Stock Annex: Saithe (*Pollachius virens*) in Division 5.a (Iceland grounds)

Stock specific documentation of standard assessment procedures used by ICES.

Stock: Saithe (pok.27.5a)

Working Group: North Western Working Group (NWWG)

Created:

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A. General

A.1. Stock definition

Saithe in Icelandic waters (Division 5.a) is managed as a one unit, though tagging have shown that in some years saithe migrates from distinct waters into Icelandic waters and vice versa. Saithe is both demersal and pelagic. They can be found all around Iceland, and most common in the warm waters south and southwest off Iceland. In last decade the distribution has gradually become more northerly and in 2017 and 2018 more than 50% of the catches were taken north-west of Iceland (Figure A.2.3).

Less is known about the spawning of saithe than for example for cod. Spawning takes place in shallow water (100–200 m) off the southeast, south and west coast of Iceland. The main spawning area is considered to be south/southwest off Iceland (Selvogsbanki, Eldeyjarbanki). Spawning was believed to be earlier than for cod but observation from a gillnet survey conducted in early April show substantial spawning of saithe in time when saithe spawning was thought to be finished. The spawning seems to take place from February–April and the timing of spawning to be variable.

The larvae drift clockwise around Iceland and in mid-June juveniles can be found in many coves, bays, and harbours, then about 3–5 cm long. At age 2 they move to deeper waters in winter. Saithe becomes mature at age 4–7.

According to available data, approximately 115 thousand saithe were tagged in the NE-Atlantic in the 20th century, most of them in the Barents Sea with total returns just under 20 thousand (Jonsson, 1996). Around 6 000 saithe were tagged in Icelandic waters in 1964–65, the recapture rate being 50% (Jones and Jonsson, 1971). Based on recaptures by area, approximately 1 in 500 of tagged saithe released outside Icelandic waters were recaptured in Icelandic waters, and 1 in 300 released in Icelandic waters were recaptured in distant waters (Jonsson, 1996). For comparison, cod long-term emigration rate from Icelandic waters is 1 in 2000 tagged fish (Jonsson, 1996), a rate almost an order of magnitude lower.

Other evidence of saithe migrations do exist, albeit of a more circumstantial nature. Sudden changes in average length or weight at age and reciprocal fluctuation in catch numbers at age in different areas of the NE-Atlantic have been interpreted as signs of migrations between saithe stocks (Reinsch, 1976; Jakobsen and Olsen, 1987; Jonsson, 1996). Since mean weight at age decreases along an approximately NW-SENE gradient, migration of e.g. northeast arctic saithe to Icelandic waters will, theoretically, be detectable as a reduction in size at age in the Icelandic saithe catches. Catch curves from some year classes, from different areas show some reciprocal variations. Inspection of the data based on the above indicate that the most likely years and ages for immigration are as follows: Age 10 in 1986, age 7 in 1991, age 9 in 1993 and the 1992 year class as age 7 saithe in 1999 and 8 in 2000. Currently only the migration of age 7 in 1991 is included in the assessment but it is the largest migration, estimated around 10 million individuals or 35 thousand tonnes. The other potential migrations are smaller and not significant if estimated on "normal scale".

A recent tagging program was conducted in Icelandic waters in 2000–2004 from which ~1750 of ~16000 tags released have been returned. The number of returns from areas other than the Icelandic EEZ has now reached 10 or around 2.5% of the recaptures outside the management area of the stock. Most were tagged at eastern localities and recaptured in Faroes waters, with a pulse of tags recovered in early 2006. Other foreign returns have come from areas west of Scotland and east of Greenland. Figure A.1.1 shows the total returns from this tagging program (2007 ICES NWWG).

A.2. Fishery

Annual landings and overview of the major fleets

Annual estimates of landings of saithe from Icelandic waters are available since 1905 but are shown here since 1955 (Figure A.2.1). The historical information is largely derived from Statistical Bulletin, with unknown degree of accuracy. The more recent landings (from 1980 onward) statistics are from the Directorate of Fisheries as annually reported to ICES.

After WWII the fishery was initially dominated by foreign fleets, mainly English and German trawlers. The former did primarily target cod and saithe was bycatch, while the latter were more directly targeting saithe as well as redfish. The domestic fleet has nearly been the sole exploiter of the saithe resource since 1978, following the expansion of the Icelandic EEZ from 50 to 200 miles in 1976.

Information on landings of the Icelandic fishing fleet by fishing gear is available since 1966 (Figure A.2.2). Largest portion of the catch is taken by trawl, with gillnet fisheries playing a secondary role. The importance of the gillnet fisheries has declined. They accounted from between 15 and 43 % of the catch in the period 1974–1995, but their share reduced from 30% to 3% in the period 1995–2018. In recent years bottom trawl accounts for more than 90% of the catches.

Information from captains logbook records, available since 1991 show that 2/3 of saithe caught in gillnets comes from settings where saithe is > 50% of the catch. Saithe was ≈14% of the catch in gillnets 1994–2012 but only 7% 2013–2018, the reduction caused by increased abundance of cod in the spawning areas south and west of Iceland. In addition, there has been a general reduction in gillnet effort that is now less than 20% of what is was from 1993–2000.

The fisheries of saithe in bottom trawl have usually been targeted fisheries where 55–85% of the catches are taken in hauls where saithe is 50% or more of the total catch and 25–60% where it is 90% or more. In recent years the fleet has not caught the saithe quota (Figure A.2.7). Captains on trawlers that land the catch fresh have extra constraints like not catching too much cod until the last day before landings. The concept of target species is not easy to identify, the captains have a request for certain composition of the catch in each fishing trip and the cod should be caught late to be very fresh when landed. Saithe is always a target species, a school of reasonably large saithe without too much bycatch is always accepted. The trawlers that freeze the catch do not have the same limitations and it turns out that they catch close to 50% of the total catch of saithe by trawlers but only 20% of the cod catch (Figure A.2.4).

Sampling from pelagic fisheries for blue whiting 2004–2006 indicated some bycatch of saithe (~0.5-2%) and the same might apply to other fisheries of pelagic species using pelagic trawl (Palsson *et al*., 2007). Saithe is reported as bycatch in pelagic fisheries in the Icelandic EEZ. The approximate amount of saithe caught in those fisheries is reported when the catch is landed and subtracted from the vessel's saithe quota. From 2010–2012 the amount of saithe caught annually was ~1000 tonnes but much less in other years.

Attempts have been made at estimating discarding in the Icelandic fisheries since 2001 (Palsson *et al*., 2008) based on a method using length measurements taken by observers on-board and measurements taken of landed fish. Discarding of saithe is hardly detectable, a somewhat excepted result as the incentive for discarding is small. Saithe quota is cheap to rent as often some quota is not used. (Figure A.2.5)

Spatial and temporal distribution catches

The saithe fishery in Icelandic waters used to be largely limited to the southern and western shores of Iceland but has expanded northward in recent years and in 2018 more than 50% of saithe is caught in the north-west. (Figure A.2.3). The saithe fishery takes place continuously throughout the year (figures A.2.6 and B.1.2).

Fleet composition

The fishing fleet operating in Icelandic waters consists of a diverse boat types and sizes, operating various types of gear. The largest share of the saithe catches (92% in 2018) is taken with trawlers. The top 35 trawler and boats took around 85% of the total saithe catch in 2018, 34 trawlers and one gillnet boat. The remainder of the saithe catch come from many smaller and larger vessels, using trawl, longlines, gillnets, handlines, jigging and Danish seine. 436 vessels landed more than 1 tonnes of saithe in 2018.

Management

The fisheries in Icelandic waters have since 1984 been managed under a TAC system, where each boat owns a certain percentage of the TAC. The fishing year is from start of September to end of. August in the following year. The system is an ITQ system, allowing free transferability of quota between boats. This transferability can either be on a temporary (one year´s leasing) or a permanent basis. This system has resulted in boats having quite diverse species portfolios, with companies often concentrating/specializing on a particular species. The system allows for some but limited flexibility with regards converting a quota share of one species into another within a boat, allowance of landings of fish under a certain size without it counting fully in weight to the quota and allowance of transfer of unfished quota between fishing years. In the fishing years prior to 2018/19, the transfer system resulted in saithe converted to other species. (Figure A.2.5). The objective of these measures is to minimize discarding, which is effectively banned. Landings in Iceland are restricted to particular licensed landing sites, with information being collected on a daily basis time by the Directorate of Fisheries (the native enforcement body). All fish landed, has to be weighted, either at harbour or inside the fish processing factory. The information on landings is stored in a centralized database maintained by the Directorate and is available in real time on the internet (http://www.fiskistofa.is). Insignificant amount of the saithe caught in Icelandic waters is landed in foreign ports. The accuracy of the landings statistics is considered reasonable, although some bias is likely.

All boats operating in Icelandic waters have to maintain a log-book record of catches in each haul. The records are available to the staff of the Directorate for inspection purposes as well as to the stock assessors at the Marine Research Institute.

A system of instant area closure is in place for many species, including saithe. The aim of the system is to minimize fishing on smaller fish. For saithe, an area is closed temporarily (for 3 weeks) for fishing if on-board inspections (not 100% coverage) reveal that more than 25% of the catch is composed of fish less than 55 cm in length. No minimum landing size of any fish species exist in Icelandic waters. The minimum allowable mesh size is 135 mm in the trawl fisheries, with the exception of targeted shrimp fisheries in waters north of the island.

The Marine Research Institute has issued a recommended annual TAC since 1984, with advice also given by ICES since 1987. The set TAC has often been set higher than the advice. The landings (by quota year) have in 6 out of 25 years exceeded the national TAC by more than 10%. With the exception of 1995/96 the landings in other years have been closed to or lower than the national TAC. Since the current management plan was adopted in 2013 TAC has been set according to the management plan but the catches have been lower than the TAC (Figure A.2.7).

A.3. Ecosystem aspects

Changes in the distribution of the large pelagic stocks (blue whiting, Norwegian spring spawning herring) may affect the propensity of saithe to migrate off shelf and between management units. This is poorly documented but well known.

Significant changes in the length and weight at age have been observed in the Icelandic saithe. It is unknown if these factors are fisheries or environmentally driven. Most of the changes in weight at age is caused by changes in length, weighting of saithe in the March survey 1994–2018 show very stable condition factor.

B. Data

B.1. Commercial catch

Sampling from the Icelandic fleet

Sampling of size and age composition of saithe in the Icelandic fisheries only started in 1974 (Figure B.1.1). In the years 1974 to 1977, the sampling was rather limited, with less than 50 independent samples taken each year. Thereof otoliths were taken in 15 samples or less, annually. In the years 1978 and 1979 a significant sampling occurred from the fisheries, with the primary objective to establish the relationship between length and weight. Since 1980 regular sampling, with the objective to calculate annual catch in number at age has taken place. During 1980–1998 the number of independent age samples were increasing from 20–50 per year, were 100–120 from 1999–2010 but decreased 2010–2018 from 100 to 50. Most of the age samples are taken from landings by the branches of the MRI but the rest by observers from the Directorate of Fisheries (Figure B.1.1). The samples from the Directorate of Fisheries are important to cover the part of fleet that fillet the catch and land it frozen.

Over the period the 1980–1998 the number of length measurements in each sample was around 200. Thereof, 100 fish were sampled for otoliths/age. In 1999 there was a change in the protocol within each sample, where the number of fish measured was reduced to 150, with 50 fish being weighted and sampled for otoliths. Since 2013 the number of aged fishes per sample has been 25 and the number of fish aged annually has reduced to 1500–2000. Systematic gutted weight measurements of fish sampled for otoliths commenced in 1995.

The sampling protocol by the staff of the Marine Research Institute has in the last decades been linked to the progression of landings within the year. The system is fully computerized (referred to as "Sýnó" by the natives) and directly linked to the daily landings statistics available from the Directorate of Fisheries. For each species, each fleet/gear and each landing strata a certain target of landings value behind each sample is pre-specified. Once the cumulative daily landings value pass the target value an automatic request is made to the sampling team for a specific sample to be taken. The system as such should thus take into account seasonal variability in the landings of any species. An overview of the cumulative landings of the saithe and the cumulative sampling of saithe seem to be in reasonable sync (Figure B.1.2), although there seem to be lesser sampling intensity in the summer months, possibly associated with summer holiday of the staff. The sampling design is not per se linked to the geographical distribution of the fisheries. However, the fishing location of the fish measured at harbour is known with reasonably accuracy, because fishing date is registered for each fish tub and can hence be linked to geographic location of the fishing at that date, based on the captain's log-book record. An overview of the sampling of Saithe based on these information (figures B.1.3 and B.1.4) show that overall, the geographical sampling intensity mirrors the geographical distribution of the fisheries (see figures A.2.3 and B.3.1).

Calculation of catch in numbers

The calculation of the annual catch in number of the Icelandic saithe has since 1989 been based on only 2 metiers, trawl and gillnet, with no splitting by season or geographic distribution of fishing. Catches in other gears (long line and Danish seine) are included with the trawl gear. This should be enough if the sampling system "Sýnó" works.

For the saithe the length and age distribution are compiled into bins of 5 cm (10 cm for saithe larger than 102 cm) and used as such in the length age key. The parameters used to convert length to weights are:

Cond = 0.024498

Power = 2.7567

Otherwise the calculations of calculation of annual catch in number and weight at age for saithe have since 1980 been calculated in the same way as was done for other species assessed by age based methods at the Marine Research Institute.

The calculations were earlier done in a menu-based system written as unix shell scripts (PAX) but has since 2009 be done with R functions using similar equations.

Catch in numbers are calculated for each area, a season and a gear combination (cell) and then combined to total catches in numbers over all areas, seasons and gears.

The length distributions and age data are divided into length groups (5 cm for most of the span but 10 cm for the largest fish). The length distributions are then converted to age via age-length keys where and the average length and weight of fish in each length category is calculated. In the older pax system the average length and weight in each length group were calculated assuming that all fish in the length group was at the middle length of the length group.

The average length and weight of fish in each length group are calculated from the samples in that category and the biomass of fish sampled in each length group is summed to get the biomass sampled in this cell. It is scaled to get the landed catch for that cell.

Conversion from length to age is done by age length keys. All samples from the year are included as “base sample” with much lower weight (0.01/0.001) where each sample in the cell has the weight 1. This is to avoid manual “borrowing” of age samples from other cells.

The same method is used to compile number and biomass by age at each station in survey, that is then the basis for age based survey indices and mean weight at age in the survey.

Catch in numbers 2000–2018 were also compiled by 12 cells i.e 2 region (N/S), 2 time intervals (Jan–May, June–Dec) and 3 fleets (bottom trawl, gillnets, other). The resulting catch in numbers are very similar (Figure B.1.5) indicating that the “Sýnó” system works.

Historical catch in numbers and weight at age: 1960–1979

Tabulated annual catch in numbers at age of the Icelandic saithe catches can be found from 1960 onwards, with the earliest record found in the Report on the Saithe (Coalfish) Working Group 1976 (ICES CM 1976/F:2). However, it is obvious that the Coalfish working group members had compiled these historical numbers (from 1960 onward) already by 1973 (Report of the Saithe (Coalfish) Working Group, ICES CM 1973/F:10), this being deduced from the resulting VPA analysis done by the 1973 group, where a tabulation of stock in numbers and fishing mortality by age is given for the period 1960-1970. From the various recent ICES assessment reports dealing with Icelandic saithe, it can be deduced that the catch in numbers as originally reported in the Coalfish reports have remained unchanged, i.e no later revisions were done to the calculated numbers.

Description on how the annual age composition of the catch for the period 1960–1980 were compiled by the ICES working group at the time are very limited and the calculation cannot be repeated. Number of annual samples, fish measured and age composition by fleet (countries) is not stated in the ICES assessment report from this time. In the 1973 Coalfish report it is noted that catch in numbers for Icelandic saithe in this early period were based only on samples from the German and English fleet. In the report it is then stated: “As a result it had to be assumed that the catches of the countries for which no data were available had the same age composition as the countries for which data were available. For each year the available age distributions of national catches were summed and the resultant age composition was then raised by the ratio of total landed weight of all countries to landed weight of countries for which age composition were known.” However, in the same report it is further noted that “young saithe recruited first to the Icelandic purse-seine and trawl fisheries, then to the English trawl fishery and finally to the German trawl fishery”. Given this, the approach of raising the catch composition from the German/UK age distribution to the total landings will most likely lead to a bias in the total catch at age distribution to some unknown degree. In particular since the Icelandic fleet took the largest share of the catches from 1967 onwards (Figure A.2.1). The earliest account where age composition from the Icelandic fleet is used as a part of the total annual catch at age matrix is in 1977 (Report of the Saithe (Coalfish) Working Group. ICES CM 1978/G:3). This is understandable since samples from the Icelandic fleet prior to that year are very limited (see above).

No information is provided in the early working group reports on how weight at age in the catches were derived. In all cases, annual weight at age used is a constant value over the period. However, as early as 1973 (Report of the Saithe (Coalfish) Working Group. ICES CM 1973/F:10) it was noted that "…in the English data there was a clear trend of reducing length at age over the past 10–12 years for saith. The rate of reduction of average length has been about 1 cm per year, and over the period of 10 or 12 years this is equivalent to more than a year's growth. Similar but less marked trend is apparent in the German data." Given this observation, the use of a constant weight at age over this time period is obviously wrong. In addition, it explains the significant discrepancy between sumproduct of catch numbers and weight at age vs that of the total landings exist, particularly in the early part of the time series. The catch weight at age has historically been used in the calculation of SSB. Using the constant weight at age results in significantly higher historical maximum SSB (Figure B.1.6, based on a simple VPA model) than if weights scaled so that the sumproducts of catch in number and weight at age are the same as the total landings (see WD02 for details of how rescaling was done).

