Data for plaice (*Pleuronectes platessa*) in Division 7.e (western English Channel – ple.27.7e) – Working document for WKBPLAICE 2024[I]

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Contents

[I] Version 2. Added clarifications for the discard weights for the plusgroup (Section 5.1) and added additional SAM explorations (Section 6.6).

1 Introduction

This document is about the following plaice stock:

- Plaice (*Pleuronectes platessa*) in Division 7.e (western English Channel) – ple.27.7e

Figure 1 shows the stock area for this stock.

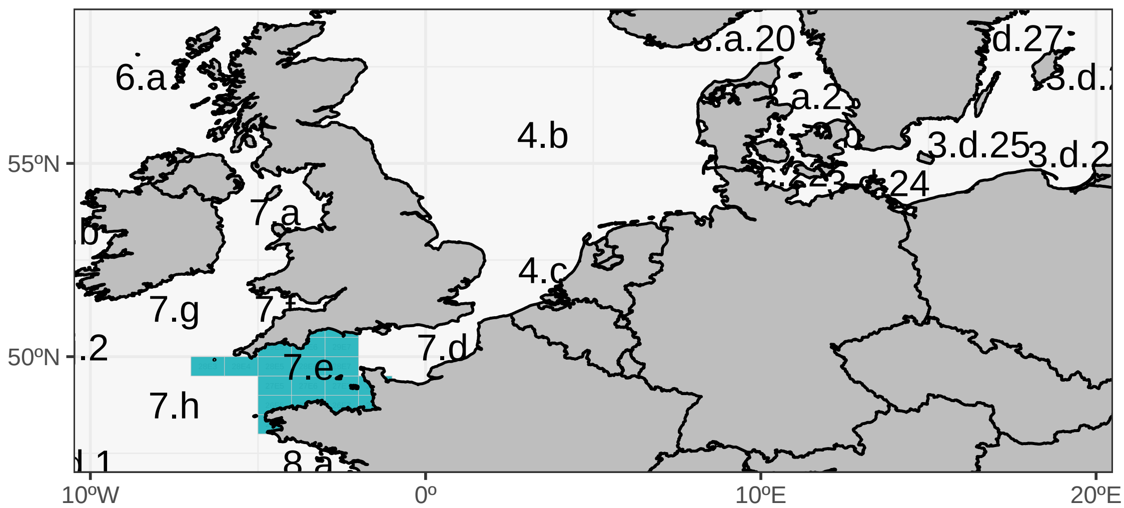


Figure 1: The stock area for plaice (*Pleuronectes platessa*) in Division 7.e (western English Channel).

The last full ICES benchmark for this stock was WKFLAT in 2010 (ICES, 2010) followed by two inter-benchmarks in 2015, IBPWCFlat (ICES, 2015a) and IBPWCFlat2 (ICES, 2015b). Until 2014, the stock was treated as a category 1 data-rich stock by ICES and assessed with the "extend survivors analysis" (XSA) stock assessment (Sheperd, 1999). Following IBPWCFlat2, the stock was downgraded to a data-limited category 3 stock because the XSA assessment exhibited large retrospective patterns and estimated reference points differed markedly from other similar plaice stocks (ICES, 2015b). Since 2015, the advice was based on the category 3 "2-over-3" rule (ICES, 2012) and applied annually. The spawning stock biomass (SSB) estimates from the XSA assessment were used as an indicator of biomass informing the 2-over-3 rule. In 2022, the ICES methods for categories 2 and 3 were revised (ICES, 2022a). ICES advice was given with the new category 3 "rfb rule" (ICES, 2017, 2018a, 2019a, 2020a; Fischer et al., 2020, 2021a,b) and one of the two survey indices (UK-FSP) was used as an indicator of biomass. The rfb rule is applied biennially and was first applied in 2022 to give advice for 2023 and 2024 (ICES, 2022b) and a second time in 2024 to give advice for 2025 and 2026 (ICES, 2024). The most recent advice (ICES, 2024) states:

> "ICES advises that when the MSY approach is applied, catches should be no more than 927 tonnes in each of the years 2025 and 2026."

The need for a benchmark for this stock arose because the last benchmark was over 10 years ago, biological data has not been updated for an even longer period, and the inclusion of discard data in the assessment has never been fully evaluated. Unlike most typical benchmarks in ICES, the aim for this stock was not to "upgrade" the stock to a category 1 data-rich stock assessment but instead to keep it in category 3 and conduct a stock-specific simulation (management strategy evaluation, MSE, in the sense of a closed-loop simulation), as recommended by ICES (2022a), and tune a category 3 empirical harvest control rule to be used as the basis for the ICES catch advice. This approach was followed based on the work by Fischer et al. (2023), who showed that an "upgrade" of this stock to a category 1 is theoretically possible but would ignore crucial uncertainties for this stock and lead to poor management performance, whereas tuning a category 3 method leads to better and more robust fisheries management performance.

