SAITHE

Pollachius virens

STOCK DESCRIPTION AND MANAGEMENT UNITS

Description of the stock and management units is provided in the stock annex (ICES, 2019b).

The stock was benchmarked, and the management plan evaluated in March 2019 (ICES, 2019a). The result was no change in assessment setup. A minor change in the management plan was introduced as $MGMTB_{trigger}$ was decreased from 65 to 61 thous. tonnes to be in line with ICES MSY $B_{trigger}$. Other reference points were unchanged except HR_{lim} and $HR_{pa.}$ were introduced to replace F_{lim} and F_{pa}.

FISHERIES-DEPENDENT DATA

Landings of saithe in Icelandic waters in 2022 are estimated to have been 61 881 t (Figure 1), increasing from 59 774 t in 2021 but much less than the TAC that was close to 80 thous. tons for fishing years 2018/2019 to 2021/2022 (Figure 4).

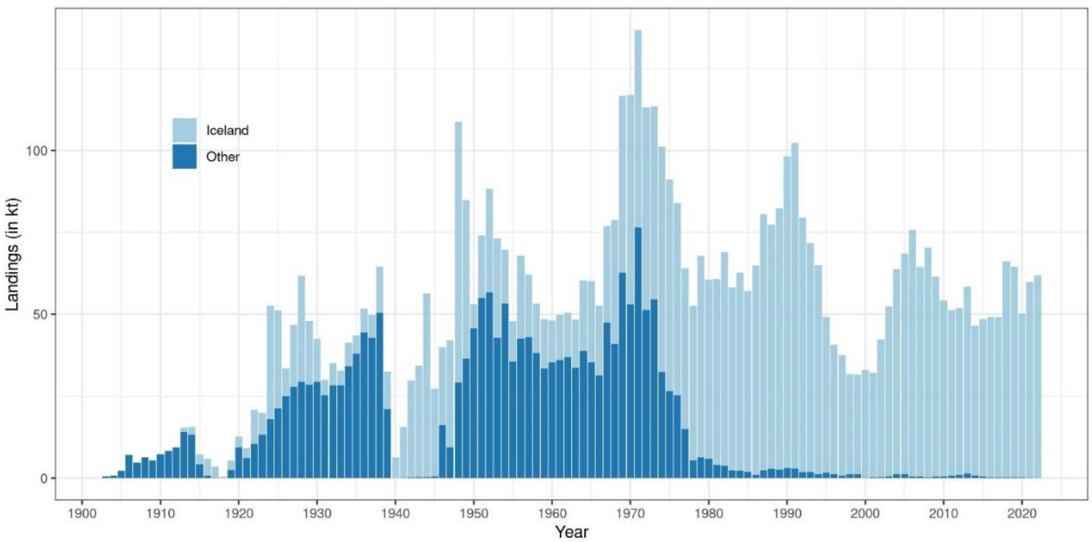
Information on landings of saithe exist since 1905. From 1905-1938 most of the catch was taken by foreigners, and also from 1950-1975 when foreigners, mostly Germans, accounted for 60% of the saithe landings (Figure 1). Mean annual catch of saithe has been 65 thous. tons since 1955, 73 thous. tons before 1980 but 60 thous. tons after 1980. Last five years the catch by foreigners has always been less than 300 tonnes and 0.5%, nearly all the catch taken by the Faroese vessels.

Of the landings, 53 736 t were caught by trawl, 2635 t by gillnets, and the rest caught by other fishing gear. In the last decade, most of the catch was taken by bottom trawl (83% in 2010–2017, 90% in 2018–2020, with gillnet and jiggers taking the majority of the rest, 5% each fleet. The share of the gillnet fleet was larger in the past, 26% in 1987–1996 compared to 9% in 1998–2020 (Figure 1). Reduction in the gillnet fisheries is caused by general reduction in gillnet boats that are mostly targeting cod and increased mesh size in gillnet fisheries targeting cod. The catch by foreigners before 1978 was nearly all taken by bottom trawl.

The reduction in the gillnet fleet was driven by boats changing from gillnets (another types of gear) to longlines, a change driven by cod and haddock fisheries. Price of large gillnet cod sold for *bacalao* reduced compared to "normal size", so it became more economical to operate longliners that supply fish evenly through the year. Increase in the haddock stock in the early 2000's and progress in automatic baiting were also an important factor. For saithe fisheries the important factor is that saithe is rarely caught by longliners, so the fleet has become much less of saithe fleet than before. The share of longlines increased gradually from 0.8% before 2000 to 2.2% in 2013–2016 reducing to the less than 1% in 2021.

The fleet using demersal trawl can be divided in two parts, those that freeze the catch and those that land it fresh. The trend in last decade has been that the proportion of the trawler fleet that land the catch fresh has increased. Freezing trawlers have taken large proportion of the catch of saithe and redfish but much less of cod and haddock (Figure 6). The main reason for this is relative price of frozen vs fresh fish for each species, but mixed fisheries issues like avoiding redfish when landing fresh fish can be a factor (redfish scratches the bycatch).

Spatial distribution of the saithe fisheries changed much from 2002–2014 (Figures 5 and 7). Before 2002 most of the saithe was caught south and west of Iceland but since 2012 40–50% of the catch have been taken northwest of Iceland. Comparable percentage before 2002 was 3–8%. Similar increase can be seen for golden redfish, but redfish and saithe have for a long time been caught by the same vessels, not necessarily in the same hauls, rather as night and day fish. The area where saithe is caught now (Hali Figure 7) has since early in the 20th century been the most important cod fishing ground for trawlers.



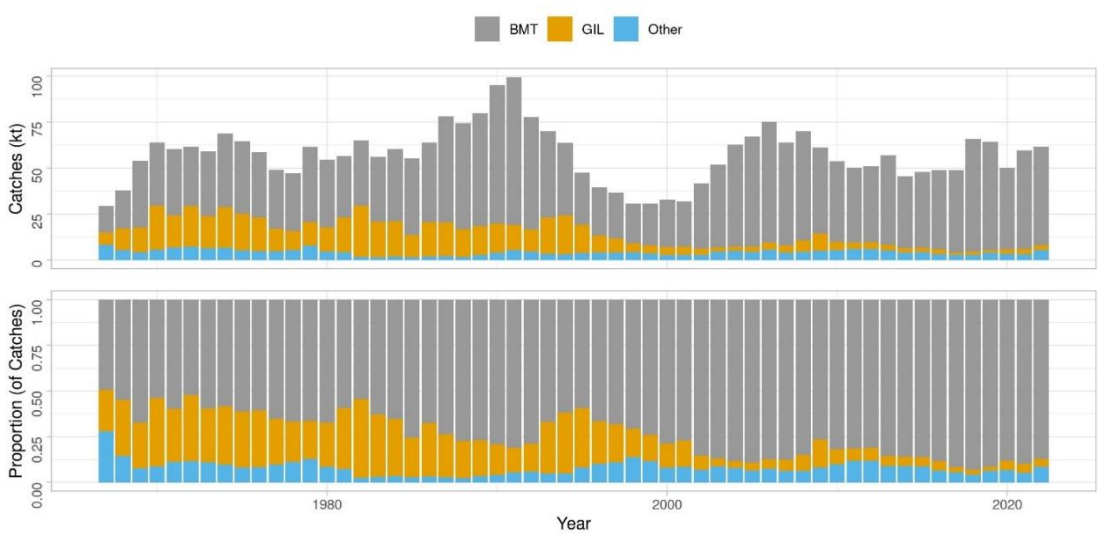


Figure 1. Saithe. Above: Total landings from Icelandic waters. Below: Total landings and percent by gear in Icelandic catches. Catches taken by foreigners before 1978 are nearly all taken by bottom trawl.

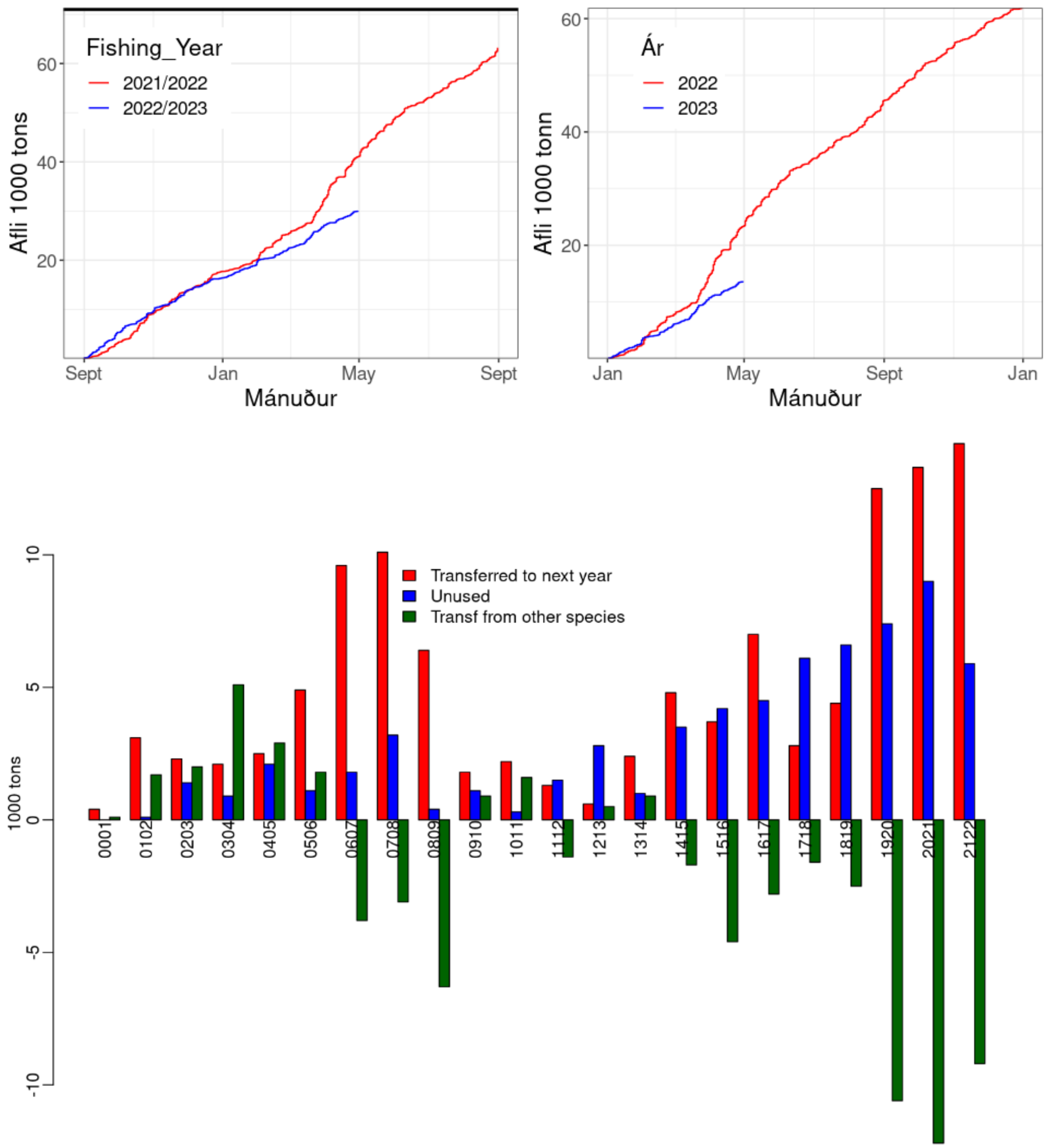


Figure 2. Saithe. Upper figure. Cumulative landings in the current fishing year (left) and calendar year (right). The vertical (green line) in the left figure shows the quota for the current fishing year. Lower figure. Transfer of quota to next fishing year, unused quota and transfer from other species (negative transfer from other species means transfer to other species).

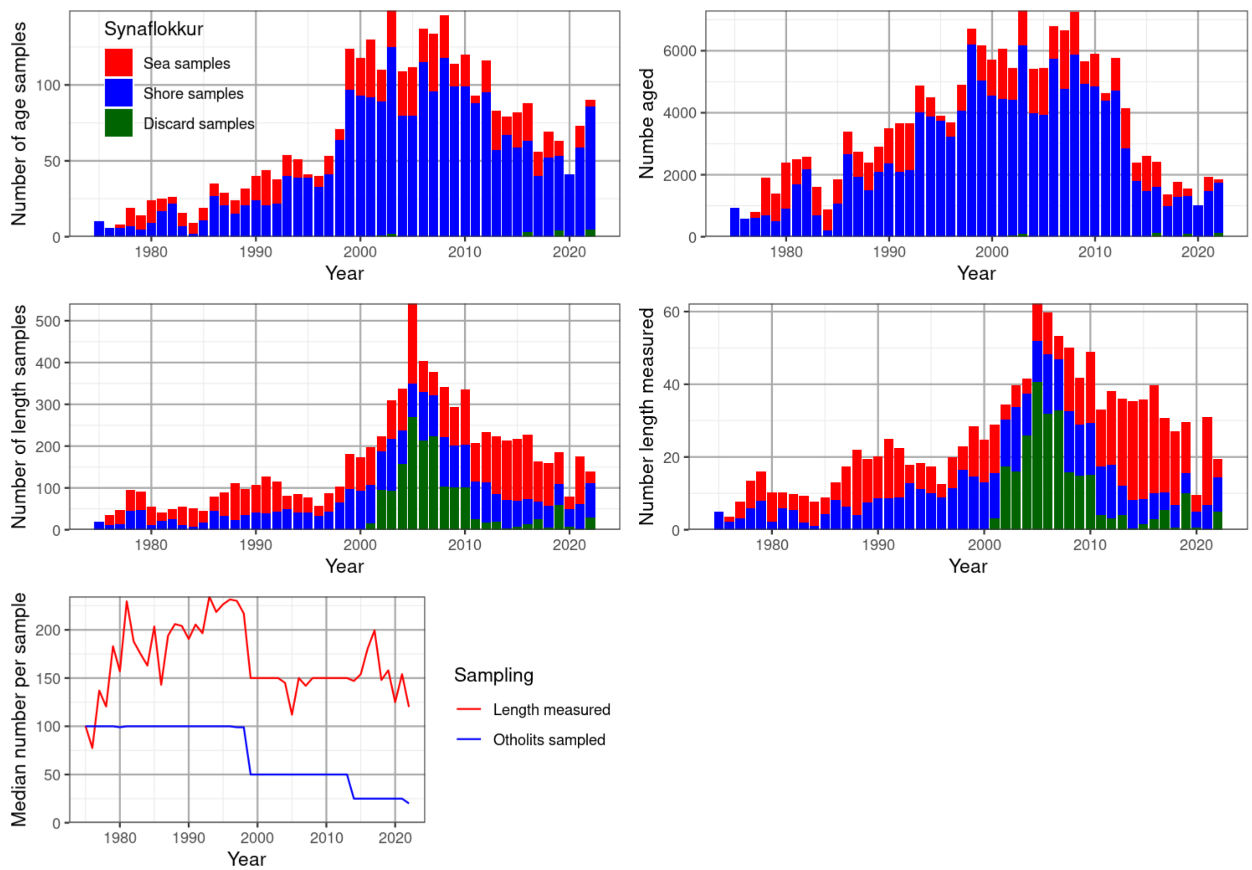


Figure 3. Saithe. Development of sampling intensity from catches. Number of length measured fishes is in thousands.

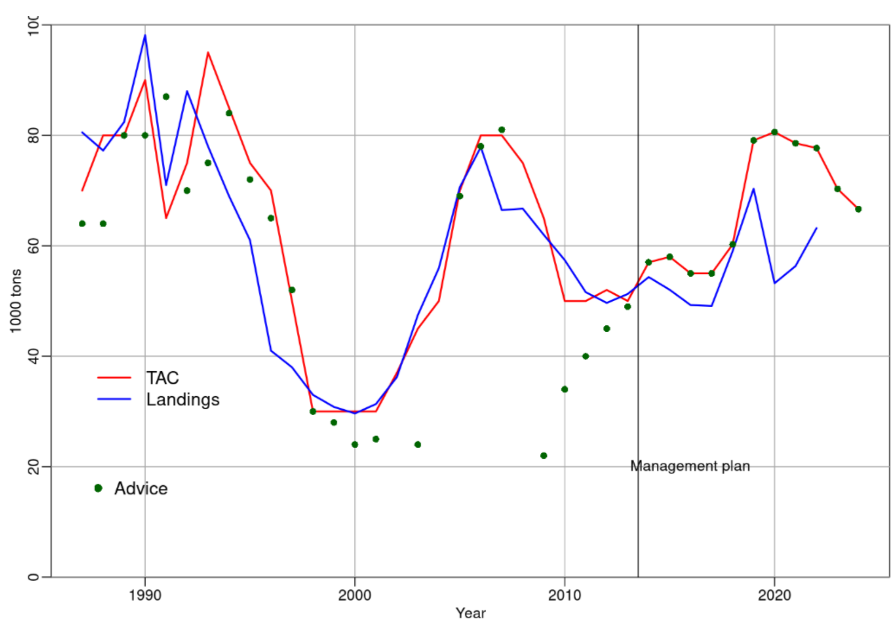


Figure 4. Saithe. ICES Advice, TAC and catch of saithe since 1987. ICES did not give advice for the fishing years 2003/04 and 2007/08 and the advice for 2001/02 was “no directed fisheries”. The X-axis indicates the latter year of the fishing year.

