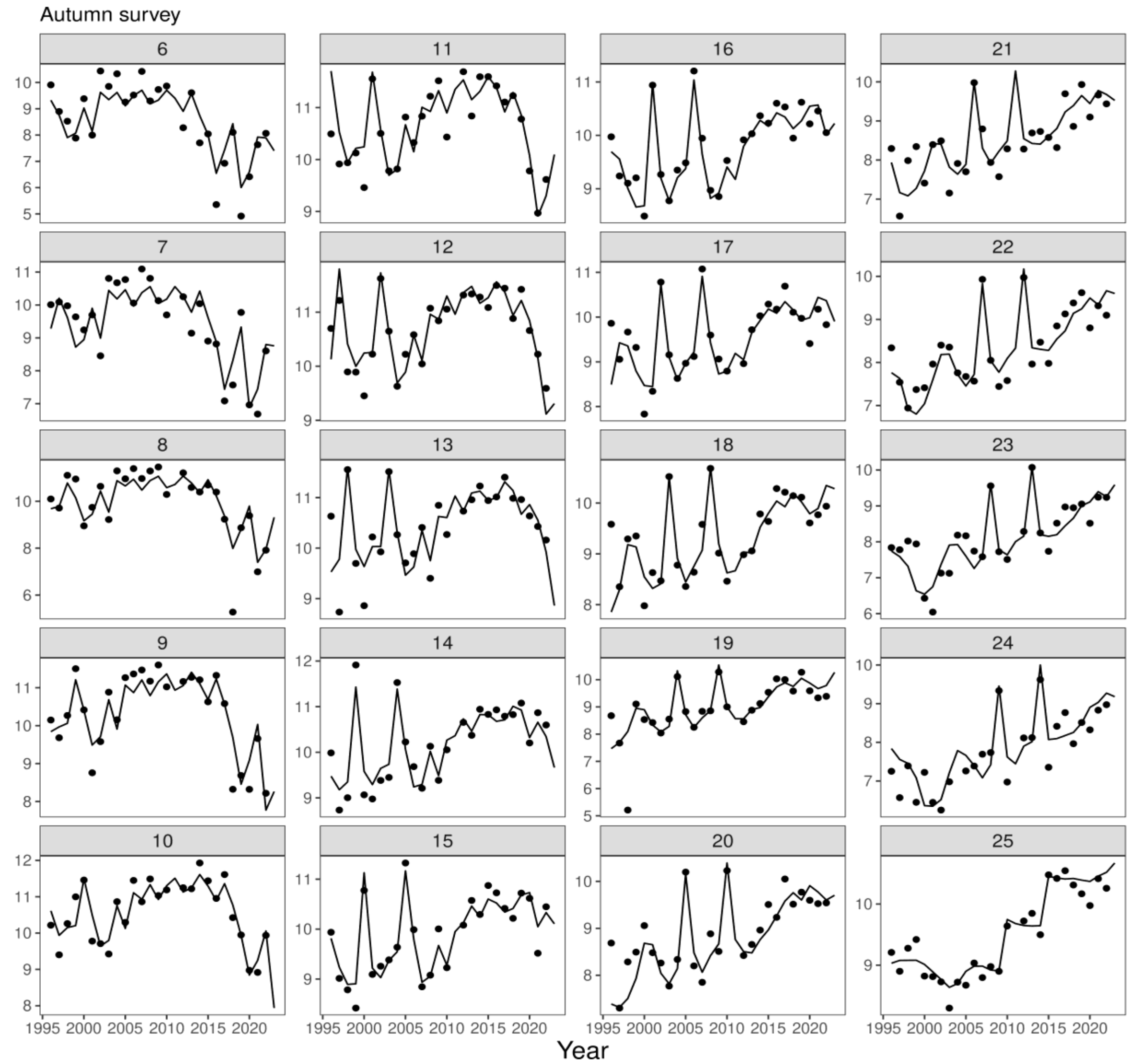


**Figure 27. Golden redfish. Fit to the numbers at age input data in the autumn survey to the proposed SAM model.**

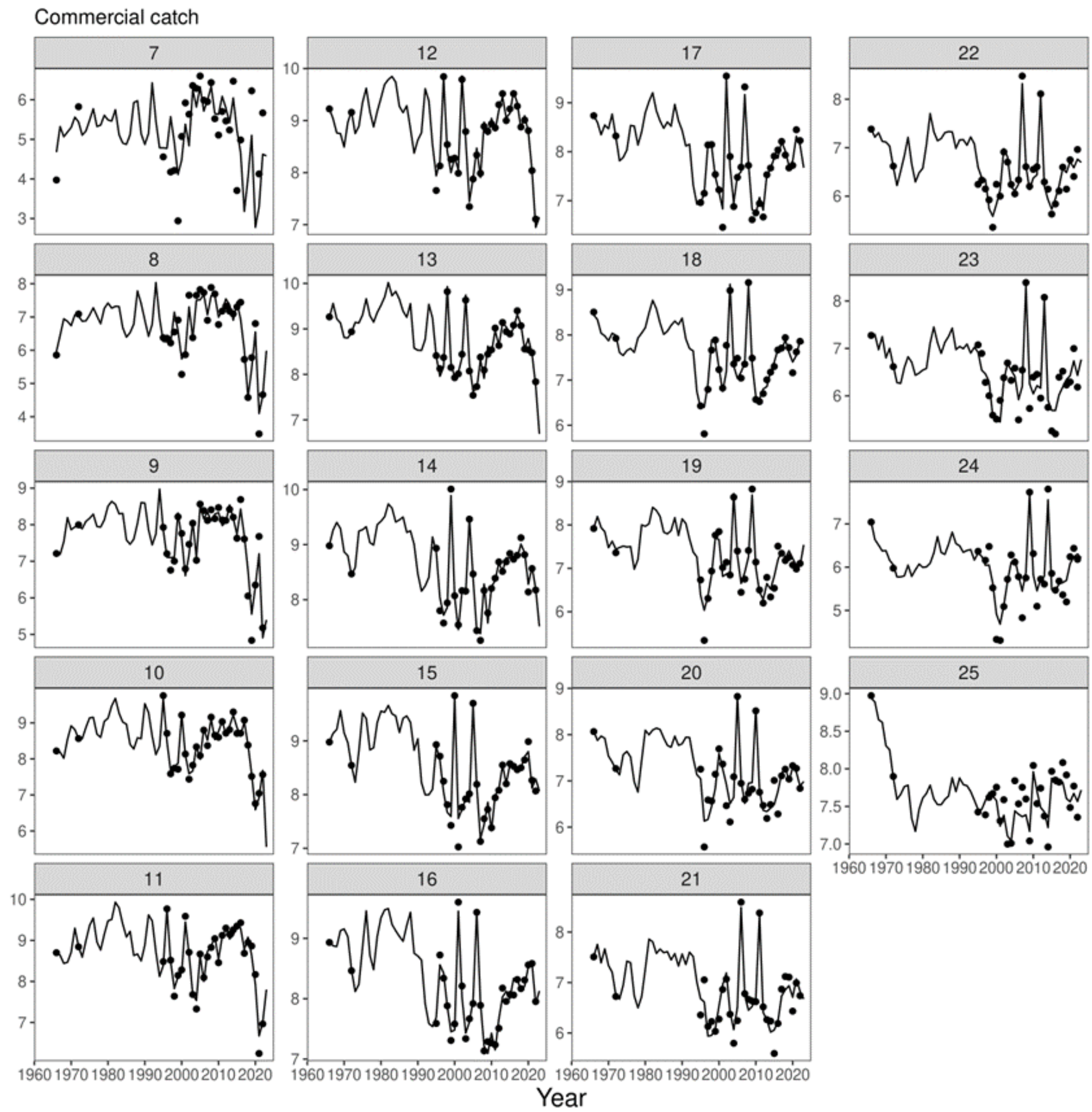


**Figure 28. Golden redfish. Fit to the numbers at age input data in the commercial catches to the proposed SAM model.