All input data and scripts used to process the data as presented in this working document are available online on GitHub at https://github.com/shfischer/WKBPLAICE2024_ple.27.7e_data.

2 Issue list

There was a growing issue list for this stock, which was kept updated online in ICES' rolling issue list platform https://sid.ices.dk/manage/RollingIssues.aspx (search for "ple.27.7e"). A snapshot of this issue list at the beginning of this benchmark is presented in Table 1.

Table 1: Issue list for ple.27.7e.

ID	Type	Problem/Aim	Work Required
40	Tuning series	Q1SWBeam survey index was revised in 2020. Changes to underlying data and generation of index should be reviewed.	Review data base and computer code to generate index.
41	Discards	Previously used age-structured stock assessment models did not include discards but discards are considered substantial.	Discard estimates are available in InterCatch for 2012-2022 and have been extrapolated back in time by WGCSE. Available discard data should be analysed, and it should be investigated whether more historical discard data are available.
42	Discards	French discard data for 2018 revised in 2020 due to inaccuracies in the methodology, however, the method has also been used for previous years	review French discard estimates prior to 2018.
43	Biological parameters	Natural mortality (time and age invariant) and maturity ogives (time invariant) were borrowed from other plaice stocks, but are not used for these stocks anymore after benchmarks.	Updates to biological data should be considered. Natural mortality is unknown and no studies for this stock area exist. The assumptions for natural mortality have a crucial influence on the output of age-structured stock assessment models and depending on the assumptions, the stock status can vary considerably. This is likely to impair the use of age-structured stock assessment models.
44	Biological parameters	Stock and catch weights are currently derived by applying a smoother to the annual weights at age from InterCatch.	The use of raw weight at age or alternative formulations (e.g. von Bertalanffy growth model) and their impact should be explored.
45	Stock identity	There is uncertainty about the stock structure and some mixing between 7.d and 7.e is considered.	Migration between different areas should be further investigated but can likely not be resolved in the near future. Assumptions about migration are likely to have a higher impact on analytical stock assessment models but are less important for category 3 empirical harvest control rules because these follow trends in the data without having to estimate population dynamics.

Table 1: (continued)

ID	Type	Problem/Aim	Work Required
46	Assessment method	The advice for this stock is based on the category 3 data-limited rfb rule. The rfb rule is applied with generic parameters leading to a precautionary advice. There is potential to explore moving the stock to a category 1 data-rich assessment or to conduct a case-specific MSE. Recently published work on a comparison of category 1 and category 3 stocks through MSE included this stock as a case study. The main conclusions were (1) that a single age-structured data-rich stock assessment can likely not capture the full dynamics of this stock because of high uncertainty, (2) a category 1 approach following ICES guidelines leads to an unacceptably high risk, and (3) that category 3 empirical methods can be tuned for this stock and provide a better management performance (higher catch, lower risk) compared to the default ICES category 1 approach.	An MSE framework for this stock already exists and only needs to be updated with the latest data. This stock is an ideal candidate for conducting case-specific MSE to tune category 3 methods.
206	Tuning series	Two scientific surveys (UK-FSP Q3 and UK-Q1SWBeam Q1) are routinely conducted for this stock. The current rfb rule only uses the UK-FSP survey. The Q1SWBeam survey was revised in 2020, data for 2022 are missing, and the cohort tracking of this survey is poor, with sometimes even negative correlations between ages.	The suitability of the surveys, particularly the Q1SWBeam survey, should be checked. It should be checked if the Q1SWBeam survey is appropriate to inform on the plaice stock.

3 The benchmark approach for plaice

There have been numerous attempts over the past years to fit age-structured and surplus production models to plaice in Division 7.e. However, these models were not able to model stock dynamics appropriately to be used as the basis for management advice. Therefore, the idea of the benchmark is to conduct a stock-specific management strategy evaluation (MSE, in the sense of a closed-loop simulation) and tune a category 3 data-limited empirical harvest control rule. This approach is explicitly encouraged by the ICES technical guidelines for category 2 and 3 stocks (ICES, 2022a). This plaice stock is relatively data-rich for an ICES category 3 data-limited stock and is an ideal candidate for conducting stock-specific simulations.