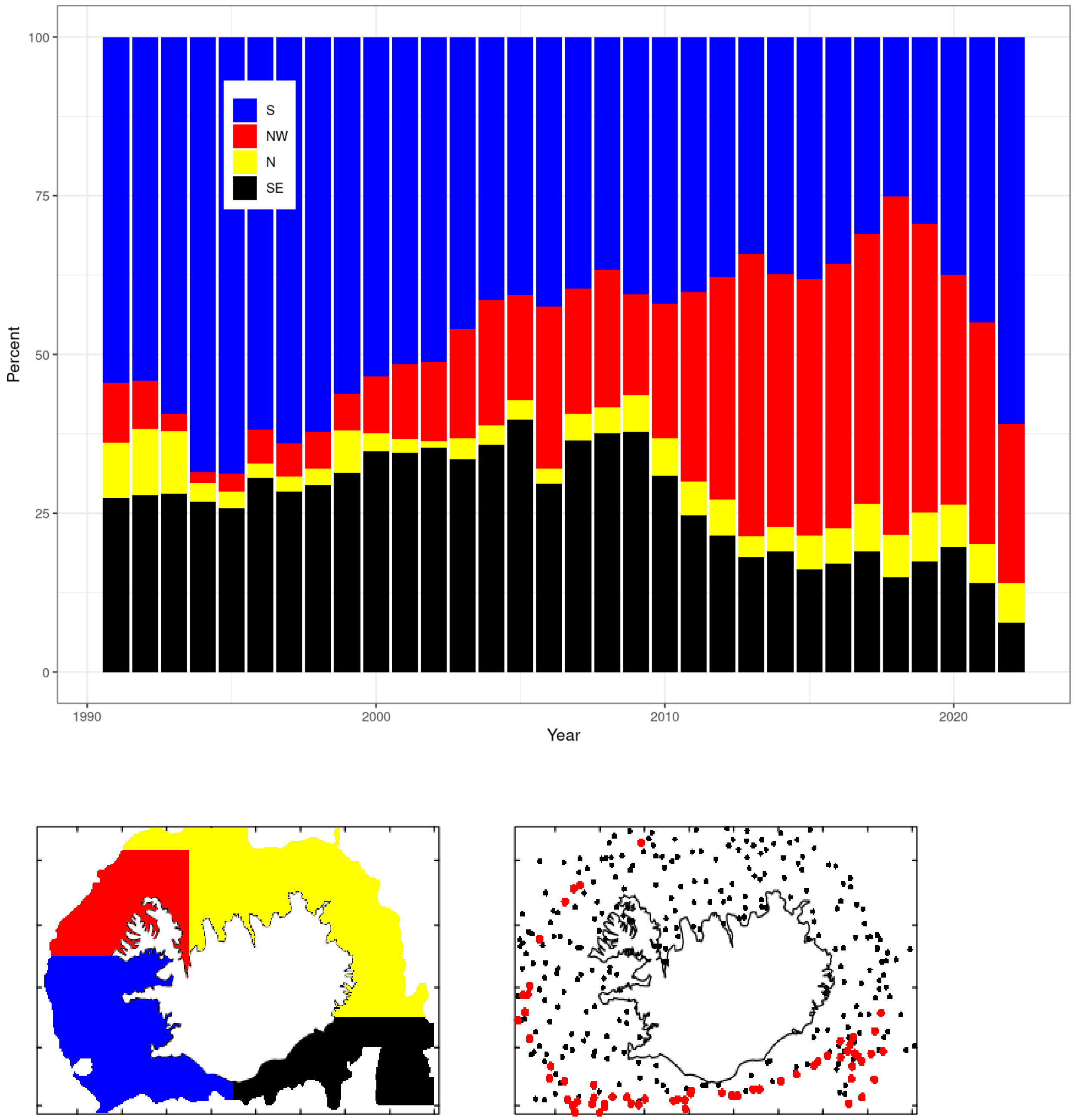


Figure 5. Saithe. Upper figure percent of landings by regions defined in the lower figure to the left. Lower right, stations added in the autumn survey in 2000 (red dots).

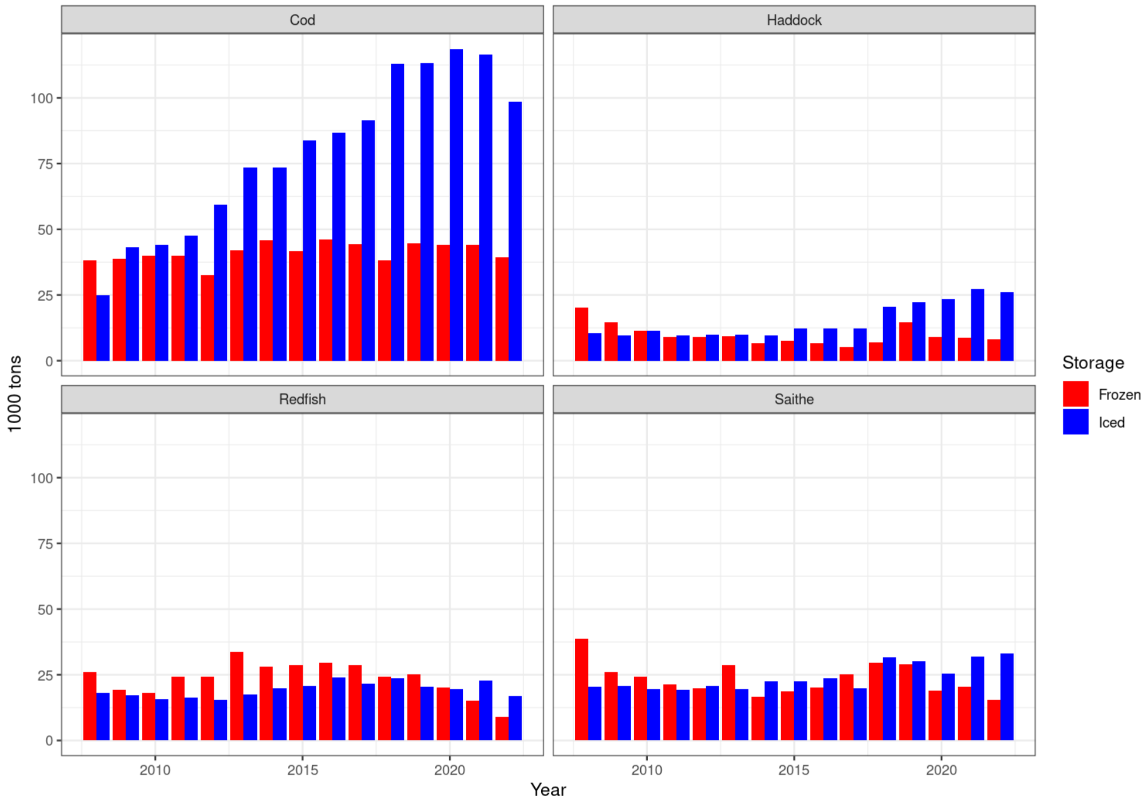


Figure 6. Saithe. Catch by trawlers divided between those that freeze the catch and those that do not. Number of trawlers landing more than 500 tonnes has been reducing gradually from 42 in 2008 to 33 in 2020.

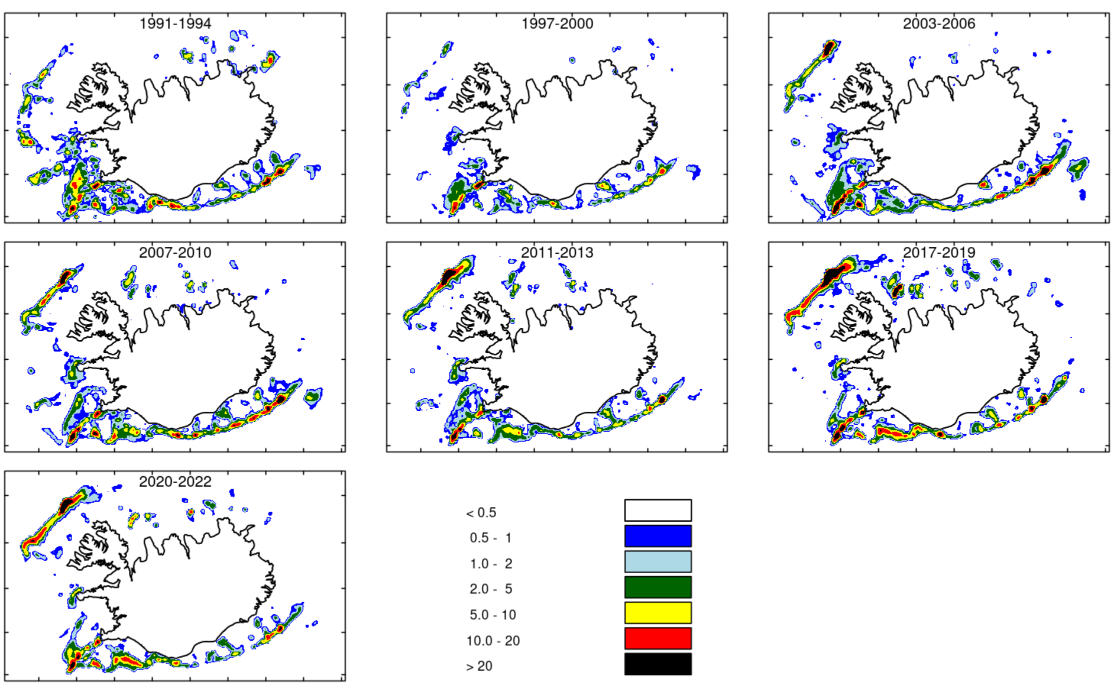


Figure 7. Saithe. Spatial distribution of saithe catches as tonnes per square nautical mile per year.

LOGBOOK DATA

Due to data problems hours trawled are missing from the Logbook data in 2022. The data do though exist but need to be linked to the database to get a coherent time series. The analysis here are therefore only based on data until 2021.

CPUE from the fleet show increasing trend over time (Figure 16 and 17). Considerable variability can be seen on top of this trend and all measures of CPUE show substantial reduction since 2018.

The GLM indices (Figure 17) are compiled by a model of the form.

$$C = T^{\gamma} \times \delta_{\text{year}}$$

$$C = T^{\gamma} \times \delta_{\text{year}}\delta_{\text{freeze}}$$

Where C is catch of saithe, T hours trawled. $\delta_{\text{year}}$is an estimated year factor δ_{freeze} a factor indicating if the catch is frozen aboard the vessel. $\gamma$is an estimated parameter showing relationship between hours trawled and catch. The models are applied to tows where saith is more than 30% of the total catch.

Those models give more stable trend compared to the indices compiled directly but the interesting observation of those models is that the models predict inverse relationship between hours trawled and saithe catch ($\gamma = -0.25$) (the models are run on all hauls where saithe is registered).

LANDINGS, ADVICE AND TAC

For all Icelandic stocks that are managed by a TAC system the TAC is given for fishing year where fishing year **y/y+1** is from September 1st in the year **y** to August 31st in year **y+1**. Assessment done in the spring of year **y**, is used to give advice for the fishing year starting September 1st the same year. For most stocks the survey conducted in March is the most influential data source and the most recent survey from March in the assessment year is used in the advice.

The management plan and assessment for Icelandic saithe have been identical since 2010 and both advice and TAC based on the 20% harvest control rule. Since 2014/2015 the set TAC has not been caught (Figure 4) but in the period 1997/1998 to 2013/2014 the TAC was caught in all years except 2007/2008 and 2008/2009. The catch in the fishing year 2021/2022 was 63 206 tons while the TAC was 77 692 tons. The catch in 2020/2021 and 2019/2020 was 66 and 53 thous tons while the TAC was 80 thous tons so only 65-70% of the TAC was caught in those fishing years. For comparison 90% of the TAC was caught in preceding fishing years.

The Icelandic Fisheries management system allows some transfer between species based on cod-equivalence factors that are supposed to reflect the price of the species compared to cod (see ICES, 2021). Transfer to cod is though not allowed in the system that is quite limited. In recent years saithe has been converted to other species (Figure 2) that are probably more economical to catch than saithe. But considerable part of the saithe quota has not been used that, might be a signal of overestimation of the stock or that catching saithe is not economical. As described before, the fleet has been less of a saithe fleet in recent years and historical assessment shows that fishing mortality of Icelandic saithe was never high, even in periods were fisheries were not limited (ICES 2002).

LANDINGS BY AGE

Compilation of catch in numbers is based on age and length distributions from the catches where the number aged is usually considerably less than number length measured. Discarding is not considered to be a problem in the Icelandic saithe fisheries, with an estimated discard proportion of 0.1% (annual reports by Palsson *et al.*, 2003 and later). Recently, the fleet does also seem to have difficulty in catching the set TAC, making discards more unlikely. Since the amount discarded is likely to be small, not taking discards into account in the total catches and catch in numbers is not considered to have major effect on the stock assessment.

Foreign landings that are 147 tonnes are included in the landings above. They are caught by longlines (75 tonnes), handlines (42 tonnes) and demersal seine (31 tonnes). All the foreign landings have in recent years been taken by the Faroese fleet.

Catch in numbers are compiled based on 2 fleets, bottom trawl and gillnets, 1 region and 1 season. Bottom trawl accounts for 90% of the landings and other fleets than bottom trawl and gillnet are included with the bottom trawl.

The samples used to derive catch in numbers are both taken by observers at sea and from shore samples. The trawlers that freeze the catch account for majority of sea samples while all shore samples are from fresh fish trawlers. In additions relatively few fishes from sea samples are sampled for otoliths but the age-length keys are similar. Few sea samples were taken in 2020 and 2022 (figure 3).

Length distributions from sea and shore samples show some difference, the shore samples show usually more of large fish (Figure 8). This difference might be reflecting the difference in composition of the catch of the trawlers that freeze the catch and those that land the catch fresh. Excluding sea samples when compiling catch in number for the year 2022 does not change the results much (green and red bars in Figure 9), the reason is likely that there are few sea samples in 2022 so they do not affect the results much.

Length distributions from bottom trawl show tendency to catch smaller fish from 2003–2017 but again larger fish in 2018–2020 (Figure 10). In 2020 the +110 cm group was especially abundant, but proportion of 60-69 cm fish was above average in 2022.

Sampling from commercial catch has been revised in recent decade, the number of samples has reduced and also the number of otoliths per sample (Figure 3) (ICES, 2019b). Sampling in 2020 was much less than in the years before, the number sea samples, and number of age samples was especially low. The main explanation seems to be the COVID-19 epidemic. In 2021 the sampling was back to the level in 2017-2019 but in 2022 the number of sea samples is very small.

90% of the length samples are taken from trawl that accounts for ~90% of the catches.

Two age-length keys are used to calculate catch at age, one key for the gillnet catch and another key for other gears combined. The same length-weight relationship ($W = 0.02498 * L^{2.75674}$) is applied to length distributions from both fleets.

Catch in numbers by age are listed in Figure 9 where they are compared to prediction from last year, fitting reasonably well (red and blue bars).

In recent decade increased proportion of saithe catches has been caught north-west of Iceland (Figure 5). This situation could lead to potential problem if the sampling effort does not follow distribution in the catches. To look at this problem catch in numbers were recompiled using 12 cells, 3 gear (bottom trawl, gillnets and handlines), 2 areas (north and south) and 2 time periods (Jan–May and June–Dec). The resulting catch in numbers are very similar (Figure 11) and using it in assessment leads to less than 1% difference of reference biomass.