**

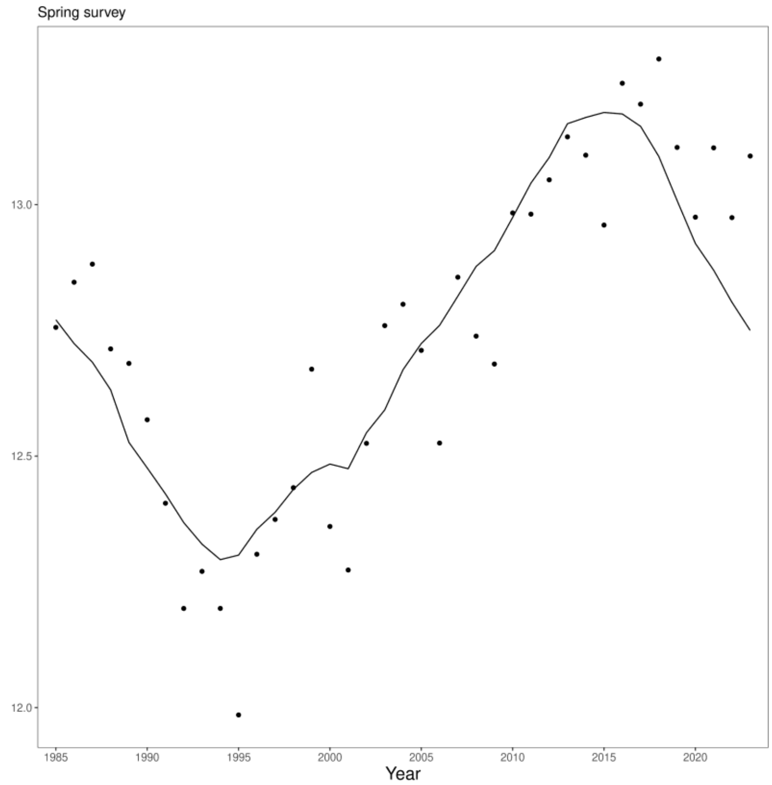


**Figure 29. Golden redfish. Fit to the spring survey data to the proposed SAM model.**

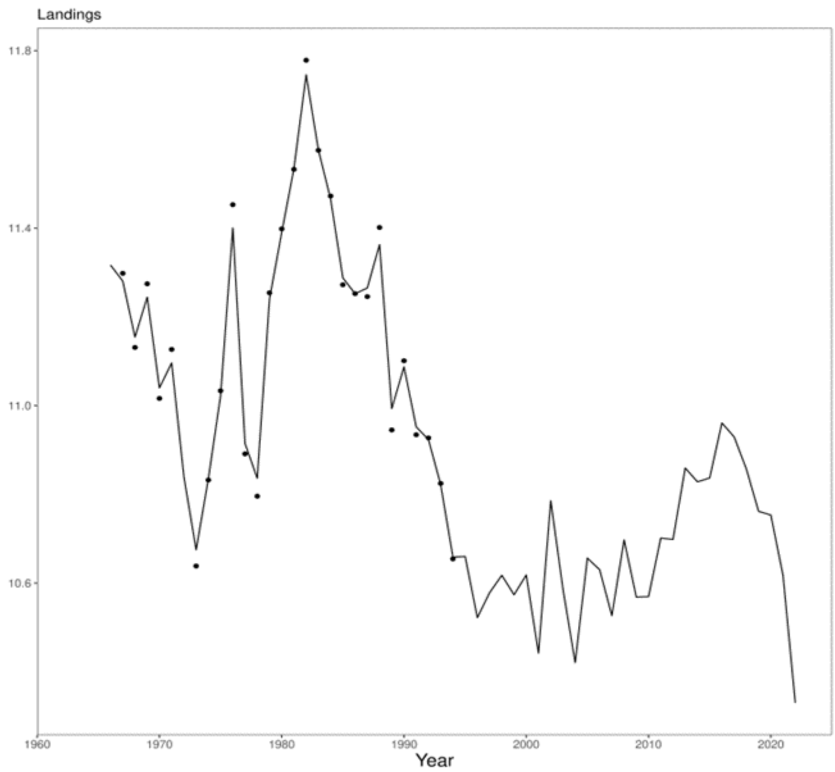


**Figure 30. Golden redfish. Fit to the landings input data to the proposed SAM model.