Given that:

- The that samples of the catch composition from the Icelandic fleet is not available in the early time period
- Fixed weight at age used in the early time period
- Sumproduct discrepancy
- Consequences different derivations have on the perception on the dynamic range

Data information prior to 1980 is not used, albeit at the cost of losing information on the dynamic history of the stock and its response to fisheries. However, based on the VPA model (Figure B.1.6) the dynamic range of SSB in the period observed from 1980 is within the range observed in the long time series.

B.2. Biological values.

Natural mortalities

A fixed natural mortality rate of 0.2 is used both in the assessment and the forecast.

The proportion of natural mortality before spawning (Mprop) and the proportion of fishing mortality before spawning (Fprop) are set to 0.

Weight at age

Mean weights at age in catches (Figure B.2.1) are compiled as described before in the section on calculations of catch in numbers. Weight at age in the catches is also used as weight at age in the reference biomass and the spawning stock. .

Predicted weights for the assessment year are estimated by applying a linear model using current survey weights (Figure B.2.3) and weight of the year class in the previous year as predictors,

$$\log(cW_{t,a}) = \beta_0 + \beta_1 \log(cW_{t-1,a-1}) + \beta_2 \log(sW_{t,a})$$

where $cW_{t,a}$ is the current year's catch weights, $cW_{t-1,a-1}$ is the previous year's catch weights, and $sW_{t,a}$ is this current year's survey weights. See Magnusson (2012) for details.

Mean weight at age has since 2010 been low, more so for the younger fish (figures B.2.1 and B.2.2).

Maturity

As described above, saithe is believed to spawn in February–April. The Icelandic groundfish survey in March is thus close enough to spawning time make visual detection of maturity stages possible. Maturity-at-age data from surveys are considered to give better estimates of maturity at age in the stock than those from landings data, in particular because of limited ungutted samples in the catches. The main problem with maturity at age data from the March survey is considerable interannual variability that can largely be characterised as noise (Figure B.2.4). Therefore maturity-at-age data from the Icelandic groundfish spring survey used in the assessment are smoothed (Figure B.2.5)

The model fitted (using R) is (ICES, 2019):

$\text{logit}(P_{a,t}) = \alpha + \beta\, age + s(year, \text{df}=7)$

where P is the proportion mature at age a in year t, and s are smoothing splines used to increase the flexibility of the model. Every 5th year the number of degrees of freedom should be increased. Results from the model are shown in Figure B.2.5 for ages 4-9 and comparison of smoothed and unsmoothed values are shown in Figure B.2.6 for ages 5 and 7.

Ages 1–3 are assumed immature, and ages 10 and older are assumed mature. The average maturity in 1985–1998 is used for the early years 1980–1984, when survey data were not available. Future projections use the predictions for the assessment year.

B.3. Surveys

The Icelandic groundfish surveys in March and October are described in https://www.hafogvatn.is/static/research/files/fjolrit-156pdf. In summary, the surveys design is a classical random stratified design with fixed stations with time. With the caveat that experienced captains given the freedom to choose particular stations within a certain predefined geographical constraint determined by the scientist. The number of stations in the spring survey are 570, the number of stations in the fall are 380. Maximum depth in the spring survey is 500 m, but 1200 m in the autumn survey.

The longer spring survey time series covers to a large degree the traditional fishing grounds of saithe (Figure B.3.1). The shorter fall survey covers almost the entire distributional range of the fisheries (Figure B.3.1), although with only half the station density. The coverage of both surveys is however very poor for juvenile saithe, which are thought largely to inhabit coastal areas very close to shore. Hence the surveys do not provide reliable measurements of incoming recruits. In 2000 a number of stations deep south of Iceland were added to the autumn survey (Figure A.2.3). Large saithe hauls are often caught at those stations that are in an area where blue whiting is the main prey of saithe.

A third survey where saithe is found is a gillnet survey in the spawning areas all around Iceland in April (Figure B.3.1). The saithe caught in this survey is relatively large (average weight ≈5kg). The indices from this survey are more stable than from the bottom trawl surveys (Figure B.3.6).

The survey indices for saithe that are used as tuning indices are derived using conventional methods. Year effects, particularly in the earlier period are very apparent in the survey biomass indices (Figure B.3.2) and result in age based indices (Figure B.3.2) when plotted as "consistency plots" look very non-consistent (figures B.3.3 and B.3.4). The "year effect" seen in the surveys is largely thought to be a result of the schooling nature of the species, with an accompanying high CV estimates in the survey abundance indices. However, there are indication that the surveys are able to track cohorts to some degree, in particular when catch curves of survey indices are plotted on log-scale, the scale that the model "sees the data" (Figure B.3.5).

B.4. Commercial CPUE

Catch per unit of effort are routinely calculated during the annual assessment process (Figure B.4.1). The overall trend in catch rates show similar trend with time, irrespective of how the indices are derived (mean, median, < 50% or > 50% saithe per haul), but the absolute values differ. The indices increased sharply from 2000–2004 but have decreased since then, but are still above the level in 1988–2000. Although this trend corresponds roughly with the perceived stock dynamics, the CPUE for Icelandic saithe has not been considered a reliable unbiased index to be used quantitatively as a tuning series in an analytical model.

C. Historical Stock Development

Historical account of models used for saithe assessments

In the 1980s and early 1990s a traditional VPA was used for assessing the Icelandic saithe. The input terminal F for the VPA was estimated by various data sources and different ad hoc methods. B.3.1

From 1993–2001 both XSA (except in 1999 and 2000) and TSA were run and compared. In all years cpue data were used as tuning series in XSA. Only catch data were used when running TSA, except in 1997 and 1999 where CPUE data were used as well. The decision taken each year was to use the terminal Fs estimated by TSA as input values for a traditional VPA.

In 2002, survey indices for saithe from the Icelandic groundfish survey in spring were used for the first time in an assessment. XSA, TSA and an ADAPT model were used. The conclusion was the same as in past years, Fishing mortality taken from TSA were put into a traditional VPA.

In 2003 Icelandic saithe was not assessed by ICES. Domestic TSA, ADAPT and camera (a separable model implementation in ADMODEL builder) were used as assessments programs. The decision taken this time was to use camera as the final run.

In 2004–2006 camera was used as a final run by ICES, but other models like TSA, cadapt (ADAPT type model implemented in ADMODEL builder), AMCI (a "flexable" separable model) and ADCAM (a forward running statistical catch at age model implemented in ADMODEL builder, allowing for "random walk" in Fay) were used as well. In 2006 XSA was also run again.

In 2007 Icelandic saithe was not assessed by ICES. Domestic TSA, camera and ADCAM were run. The use of camera was rejected due to shifts in the age composition of the landings and it was not considered realistic to assume a fixed selection pattern for the whole assessment period like camera did. Then ADCAM was the basis of advice until 2010. For comparison TSA was also been run every year.

Current model used (3 selectivity periods)

A forward-running separable statistical catch at age model, allowing changes in selectivity to occur in specified years has used since the benchmark in 2010 (ICES, 2010). The software used is AD Model Builder, adapted to the saithe by Höskuldur Björnsson, MRI. The source code and a Linux executable version are stored by ICES. The model is set up so that both stock assessment and predictions are at the same time. The code is to a large extent the same as was used by ICES for run the HCR evaluation of Icelandic cod in December 2009. The model has recently been extended and is now available at github under the name muppet. https://github.com/fishvice/Muppet_HCR. Every year a number of other models have been run for comparison and even though the adopted assessment is based on the survey in March, the signal seen in the other surveys is also investigated. The assessment was benchmarked again in 2019 (ICES, 2019).

Assessment model.

The biological model is a simple single-species age structured population following the classical exponential stock-equation:

$$N_{a+1,y+1} = N_{ay} e^{-\left(F_{ay}+M_{ay}\right)}$$

The age groups in the model are 1 to 14 years, with age 3 the youngest age in the landings. In the settings here, the oldest group (14 years) is not a plus group.

Migration events are estimated at specific year and age, and are added to the number in stock at the beginning of the year. The size of migration events is estimated as an additional parameter, equivalently as annual recruitment estimates.

Catches are taken according to the catch-equation:

$$\hat{C}_{ay} = \frac{F_{ay}}{F_{ay}+M_{ay}} \left(1-e^{-(F_{ay}+M_{ay})}\right) N_{ay}$$

$$\hat{C}_y = \sum_a \hat{C}_{a,y} W^c_{a,y}$$

Fishing mortality by year and age is modelled as:

$$F_{ay} = s_a F_y$$

The time period where catch-at-age data are available can be divide in a number of subperiods with the selection pattern s_a estimated separately for each period. The selection pattern of ages 11-14 is assumed to be identical and defined as 1.

Spawning is assumed to occur in the beginning of the year so no mortality takes place before spawning. This is not strictly correct but a good approximation.

The spawning stock is then calculated by

$$SSB_y = \sum_a N_{y,a} W^{ssb}_{y,a} \; p_{y,a}$$

where $p_{y,a}$ is the proportion mature by year and age.

The predicted recruitment is calculated as a simple hockey-stick given the data available at the time.

Reference biomass is calculated from

$$B_y^{ref} = \sum_{a=4}^{a=14} N_{ay} W_{ay}^{c}$$

where W_{ay}^{c} are the mean weight at age in the landings.

Observation model and objective functions

The model parameters are estimated by minimizing a negative log-likelihood that is the sum of 4 components.

1) Landings in numbers

$$\Psi_1 = \sum_{a,y} \frac{\log \frac{C_{ay}+\delta_a}{\hat{C}_{ay}+\delta_a}}{2(\Omega_1\sigma_a)^2} + \log\left(\Omega_1\sigma_a\right)$$

where Ω_1 is an estimated parameter but the pattern of the measurement error with age σ_a is read from the input files. The values δ_a are input from file. They are supposed to reflect the value where the error goes from being lognormal to multinomial. Typical value could be corresponding to 3-5 otoliths sampled.

2) Landings in tonnes

$$\Psi_2 = \sum_{a,y} \frac{\log \frac{C_y}{\hat{C}_y}}{2\Omega_2{}^2} + \log \Omega_2$$

where C_y are the "real" landings in tonnes in year y, $\hat{C}_y$ the modelled landings and Ω_2 the assumed standard error of the landings. The value of 0.05 was used for Ω_2 in these runs. The likelihood component Ψ_2 is somewhat redundant as it is already incorporated in Ψ_1. Leaving Ψ_2 out will on the other hand lead to unacceptable deviation between observed and predicted landings in numbers.

3) Survey abundance in numbers

Initially the survey likelihood was calculated by.

$$\Psi_3 = \sum_{a,y} \frac{\log \frac{I_{ay}+\delta_a^s}{\hat{I}_{ay}+\delta_a^s}}{2(\Omega_3\sigma_a^s)^2} + \log\left(\Omega_3\sigma_a^s\right)$$

were Ω_3 is an estimated parameter but the pattern of the measurement error with age σ_a^s is read from the input files. The values δ_a^s are input from file and are similar to δ_a in Ψ_1. The predicted survey numbers $\hat{I}_{ay}$ are calculated from the equation

$\hat{I}_{ay} = q_a N_{ay}^{b_a}$. The parameters q_a are estimated, but the parameters b_a are set to all set one as the survey indices are considered too noisy to estimate those extra parameters.

For Icelandic saithe year effects are apparent in the survey and were taken into account by modelling the survey residuals by a multivariate normal distribution.

$$\Gamma = \log \frac{I_{ay} + \delta_a^s}{\hat{I}_{ay} + \delta_a^s}$$

a=2:10 is the vector of survey residuals in a given year.

$$\Psi_3 = 0.5 \sum_y \text{logdet } \Theta_6 + \Gamma_y{}^T \Theta_6^{-1} \Gamma_y$$

The matrix Θ_6 is calculated from the equation. $\Theta_{6ij} = \Omega_3^2 \sigma_i^s \ \sigma_j^s \ \kappa^{abs(i-j)}$ where κ is an estimated parameter and the parameters Ω_3 and σ_a^s are explained above. When the value κ is high the equation approaches modelling the survey indices as a year factor.

4) Stock – recruitment parameters

$$\Psi_4 = \sum_{a,y} \frac{\log \frac{N_{1y}}{\hat{N}_{1y}}}{2\Omega_4{}^2} + \log \Omega_4$$

where $\hat{N}_{1y}$ is the estimated recruitment from the stock –recruitment function and Ω_4 is an estimated parameter. Ω_4 can be set as a function of SSB (usually increasing with smaller SSB) but that option was not used in the simulations in the 2010 Benchmark. Autocorrelation of the residuals are quite high for saithe exemplified by periods of good and bad recruitment. The modelling of the autocorrelation is done in the same way as the modelling of the yearfactor in the survey.

$$\Gamma_y = \log \frac{N_{1y}}{\hat{N}_{1y}}$$

y=1980:2018 is the vector of recruitment residuals in a given year.

$$\Psi_4 = 0.5 \sum_y \text{logdet } \Theta_7 + \Gamma_y{}^T \Theta_7^{-1} \Gamma_y$$

The matrix Θ_7 is calculated from the equation. $\Theta_{7ij} = \Omega_4^2 \ \rho^{abs(i-j)}$ where ρ can be an estimated parameter and the parameters Ω_4 explained above.

The stock recruitment models used were either constant recruitment or Hockeystick recruitment with the breakpoint estimated.

5) Overall objective function

The total objective function to be minimized is ρ is in used to in a first order AR model in future predictions. The estimated value is 0.45 and inclusion of it does not have much effect on the outcome of prognosis.

$$\Psi = \sum_{i=1}^{i=4} \Psi_i$$

Parameter estimated

The estimated parameters in most of the runs are:

- Effort F_y for each year
- Selection pattern s_a for ages 3-10 (set to 1 for ages 11-14) in 3 periods: 1980–1996, 1997–2003, and 2004 onwards.
- One number for CV in the catches Ω_1 that multiplies the given pattern with age.
- Number of age 2 saithe 1980 to the present.
- Initial number in each age group (2–14) in 1980.
- Migration events. Age 7 1991 is only included
- Parameters of the stock recruitment function. The assessment setup is based on Hockey stick function with R_{max} and SSB_{break} and CV estimated. Autocorrelation of recruitment ρ is not estimated in the assessment phase.
- Catchability the survey q_a for ages 1–7 with 8–10 same as 7. One parameter Ω_3 is estimated for CV in the survey and one parameter κ for the correlation between age groups in the survey.

Short term prediction and advice with 20% harvest control rule

In April 2013, the Icelandic government adopted a management plan for managing the Icelandic saithe fishery. ICES evaluated this management plan and concluded that it was in accordance with the precautionary approach and the ICES MSY framework. The management plan was re-evaluated by in 2019 (ICES, 2019) and found to be precautionary and in conformity with the ICES MSY approach.

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 20% HCR consists of two equations, as follows.

When $SSB \geq B_{\text{trigger}}$, the TAC set in year *t* equals the average of 0.20 times the current biomass and last year's TAC: B.3.1

$$TAC_t = 0.5 \times 0.20\, B_{t,4+} + 0.5\, TAC_{t-1} \qquad \text{(Eq. 1)}$$

When SSB is below B_{trigger}, the harvest rate is reduced below 0.20:

$$TAC_t = SSB_t/B_{\text{trigger}}\, [\, (1 - 0.5\, SSB_t/B_{\text{trigger}})\, 0.20\, B_{t,4+}) + 0.5\, TAC_{t-1}\,] \qquad \text{(Eq. 2)}$$

Equation 1 is a plain average of two numbers. Equation 2 is continuous over SSB_t/B_{trigger}, so the rule does not lead to very different TAC when SSB_t is slightly below or above B_{trigger}.

Reference points were also revisited in the benchmark and HCR evaluation in 2019. The reference points are listed in the table in section E.

According to the management plan TAC is based on B_{t4+} in the assessment year and SSB in the assessment year. B_{t4+} is based on catch weights and SSB is based on catch weights and maturity at age from the survey in March in the assessment year. The maturity at age values are available at the time of assessment but have to be smoothed.

Catch weights in the assessment year is as described in Section B.2 on weight at age compiled by the lm model.

$\log(cW_{t,a}) = \beta_0 + \beta_1 \log(cW_{t-1,a-1}) + \beta_2 \log(sW_{t,a})$

No further projection are needed to compile the TAC for next fishing year. Short term prognosis are compiled based on the assumption that weight and maturity are the same as in the assessment year. The projections are done by the assessment model where cohorts with no data are estimated from the stock-recruitment function.

The selection pattern used in the 2019 Benchmark prediction was the selection pattern of the last "selection period" (2004–2018). No stochasticity is modelled in the selection pattern but the uncertainty in the estimated selection pattern is transferred to the prediction. The effect of the selection pattern is not large as it is not used to compile the TAC.

The settings adopted in the 2019 benchmark are with 3 selection patterns. Identifying when selection has changed is somewhat delayed process, recognising patterns in catch residuals. Allowing for a change in selection pattern should therefore be possible without an interbenchmark.

CV of residuals in the catch and the survey estimated, with and one multiplier estimated the survey and one for the catch. The *a priori* set age group patterns (σs) and stabilizers (εs) are given in the text table below: δ_a is set to 1% of the total catch in numbers each year.