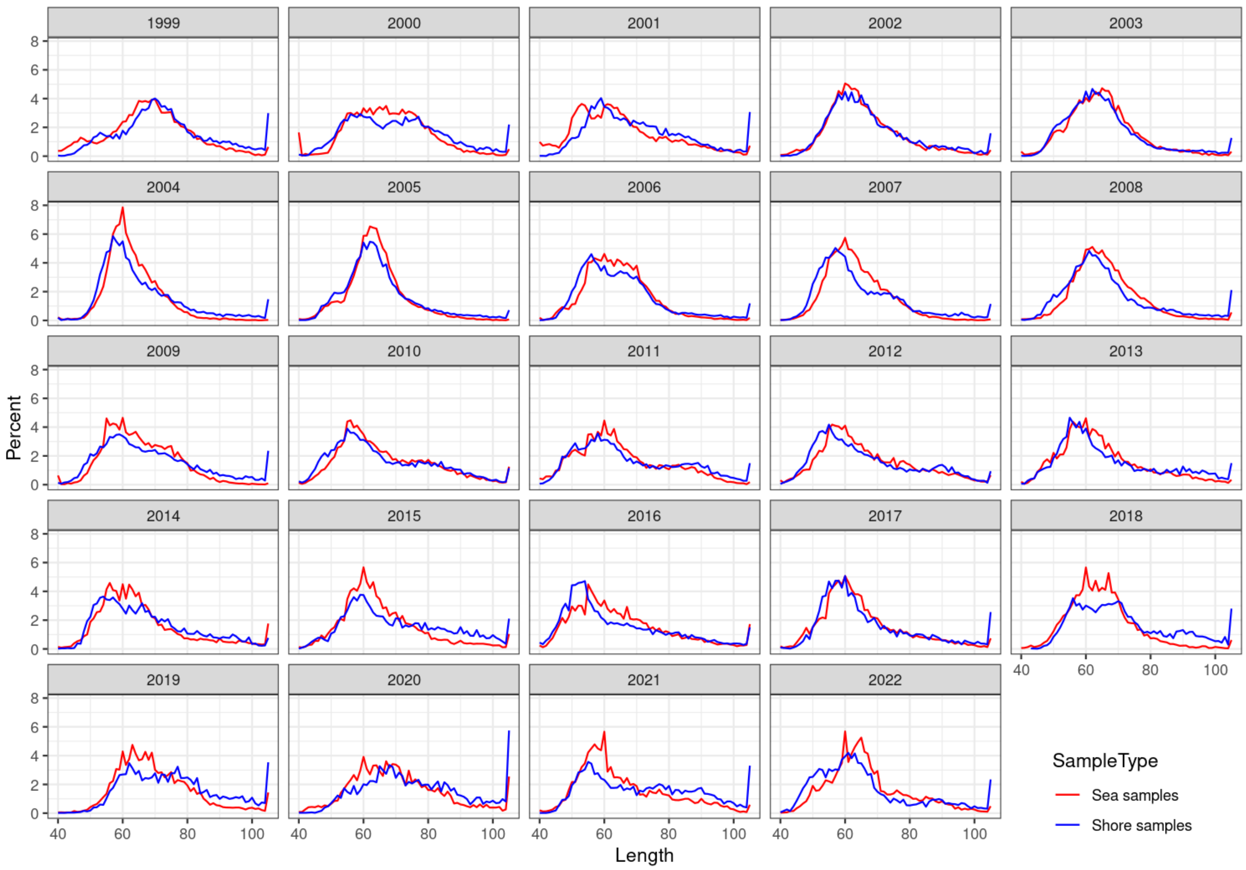


Figure 8. Saithe. Length distributions from sea and shore samples. 105 cm is a plus group and the value there shows how large proportion of number caught is 105cm and larger.

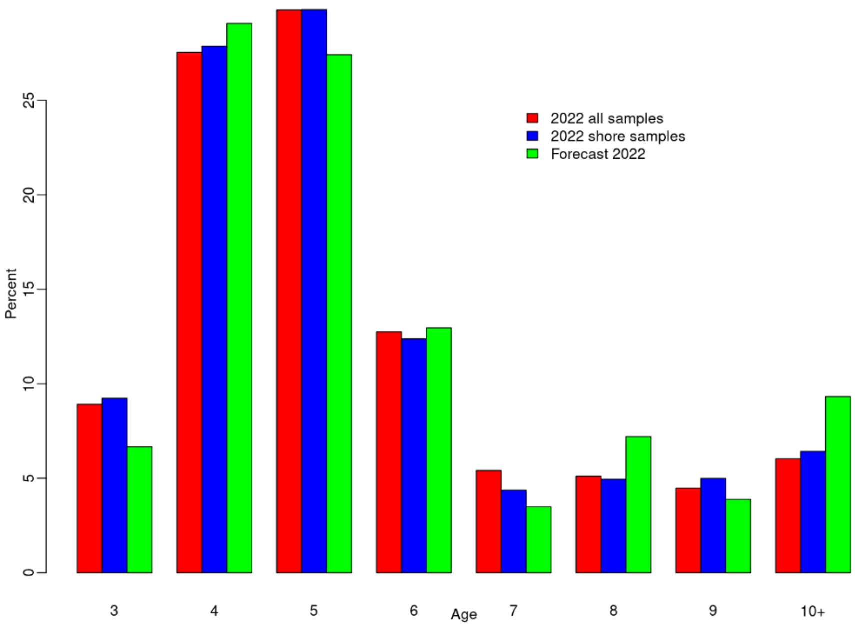


Figure 9. Saithe. Catch in numbers 2022 compared to last year's prediction. The green bars show catch in numbers only based on shore samples.

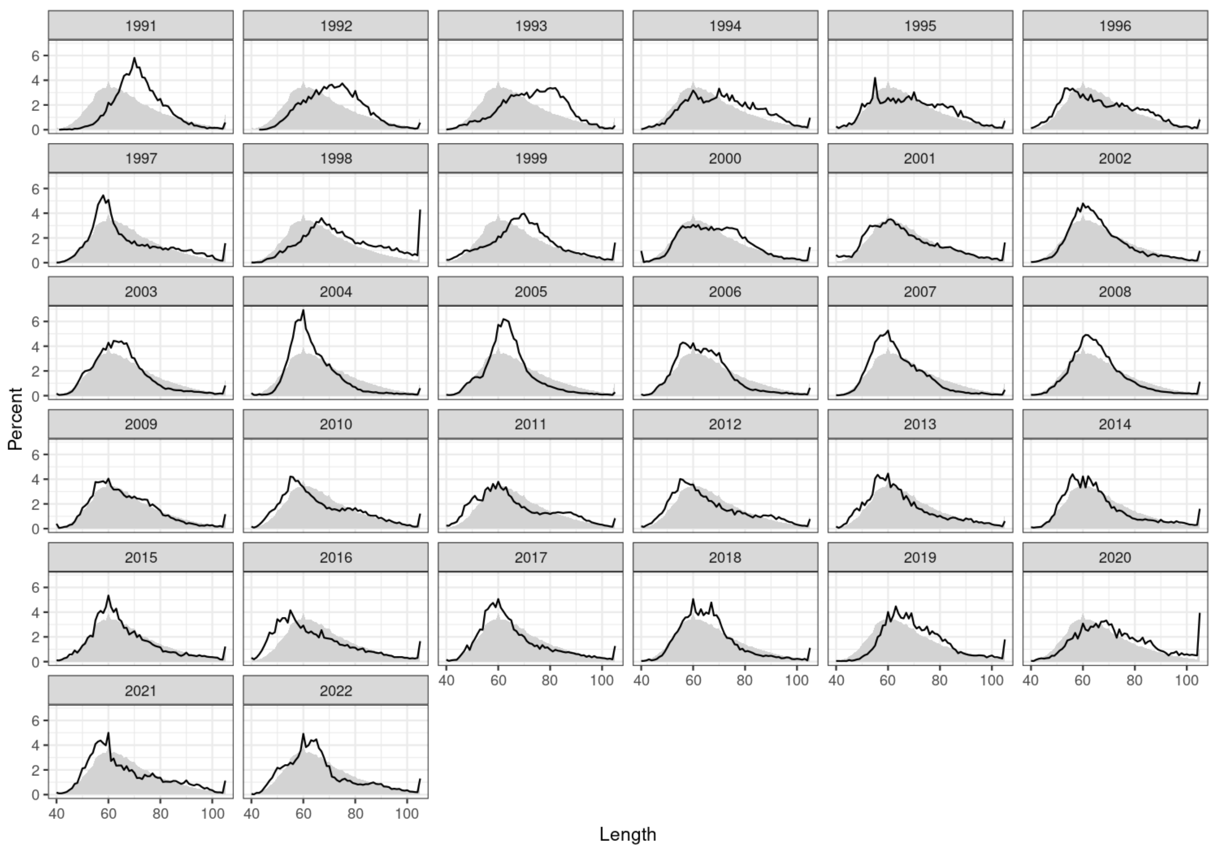


Figure 10. Saithe. Length distributions from bottom trawl catches (lines) compared to average (grey shading). 105cm is a plus group and the value there shows how large proportion of the number caught is 105 cm and larger.

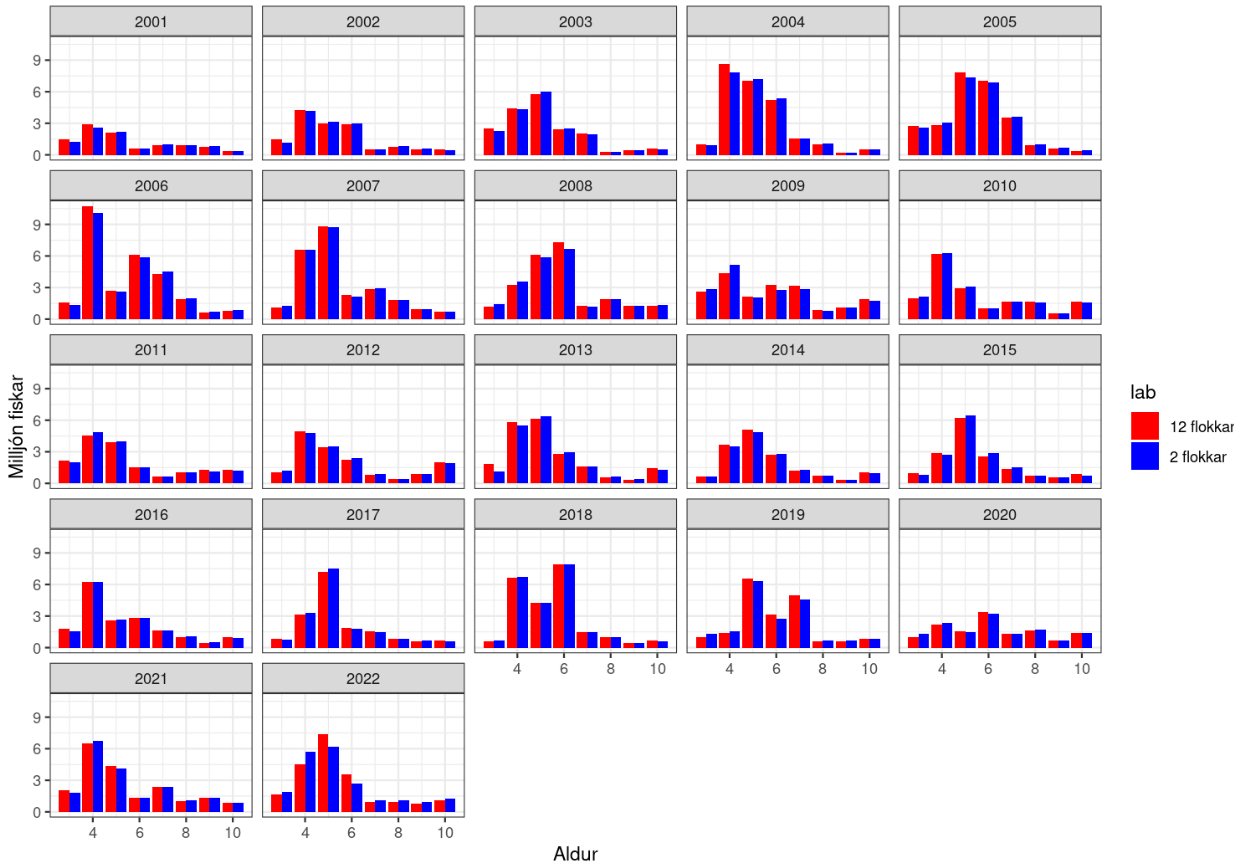


Figure 11. Saithe. Catch in numbers 2000–2021 compiled by 1 region and 1 time interval (old) compared to catch in numbers compiled by two regions and two time-intervals (new). The regions are shown in Figure 5, north red and yellow and south blue and black.

MEAN WEIGHT AND MATURITY AT AGE

Weights of ages 3–6 have been low in recent years, but older ages are close to average weight (figures 12–14). The large 2012 cohort has the lowest mean weight of all year classes, both in catches and in the survey. This is in line with density dependent growth that has been observed in this stock and can for example be seen for year classes 1984 and 2000 that are both large. Year classes 2013 and 2014 that seem to be above average have higher mean weight at age than the 2012 cohort. The long-term trend since 1980 has been a gradual decline in the mean weight of all ages. Mean weight at age in catches was close to average in 2022 for most age groups, little lower than in 2021.

Weight at age in the landings are used to compile the reference biomass (B4+) that is the basis for the catch advice. Catch weights are also used to compile the spawning stock. Catch weights for the assessment year are predicted by applying a linear model using survey weights in the assessment year and the weight of the same year class in catches in the previous year as predictors (Magnusson, 2012; ICES, 2019b).

Maturity at ages 4–9 has decreased in recent years and is currently below average since 1985 (Figure 11). A model using maturity at age from the Icelandic groundfish spring survey is used to derive smoothed trends in maturity by age and year (ICES, 2019b).

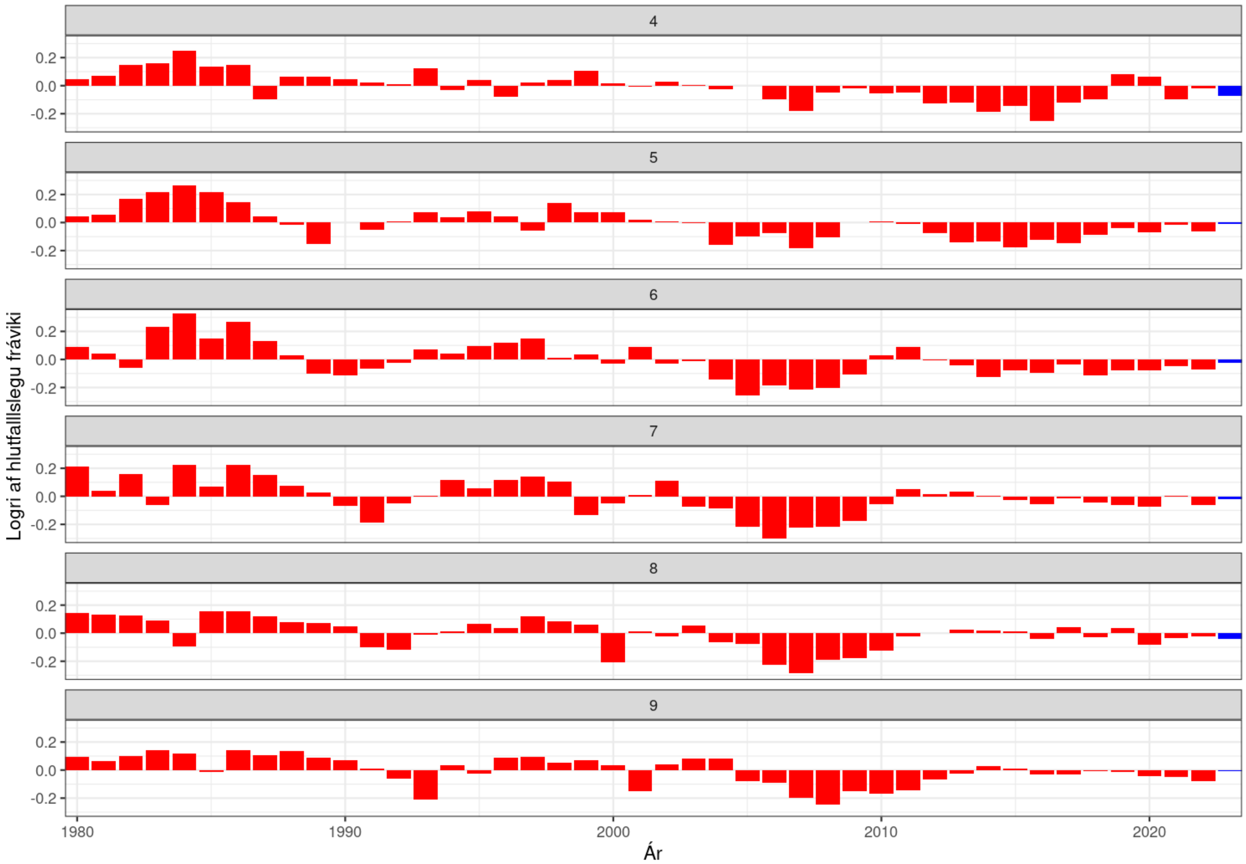


Figure 12. Saithe. Weight at age in the catches, as relative deviations from the mean. Blue bars show prediction.