**

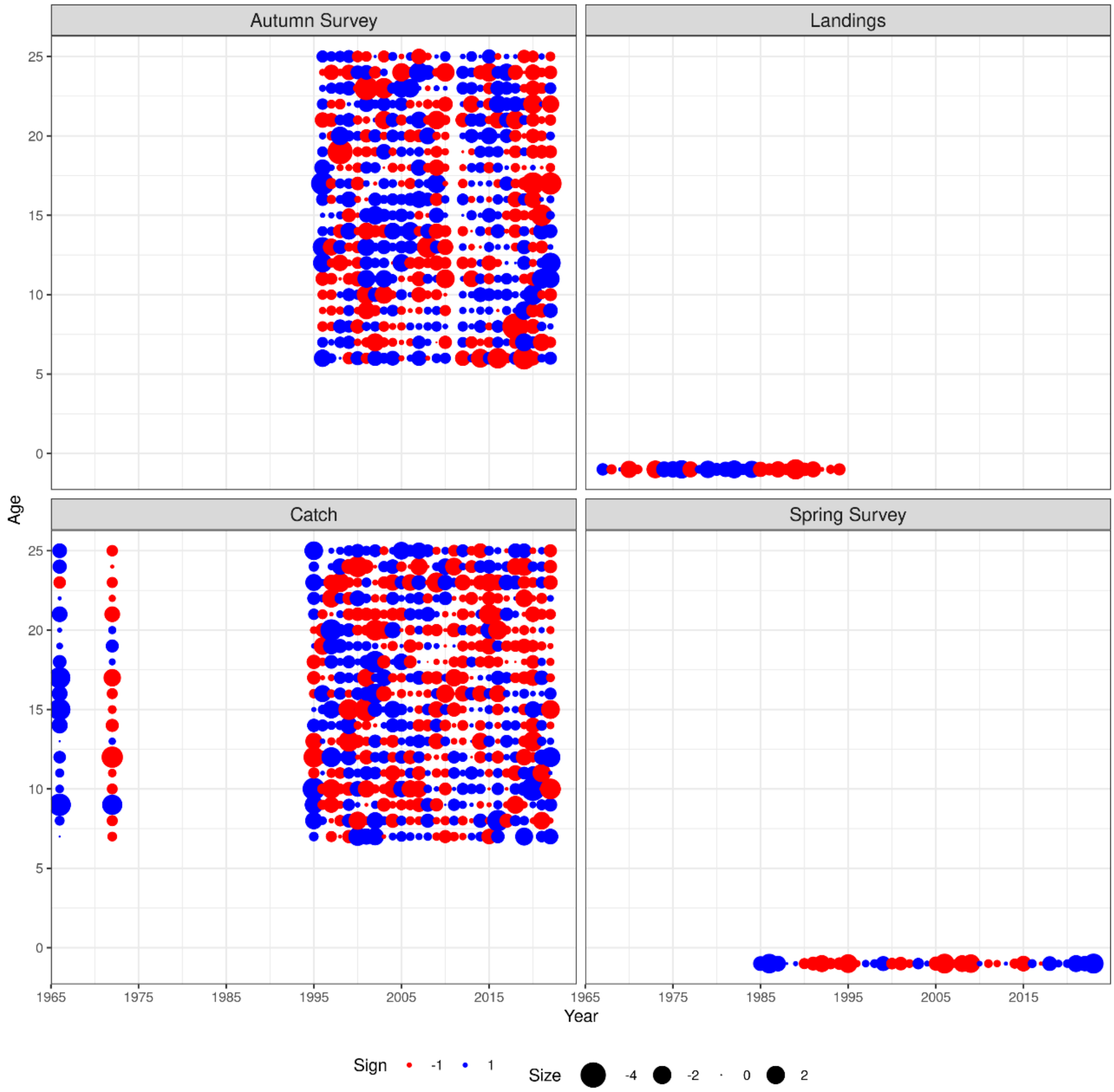


**Figure 31. Golden redfish. Residuals from the fit between model and survey indices. The red circles indicate positive residuals (sur- vey results exceed model prediction). Largest residuals correspond to log(obs/mod) = 1.**