AGE	CATCH	SURVEY	SUVEY
Group	σ_a	δ_a^s	σ_a^s
1			
2		1	0.50
3	0.17	0.5	0.30
4	0.13	0.5	0.22
5	0.11	0.5	0.19
6	0.10	0.5	0.16
7	0.10	0.3	0.19
8	0.10	0.3	0.24
9	0.11	0.3	0.35
10	0.12	0.3	0.45
11	0.15		
12	0.19		
13	0.26		
14	0.37		

Linear catchability relationship for all age groups in survey. Nonlinearity exists

Weights and maturity have been given with matrices based on different data to produce alternative versions/flavours of stock and SSB biomass.

Migration is estimated for 1 events, i.e. for age group 7 in 1991. Four other events are hypothesised, i.e age 10 in 1986, 9 in 1993, 7 in 1999 and 8 in 2000, but only age 7 in 1991 was included in the Benchmark 2019. The timing of these migration events and the age groups included are determined/based on loose indications from deviations from 'normal' weight at age, i,e. abnormally low and anomlaies in number caught. Potential future migrations will be evaluated using the same procedure.

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1980-onward		Yes
Canum	Catch at age in numbers	1980-onward	3-14	Yes
Weca	Weight at age in the commercial catch	1980-onward	3-14	Yes
West	Weight at age of the spawning stock at spawning time.	1980-onward	3-14	Weca is used as West.
Mprop	Proportion of natural mortality before spawning	1980-onward	3-14	No, kept fixed at 0.
Fprop	Proportion of fishing mortality before spawning	1980-onward	3-14	No, kept fixed at 0.
Matprop	Proportion mature at age in the survey	1980-onward	3-14	Yes, but modelled with a smoother.
Natmor	Natural mortality	1980-onward	3-14	No, kept fixed at 0.2.

The input data used in the 2019 benchmark are archived on the 2019 Benchmark sharepoint site

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	Icelandic spring groundfish survey	1985-onward	1-10

D. Short-Term Projection

Model used/software used: The same software (Muppet) is used for forward projections as the assessment. No additional data are required for the forward projection.

E. Biological Reference Points

Biological reference points were revisited at WKICEMSE 2019 following most recent ICES guidelines. The stock was categorized type 6 stock and therefore $B_{pa} = B_{loss}$ = 61 thous. tonnes and B_{lim} = Bpa/1.4 = 44 thous. tonnes. $MGMTB_{trigger}$ was changed from 65 to 61 thousand tonnes to be in line with ICES $MSSY_{Btrigger}$. The table below is a complete mesh but the main message is that 0.2 and $B_{trigger}$ = 65 thousand tonnes works but using lower harvest rate would not hurt.

	Refpoint	**Value**
1	B_{pa}	61
2	B_{lim}	44
3	$MSYB_{trigger}$	61
4	$MGMTB_{trigger}$	61
5	HR_{MSY} with implementation error	0.19
6	HR_{p05} with implementation error	0.22
7	HR_{MSY} witout implementation error	0.19
8	HR_{MSY} without stabiliser and implementation error	0.20
9	HE_{NGMT}	0.20
10	F_{lim}	0.5
11	HR_{lim}	0.36
12	F_{PA}	0.36
12	HR_{PA}	0.26

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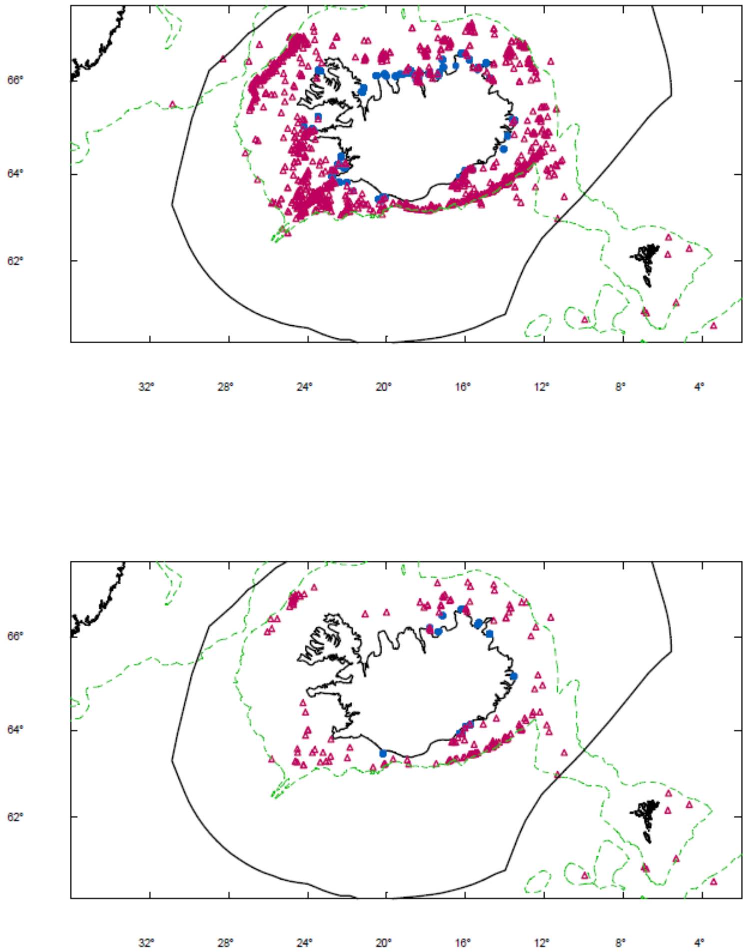


Figure A.1.1 Results from taggings in 2000–2004. Total returns, above; returns after more than 560 days at liberty (the shortest period at liberty in the recaptures from the Faroes) from the set of stations from which tags were recaptured at the Faroes or on the Faroe-Iceland Ridge, below. Blue dots denote tagging locality, violet triangles recapture location, the 500 m isobath and approximate Icelandic EEZ boundary are also shown.

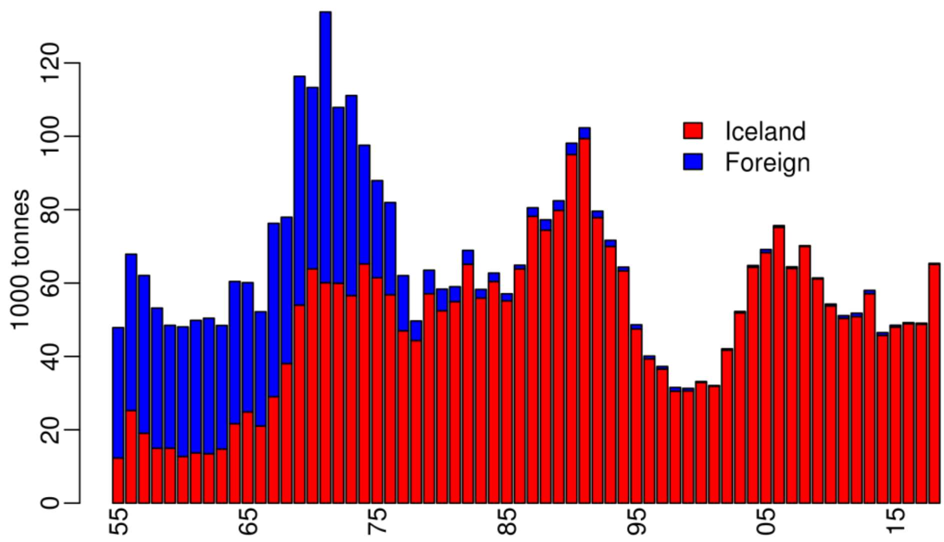
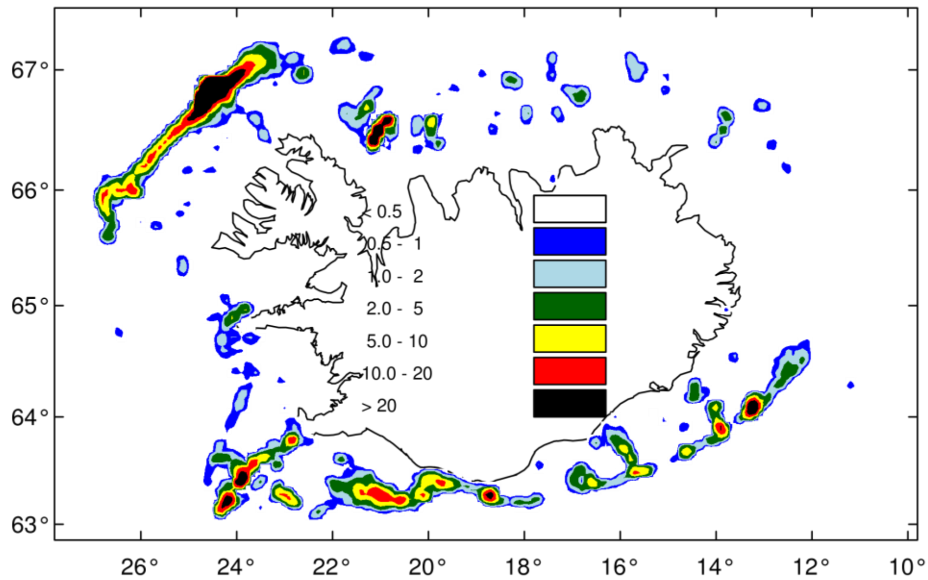


Figure A.2.1. Catch of saithe in Icelandic waters.



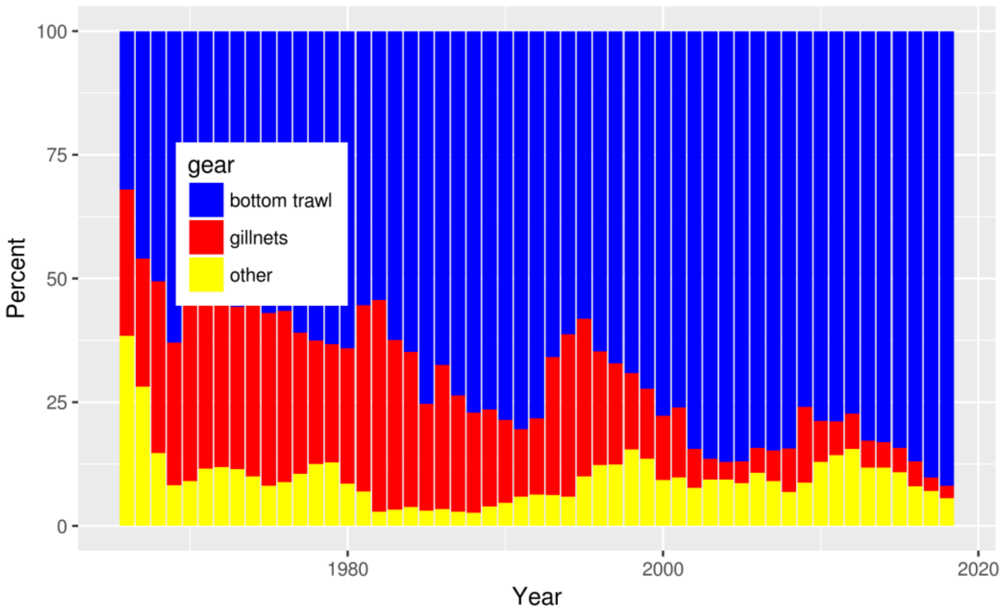
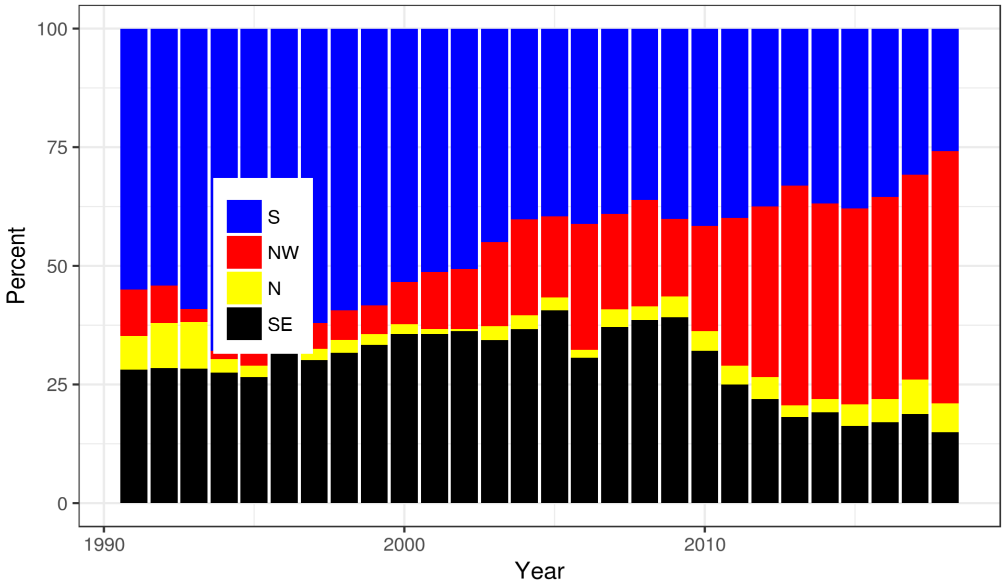


Figure A.2.2.Upper figure. Catch of saithe 2017 8 in tonnes per square nautical mile. Development of the proportion of saithe catch caught by each gear



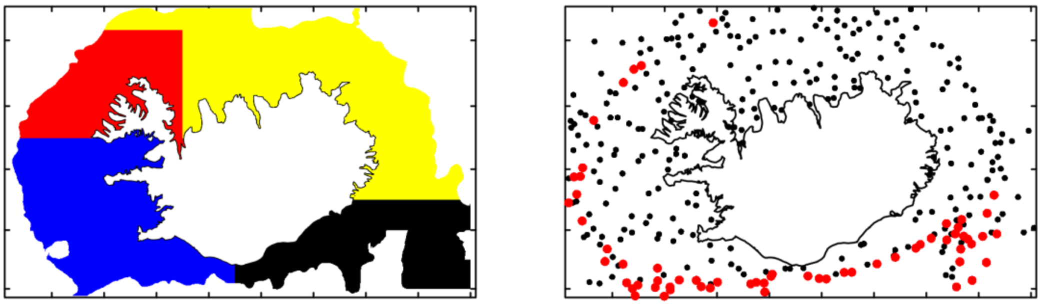


Figure A.2 3. Top figure. Catch of saithe 2017 in tonnes per square nautical mile. Middle figure. Proportion of saithe catch in each region. Bottom left, definition of regions S,NW,N and SE. Bottom right, stations added in the autumn survey in 2000, shown as red symbols.

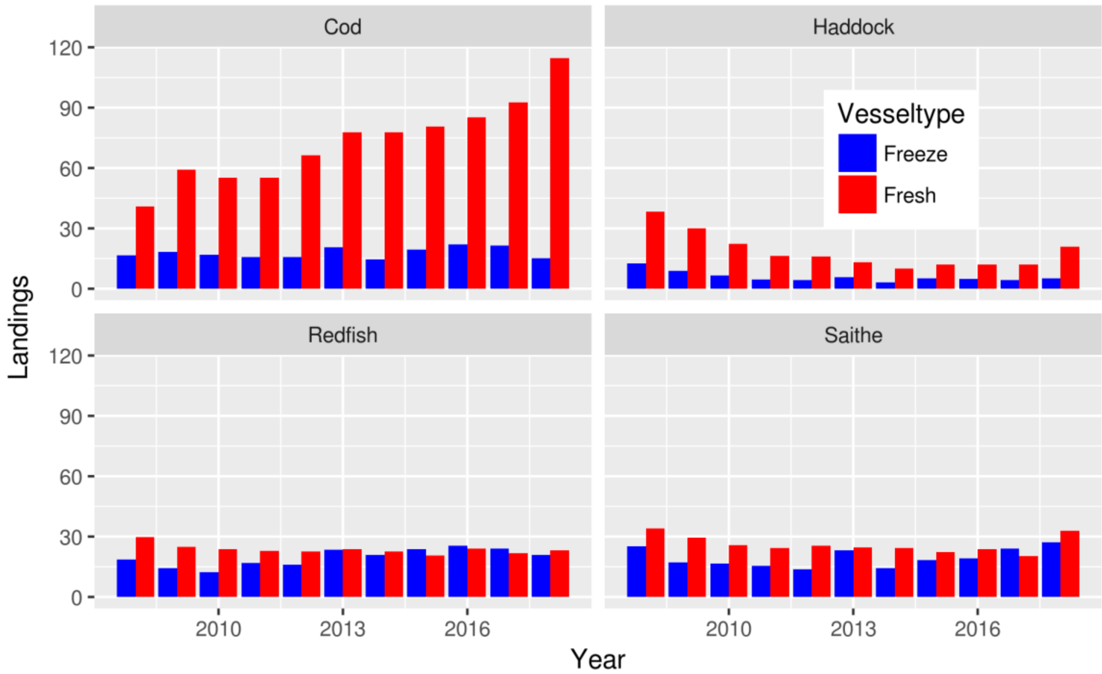


Figure A.2.4. Catch of cod, haddock, redfish and saithe in bottom trawl by year and vessel type i.e. trawlers where the catch is frozen vs those where it is landed fresh.