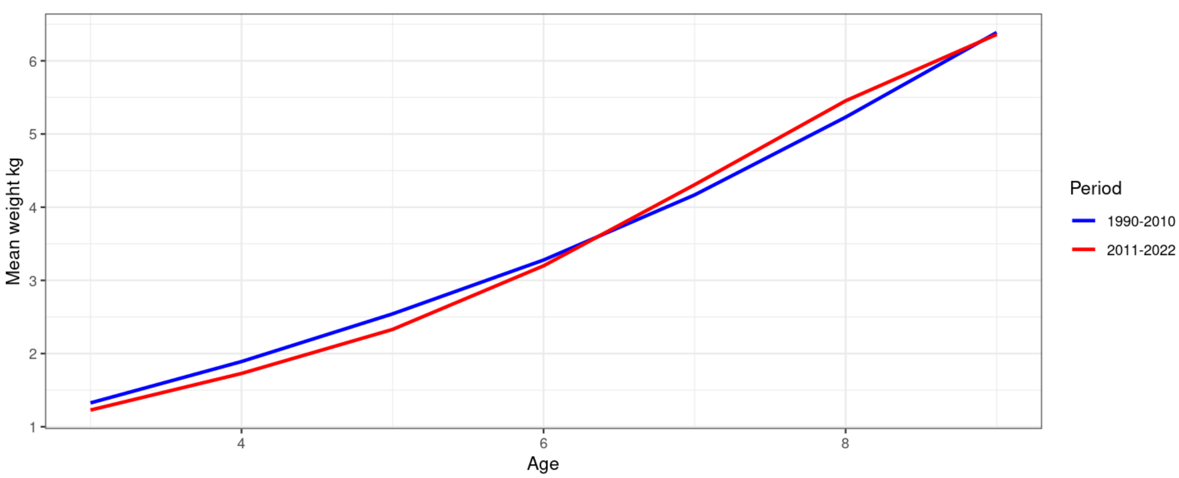


Figure 13. Saithe. Weight at age in the catches shown as average for 2 periods.

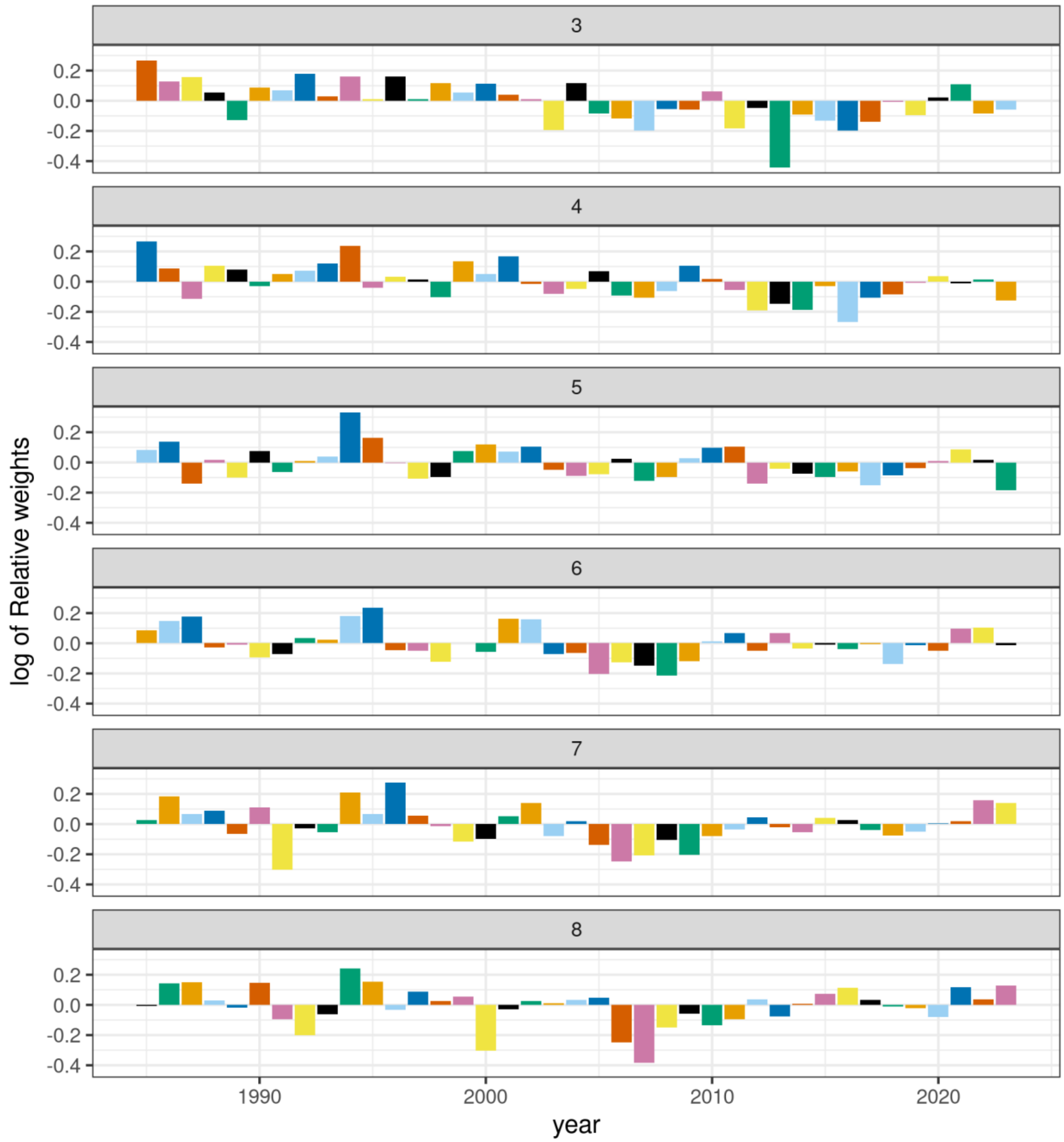


Figure 14. Saithe. Weight at age in the survey, as relative deviations from the mean. Colours indicate year classes.

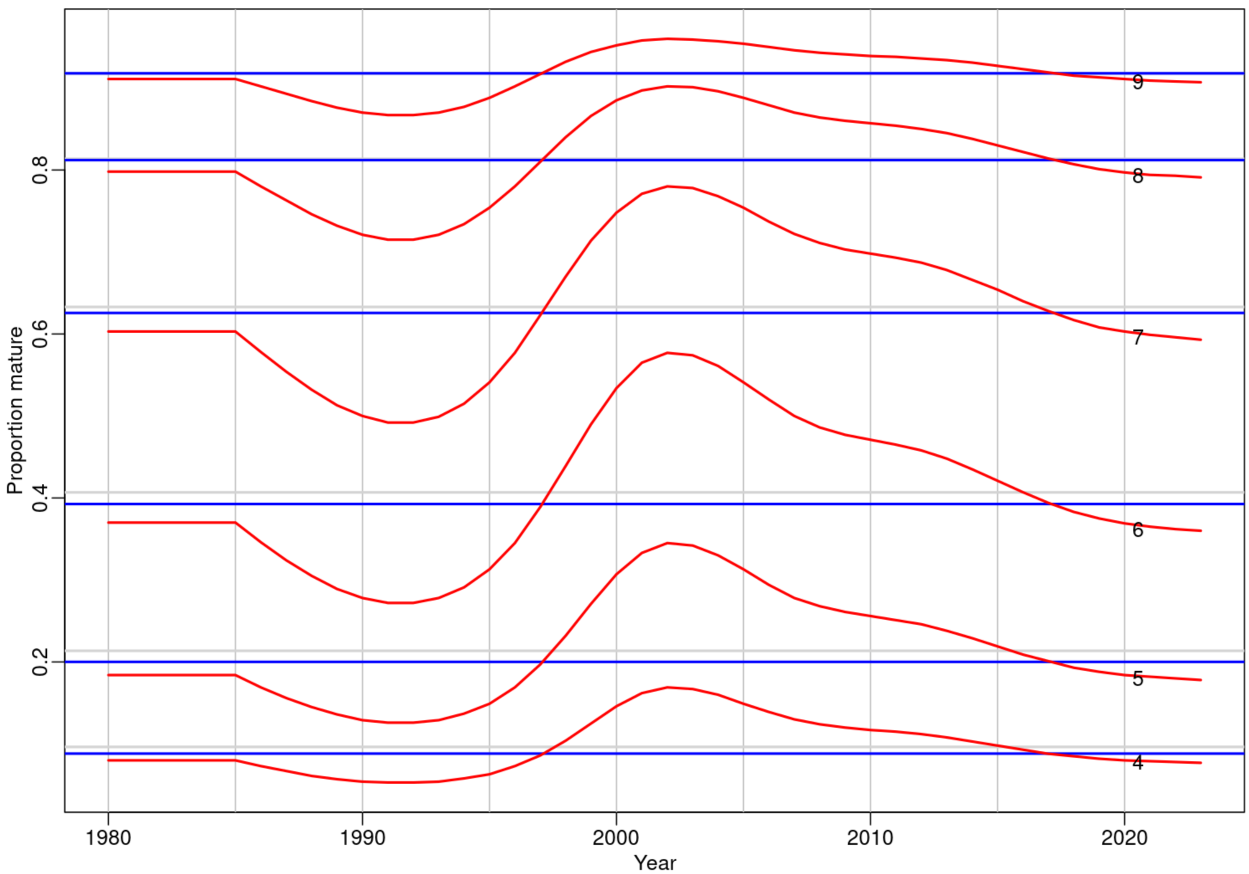


Figure 15. Saithe. Maturity at age used for calculating the SSB. The horizonal lines show the average of last 10 years (blue lines) and the average since 1985 (grey lines).

SCIENTIFIC SURVEYS

In the benchmarked assessments from 2010 and 2019, only spring survey data are used to calibrate the assessment. Compared to the autumn survey the spring survey has larger number of stations (lower CV) and longer time series. Saithe is among the most difficult demersal fishes to get reliable information from bottom trawl surveys. In the spring survey, which has 500–600 stations, a large proportion of the saithe is often caught in relatively few hauls and there seems to be considerable inter-annual variability in the number of these hauls.

The biomass indices from the spring survey (Figure 12) fluctuated greatly from 1985–1995 but were consistently low from 1995–2001. Since 1995 the indices have been variable but compared to the period 1985–1995 the variability seems "real" rather than noise. This difference is also seen by the estimated confidence intervals of the indices that are smaller after 1995. In 2018 the indices were the highest in the series and had tripled since 2014 (Table 7 and Figure 12). Most of the increase was caused by year class 2012 that was strong in the surveys 2015–2018 (Figure 14). The index reduced much from 2018-2020. It has been variable in last 4 years, was lowest in 2022 but increased again in 2023.

Estimated CV from the survey is often relatively high and many relatively low values appear in the survey matrix, both for the youngest and oldest age groups. The youngest age group (age 3–4 and younger) are considered to inhabit waters shallower than the survey covers and the older age groups are reducing in numbers and could also be pelagic. The high index in 2018 came from relatively large catches in many hauls so the estimated CV was around average. CV in 2023 was low.

The autumn survey shows similar trend as the spring survey and the index is at high level in 2017 (2004 and 2018 are outliers due to large CV). The values before 2000 might be underestimate due to stations added in 2000 (Figure 5) where large schools of saithe are sometimes found. Excluding these stations leads to lower but more stable index. An index based only on the stations taken since 1996 shows much difference between 1996-2000 and 2001-2022.

Catch curves from the survey indicate that Z ~ 0.5 assuming similar q with age (Figure 22).

Indices from the gillnet survey (SMN) conducted south and west of Iceland since 1996 were at highest level in 2019 but have decreased since then (Figure 13). Compared to earlier years the 2023 index in SMN is high. SMN is mostly targeting large saithe (mean weight in 2023 was 6.6 kg). The indices from SMH and SMN that are not used for tuning in the assessment indicate relatively good state of the stock.

To summarize, survey indices and CPUE from last 4-5 years indicate decreasing stock but looking over a longer period they indicate stock size above average.

The high index in March 1986 (Figure 18) is mostly the result of one large haul that is scaled down to the second largest haul when compiling indices for tuning. The scaling is from 16 tonnes to 1 ton.

Internal consistency in the March survey measured by the correlation of the indices for the same year class in 2 adjacent surveys is relatively poor, with R^2 close to 0.46 where it is highest (Figure 21).

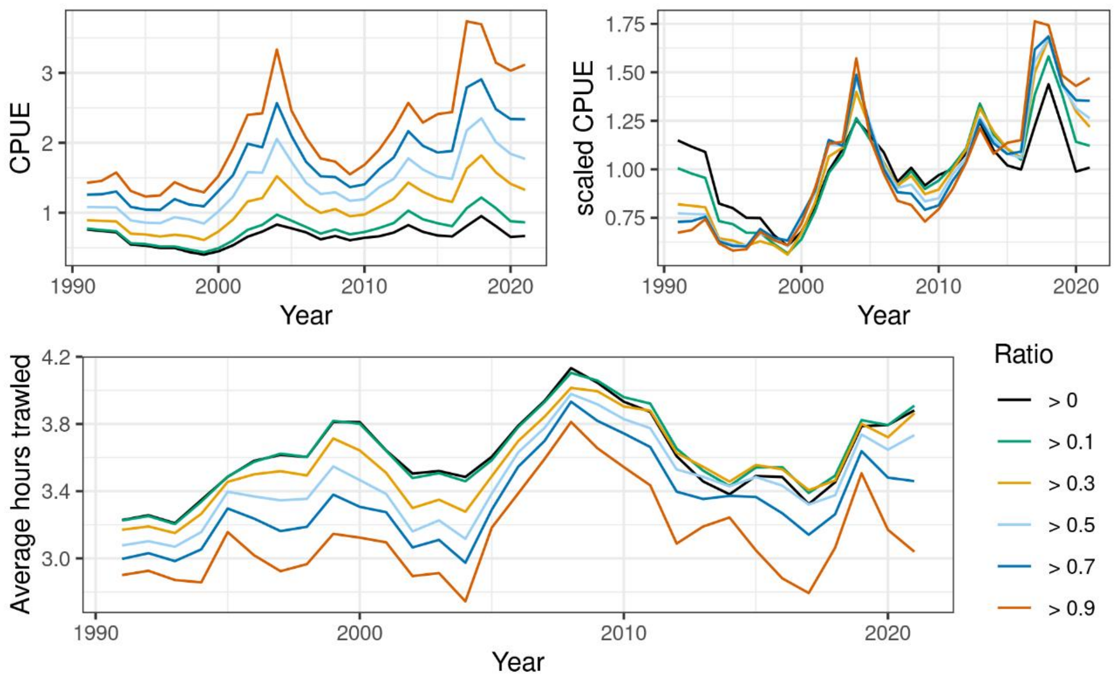


Figure 16. Saithe. CPUE, CPUE scaled to an average of 1 and average numbers of hour trawled. Different colours indicate selection of tows where proportion of saithe of the total catch exceeds certain specified value.

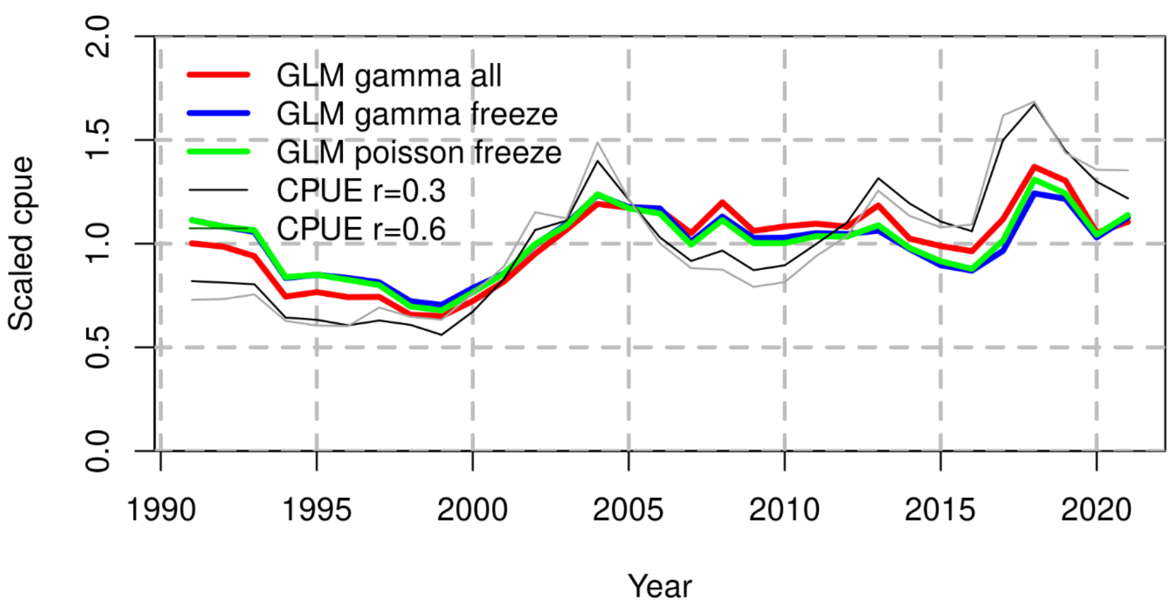


Figure 17. Saithe. CPUE compiled from 3 different models compared to CPUE compiled in similar way as shown in figure 16. All curves scaled to an average of 1.