Recently, work on a comparison of the new ICES category 3 data-limited empirical harvest control rules and the ICES data-rich category 1 MSY rule was published by Fischer et al. (2023) and included this plaice stock as a case study. The conclusion was that although an upgrade of the stock to category 1 is possible, this is likely not a good idea because (1) a single age-structured stock assessment model cannot model the full uncertainty about the stock dynamics and data and (2) the use of the ICES MSY rule with reference points estimated by EqSim leads to fisheries management that violates the ICES precautionary approach. Furthermore, an upgrade of the stock to category 2 with a surplus production model (e.g. SPiCT; Pedersen & Berg, 2017) is infeasible because it has been shown several times over the years that SPiCT cannot model the stock dynamics of this stock and would lead to unacceptably high uncertainty bounds. However, the category 3 methods (rfb and chr rules) work as intended and can be tuned with a stock-specific MSE simulation.

There are substantial unknowns about data for this stock, such as the total level of catch, discard survival, migration, natural mortality, and recruitment. To address these uncertainties, a range of operating models with different input data and assumptions will be created, covering a range of possible scenarios. These will include more plausible scenarios in a reference set of operating models (e.g. different assumptions about catch or natural mortality) and less plausible robustness scenarios (e.g. recruitment failure). These operating models will be conditioned on model fits of the state-space stock assessment model (SAM; Nielsen & Berg, 2014). Uncertainty in the operating model (e.g. process and observation error) will be generated by sampling from the variance-covariance matrix of SAM model fits, which allows a characterisation of the level and structure of the uncertainty and follows the approach developed for the recent North Sea MSE benchmark (WKNSMSE; ICES, 2019b).

Candidate harvest control rules will be selected from the options available for ICES category 3 data-limited stocks, i.e. the trend-based rfb rule and the harvest rate-based chr rule (ICES, 2022a). These management strategies will then be tuned to meet ICES management objectives. These include the ICES interpretation of the precautionary approach (i.e. the risk of the stock falling below a point where productivity is likely to be impaired, should not exceed 5% in the long term) and MSY (i.e. maximise yield). The tuning involves changing the parameters of the harvest control rules to find those that meet management objectives best by using optimisation procedures such as genetic algorithms and high-performance computing.

The work by Fischer et al. (2023) concluded that the chr rule (ICES, 2022a; Fischer et al., 2022) showed the most promise, with the best fisheries management performance (highest catch while being precautionary) and was most robust to uncertainty. Consequently, this benchmark MSE will focus on the chr rule.

The ideal outcome of this MSE is a simple empirical harvest control rule that is robust to uncertainty. The MSE framework, including the optimisation routine, already exists, has been applied to the plaice stock, and has been peer-reviewed and published in Fischer et al. (2023). Therefore, the work for the benchmark can be based on this and only requires updating the operating models by using the latest available data and possibly data sources not considered before, and then re-running the simulations.

The MSE for this work will follow MSE best practices (Punt et al., 2016), ICES guidelines on MSE (ICES, 2013, 2018b, 2020b), and recommendations for ICES stock-specific data-limited MSE (ICES, 2023b).

4 Stock identity and migration

Plaice in ICES Division 7.e (western English Channel, ple.27.7e) is assumed to be a biological stock. However, the stock identity is not well defined and migration is known to occur. *For this benchmark (WKBPLAICE 2024), no new information regarding stock identity or migration was available.*

Mature plaice from Division 7.e are known to migrate to Division 7.d (the eastern English Channel) to spawn in quarter 1. This is based on an analysis of historical tagging data from 1960–2006 conducted for the WKFLAT benchmark (ICES, 2010). WKFLAT concluded that, in quarter 1, of the catches of plaice in Division 7.d (eastern English Channel), 15% originate from the Division 7.e stock and 50% from the North Sea and should be excluded from the Division 7.d stock assessment and instead be included in the respective stock assessments. Subsequently, IBPWCFlat2 (ICES, 2015b) revised this migration correction to only include mature individuals caught in quarter 1 in 7.d. Since then, the assessment for the Division 7.e stock has been based on the catches in 7.e plus the migration correction catch (15% of mature quarter 1 catches in 7.d). This migration correction catch is provided by the stock assessor for the Division 7.d stock and comprises landings and discards, including the corresponding age structures. Figure 2 illustrates the catch time series, split into landings and discards, and split by ICES Division.

The plaice stock in Division 7.d will be included in another benchmark workshop planned for 2024/2025, which may lead to a revision of historical 7.d catches because some of the historical catches were reconstructed with a stock assessment model. This may also lead to a revision of the migration component assumed to belong to the Division 7.e stock. However, the data were not available in time for the WKBPLAICE 2024 workshop.