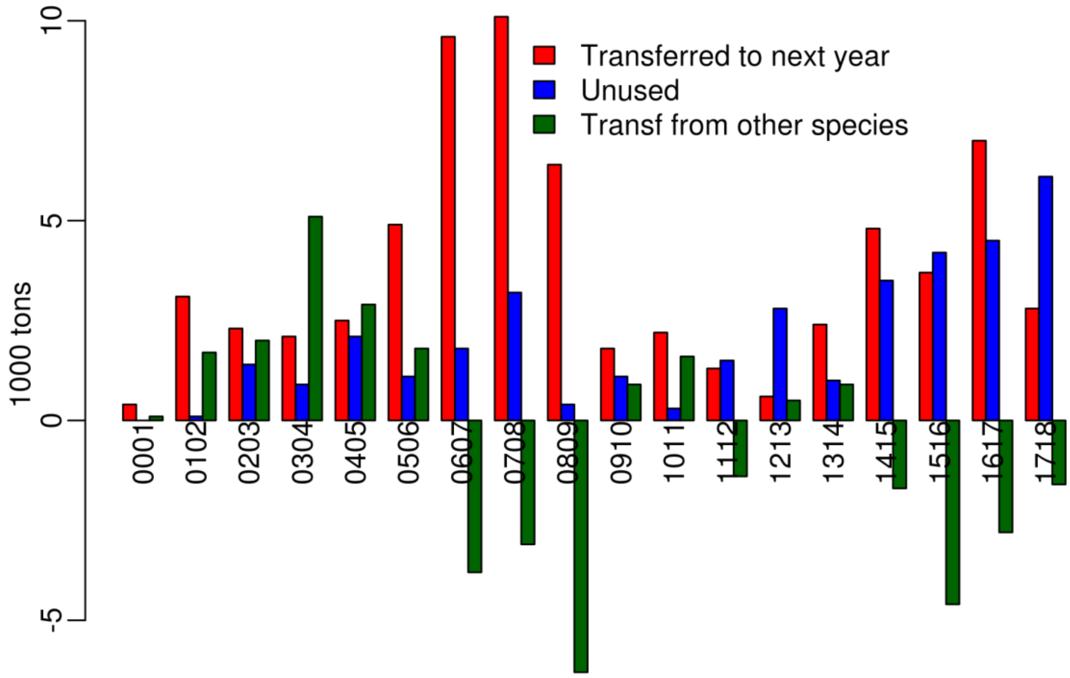
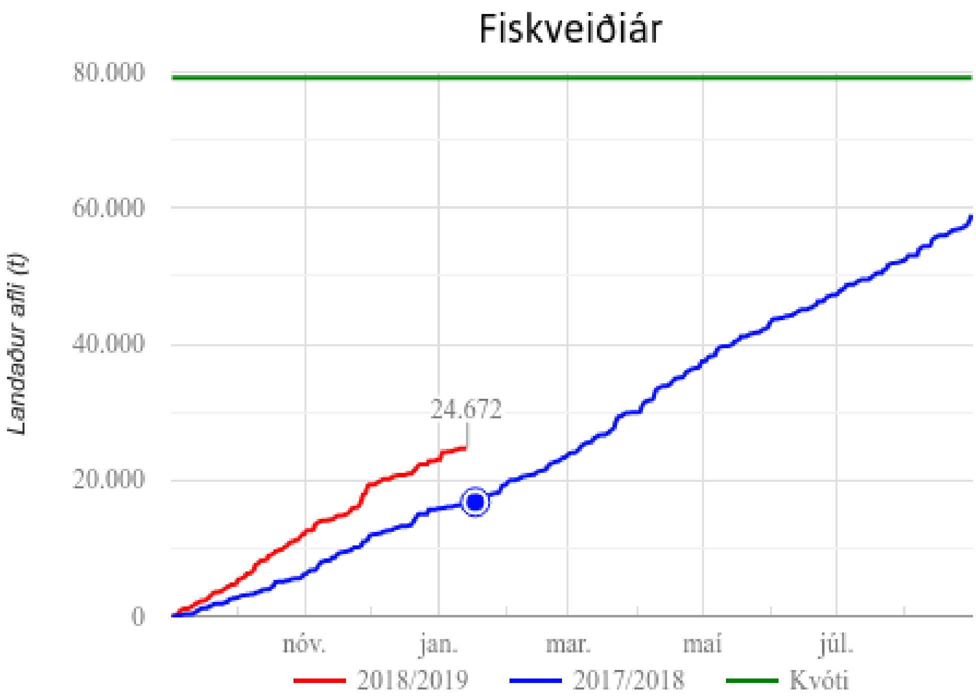


Figure A.2.5. Saithe quota transferred to next fishing year, unused quota and transfer from other species. Last year negative quota was transferred from other species i.e. saithe was converted to other species. Some quota has been unused most of the time, especially in recent years.



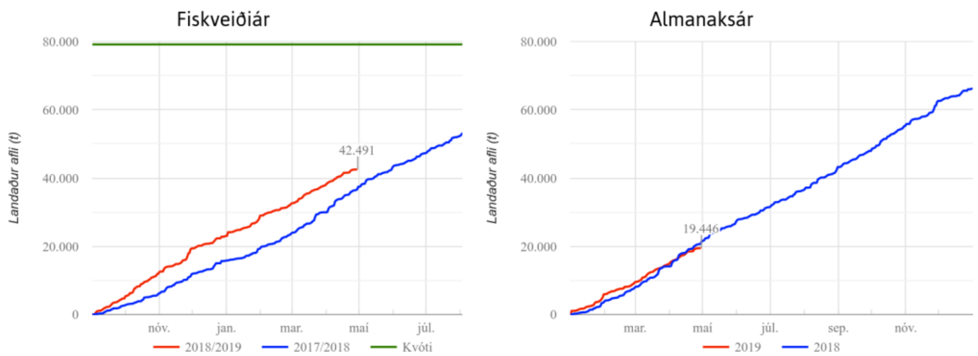


Figure A.2.6. Development of landings in the fishing years 2018/2019 and 2017/2018. The horizontal line shows the TAC for 2018/2019. Since 2013 TAC has been set according to the Harvest Control Rule. Fiskveiðiár means Fishing year and Kvóti TAC

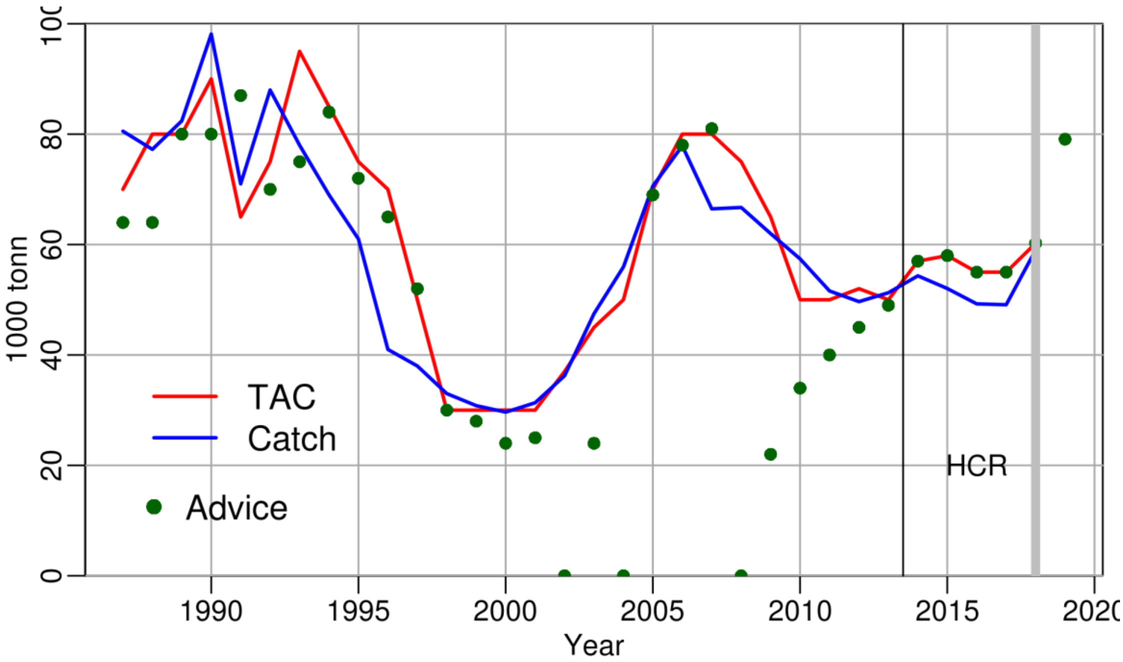


Figure A.2.7. Advice, TAC and catch for saithe since 1987.

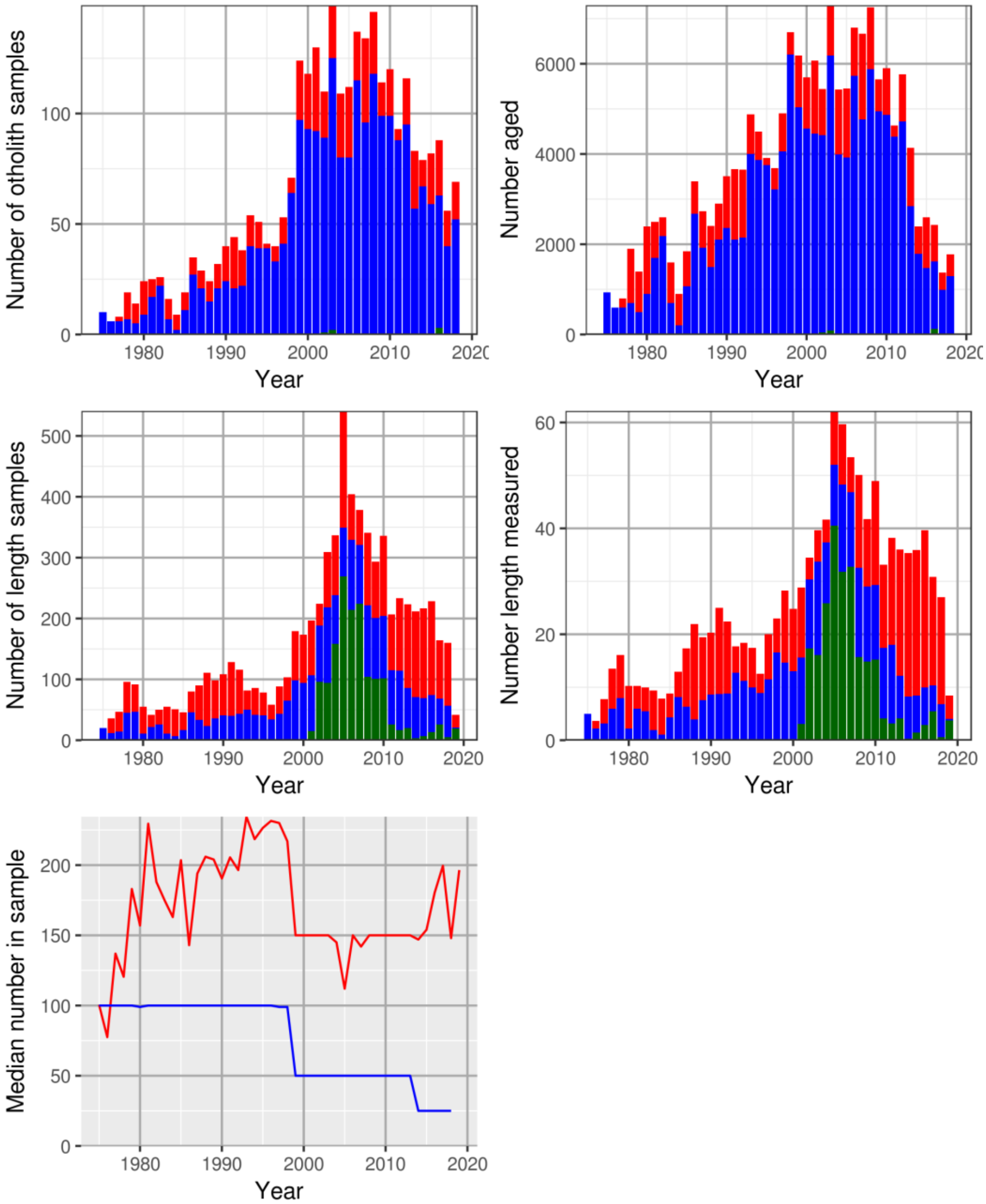


Figure B.1.1. Top left. Number of otolith samples from the catches. Top right. Number of aged saithe from catches. Middle left. Number of length samples from catches. Middle right. Number length measured. Bottom left median number of fish in a sample. Blue aged, red length measured. The shading indicates different type of samples. Green discard samples. Blue samples from landings by the MRI and red samples taken aboard the vessels by employees of the Fisheries Directoriate.

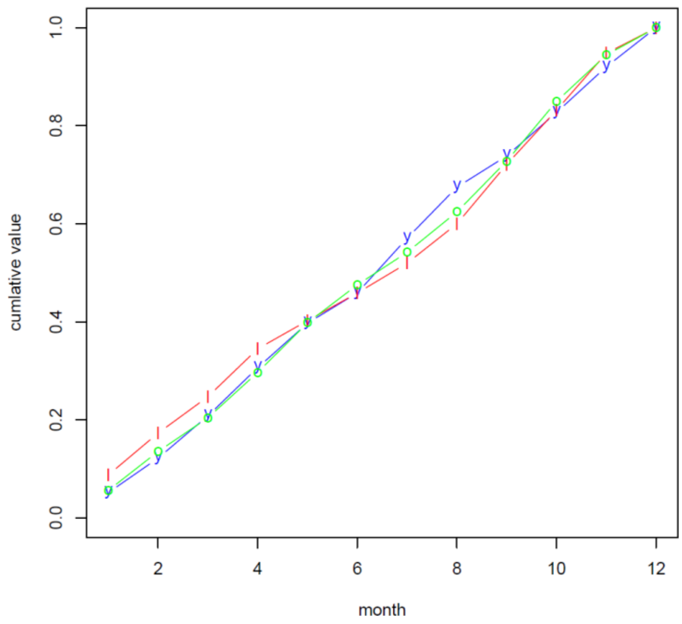


Figure B.1.2. Saithe in Va. Cumulative plot of landings (y: blue) and length (l: red) and otolith (o: green) sampling by month over the period 2005 to 2008.

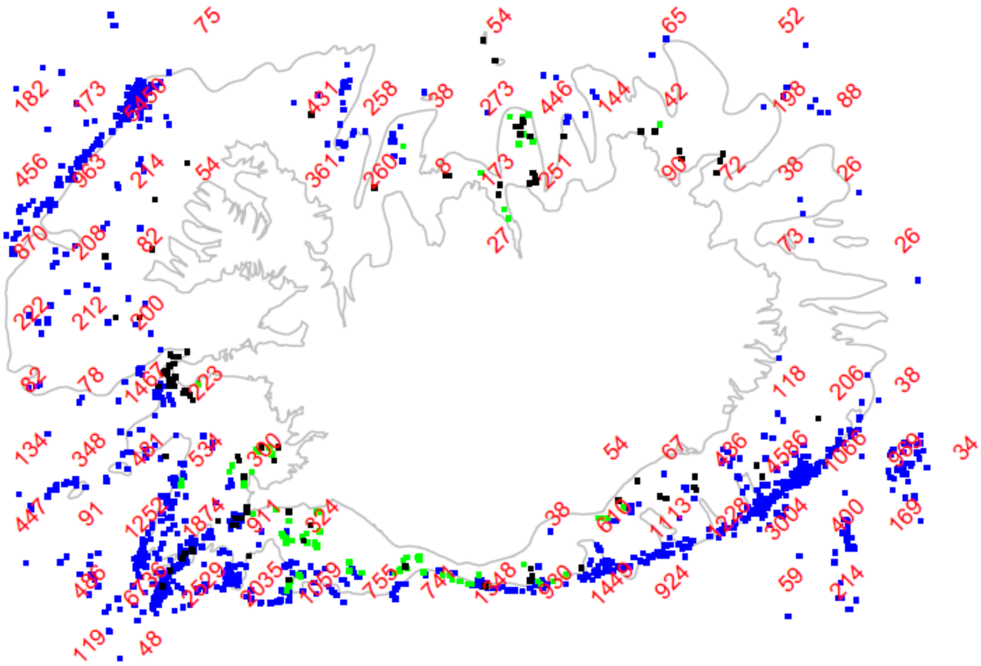


Figure B.1.3. Length samples: Location and average annual number sampled by statistical square for in 2005 to 2008. Blue dots indicate trawl sample, green gill net samples and black dots other gear.

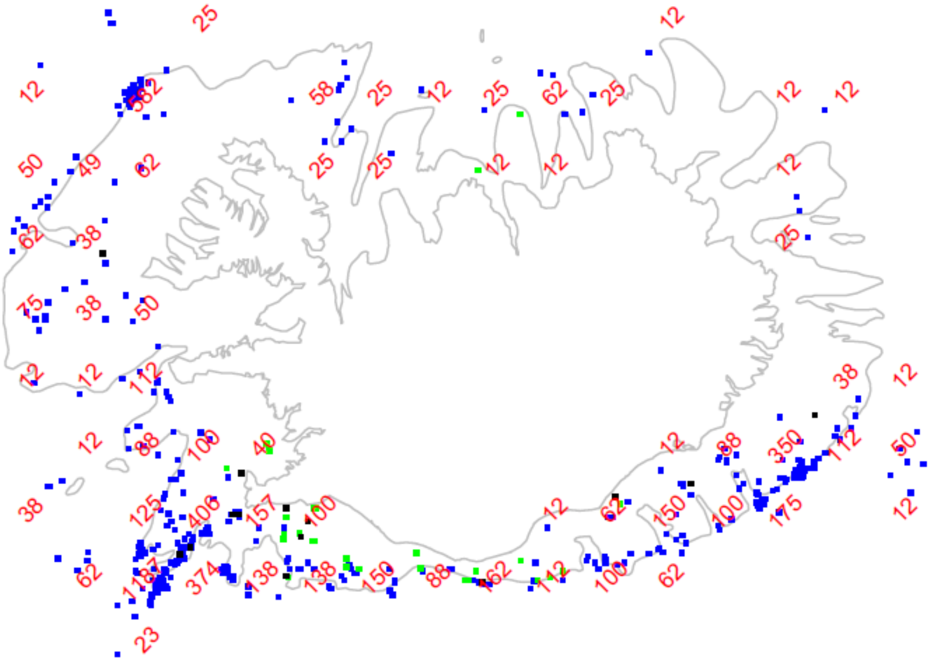


Figure B.1.4. Saithe in Va. Otolith samples: Location and average annual number sampled by statistical square for in 2005 to 2008. Blue dots indicate trawl sample, green gill net samples and black dots other gear.