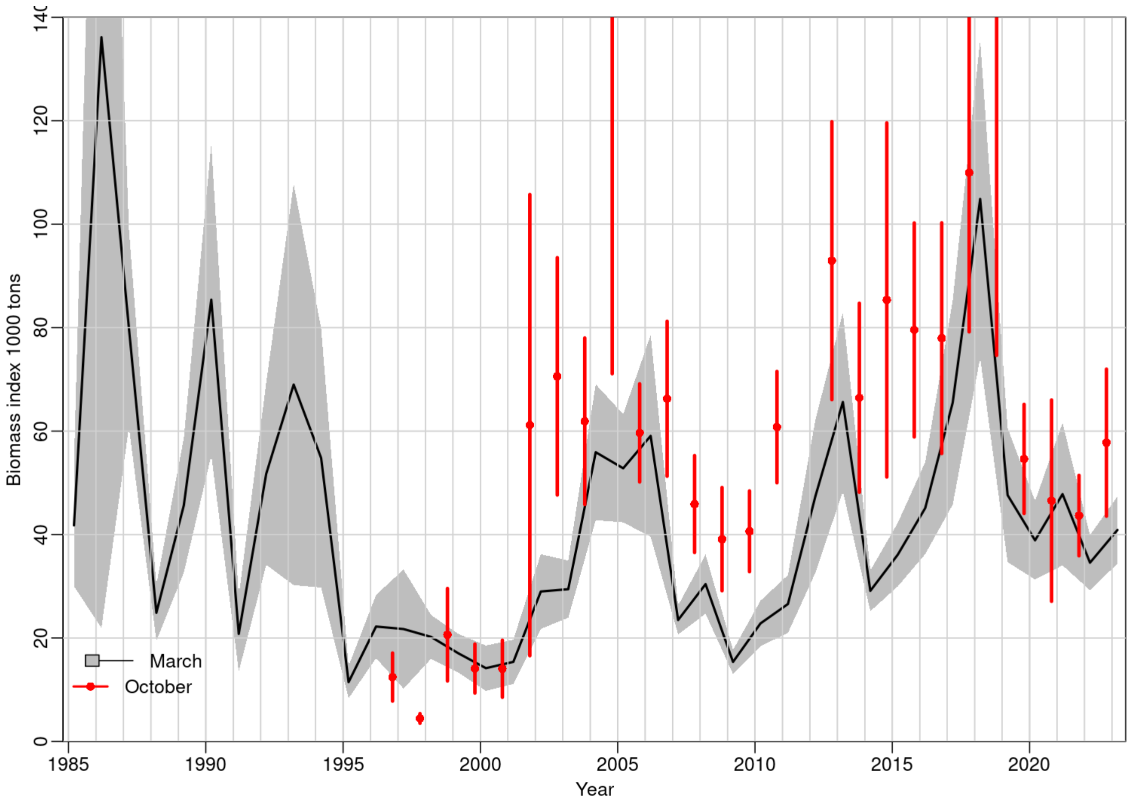


Figure 18. Saithe. Biomass index from the groundfish surveys in March and October.

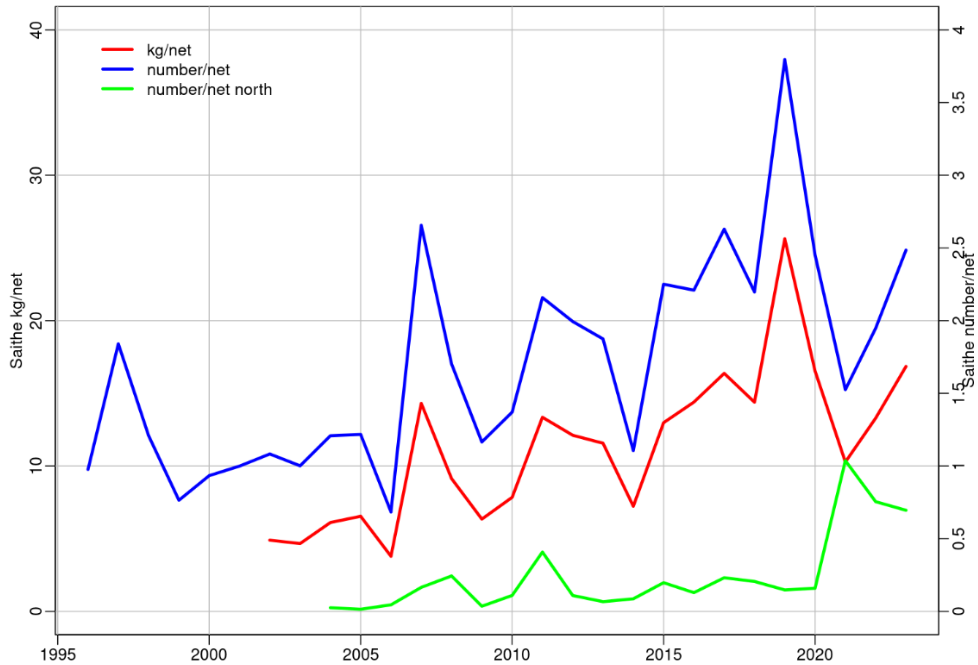


Figure 19. Saithe. Indices from the gillnet survey in April 1996–2022. Saithe was not length measured in the survey before 2002 so catch in kg cannot be compiled.

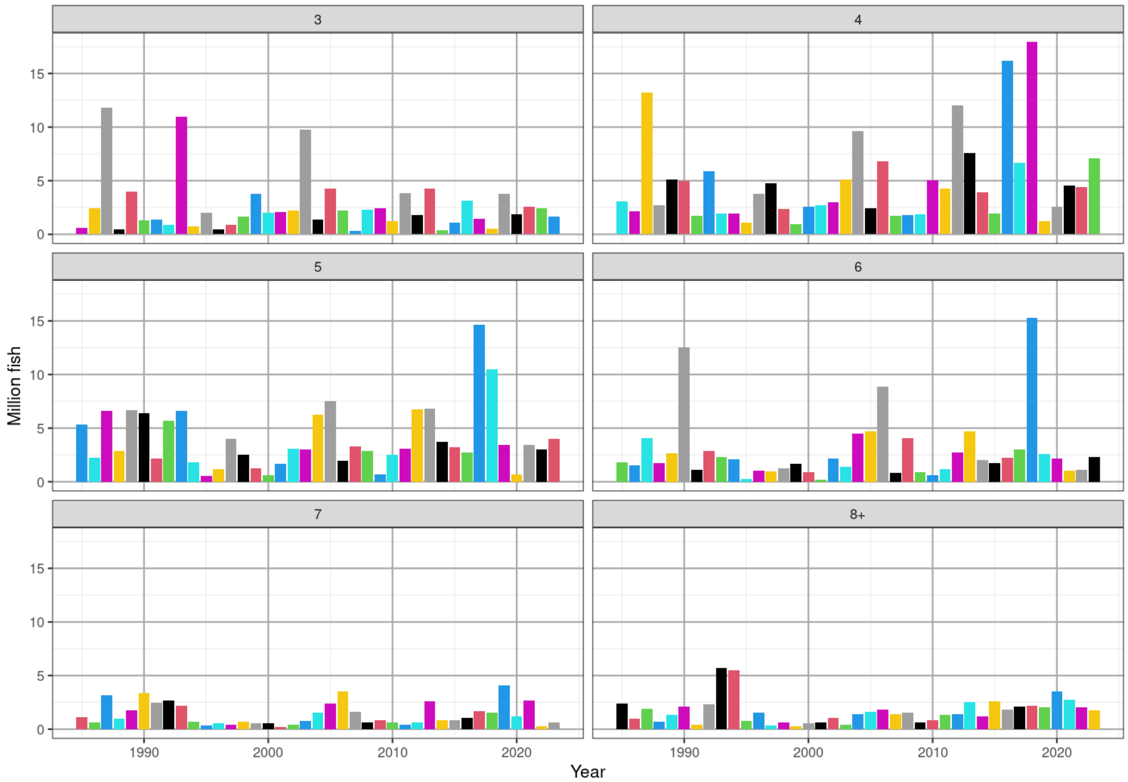


Figure 20. Saithe. Survey indices by age from the spring survey. The colours follow year classes except of course for age 8+.

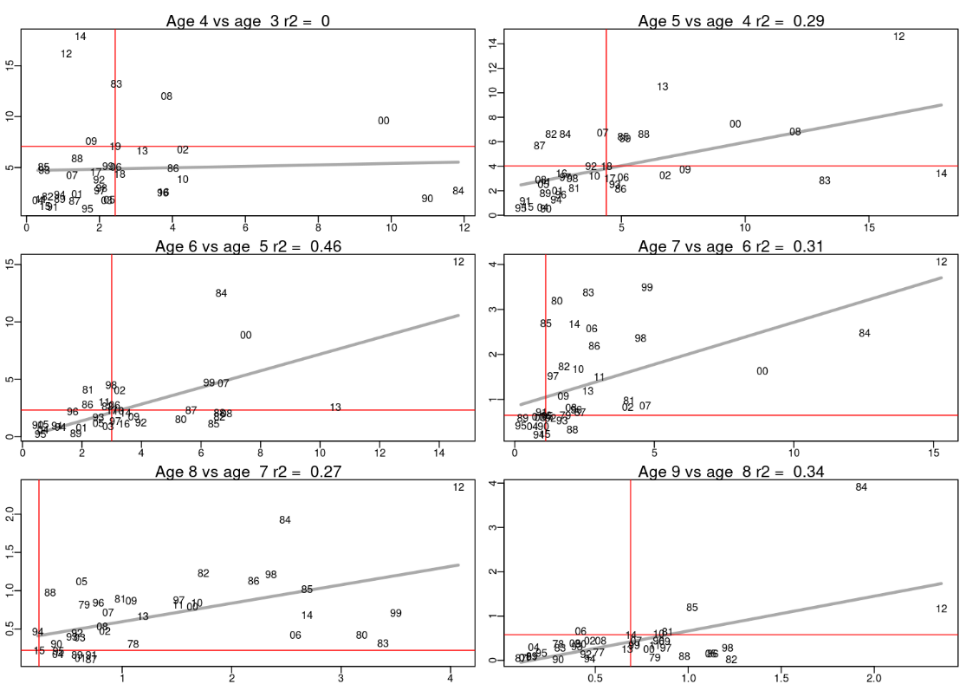


Figure 21. Saithe. Survey indices by age from the spring survey plotted against indices of the same cohort one year earlier. Most recent pair is shown by intersection of the red horizonal and vertical lines.

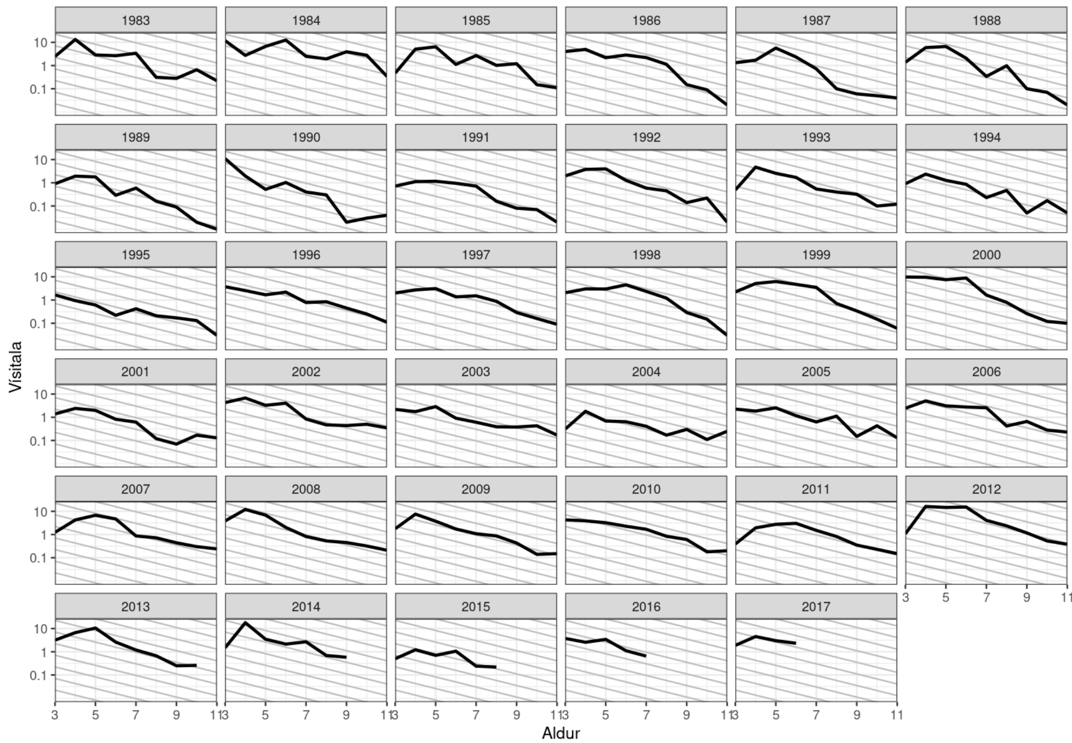


Figure 22. Saithe. Survey indices by age from the spring survey plotted as catch curves for each year class. The grey lines correspond to Z=0.5.

ASSESSMENT METHOD

In accordance with the recommendation from the benchmark (ICES, 2019a), a separable forward-projecting statistical catch-age model Muppet (Björnsson 2019), developed in AD Model Builder, is used to fit commercial catch at age (ages 3–14 from 1980 onwards) and survey indices at age (ages 2–10 from 1985 onwards). The selectivity pattern is constant within each of 3 periods (Figure 23). Natural mortality is set at 0.2 for all ages.

To take low values in the survey series into account the survey residuals are compiled as $\frac{log(I+\epsilon)}{log(\hat{I}+\epsilon)}$ where ϵ is a number that should avoid giving low values too much weight as they do in log-log fit. Typical value of ϵ is the value that 3–4 otoliths will give, that would be 0.15 for saithe. Higher values are used for saithe 0.3 for the older ages, 0.5 for ages 3–5 and 0.7 for age 2, a value giving age 2 very low weight except the index if very high. The survey residuals ($\frac{log(I+\epsilon)}{log(\hat{I}+\epsilon)}$) are modelled as multivariate normal distribution with the correlation estimated (one coefficient).

The assessment model is also used for short term forecast, the Muppet model can't be run without prediction. Future weights, maturity, and selectivity for short term prognosis are assumed to be the same as in the assessment year, as described in the stock annex. Recruitment predictions are based on the segmented stock-recruitment function estimated in the assessment model which is essentially geometric mean when the stock is above estimated break point that is near B_{loss}.

REFERENCE POINTS AND HCR

In April 2013, the Icelandic government adopted a management plan for managing the Icelandic saithe fishery (Ministry of Industries and Innovation, 2013). ICES evaluated this management plan and concluded that it was precautionary and in conformity with ICES MSY framework.

The management plan for the Icelandic saithe fishery, adopted for the first time in 2013 was re-evaluated by ICES in March 2019 and found to be precautionary and in conformity with ICES MSY approach (ICES, 2019a).

The TAC set in year t is for the upcoming fishing year, from 1 September in year t, to 31 August in year t+1. The TAC according to the management plan is calculated as follows.

If $\mathrm{SS}B_y \geq MGMTB_{\mathrm{trigger}}$

$$\mathrm{Ta}c_{y/y+1} = \frac{\mathrm{Ta}c_{y-1/y} + 0.2 \times B_{4+,y}}{2}$$

If $\mathrm{SS}B_y \leq MGMTB_{\mathrm{trigger}}$

$$\mathrm{Ta}c_{y/y+1} = \alpha \times Tac_{y-1/y} + (1-\alpha) \times \frac{\mathrm{SS}B_y}{\mathrm{MGMTB}_{\mathrm{trigger}}} \times 0.2 \times B_{4+,y}$$

$$\alpha = 0.5 \times \frac{\mathrm{SS}B_y}{\mathrm{MGMT}B_{\mathrm{trigger}}}$$

Where $\mathrm{Ta}c_{y/y+1}$ is the TAC for the fishing year starting 1 September in year y ending 31 August in year $y+1$. $B_{4+,y}$ the biomass of age 4 and older in the beginning of the assessment year compiled from catch weights. The latter equation shows that the weight of the last years Tac does gradually reduce from 0.5 to 0.0 when estimated SSB changes from $\mathrm{MGMTB}_{\mathrm{trigger}}$ to 0.

Reference points were also re-evaluated at WKICEMSE 2019 (See table below and ICES, 2019a). B_{lim}, B_{pa}, $MSYB_{trigger}$, HR_{MSY} and HR_{Mgt} were unchanged, $MGMTB_{trigger}$ changed from 65 to 61 thous. tonnes and HR_{lim} and HR_{pa} were defined but earlier F_{lim} and F_{pa} had been defined.

Item	B_{lim}	B_{pa}	$MSYB_{trigger}$	$MGTB_{trigger}$	HR_{MSY}	HR_{Mgt}	HR_{lim}	HR_{pa}
Value	44	61	61/65	61	0.2	0.2	0.36	0.26/0.25
Basis	B_{loss}/1.4	B_{loss}	B_{pa}	B_{pa}	Stochastic simulations.			