The ICES advice for plaice in Division 7.e gives both advice for the stock (headline advice, including migration correction) and advice for the Division 7.e area. The headline advice is based on the stock, and the area-based advice is then calculated from the advice for the stock. Until 2022, the area-based advice was calculated by removing a proportion of the advice for the stock, based on the proportion caught in Division 7.e in the past. In response to an EU/UK special request to ICES for consistency between ICES advice for the plaice stocks in the North Sea (ple.27.420), the eastern English Channel (ple.27.7d) and the western English Channel

Figure 2: Catches of ple.27.7e, for the stock (top row), and split by ICES Division. The bottom row shows the migration correction catch and represents 15% of the mature catches in quarter 1 in Division 7.d.

(ple.27.7e), the calculation of the area-based advice was changed (ICES, 2023a). Since 2023, the short-term forecast for the Division 7.d plaice stock includes a consideration of how much of the advised catch belongs to the other plaice stocks. This means that the area-based advice value for plaice in Division 7.e is now calculated by taking the stock-based advice, and deducting the value calculated by the forecast for Division 7.d plaice.

Until 2023, the total allowable catch (TAC) was given for the entire English Channel, i.e. ICES divisions 7.e and 7.d (EU, 2023). Since 2024, the TAC (for 2025) also includes values for how much can be caught in each of the divisions (EU, 2024).

In conclusion, there exists a degree of uncertainty about the stock structure and identity, particularly because no recent data on migration are available. This means that the total catch of the "stock" is not known with certainty, which affects the estimation of total stock size. The baseline operating model in the MSE was based on the assumption that the migration element from Division 7.d is part of the stock. However, an alternative operating model excluding the migration element was also considered, essentially, covering the two extremes.

5 Data

5.1 Catch data

5.1.1 Catch time series

The catch time series for this stock starts in 1980. Catch data have been available from InterCatch since 2012 and include landings, discards, and their age structure. Discards before 2012 are based on limited samples. However, WKFLAT (ICES, 2010) estimated discard tonnages prior to 2012. WGCSE 2020 (ICES, 2021a) used these discard tonnages to reconstruct discards for 2002–2011 by using the age structure (for discard numbers at age and discard weights at age) from the following five years (2012–2016).

Figure 3 illustrates the full available catch time series and discard rates. The large majority of catches are caught by the United Kingdom (England, Figure 4). The main gear type catch plaice are beam trawls (mainly with TBB_DEF_70-99, Figure 5).

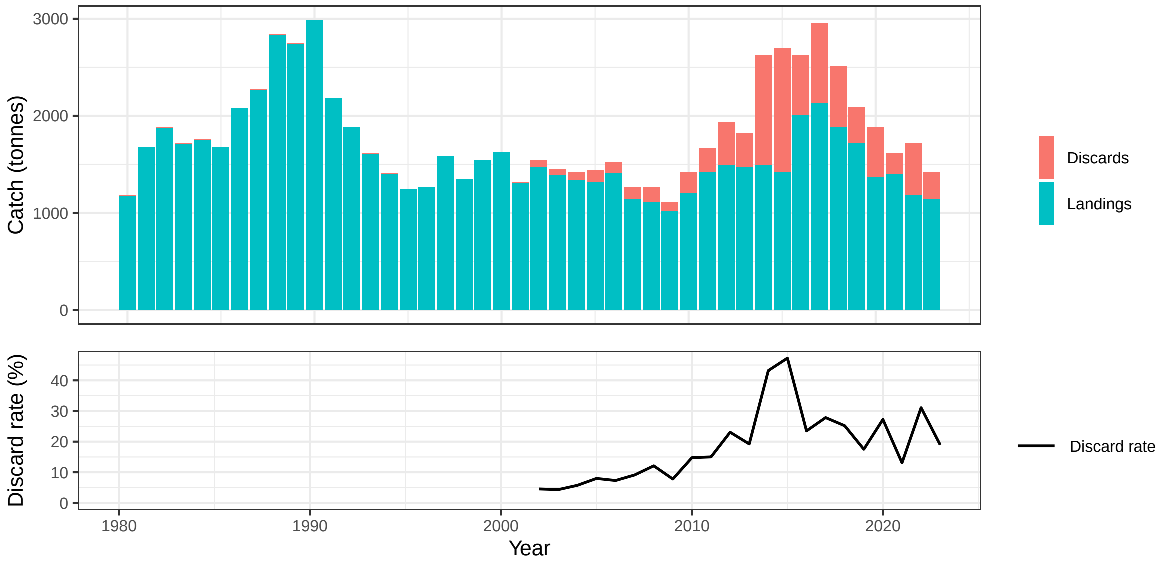


Figure 3: Catches of ple.27.7e, split by landings and discards.