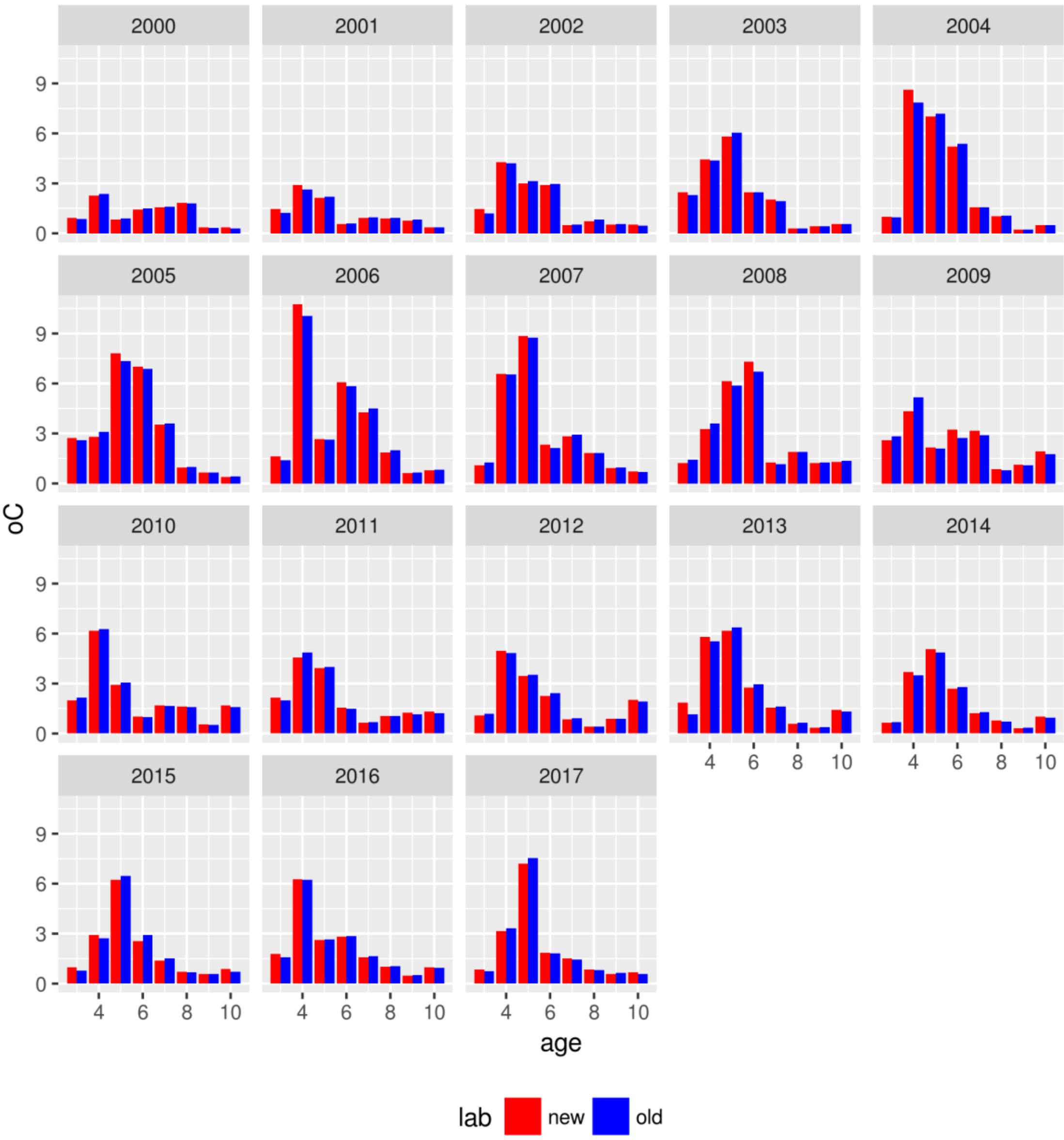


Figure B.1.5. Comparison of traditional catch in numbers compiled by 1 region, 1 time interval and 2 gears (gillnets and trawl) and catch in numbers compiled by 2 regions and 3 gears (handline, gillnets and trawl). Age 10 is a plus group (10-14 in the old data, 10+ in the new data)

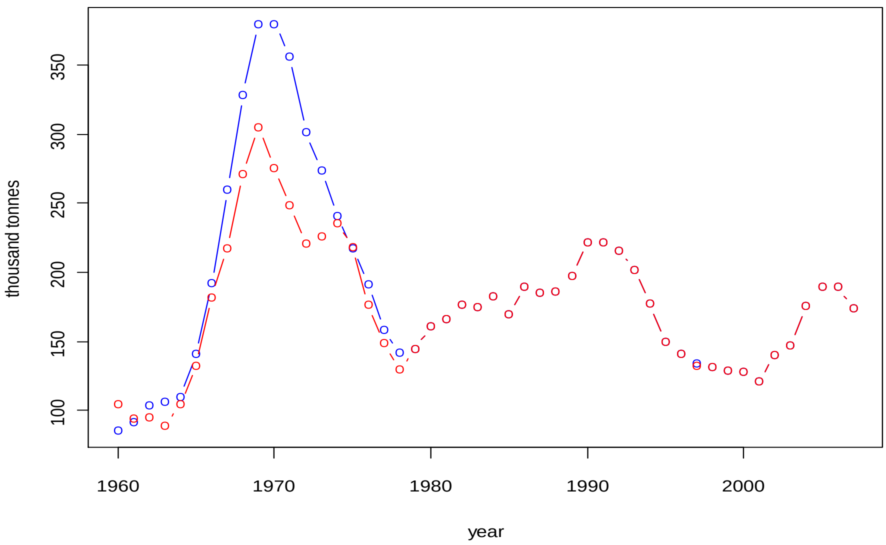


Figure B.1.6. Saithe in 5.a. Comparison of SSB trajectory based on constant weight at age (blue) matrix in period prior to 1979 and one where weights in that period were rescaled (red).

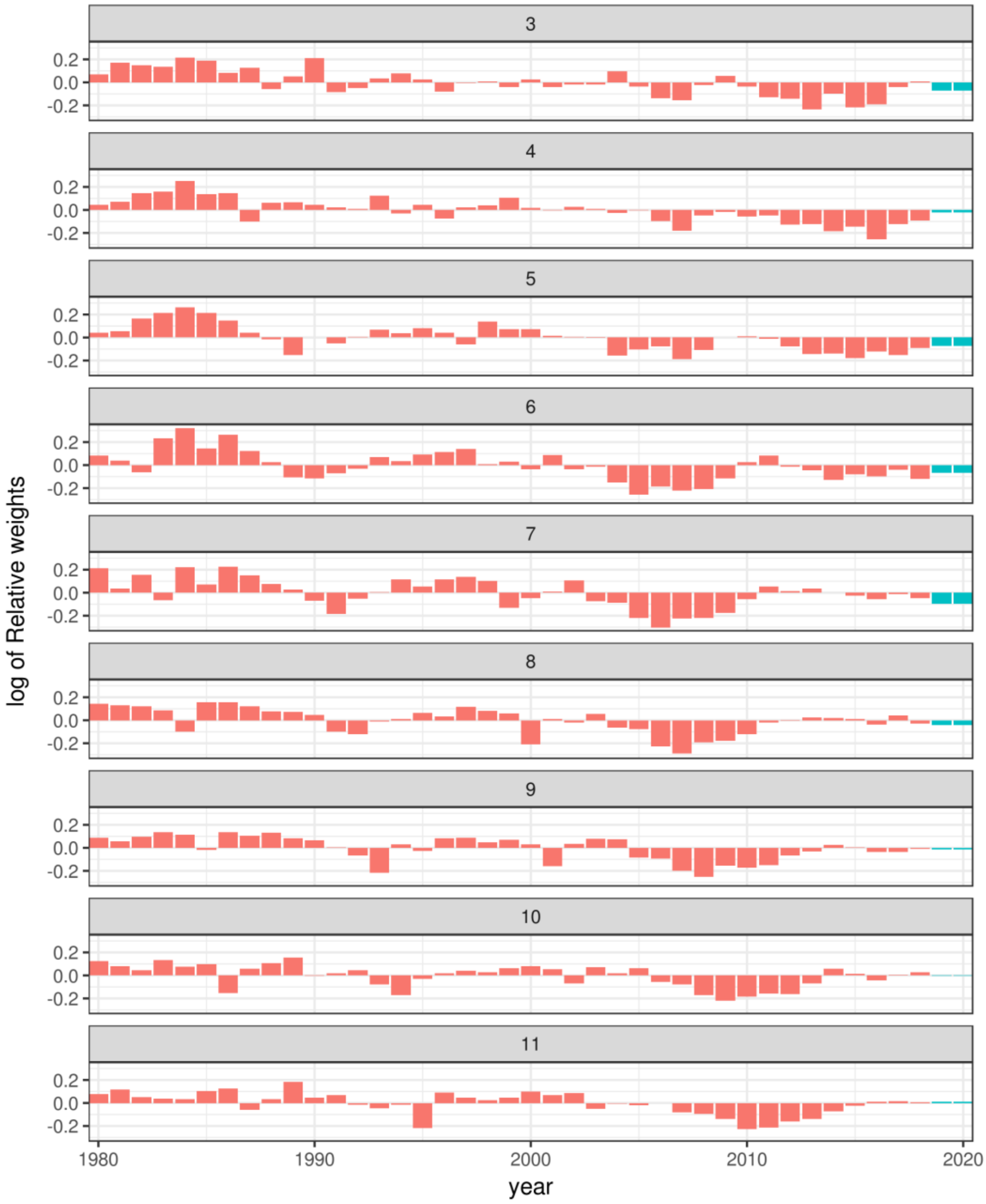


Figure B.2.1 Development of mean weight at age in the landings shown as log of residuals from the average. Predictions are shown with blue color.

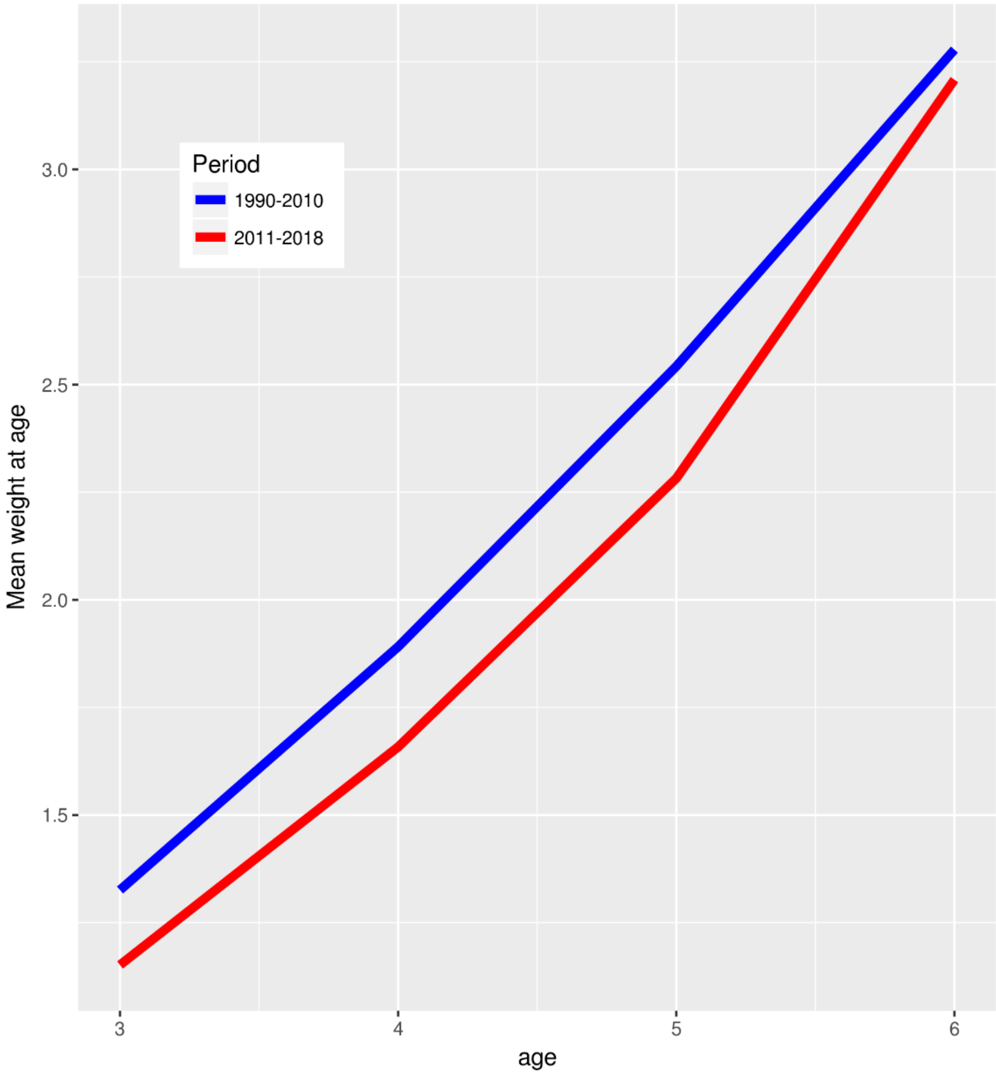


Figure B.2.2 Mean weight at age in catches by periods.

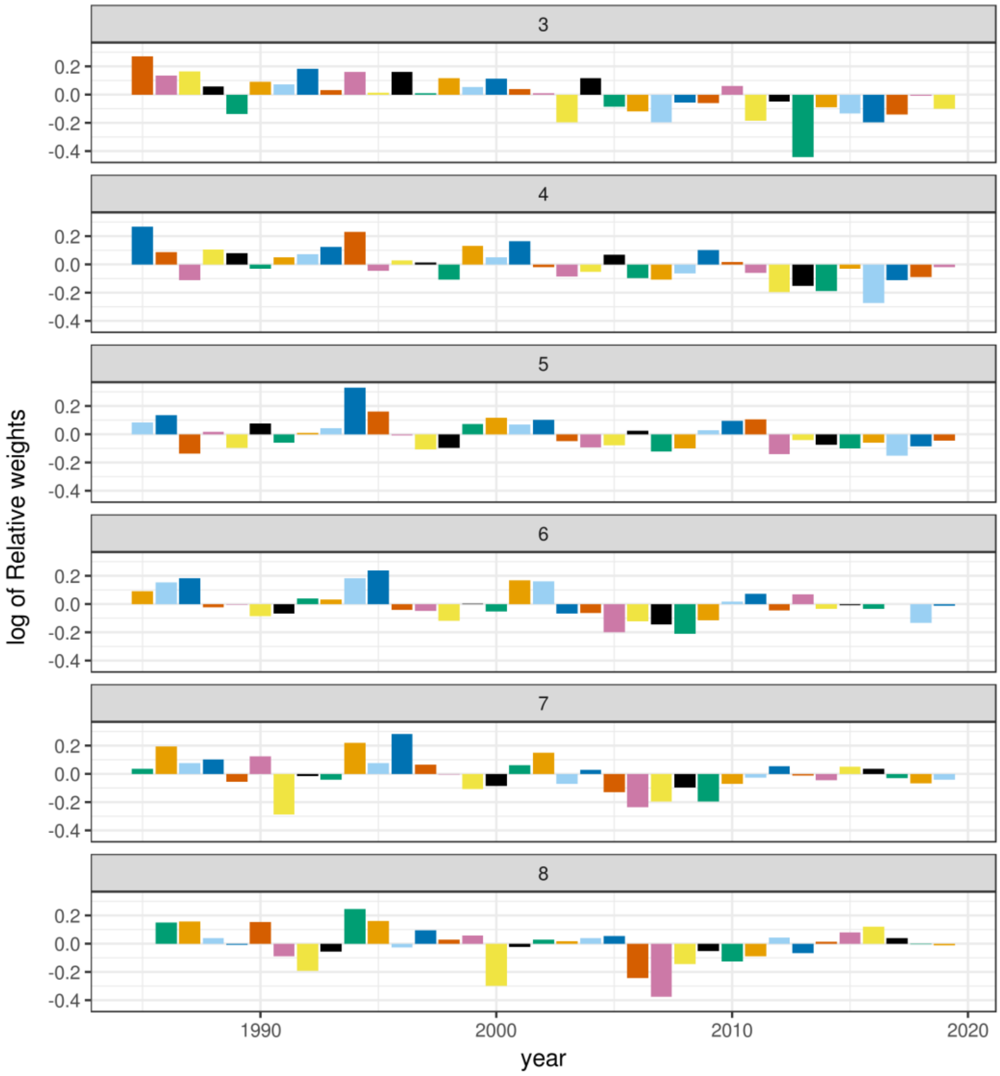


Figure B.2.3 Development of mean weight at age in the March survey shown as log of residuals from the average. Colors are used to follow year classes.