The recipe to evaluate MSY $B_{trigger}$ and HR_{pa} has changed since 2019 so those reference points were evaluated based on the same simulations as in 2019, leading to MSY $B_{trigger}$ = 65 thousand tonnes and HR_{pa} = 0.25.

Harvest rate was changed in the 2023 assessment from $HR_y = \frac{C_{y/y+1}}{B_y}$ to $HR_y = \frac{C_y}{B_y}$. The former method is thought to indicate better how the manage plan works but the latter method was considered by an advice group as a better indicator of fishing pressure.

STATE OF THE STOCK

The results of the principal stock quantities (Figure 24) show that the reference biomass (B4+) has historically ranged from 136 to 415 kt (in 1999 and 1988), but this range has been narrower since 2003, between 235 and 335 kt. The current estimated stock size of $B4+_{2023}$ = 309 kt is above average (75th percentile). Spawning biomass is estimated as 142 kt, also near 75th percentile since 1980 and well above B_{pa} (61 thous tons).

The harvest rate peaked around 32 % in the mid 1990's but has since 2013 been below HR_{Mgt} target of 20% on the average. The explanations for close to intended harvest rate since 2013 are two factors that cancel each other out.

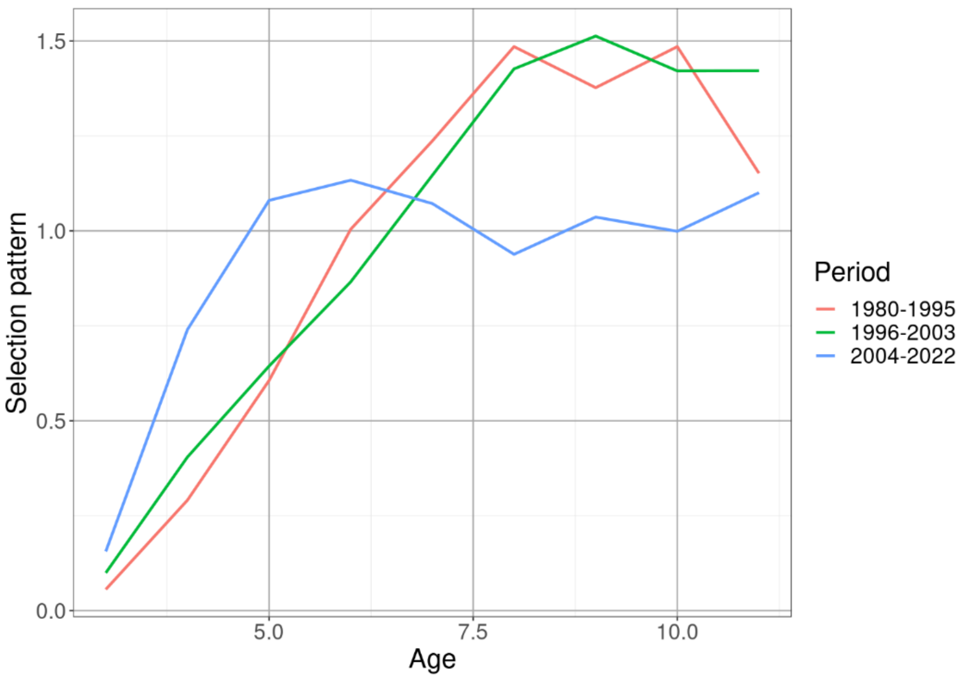
- The allocated TAC has not been caught.
- The stock has on the average been overestimated.

Fishing mortality has been low since 2000 compared to before that. Part of the difference is caused by change in selection pattern (Figure 23) that leads to $F_{4\text{-}9}$ before and after 2003 not being comparable measures of fishing pressure. SSB has been at a relatively high level during the last ten years.

Recruitment has been relatively stable since year class 2006, and slightly higher than before. Year class 2012 is estimated to be strong and year classes 2013 and 2014 above average. Year class 2015 is estimated as poor but year classes 2017–2019 above average. Geometric mean is the first guess in the model for each year class. Deviations from the mean are then driven by the survey and catches but survey indices for ages 3 and 4 have been around average in recent years, except for year class 2015 where all survey indices have been low and the year class estimated poor since in the 2018 assessment.

The commercial catch-at-age residuals in 2022 (Figure 28) are negative for age 10 but positive for age 7. Age 10 is the largest yearclass for 20 years (2012) and age 7 the smallest (2007). The survey residuals (Figure 27) show large positive values in 2017 and 2018 for ages 4–7, the age groups accounting for most of the biomass, therefore the survey biomass in 2018 exceeds prediction by large margin (Figure 26). The survey residuals in 2023 are small and the survey biomass in 2023 is above prediction (Figure 8.26).

Assumptions about catch in the assessment year deviate from the stock annex (ICES, 2019b) that specifies the catch in the calendar year 2023 as the remaining TAC from the fishing year 2022/2023 on 1 January 2023 plus 1/3 of the catch in the fishing year 2023/2024. 55 thousand tonnes of the catch for the fishing year 2022/2023 were remaining 1 January and the total catch for the year 2023 will be 77 thousand. tonnes following this procedure. Development of landings (Figure 2) indicate that the catch for the fishing year 2022/2023 will be around 56 thous. tonnes so the parameter "remaining TAC" in the model is set to 40 thousand tonnes. The advice for next fishing year is based on biomass in the beginning of the assessment year so assumptions about catch in the assessment year do not affect the advice.



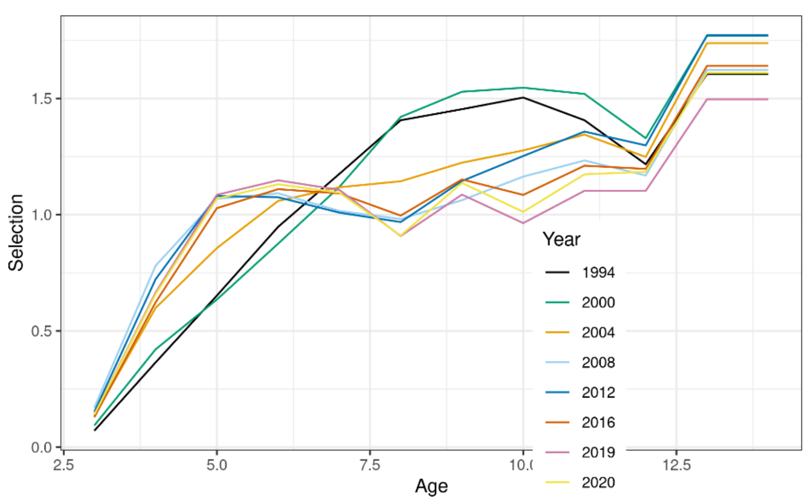


Figure 23. Saithe. Upper figure. Estimated selectivity patterns for the 3 periods, 1980–1996, 1997–2003 and 2004–2021. Lower figure estimated selection from the SAM model. The timing of selection change around 2004 is also evident in the SAM model results.

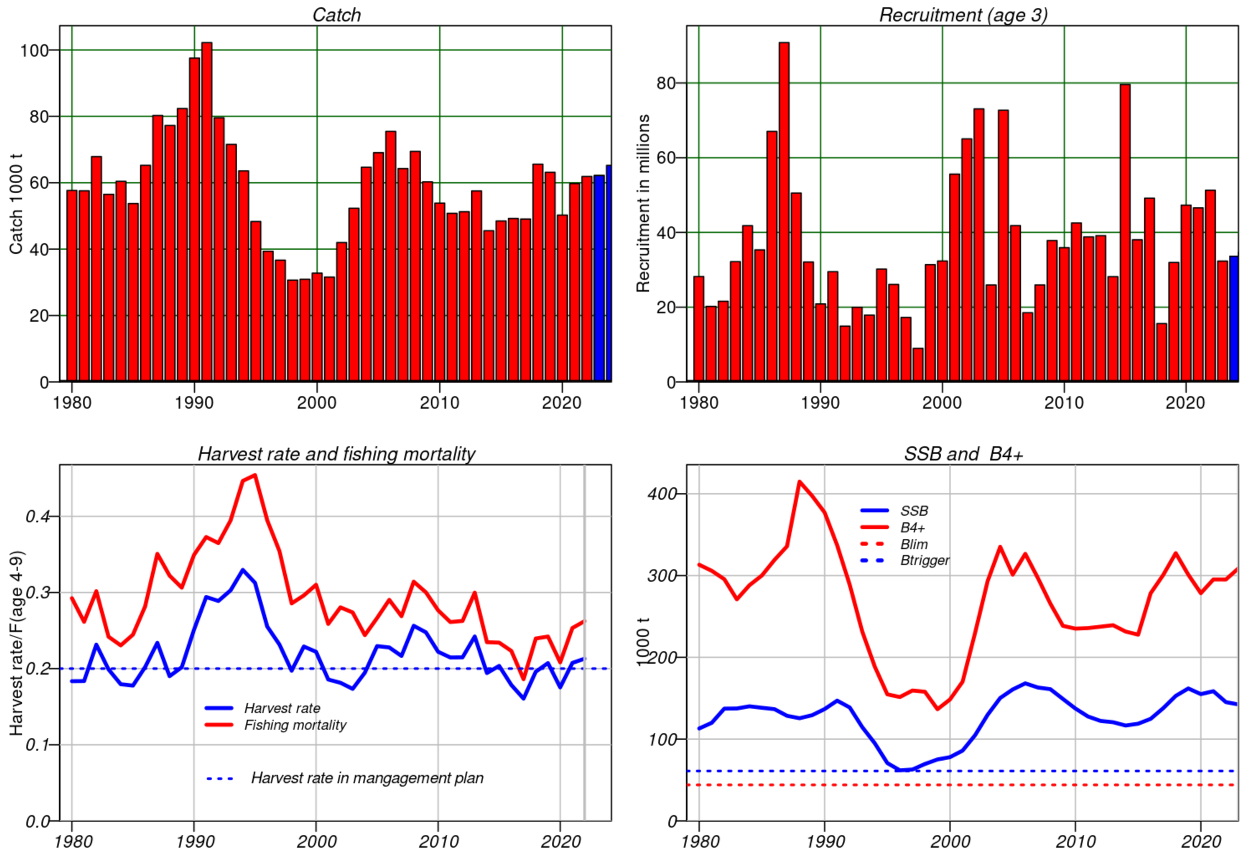


Figure 24. Saithe. Results from the adopted benchmark (SPALY) model and short-term forecast.

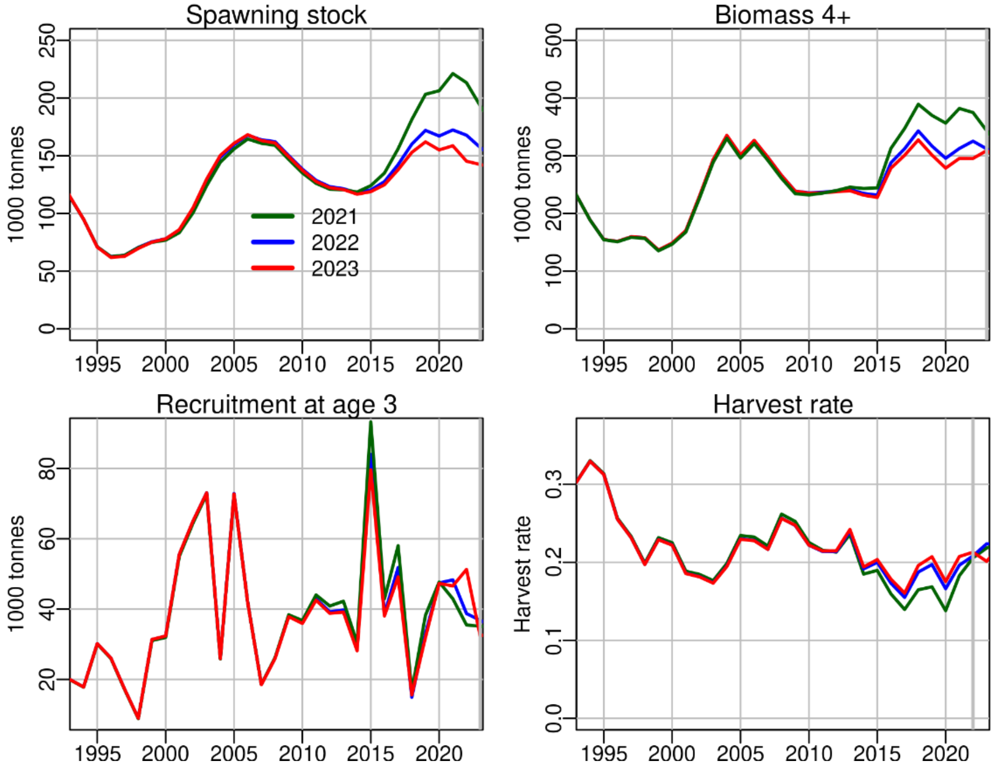


Figure 25. Saithe. Comparison of this year's assessment and short term forecast with results from two earlier years.

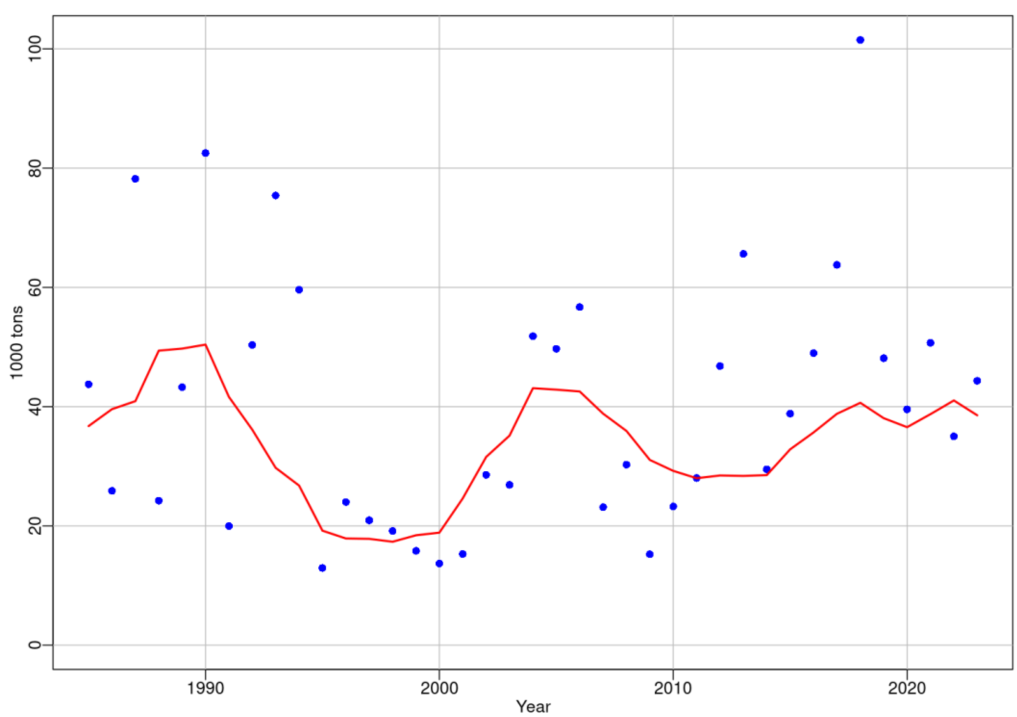


Figure 26. Saithe. Observed and predicted survey biomass from the "adopted model".

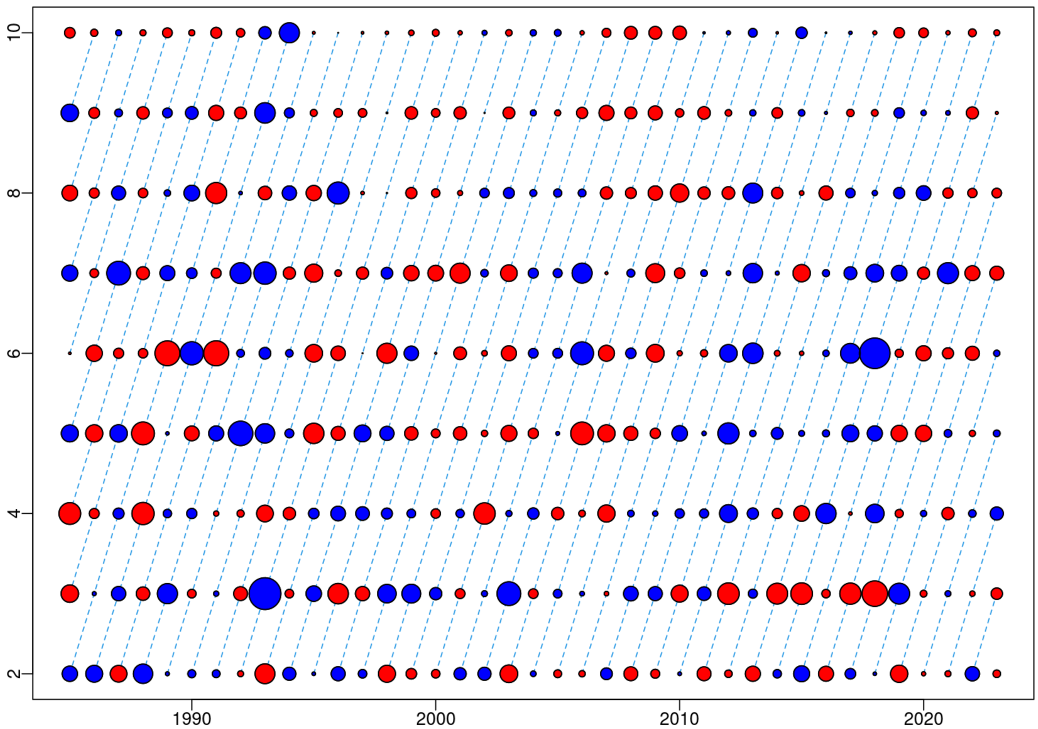


Figure 27. Saithe. Survey residuals from the "adopted model". The residuals are standardised. Blue circles indicate positive residuals.