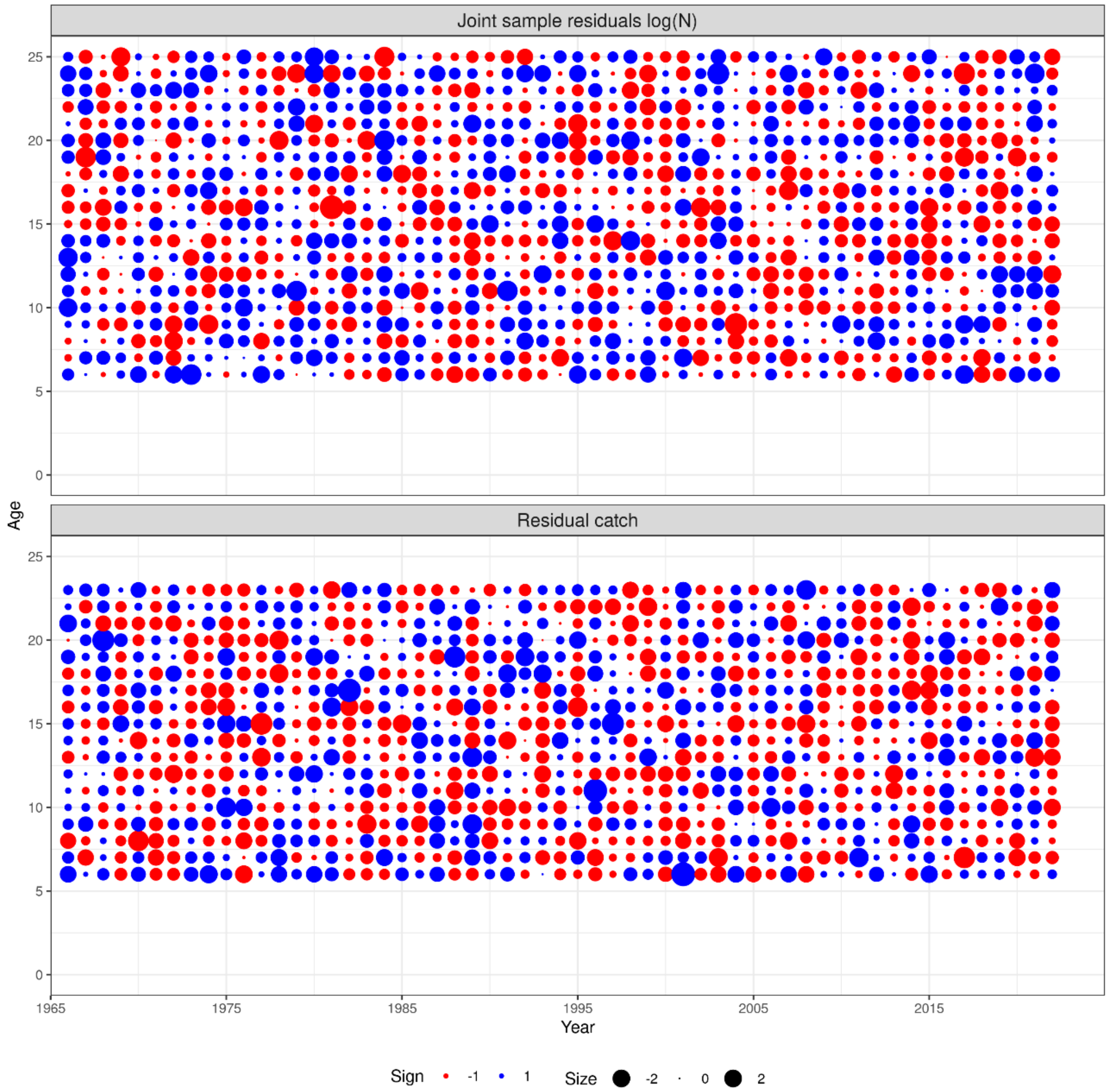


**Figure 32. Golden redfish. Residuals from the fit between model and survey indices. The red circles indicate positive residuals (sur- vey results exceed model prediction). Largest residuals correspond to log(obs/mod) = 1.**