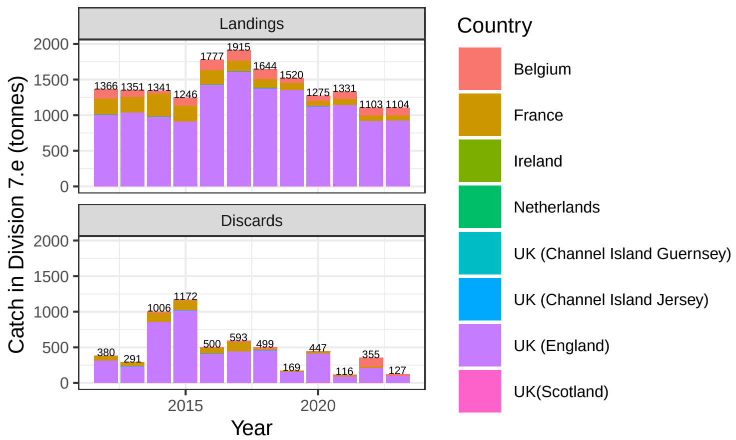


Figure 4: Catches of ple.27.7e, split by country.

5.1.2 Catch age structure

Sampling coverage of catches in InterCatch has been high in recent years (Figure 6), apart from low discard sampling in 2020 due to the impacts of reduced sampling during the Covid pandemic. Age samples were provided by the United Kingdom, France, and Belgium. A consistent approach for raising catches (i.e. estimating discards for gears without reported discards) and allocating age structures (i.e. allocating age structures for gears without reported

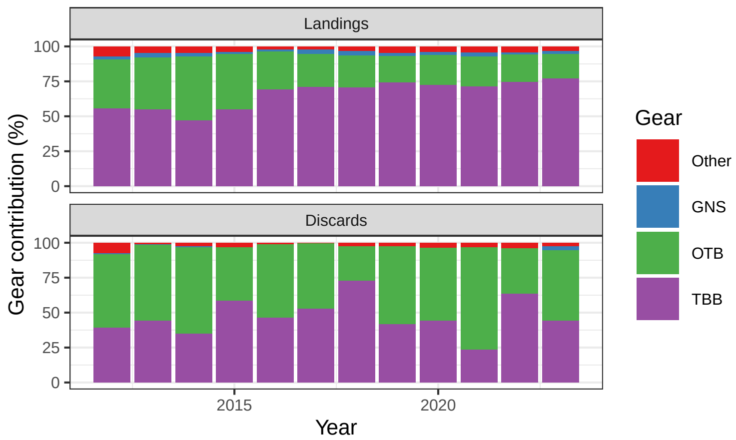


Figure 5: Catches of ple.27.7e, split by gear (TBB: beam trawls, OTB: otter trawls, GNS: gill nets, Other: any other gears).

age samples) has been applied since 2012 in InterCatch. This approach consists of (1) borrowing data from other seasons (by catch category, country, gear), (2) borrowing data from other countries (by catch category, gear), and (3) grouping the rest. Figure 7 shows an example of the age samples submitted to InterCatch for 2023.

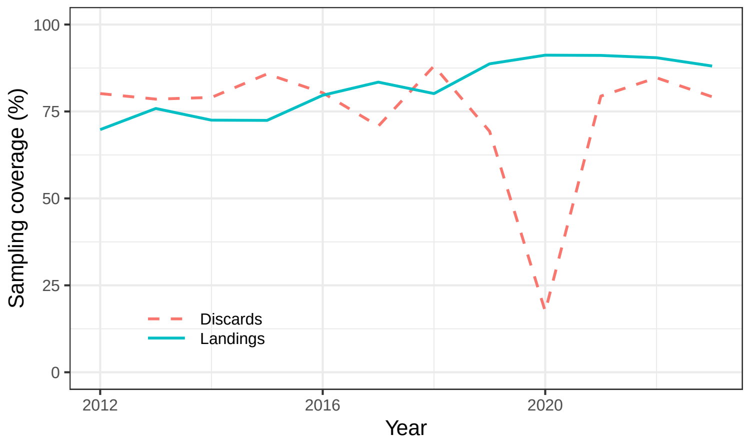


Figure 6: Sampling coverage of catches of ple.27.7e available in InterCatch. Sampling coverage shown here is by the lowest InterCatch level, i.e. by catch category, year, quarter, country, and gear.