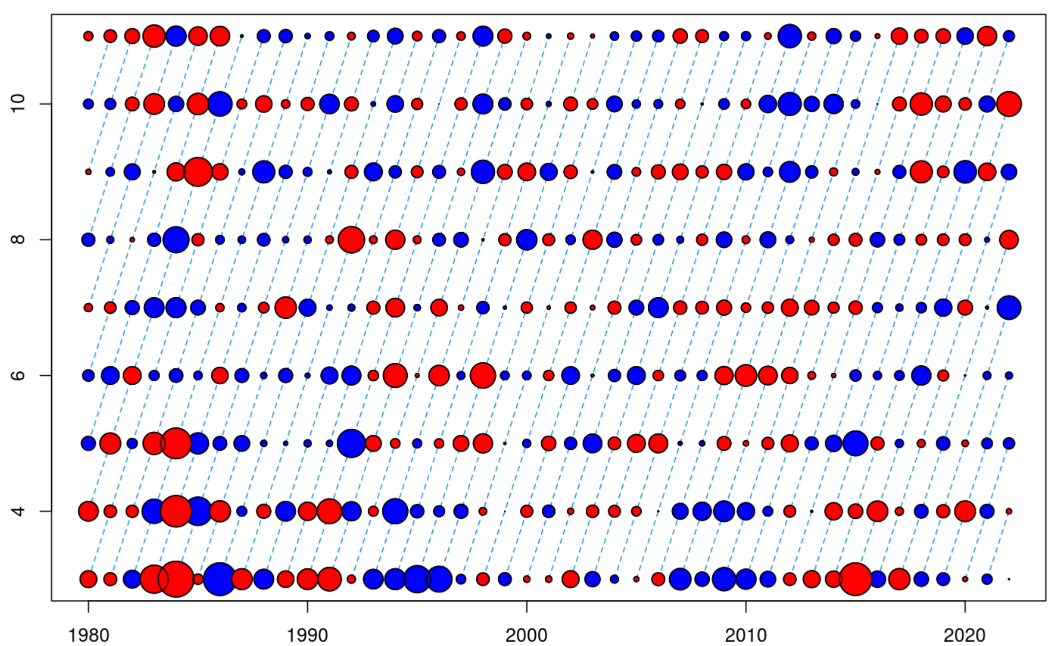


Figure 28. Saithe. Catch residuals from the "adopted model". Blue circles indicate positive residuals observed > predicted.

UNCERTAINTIES IN ASSESSMENT AND FORECAST

The assessment of Icelandic saithe is relatively uncertain due to fluctuations in the survey data, poor recruitment estimates and irregular changes in the fleet selectivity. The internal consistency in the spring bottom trawl surveys is low for saithe (Figure 21). This is not surprising, considering the nature of the species that is partly pelagic, schooling, and relatively widely migrating. Uncertainty estimates in the assessment model indicate that CV of the biomass 4+ is around 19%, rather high value for this kind of estimate that is usually underestimation of the real uncertainty.

The 2023 assessment is downward revision of the stock compared to the 2022 assessment, biomass 4+ is estimated 6% lower than last year.

The retrospective pattern (Figure 29) reveals some of the assessment uncertainty. The harvest control rule evaluations incorporated uncertainties in assessment (based on difference between converged and contemporary assessments) as well as other sources of uncertainty (ICES, 2019a).

Using retrospective pattern based on the assessment years 2018–2022 Mohns ρ is 0.3 for the reference biomass, -0.20 for the Harvest rate, 0.35 for SSB and 0.1 for recruitment (Table 1). The retrospective pattern in the last 5 years is caused by the high 2017-2018 indices and then again, the relatively high 2021 index. Higher Mohns ρ for the SSB than for B4+ is not unexpected as old/large saithe are due to pelagic behaviour difficult to catch by demersal gear. Low harvest rate leads to downward revision of the stock extending many years back.

Looking at metrics from nearly converged assessment the values are shown in Table 2 based on assessment years 2000–2018 (The adopted assessment is called Stdsettings).

Bias is defined as $\overline{log(\frac{B_{y,y}}{B_{y,assY}})}$ and CV as $\sigma^{log(\frac{B_{y,y}}{B_{y,assY}})}$. Mohns rho is really another way to present bias.

CV of B4+ from the adopted model is 0.22, first order autocorrelation 0.5 (uncertain estimate) and bias -0.0 compared to Mohns ρ of 0.25 based on the 5 years peel (5 last assessments). The 2018 assessment has large effect for the past 5 years but the pattern since 2000 has been periods of over and underestimation and Mohns ρ based on 5-year peel would have varied considerably during this period, an indication of autocorrelation of assessment error (figure 33).

Alternative settings of the Muppet model and one SAM run were tested (Figure 30). The result show low estimated biomass when the survey data are downweighed, the same result is obtained with the leaveout run in SAM, both indicating that catch in numbers indicate smaller stock compared to survey indices. The estimated uncertainty in the run where the survey is downweighted though very high ($CV_{b4+} \approx 0.4$). Winsorized survey results lead to less noise and more weight on the survey in the assessment. The Adapt model used is just the Muppet model, using N of the oldest fish from the forward running model. The backwards running model is selected by changing one number in the main input file. A major advantage with the Adapt model is that CV of survey can be estimated independently for each age group, if attempted in a catch at age model the survey CV of one age will be set to minimum. The "reweighted" model shows lower biomass than the Std settings but does also converge to lower biomass as the selection pattern of the older fish is different. Compared to last years the difference in B4+ from different models is smaller.

All the models except the model with less weight on survey show similar retrospective pattern in recent years (≈30% reduction in B4+ between assessment years 2018 and 2023).

The table below show $B4+_{2023}$, the number that matters for the advice. The values are in thousand tonnes.

Std settings 2023	Winchorised survey	Adapt	LessWeight on survey	Reweighed surveyCV	Ages 3-14 in survey.	Survey CV	Std settings 2022	SAM
309	391	290	196	274	348	287	312	334

This year and last year the adopted model is in the middle of the variants presented while it was near the high end in the 2021 assessment.

The SAM settings are correlated random walk, 3 observation variance blocks for the catches and 4 for the survey.

One problem in the assessment is the fact that the TAC has not been fished in some recent years (Figure 4). In spite of overestimation of the stock, the assessment models do not indicate high fishing mortality nor harvest rate in last 6 years (Figure 24), mostly because the TAC has not been fished. The selection pattern observed since 2004 (Figure 23) indicates that the fisheries are targeting younger fish than before, something that could be interpreted as lack of large fish. This trend is even greater than observed in the figure as mean weight at age of ages 4–5 have been low in recent years (Figure 12). The gillnet survey that is an indicator of large saithe shows high abundance in 2023 (Figure 19) and the autumn survey shows similar more positive trend compared to the March survey.

The problem seen in recent years is not new and the fact that fishing mortality of saithe was never high (ICES 2002), indicates that it is difficult to catch saithe. One reason is that most of the gear is demersal while saithe is partly pelagic. Change of fleet and fishing practice in recent 20 years might also have effects. But the fact that TAC has not been caught could indicate that the stock might be overestimated or at least that the TAC is too high.

The effect of too high TAC is increased catch of some other species through the transfer system and increased trawling effort trying to catch saithe but avoid other species. The best way to handle this problem is to reduce HR_{mgt} to make saithe fisheries fitting better in mixed fisheries. That solution would also help if the problem was bias in the assessment.

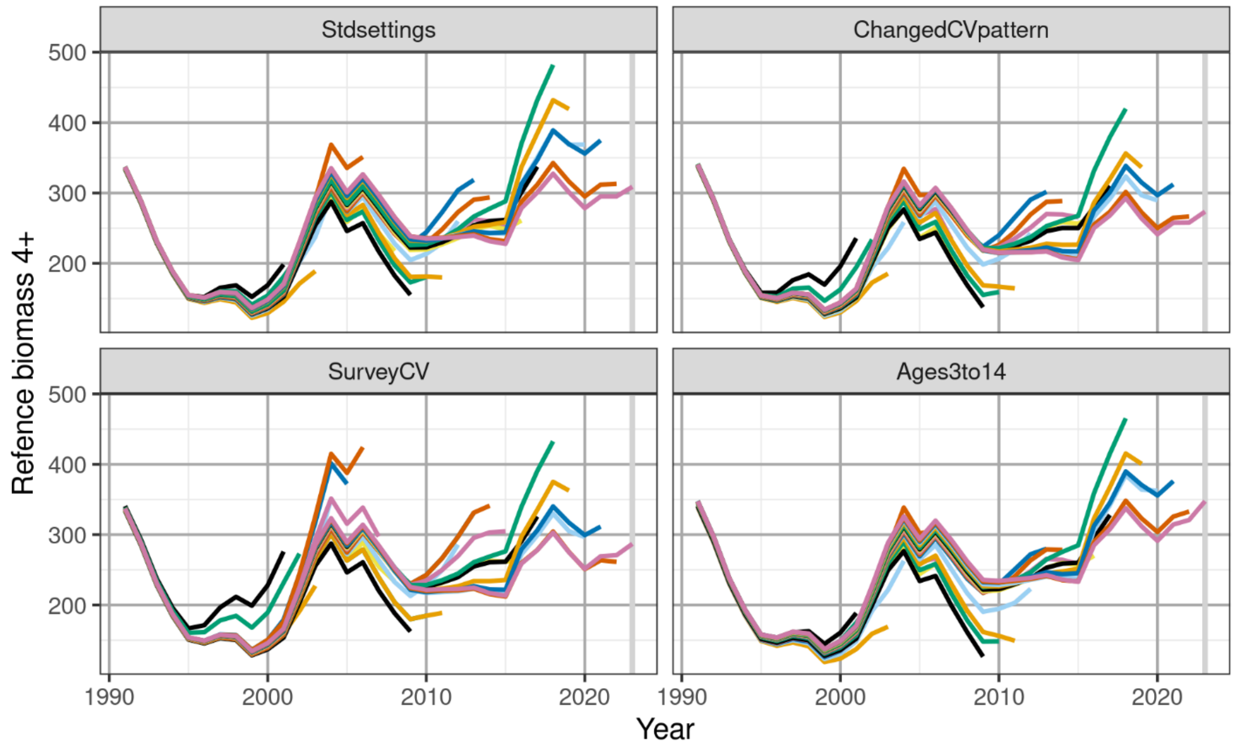


Figure 29. Saithe. Retrospective pattern for the adopted assessment model (Stdsettings) and alternative configurations of the model. The figure shows estimate of B4+, the metric affecting advised catch. The grey vertical lines show the year 2023.

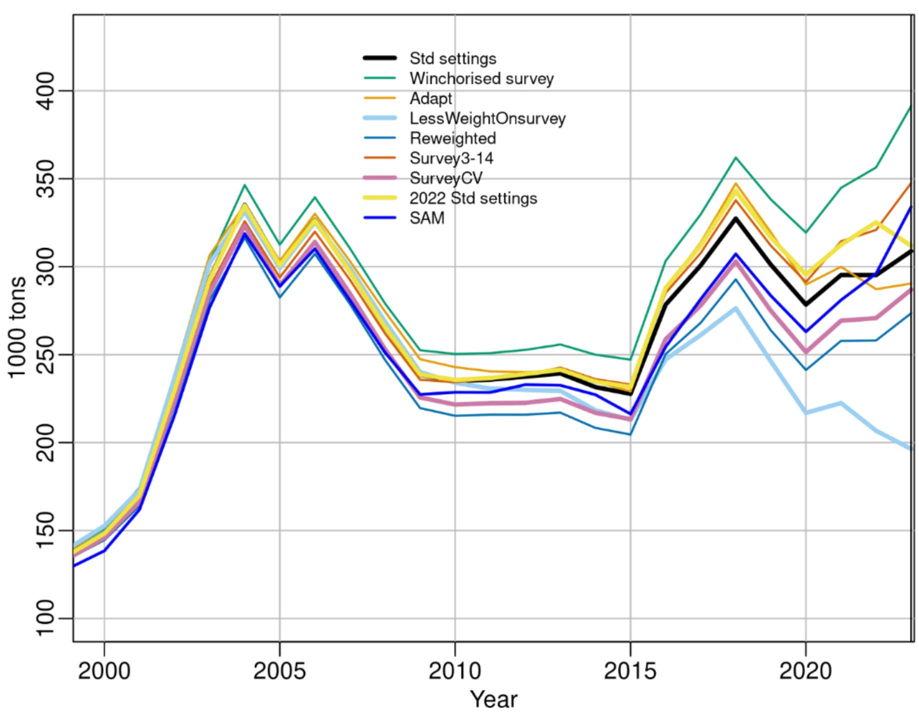


Figure 30. Saithe. Comparison between the default separable model (Muppet) and alternative assessment model settings.

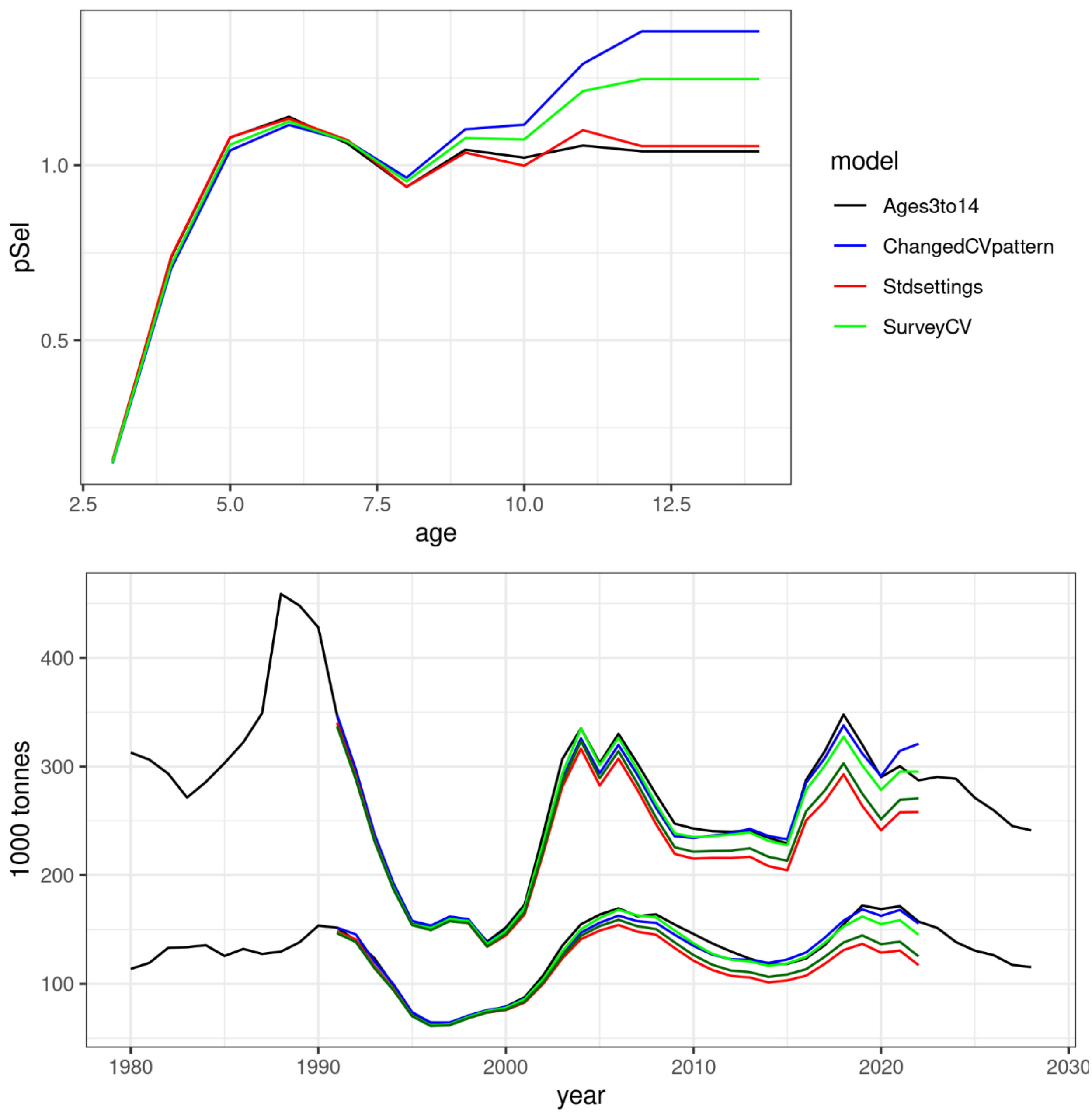


Figure 31. Saithe. Comparison between 2023 assessment results of the models shown in Figure 29. The Adapt model is added to the list shown there to see the “converged biomass”. The lower figure shows B4+ and SSB.