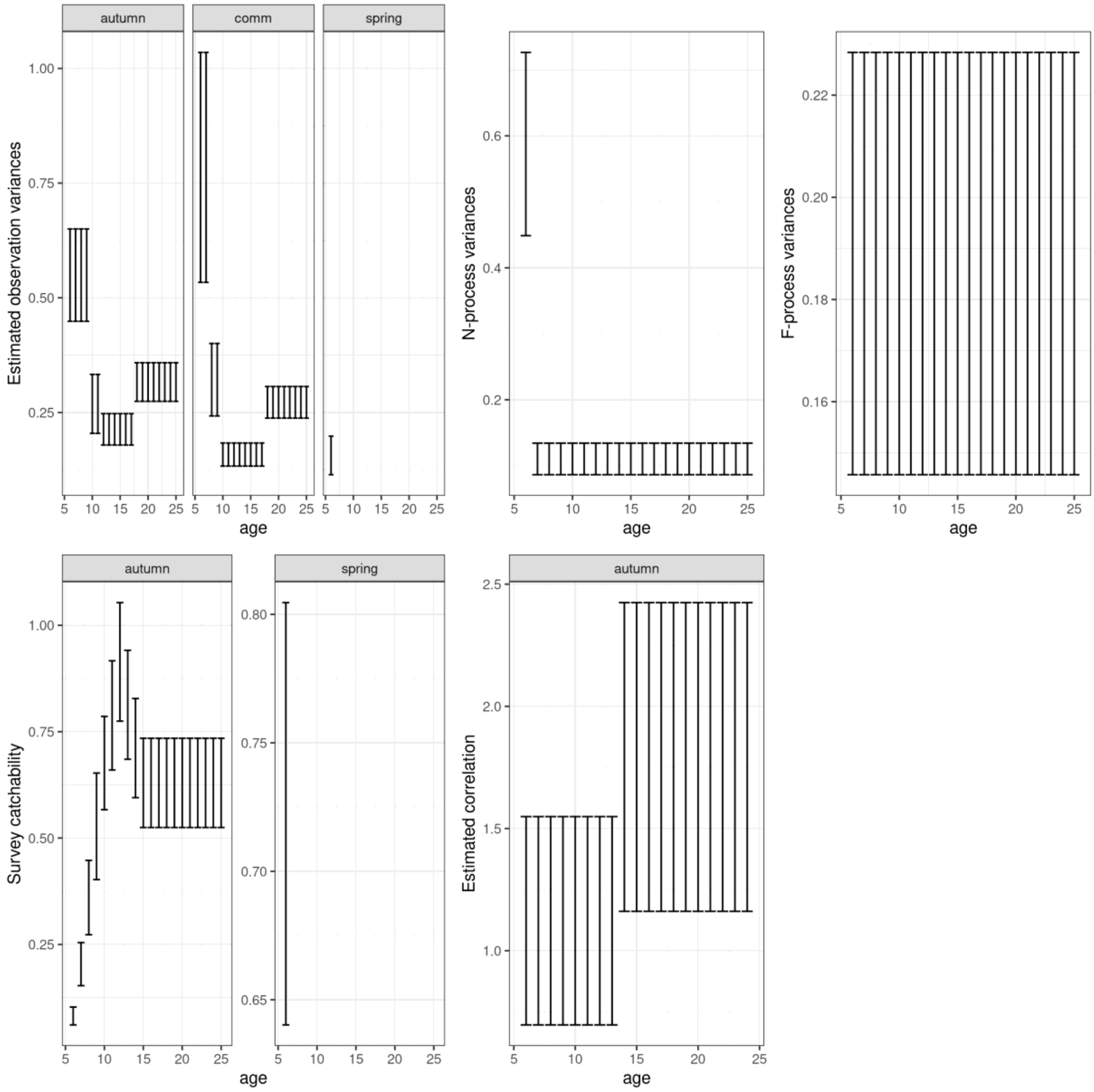


**Figure 33. Golden redfish. Overview of model parameter estimates.**

## LEAVE-ONE-OUT ANALYSIS

Figure 34 shows the results comparing the full model estimates with estimates where the survey time series has been omitted from the observation likelihood. The results show that the model relies mostly on the spring survey data in addition to the catch at age data. When leaving out the autumn survey the model did not converge.