InterCatch data are routinely extracted up to age 15. Figure 8 shows the catch numbers at age, Figure 9 the catch biomass at age, and Figure 10 the catch numbers standardised by age.

5.1.3 Catch weights at age

The traditional approach of deriving catch weights at age for this plaice stock was to fit a second-degree polynomial to the internationally collated catch weights:

$$f(x) = a\ w_t^2 + b\ w_t + c \tag{1}$$

where w_t is the catch weight at age t, and a, b, and c are the model parameters. This approach

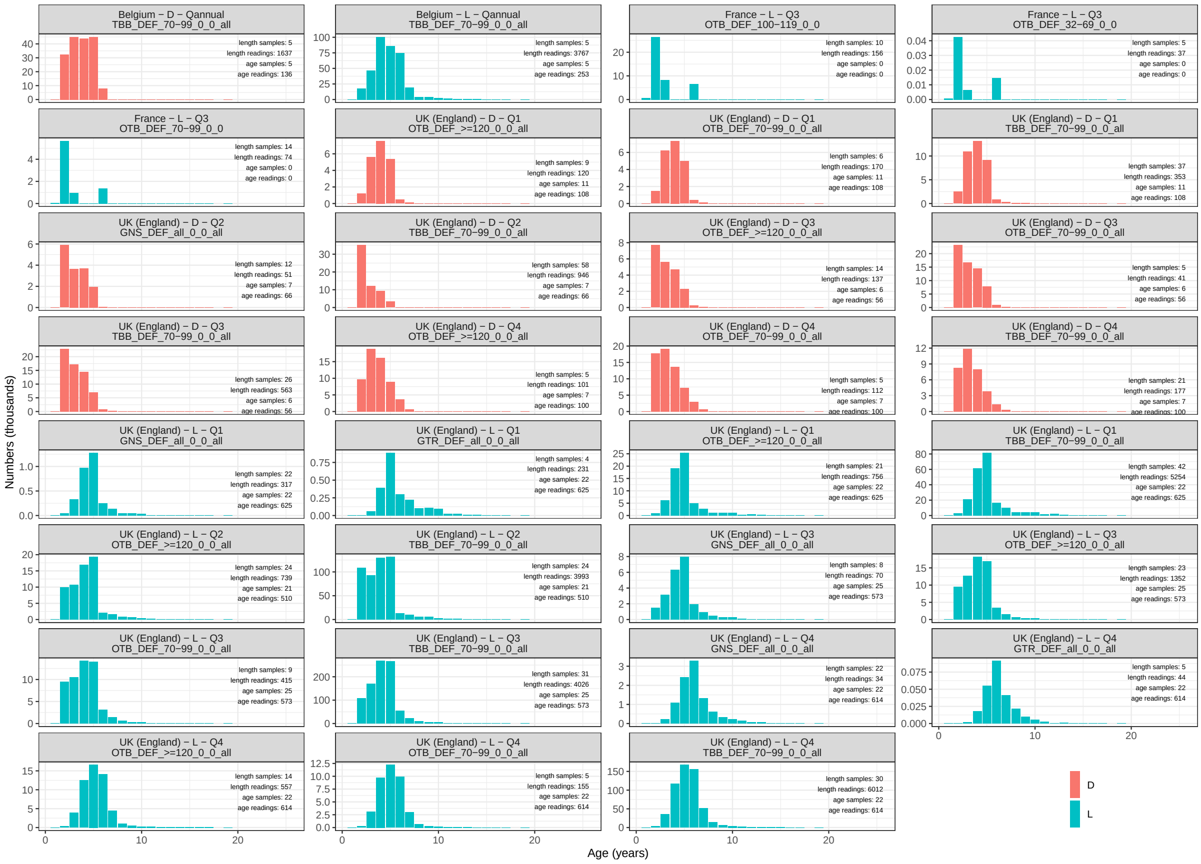


Figure 7: Age samples submitted to InterCatch for 2023, split by Country, catch category (L: landings, D: discards), quarter (Q1, Q2, Q3, Q4), and gear.

led to a smoothing of the catch weights and is illustrated in Figure 11. Catch weights were assumed to be mid-year values (e.g. age 1 was set to 1.5 years), and the catch weights in the stock assessment were then the weights estimated by the model. This approach was also used to derive the stock weights at age by estimating the weight at the beginning of the year.

While smoothing catch weights with Equation 1 can reduce noise in the data, it also entailed several issues. The approach was initially developed when only landings were available. However, since then, discard estimates have been included, and there is no clear approach on how to split catch weights into landings and discard weights and discard weights are often based on fewer samples. Furthermore, the polynomial function is not fixed and can shift left/right, which means that the minimum can be at an age above 0.