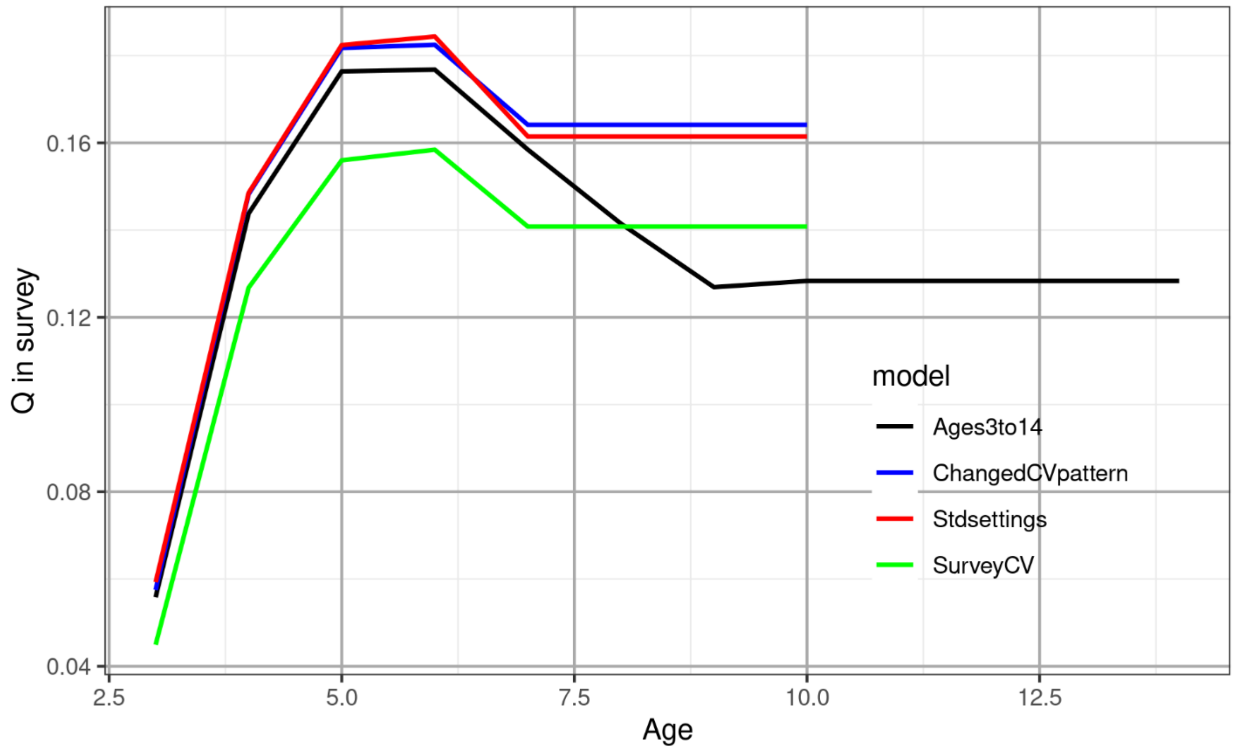


Figure 32. Saithe. Q by age in the March survey for the different models.

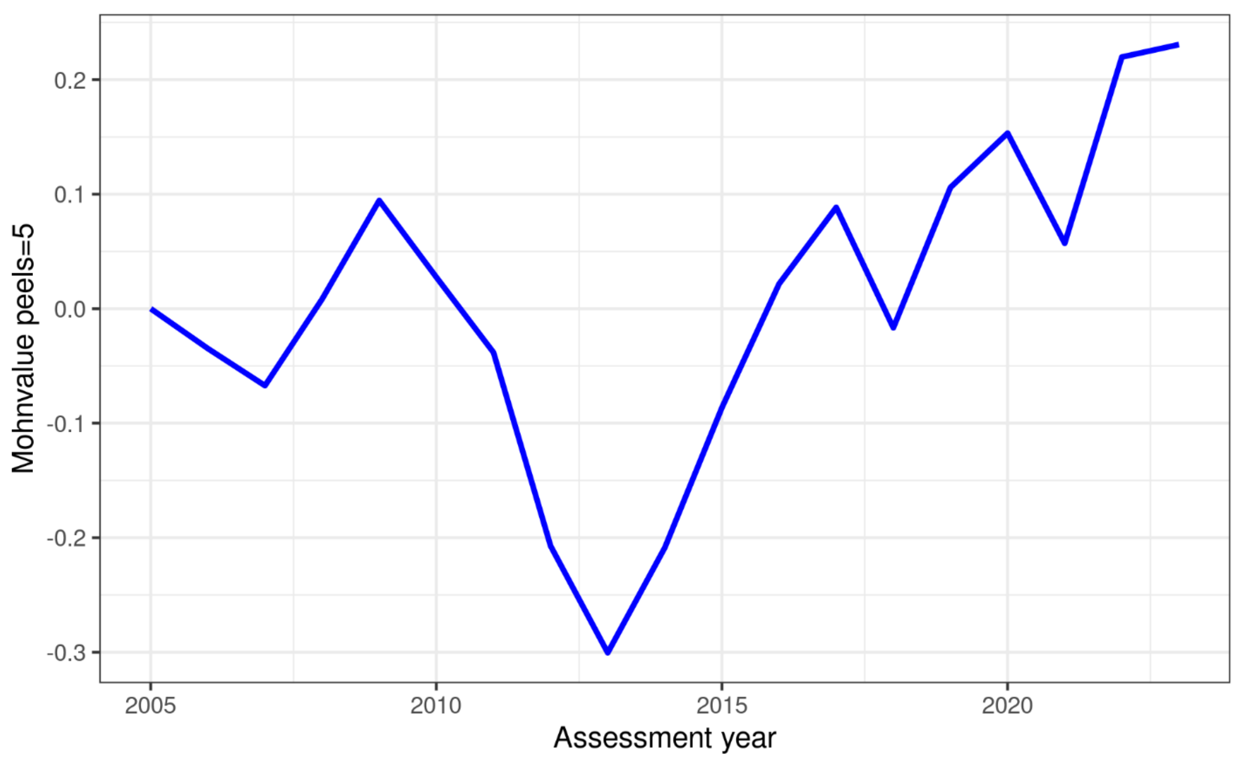


Figure 33. Saithe. Retrospective pattern of Mohns rho for B4+.

ECOSYSTEM CONSIDERATIONS

Changes in the distribution of large pelagic stocks (blue whiting, mackerel, Norwegian spring-spawning herring, Icelandic summer-spawning herring) may affect the tendency of saithe to migrate off shelf and between management units. Saithe is a migrating species and makes both vertical and long-distance feeding and spawning migrations (Armannsson *et al.*, 2007, Armannsson and Jonsson, 2012, i Homrum *et al.*, 2013). The evidence from tagging experiments (ICES, 2008) shows some migrations along the Faroe-Iceland Ridge, as well as onto the East Greenland shelf.

Saithe is an important predator of capelin and is included in the predation model used to compile advice for Icelandic capelin.

POSSIBLE CHANGES IN ASSESSMENT SETUP

The assessment of Icelandic cod was benchmarked in 2021 and a number of changes done in the model formulation that lead to substantial downward revision of the biomass (ICES 2021). All the changes had to do with treatment of survey indices in the model.

1. With lower fishing effort the abundance of old age groups increased. For some of those age groups (10+) the number caught had been so low that sampling error related to few otoliths had been the most important uncertainty. Ages 11 and older in the surveys were earlier not used in the tuning as they were minor part of the stock (1–2%). Not including them in the survey lead to "ghostfish" i.e dome shaped selection pattern of the fleet, not an impossible pattern but not acceptable without some proofs, especially when the older fish becomes larger part of the stock.
2. For ages 6–9 abundance increased, and nonlinear relationships started to show up, that was not apparent when range of values was smaller.
3. The relationship between abundance indices of ages 1–3 and older fish changed. The change can either be related to increased mortality or changed behaviour or less coastal spatial distribution.
4. The VPA version of Muppet was run and CV in the survey estimated for each age group using a VPA model. That pattern was then used in the separable model with one estimated multiplier.

Looking at saithe only factor 4 was relevant. Estimating power curves turned out to lead to no improvement of fit and the power coefficients were not far from 1 and quite variable in retrospective runs. Age composition of saithe has not been changing dramatically in recent years, but old saithe has always been common compared to old cod. Looking at all aged fish since 1980 number of cod otoliths is 3.5 times the number of saithe otoliths but for ages >12 years the number of saithe is larger than number of cod. Changes in spatial distribution of recruits could be relevant for saithe but the recruitment indices are of too low quality to be able to detect such changes. The common perception about saithe is that the nursery areas are close to shore while the nursery areas of cod are both close to shore and in deeper waters.

What was then left was to re estimate the survey CV pattern with age (like redefining observation error blocks in SAM) and increase the number of age groups in the tuning fleet. In addition, a version of the model that uses the estimated survey CV was run.

To revise the pattern of survey CV with age the VPA model is used, estimating CV in the survey for each age group. The VPA model used is just the Muppet model, first the model is run in the forward model but then the number of fish in the oldest age group is used for VPA. If large changes in the CV pattern are observed the procedure might be reiterated.

To look again at the value of ϵ in survey residuals in ($\frac{log(I+\epsilon)}{log(\hat{I}+\epsilon)}$) the number of aged saithe in the survey is 900 and the average total index around 20. Four otoliths do therefore correspond to ϵ = 0.15 which would be the suggested value to use for all age groups based only on this consideration. Other factors like poor spatial coverage of recruits might be used to justify higher values. In some of the alternative tested, age 2 was not included in the tuning fleet.

When doing the reweighting scheme, the pattern of ϵ must be exactly the same in the linked separable and VPA model. In principle the objective function for models using the same pattern of ϵ can be compared but if ϵ is different the comparison might be questionable.

When compiling the survey indices, relative standard error in the estimation of the indices is also compiled $CV_{s,y,a} = \frac{\sigma_{I_{y,a}}}{I_{y,a}}$ where $\sigma_{I_{y,a}}$ is standard error in the indices. High value indicates that few stations are responsible for large part of the index, it is the part of the uncertainty that can be improved by increasing the number of stations. There are other uncertainties that cannot be reduced by increasing the number of stations in the same area, like the proportion of fish that is pelagic or closer to coast that the survey covers. The model setup is to use $CV_{s,y,a}$ but add to that an estimated CV by age called $CV_{2,a}$ $CV_{s,y,a} = \frac{\sigma_{I_{y,a}}}{I_{y,a}}$. $CV_{tot,y,a}$ = $\sqrt{\left(CV_{s,y,a}^2 + CV_{2,a}^2\right)}$.

$CV_{2,a}$ can here be estimated for each age group as $CV_{tot,y,a}$ is never going to be 0.

Using this approach, the variance-covariance matrix (approximately 9x9) must be recalculated and inverted at every timestep.

In Figures 29 and 31 and the Tables 1 and 2 the results of 4 settings are compared. All the settings are based on the same data except the number of age groups in the survey varies.

1. Oldsettings. The adopted model from the benchmark 2019.
2. ChangedCVpattern. ϵ = 0.1 for all age groups. Age 2 not included and pattern of CV by age in the survey re-estimated.
3. surveyCV. Model uses estimated $CV_{y,a}$in survey as described above.
4. Ages3to14. ϵ = 0.1 for all age groups. Survey indices age 3–14. Pattern of CV by age in the survey estimated.

Model 1 is tuned with ages 2–10, 2 and 3 with ages 3–10 and 4 with 3–14. Models 1–3 are based on constant q by age for ages 7 and older but model 5 with constant q for ages 10 and older. Assumptions about age above which q does not change is an important factor in the settings.

Looking at Mohns ρ, model 3 performs best for last 5 years. Looking at difference between contemporary and converged assessment in the years 2001–2018 model 1 performs best but the metrics for models 1 and 3 are similar. The Mohns ρ indicates that recruitment estimates are good in last 5 years but historically recruitment of saithe is not well estimated, this is just coincidence for this short period. Mohns rho from the SAM model is around 0.3 (for SSB), similar to the other models.

Comparing models 1 and 2 B4+2023 is 309 vs 274 thousand tonnes, and the objective function -794.7 vs -777.7. Model 1 fits the data better and indicates larger stock. Retrospective performance of model 1 is also better. Model 3 has an objective function of -879.6 but with 8 more parameters than model 1, might indicate that the approach used was promising. Model 4 uses more data than the other models and the objective function is therefore not comparable.

An interesting factor to look at in the models is estimated q from the surveys (Figure 32). Model 4 uses ages 3-14 for tuning, but the other models 2-10 or 3-10. q in constrained to be identical for ages 9 and older in model 4 but ages 7 and older for the other models that use age groups until 10. This assumption when does q become constant has considerable effect on stock size, reducing q by age as in model 4 leads to larger stock.

Estimated selection (since 2004) in the models is also somewhat different (Figure 8.33). Models 1 and 3 have different selection pattern for older fish and do therefore not converge to exactly the same biomass in the period after 2003. The Adapt model (shown in figure 30) might be considered as some kind of truth in this respect although is not completely insensitive to the number in the oldest age group that it gets from a separable model.

In summary no obvious choice can be pointed at if a new model was adopted today. What works best for last 5 years according to Mohns ρ does not work best when comparing contemporary and converged assessment 2001 – 2018.

Basing the analysis only on nearly converged assessment and ignoring assessment years 2019-2023 as done to get the results in table 2023 might be questionable as the deviations last 5 years are very large and that deviation will not change much when the assessment has "converged".

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Table 1. Mohns rho for the 5 models compared as candidate assessment model. The value is based on assessment years 2018–2022. Stdsettings is the adopted model today. The lower table applies if year < Assessment year but the upper table if year <= Assessment year.

model	B4+	ssb	N3	hr	f4-9
Stdsettings	0.304	0.3407	0.102	-0.2001	-0.229
ChangedCVpattern	0.2307	0.2806	0.0529	-0.1593	-0.1868
SurveyCV	0.2097	0.2472	-0.0089	-0.1433	-0.1698
Ages3to14	0.2279	0.255	-3e-04	-0.161	-0.1879

model	B4+	ssb	N3	hr	f4-9
Stdsettings	0.263	0.2777	0.1848	-0.2001	-0.229
ChangedCVpattern	0.203	0.2356	0.1328	-0.1593	-0.1868
SurveyCV	0.1841	0.2063	0.1463	-0.1433	-0.1698
Ages3to14	0.2007	0.2061	0.1305	-0.161	-0.1879

Table 2. Bias, CV and Mohns rho for the 4 models compared as candidate assessment model based on "converged assessment" i.e. results from assessment years 2000–2018 compared to results for same years from the 2023 assessment.

Parameter	Model	Bias	CV	Mohns rho
b4p	Stdsettings	-0.032	0.234	-0.006
b4p	ChangedCVpattern	-0.013	0.277	0.023
b4p	SurveyCV	0.133	0.25	0.175
b4p	Ages3to14	-0.133	0.267	-0.095
fbar	Stdsettings	0.003	0.264	0.037
fbar	ChangedCVpattern	-0.022	0.304	0.023
fbar	SurveyCV	-0.146	0.269	-0.105
fbar	Ages3to14	0.099	0.297	0.152
hr	Stdsettings	0.007	0.218	0.03
hr	ChangedCVpattern	-0.018	0.249	0.012
hr	SurveyCV	-0.124	0.229	-0.093
hr	Ages3to14	0.082	0.24	0.116
n3	Stdsettings	-0.247	0.346	-0.176
n3	ChangedCVpattern	-0.271	0.317	-0.201
n3	SurveyCV	-0.141	0.283	-0.1
n3	Ages3to14	-0.344	0.307	-0.259
ssb	Stdsettings	-0.057	0.293	-0.018
ssb	ChangedCVpattern	-0.016	0.355	0.042
ssb	SurveyCV	0.131	0.315	0.192
ssb	Ages3to14	-0.166	0.344	-0.107