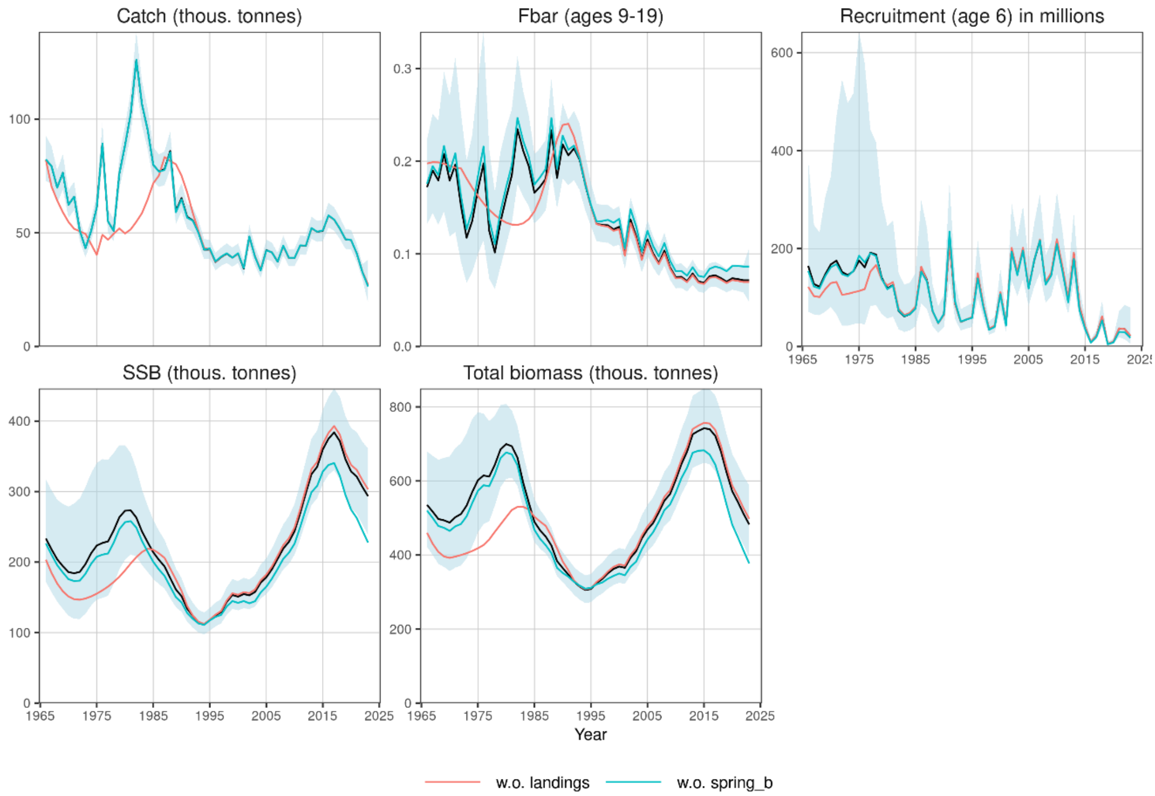


**Figure 34. Golden redfish. Leave-out estimates of SSB, total biomass, catch, F and recruitment.**

## REFERENCE POINTS

During the 2023 Benchmark meeting, reference points were updated (Table 1). In line with ICES technical guidelines, the MSY $B_{trigger}$ is set to be set at $B_{pa}$ in simulations with the ICES advice rule implemented (i.e., constant target fishing rate above $B_{trigger}$, which is scaled down by the ratio SSB/$B_{trigger}$ when SSB < $B_{trigger}$). Maximum yield is estimated to be obtained at an F of 0.112. $F_{p05}$, i.e., the maximum F that has less than 5% chance of SSB going below $B_{lim}$ when the advice rule is applied, is more than the F maximizing yield 0.112, thus not limiting the estimate of $F_{MSY}$.

**Table 1. Golden redfish in subareas 5, 6, 12, and 14. Reference points, values, and their technical basis. All weights are in tonnes.**

| FRAMEWORK | REFERENCE POINT | VALUE | TECHNICAL BASIS | SOURCE |
|---|---|---|---|---|
| MSY approach | MSY $B_{trigger}$ | 154 094 | $B_{pa}$ | ICES (2023a) |
| | FMSY | 0.112 | Fishing mortality that leads to MSY; estimated using stochastic simulations. | ICES (2023a) |
| Precautionary approach | $B_{lim}$ | 110 893 | $B_{loss}$. Lowest SSB (1994) | ICES (2023a) |
| | $B_{pa}$ | 154 094 | Blim x exp(0.2×1.645) | ICES (2023a) |
| | $F_{lim}$ | 0.167 | Fishing mortality that in stochastic equilibrium will result in median SSB at Blim | ICES (2023a) |
| | $F_{pa}$ | 0.114 | Maximum F at which the probability of SSB falling below $B_{lim}$ is <5% | ICES (2023a) |

## STATE OF THE STOCK

The results from SAM assessment model indicate that fishing mortality has been low and below $F_{MSY}$ since 2009 (Figure 25, Table 1). Total biomass and SSB has been decreasing since 2016 but remain high. Results from surveys in Iceland and East Greenland indicate that cohorts from 2009 to ca. 2019 are poor. There are, however, indications in the 2021–2023 surveys in both areas of increased number of small golden redfish (<12 cm). The accuracy of the surveys as an indicator of recruitment is not known but recruitment in the next few years is expected to be poor.