Raw catch weights at age data for the entire time series (1980–2023) are presented in Figures 13 and 14. Catch weights at age before 1999 were already smoothed, and raw values were not available for this benchmark. Unlike other plaice stocks, there does not appear to be a long-term trend in the weights at age, and values now (2023) are similar to those early in the time series (Figure 14).

WKBPLAICE decided to use raw weights at age for the catch (split into landings and discards), where available, and discontinue the smoothing process.

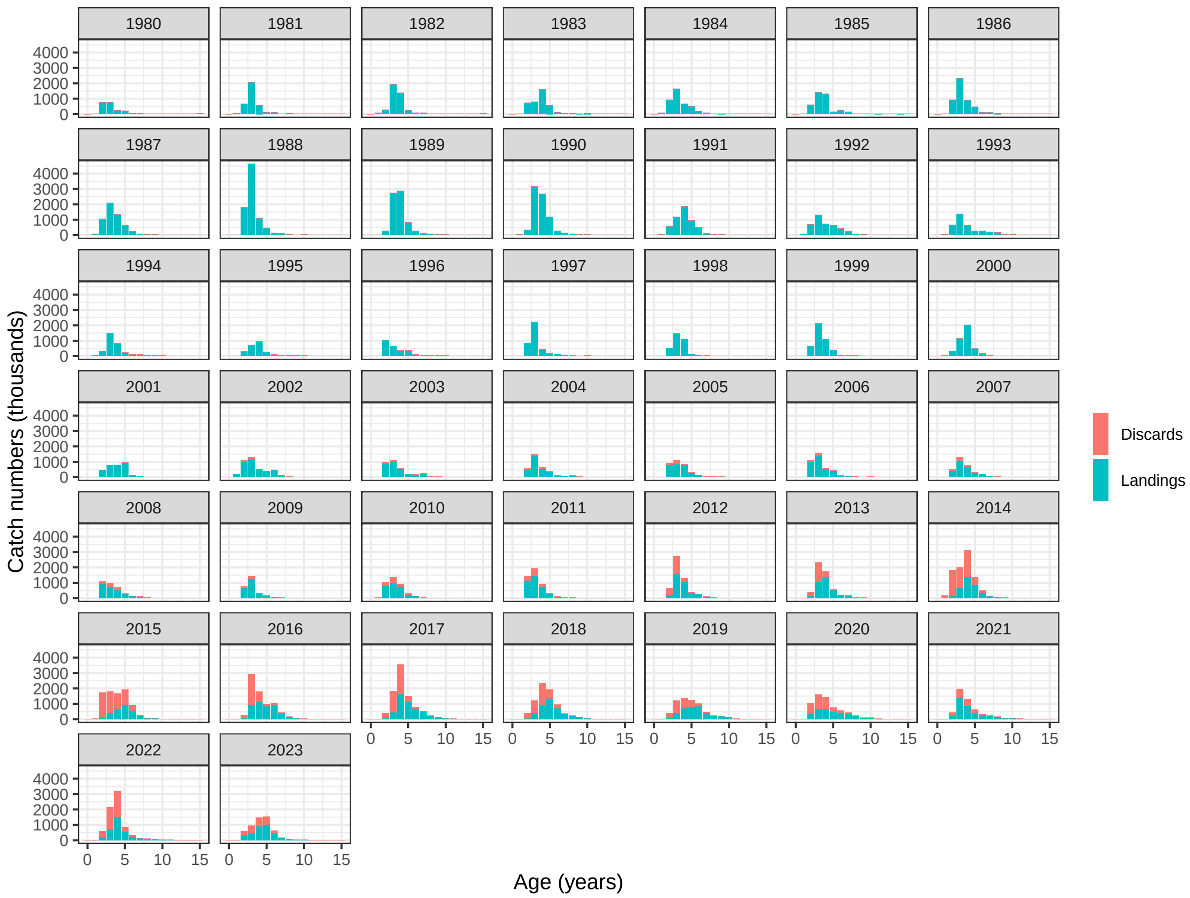


Figure 8: Catch numbers at age, by year.

5.1.4 Age range and plus group

The previously used XSA assessment included ages 2–10 only. The catch data contained very few fish below age 2 and above age 10. Furthermore, both scientific surveys (see Section 5.3) use commercial beam trawls with an 80mm mesh size that does not fully retain or target juvenile fish and also does not catch many older fish. This means that survey catches of fish below age 2 were only sporadic, and there were not many fish above age 10 either. Consequently, WKBPLAICE suggested keeping the previously used age range of 2–10 years, where age 10 is a plusgroup.