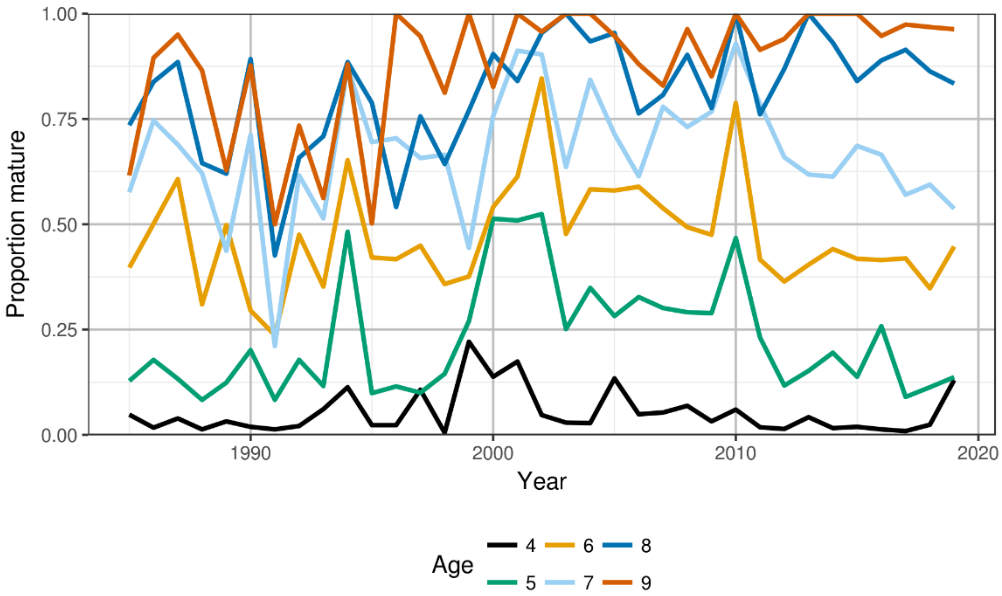


Figure B.2.4 Maturity at age from the March survey.

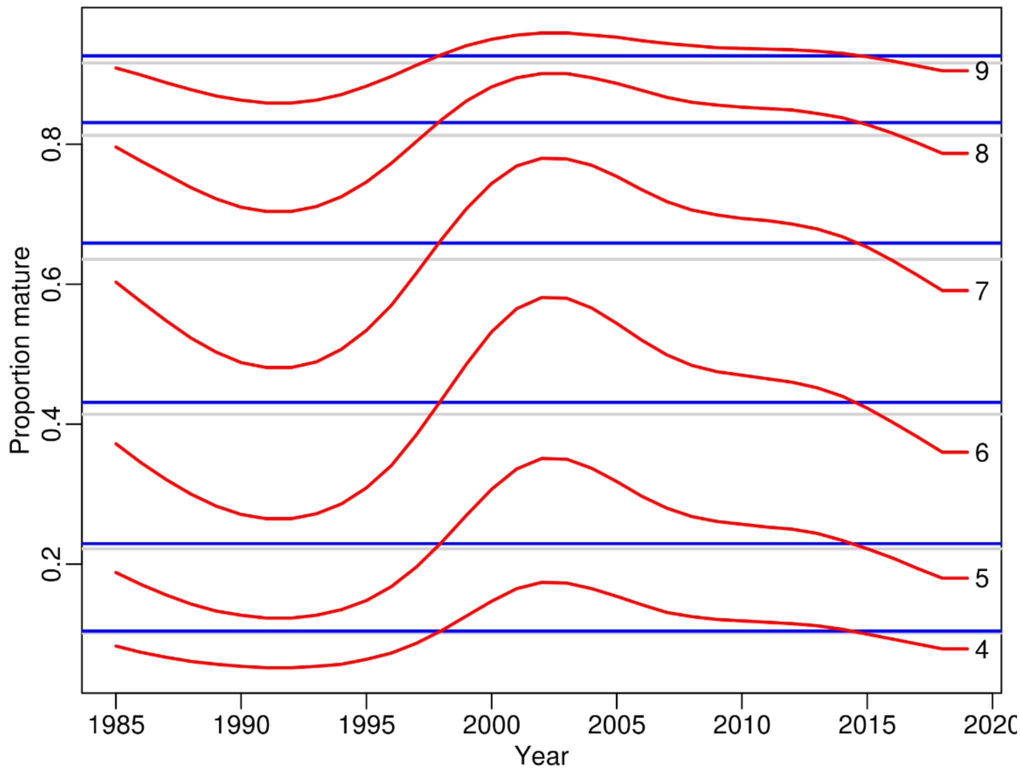


Figure B.2.5. Development of smoothed maturity at age. The grey lines show the average 1985–2018 for each age group. The blue line shows the average of last 10 years and the grey lines average for the period 1985–2018.

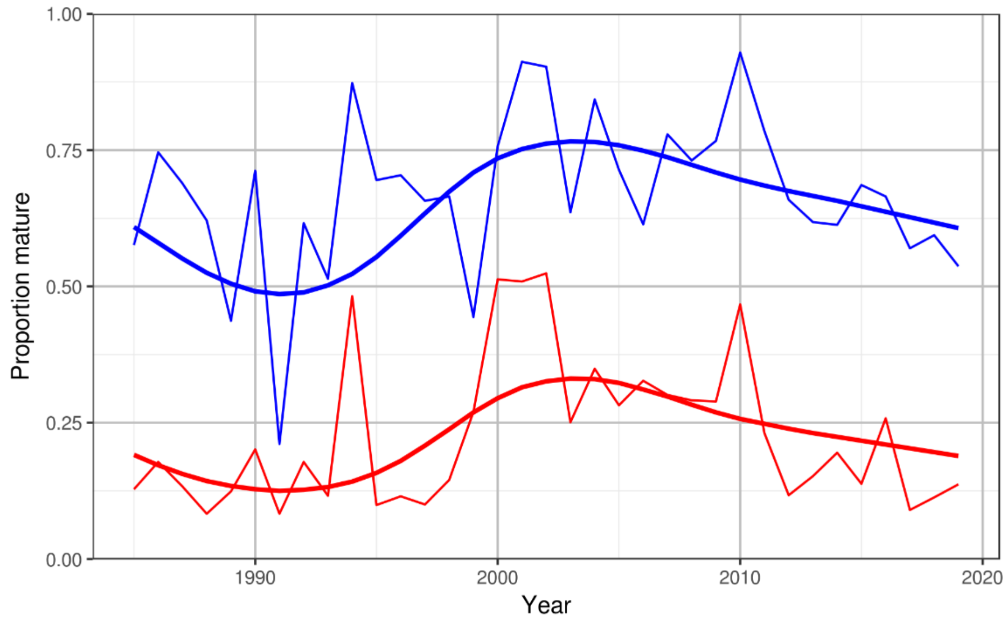
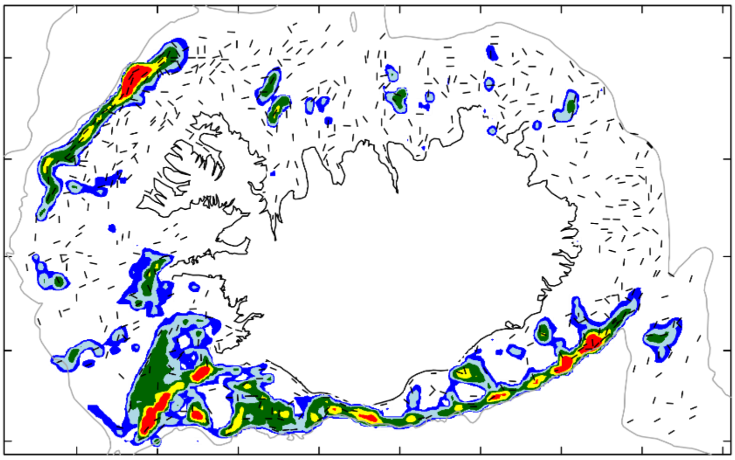
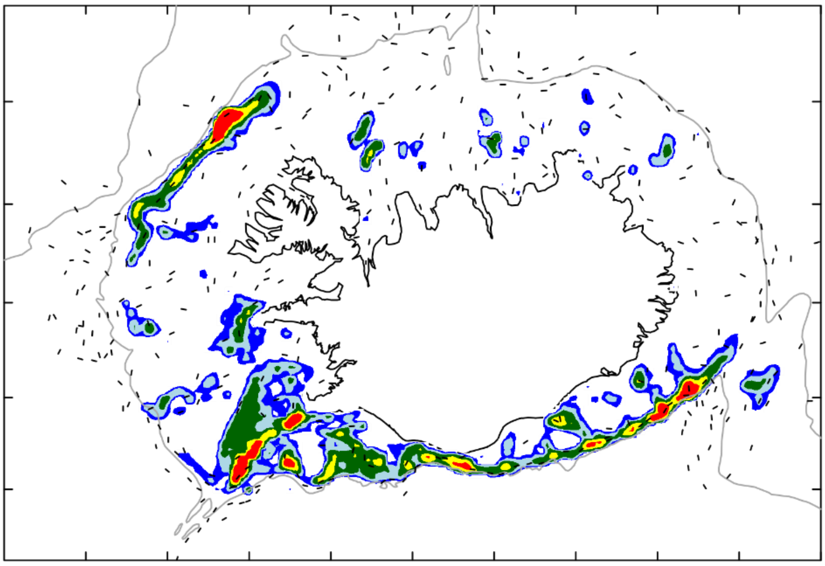


Figure B.2.6. Comparison of smoothed and unsmoothed maturity for ages 5 and 7.

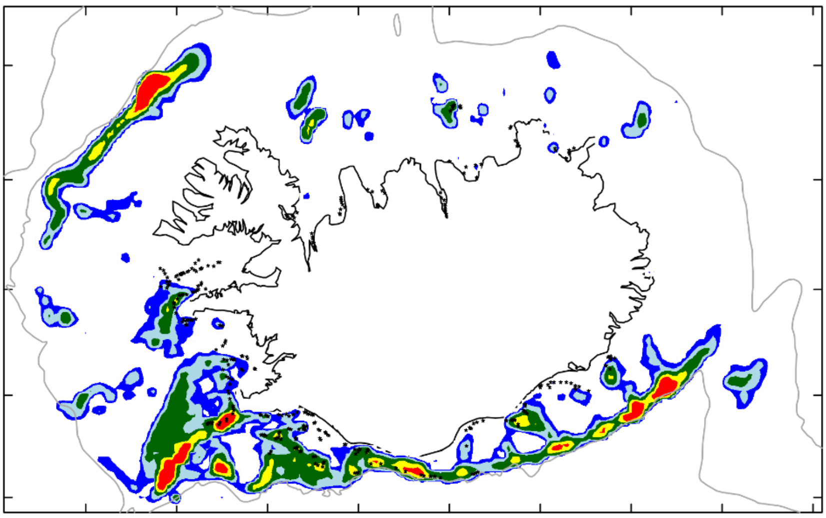
Bottom trawl survey in March since 1985



Bottom trawl survey in October since 1996



Gillnet survey in April since 1996



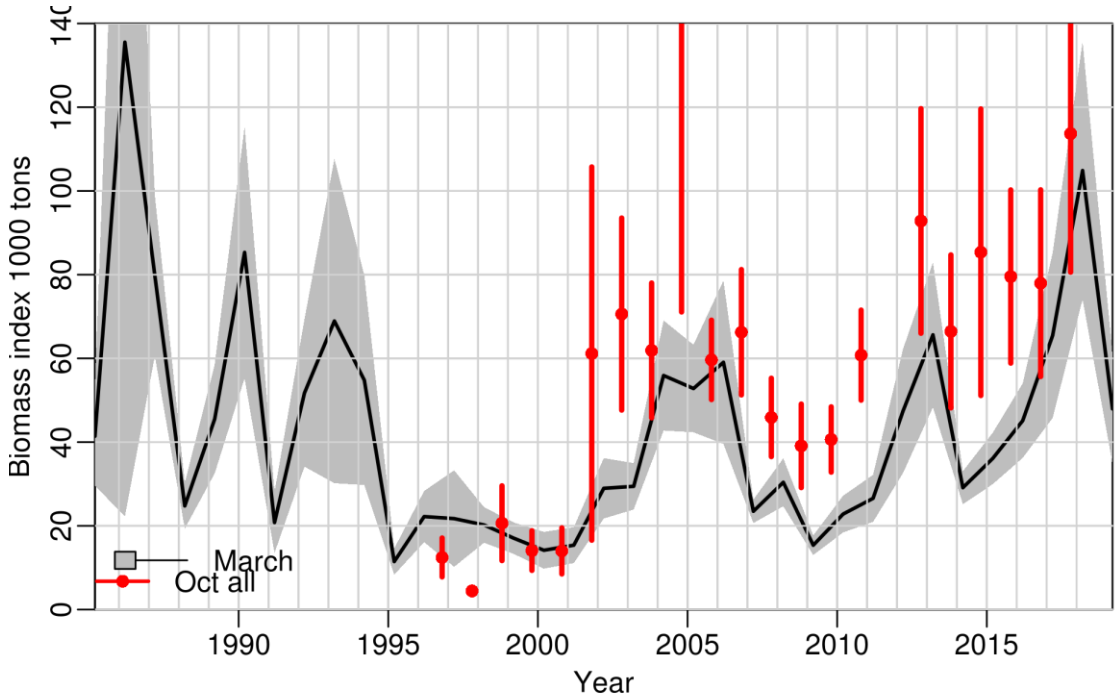


Figure B.3.2. Index of total biomass from the surveys in March and October. The shaded areas and bars show 1 standard deviation in the estimates.

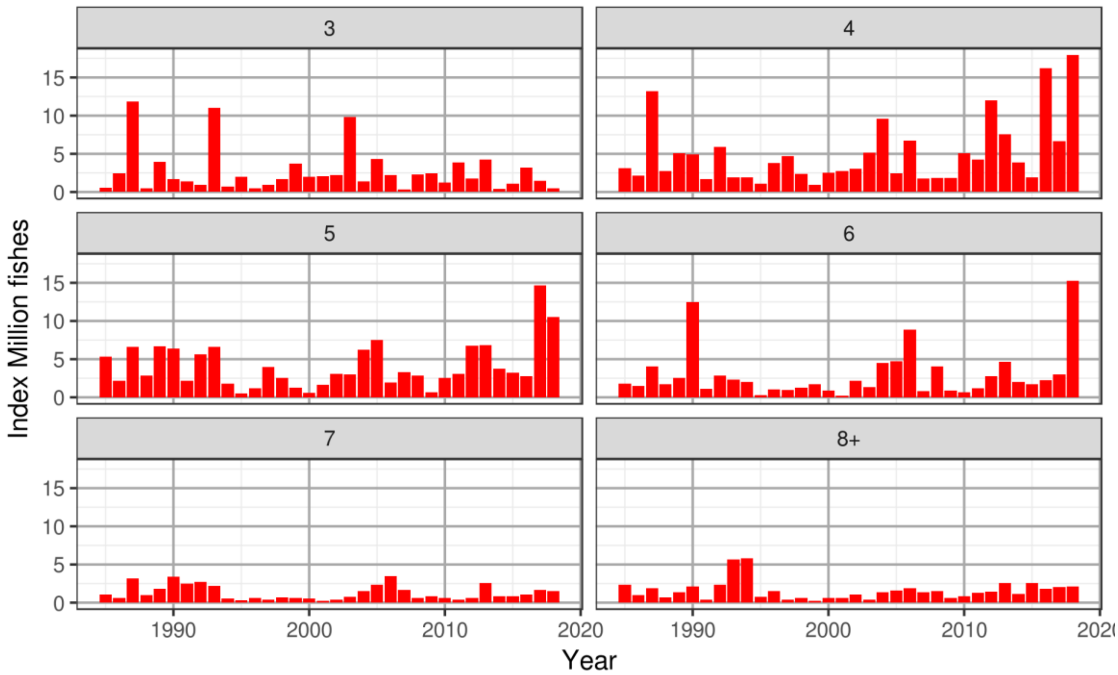


Figure B.3.2 Age disaggregated index from the groundfish survey in March

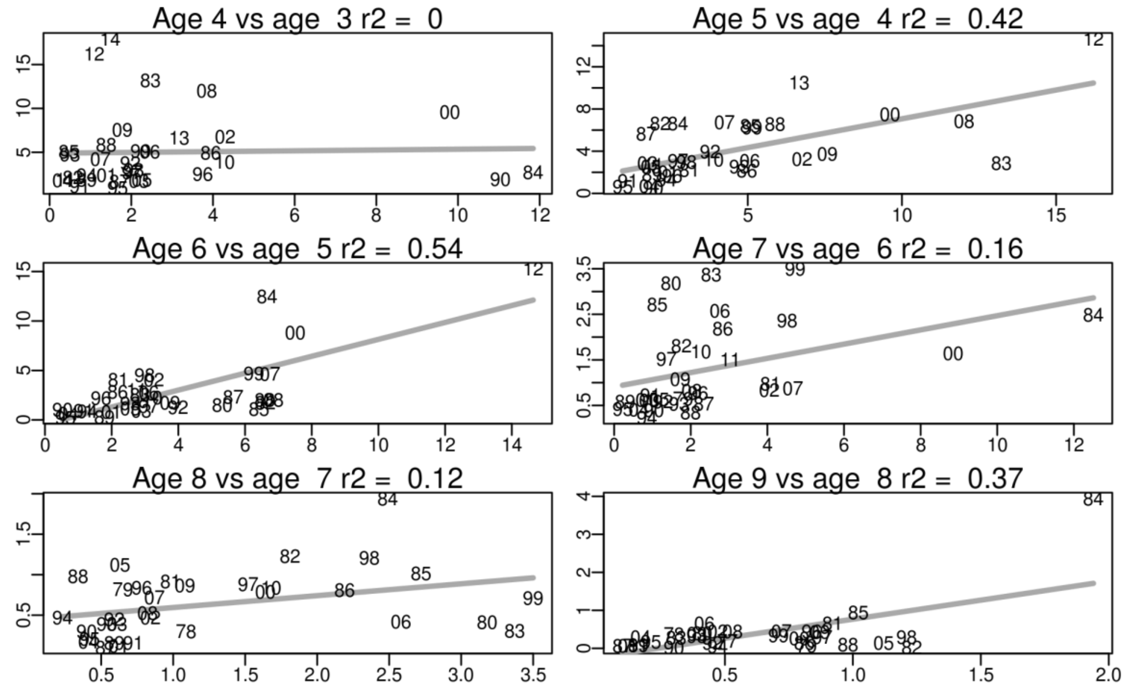


Figure B.3.3 Indices from the survey in March plotted against indices of the same year class the year before. The labels denote year class.