## SHORT TERM FORECAST

Short term projections are performed using the standard procedure in SAM using the forecast function. Three-year averages are used for stock and catch weights, and maturity. From this projection the advice is derived. As recruitment over the past 8 years has been consistently lower than historical values, the stock is projected as the mean recruitment over the previous 5 years, continuing current practice from recent years. Catches in 2023 were set as the sum of expected landings, accounting for interannual transfer from 2022.

The results from the short-term prognosis with different fishing mortality is shown in Table 2. The results indicate that when fishing according to the ICES MSY approach the SSB is expected to decrease but is well above MSY $B_{trigger}$ (Table 2).

**Table 2. Golden redfish. Assumption and output from short term prognosis. All weights are in tonnes.**

| SSB (2024) | $F_{9-19}$ (2023) | Landings (2023) | $R_{age\ 6}$ (2023) | SSB (2023) |
|---|---|---|---|---|
| 264 167 | 0.086 | 32 327 | 21 936 | 293 541 |

| Basis | Total catch (2024) | $F_{9-19}$ (2024) | SSB (2025) |
|---|---|---|---|
| MSY | 41 286 | 0.112 | 242 246 |
| **Other catch options** | | | |
| $F_0$ | 0 | 0 | 269 068 |
| $F_{sq} = F_{2022}$ | 27 273 | 0.072 | 254 058 |

## UNCERTAINTIES IN ASSESSMENT AND FORECAST

It is clear that large changes in growth have occurred in recent years in golden redfish, both for older and younger fish. It is possible that these changes could be due to density dependence, but ecosystem shifts have also been observed in other species around Iceland. If it becomes clear that growth shifts as expected during the decline of the stock expected over the next 5-10 years, then growth may be predicted by a cohort or annual effect, and this may improve short-term forecasts and how closely actual harvest rates result from those expected under implementation of the ICES advice. As these changes in growth have likewise modified our current view of spawning stock biomass, it would also be prudent to know whether the changing age structure of the spawning stock biomass affects recruitment.