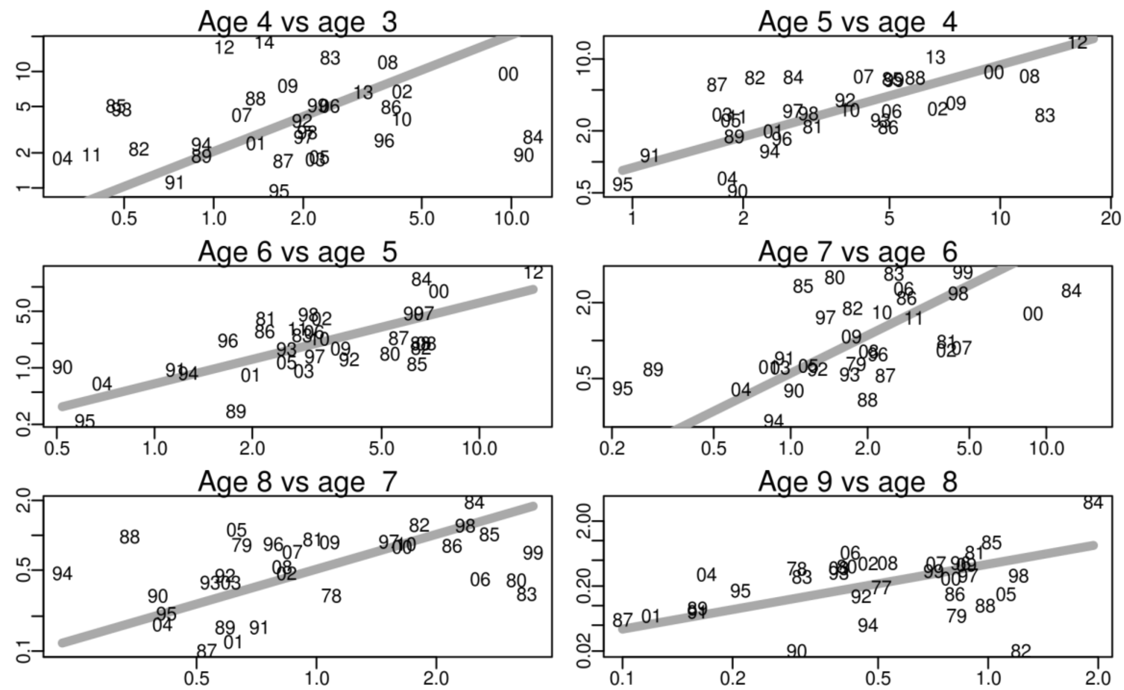


Figure B.3.4. Indices from the survey in March plotted against indices of the same year class the year before on log scale. The labels denote year class.

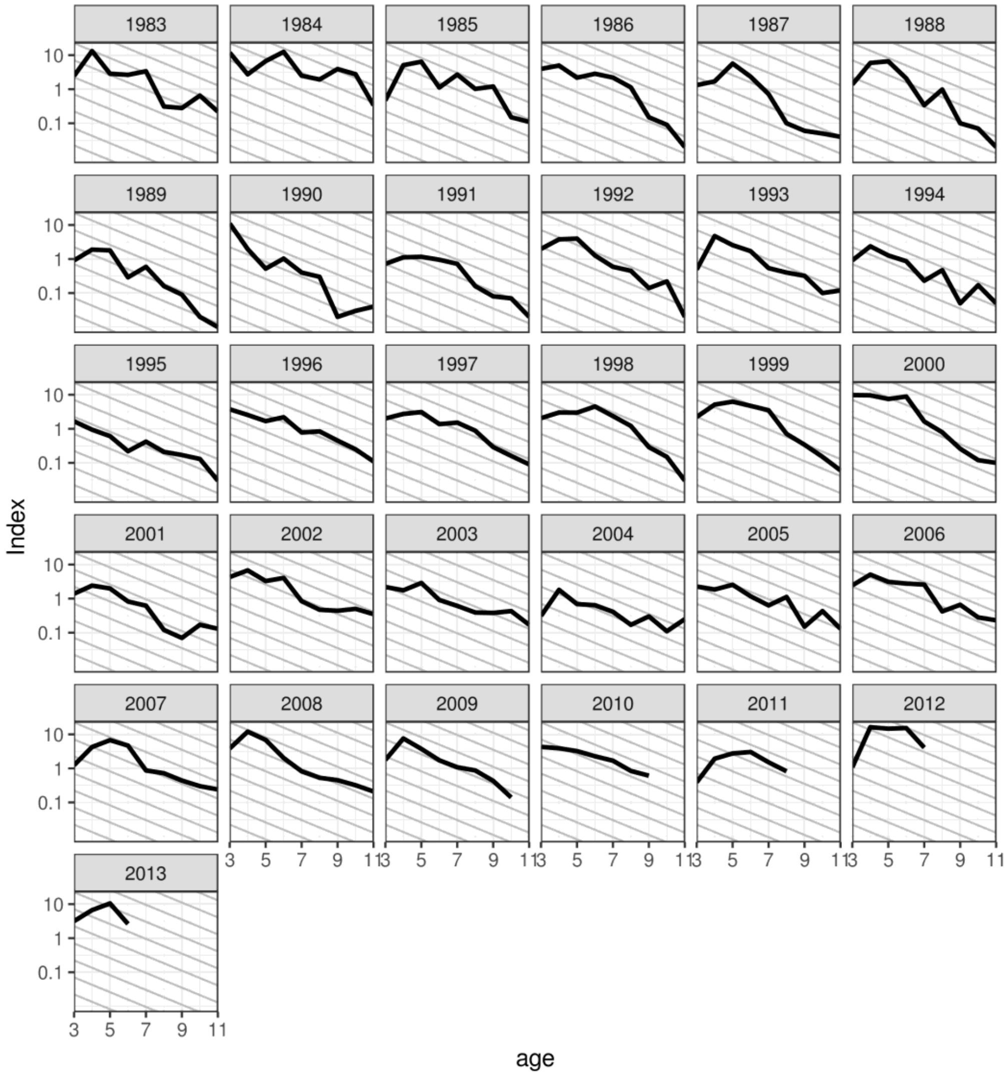


Figure B.3.5. Abundance Indices from the survey in March plotted on log-scale. Each panel represents a cohort and the grey lines correspond to Z = 0.5.

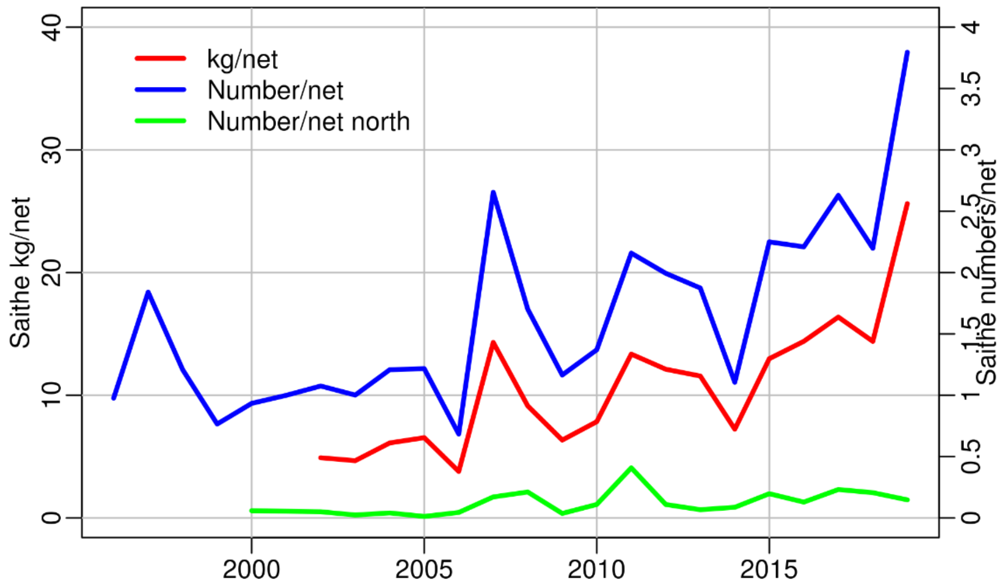
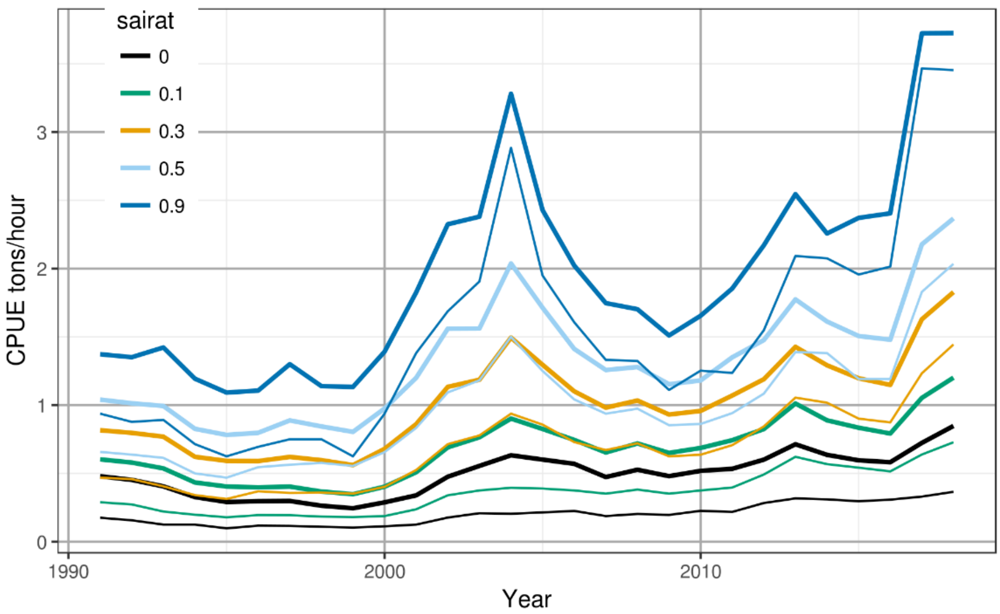


Figure B.3.6 Abundance indices of saithe from the gillnet survey in April.



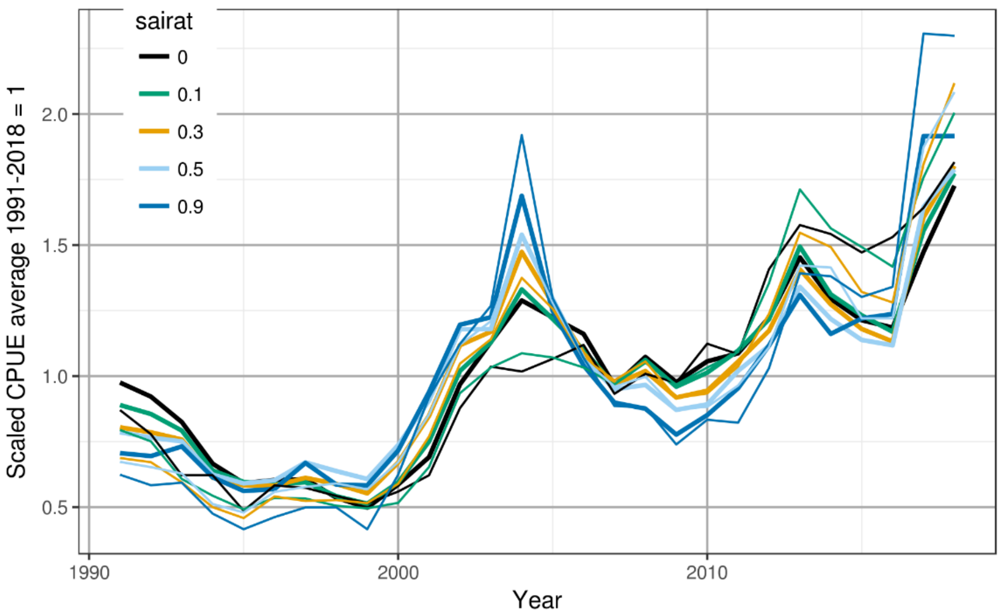


Figure B.4.1 CPUE of saithe from bottom trawl. The colour shows selection of tows, where proportion of saithe of the total catch is > 0, 0.1, 0.3, 0.5 and 0.9. The thin lines show median of Catch/hours while the wide line show sum(Catch)/sum(hours towed) over the year. The upper picture shows the value but the curves in the lower figure are scaled so the average 1991–2018 is one.

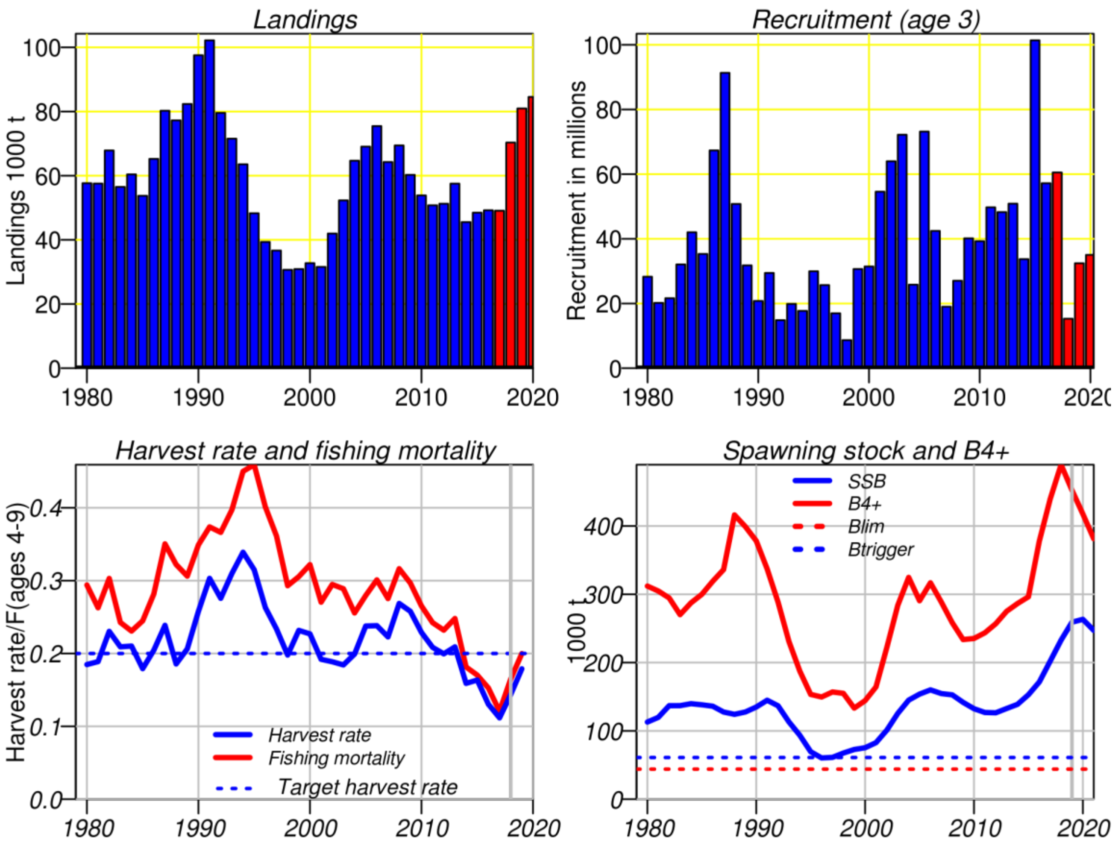


Figure C.1.1. Summary of the 2018 assessment that was the basis of the management plan evaluation in March 2019. Short term redictions using the HCR are shown.