It is not 100% clear whether survey selectivity patterns vary logistically with age or are more dome-shaped, as both configurations gave a similar fit to the data, but different views of total stock biomass. As changes in growth have recently coincided with shifts in commercial selectivity that appear to be due to spatial shifts in fishing effort, it may also be useful to research whether density dependent shift in growth is spatially explicit.

## COMPARISON WITH PREVIOUS ASSESSMENT AND FORECAST

In 2014–2022, the Gadget model (Globally applicable Area Disaggregated General Ecosystem Toolbox) was used for the assessment of golden redfish. Several issues have come up regarding this assessment framework, prompting a need for this benchmark. First, length-based survey indices of different length ranges are in disagreement with each other. That is, if the assessment is to fit the index of the smallest length range of golden redfish, then it will have to disregard patterns in the largest length range, and vice versa. Second, this disagreement in length indices is also apparent in length distribution data as narrowed distributions with little recruitment visible in recent years, but also little indication of larger sized fish, despite its high longevity. Finally, growth appears to differ slightly by region, but length-at-age data are highly variable and shows a trend toward larger fish at younger ages in recent years. It is possible this is a result of density-dependent somatic growth.

Age-based models give more stable results than then Gadget counterpart when differences in growth are accounted for by applying region- and time-specific age-length keys (ALKs) while generating total catch and survey data.

## BASIS FOR ADVICE

ICES MSY approach agreed during the WKBNORTH meeting (ICES 2023).

## MANAGEMENT CONSIDERATION

In 2009 a fishery targeting redfish was initiated in Subarea 14 with annual catches of between 6000 and 8500 t in 2010–2019, highest in 2015 and lowest in 2018. The fishery does not distinguish between species, but based on survey information, golden redfish is estimated to be between 1000 and 2700 in 2010–2015 but increased to 3000–5400 t in 2016–2021.

Subarea 14 is an important nursery area for the entire resource. Measures to protect redfish juveniles in Subarea 14 should be continued (sorting grids in the shrimp fishery).

No formal agreement on the management of *S. norvegicus* exists among the three coastal states, Greenland, Iceland, and the Faroe Islands. However, an agreement was made between Iceland and Greenland in October 2015 on the management of the golden redfish fishery based on the management plan applied in 2014. The agreement was from 2016 to the end of 2018. The agreement states that each year 90% of the TAC is allocated to Iceland and 10% is allocated to Greenland. Furthermore, 350 t are allocated each year to other areas. The plan has not been renewed so no management plan is effective.

In Greenland and Iceland, the fishery is regulated by a TAC and in the Faroe Islands by effort limitation. The regulation schemes of those states have previously resulted in catches more than TACs advised by ICES.

Since 2009, surveys of redfish in the stock area have consistently shown very low abundance of young redfish (<30 cm). Biomass (SSB and the harvestable biomass) increased from 1995 to 2015 because of recruitment of several strong year classes to the stock. Since then, biomass has declined. The absence of any indications of any incoming cohorts raises concerns about future productivity of the stock.

## REGULATIONS AND THEIR EFFECTS

In the late 1980s, Iceland introduced a sorting grid with a bar spacing of 22 mm in the shrimp fishery to reduce the bycatch of juveniles in the shrimp fishery north of Iceland. This was partly done to avoid redfish juveniles as a bycatch in the fishery, but also juveniles of other species. Since the large year classes of golden redfish disappeared out of the shrimp fishing area, there in the early 1990s, observers report small redfish as being negligible in the Icelandic shrimp fishery. If the sorting grids work where the abundance of redfish is high is a question but not a relevant problem now in 5.b as abundance of small redfish is low and shrimp fisheries limited.

There is no minimum landing size of golden redfish in Division 5.a. However, if more than 20% of a catch observed on board is below 33 cm a small area can be closed temporarily. A large area west and southwest of Iceland is closed for fishing to protect young golden redfish.

There is no regulation of the golden redfish in Division 5.b.

Since 2002 it has been mandatory in the shrimp fishery in Subarea 14 to use sorting grids to reduce bycatches of juvenile redfish in the shrimp fishery.

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