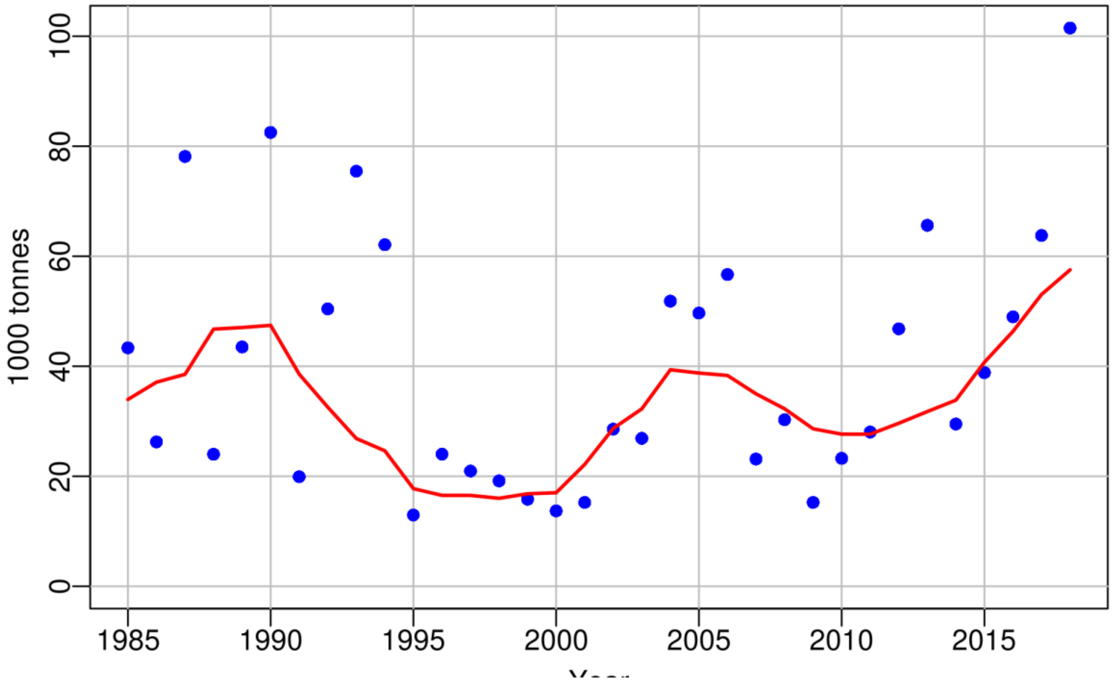


Figure C.1.2 Observed and predicted survey biomass in the 2018 assessment.

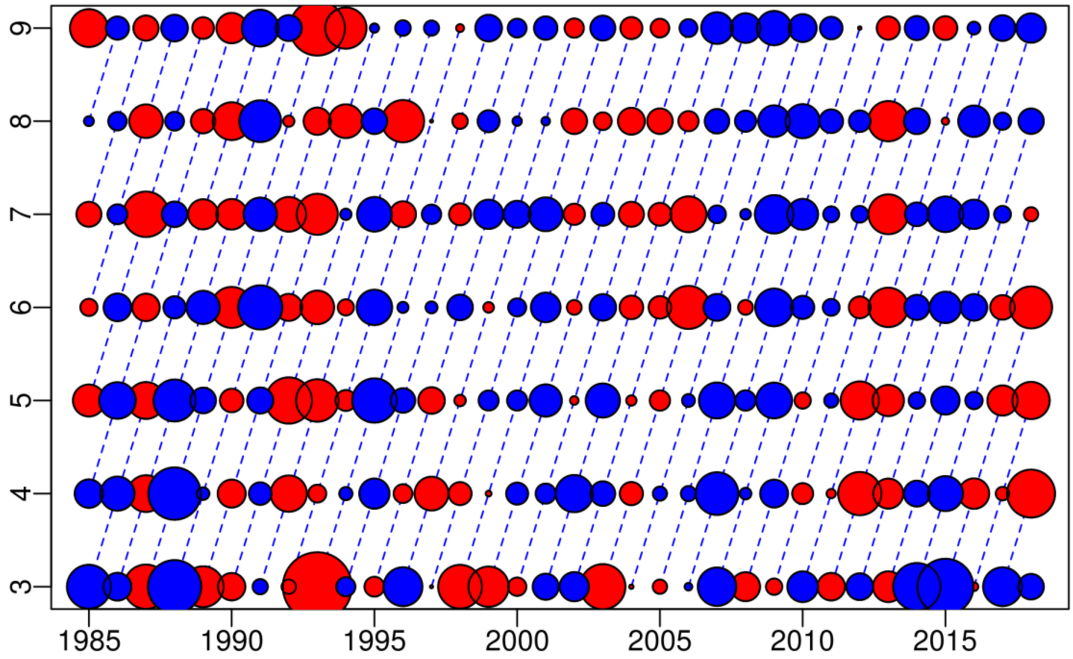


Figure C.1.3. Survey residuals in the 2018 assessment, largest circle corresponds to 1.92.

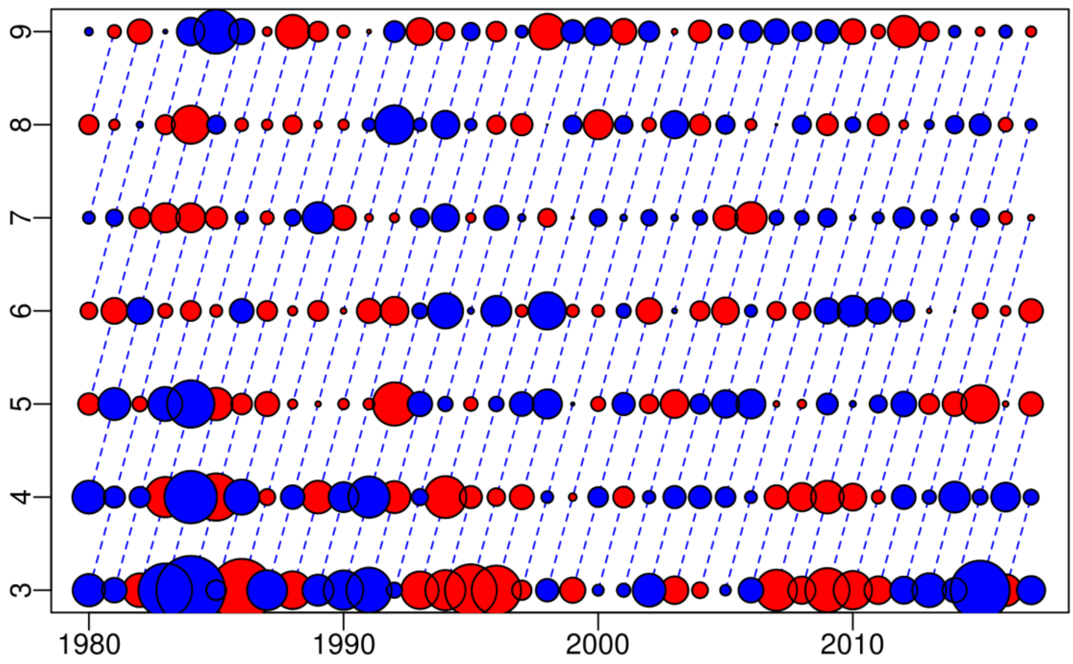


Figure C.1.4. Catch residuals in the 2018 assessment, largest circle corresponds to 1.07.

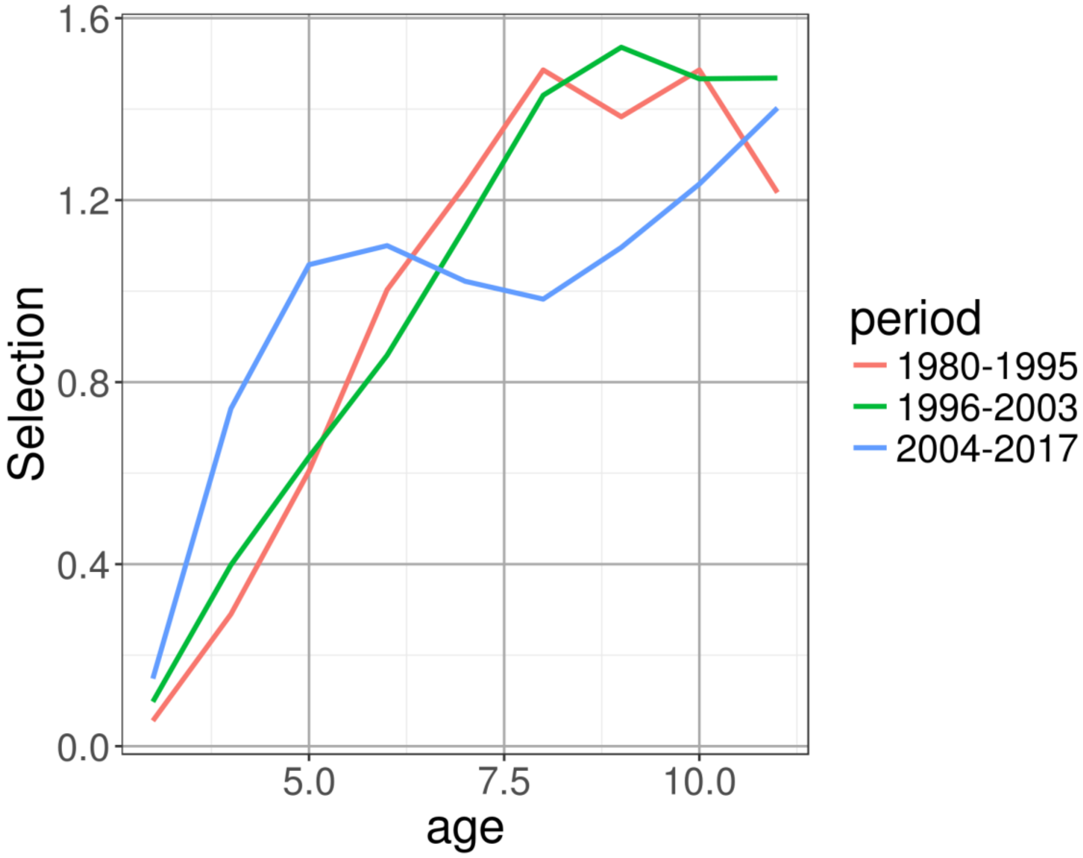


Figure C.1.5 Selection at age for the 3 periods 1980–1995, 1996–2003 and 2004–2017.

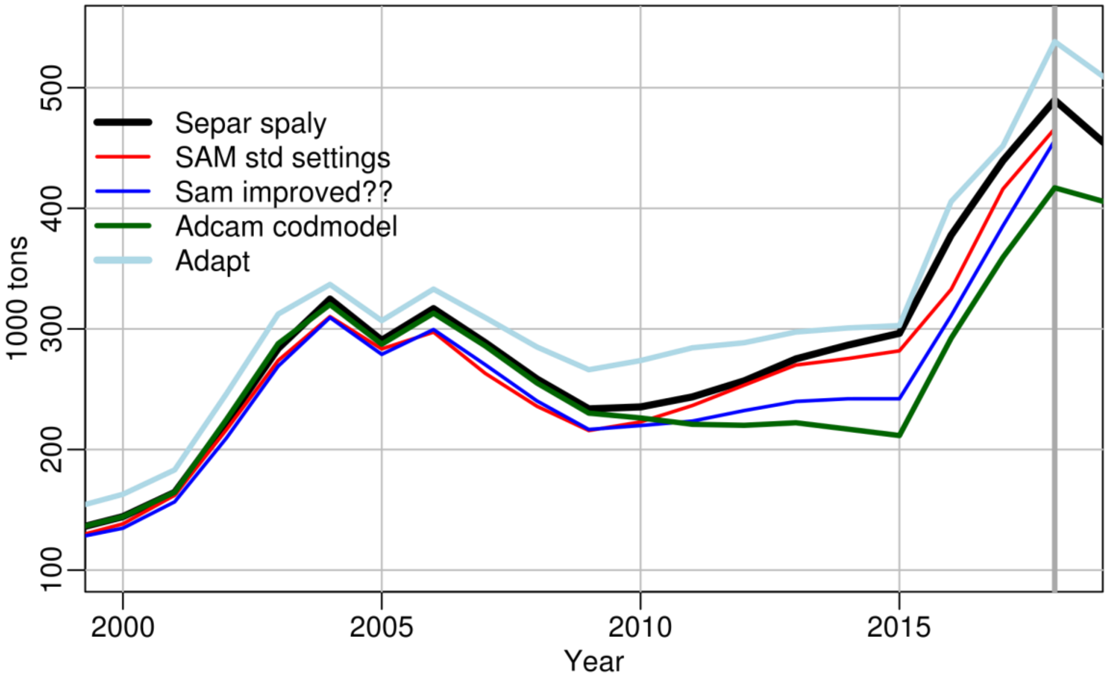


Figure C.1.6. Results from few assessment models run on the data used in the 2018 assessment. Adcam codmodel is a model where fishing mortality is modelled as correlated random walk.

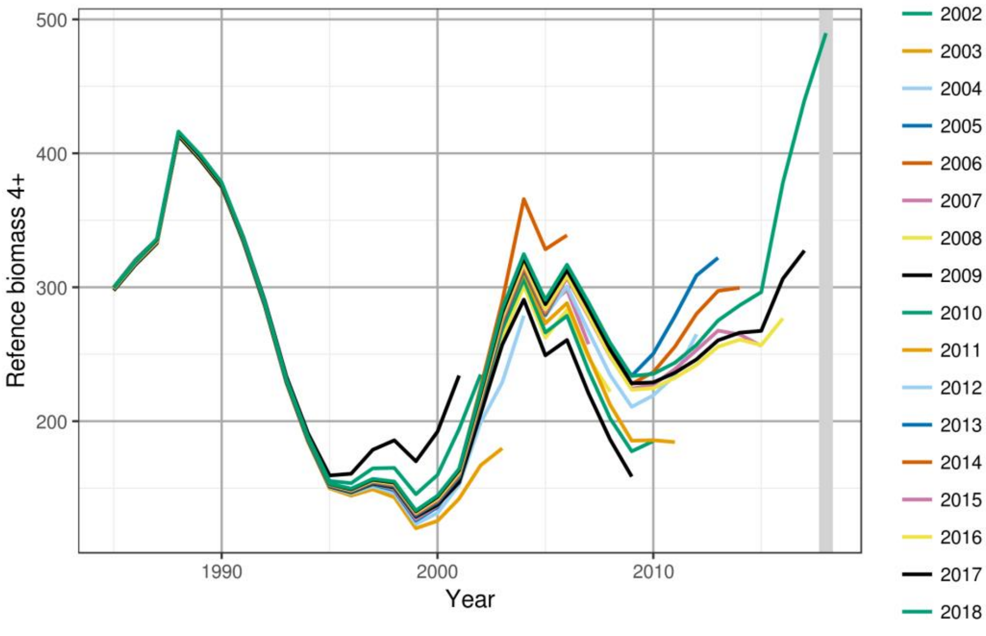


Figure C.1.7. Analytical retros of the reference biomass based on the assessment years 2001–2018.

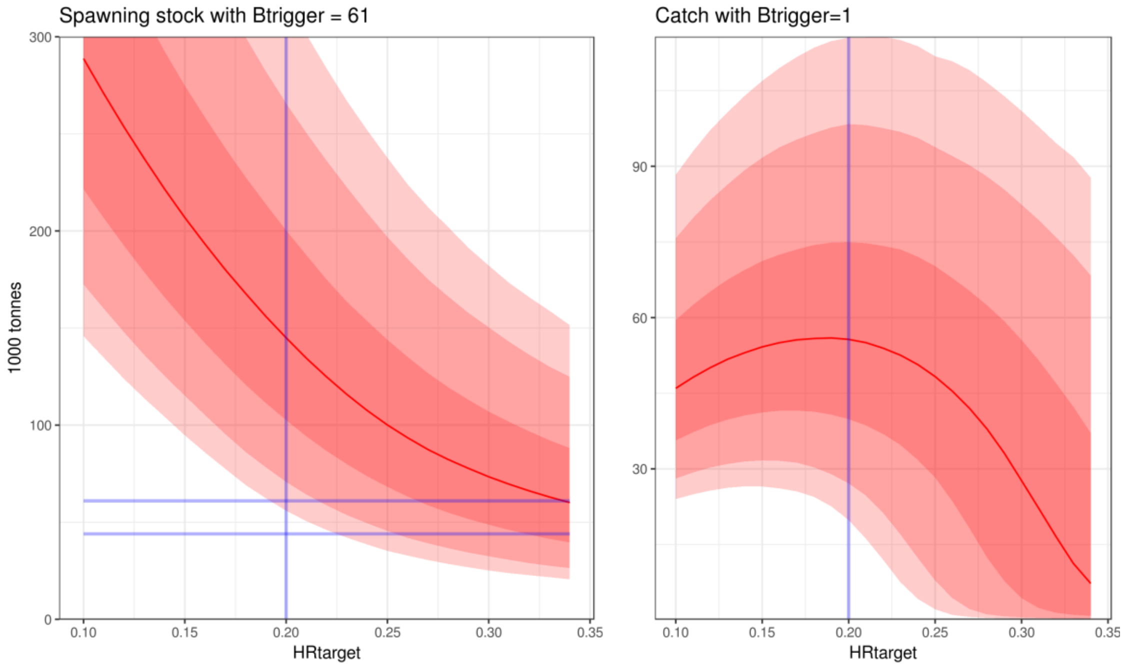


Figure C.1.8. Spawning stock and catch as function of HR_{target} The shaded areas show 5, 10, 25, 75, 90 and 95th percentiles and the red. $B_{trigger}$ = 61 kt for the SSB figure but 1 for the catch figure (i.e no . . $B_{trigger}$).