Figure 15 shows the sum of products (SOP, i.e. numbers at age multiplied by weights at age, summed up over all ages, divided by the submitted total catch values) for the catch, which showed good consistency and a low SOP error. There was only one outlier for the discards in 2016 (5%), which was caused by the discards from the migration correction from Division 7.d. As before, the SOP error is accounted for by adjusting the weights at age, but the change to the weights is negligible.

The final catch data, for ages 2–10+ and SOP-corrected, are shown in Figure 16 (numbers at age) and Figure 17 (weights at age).

The discard weights for fish in the plusgroup (10+) in the last three years (2021–2023) appeared very low (Figure 17). This was because discards for older fish were very low (Figure 16, $<1\%$ of fish in the plusgroup were discarded) and based on very low sample numbers.

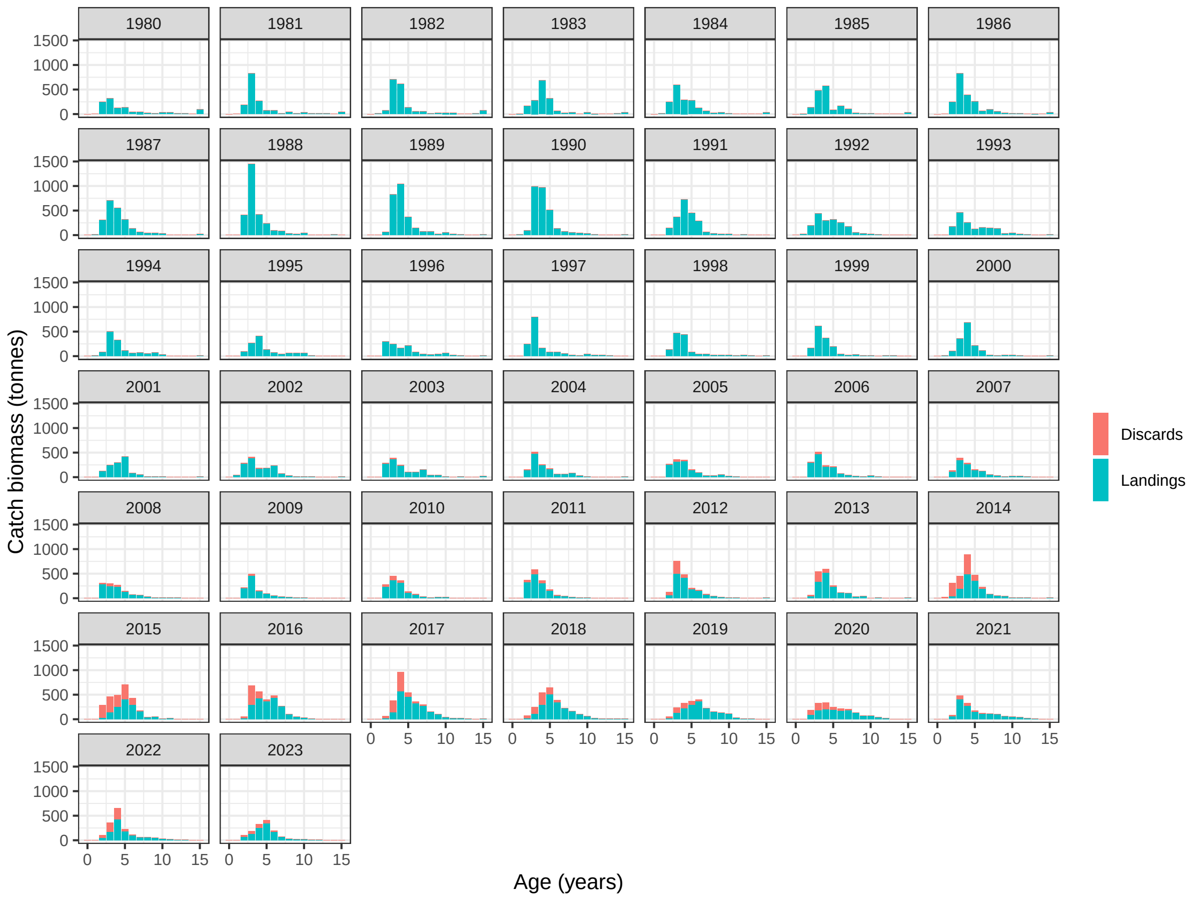


Figure 9: Catch biomass at age, by year.

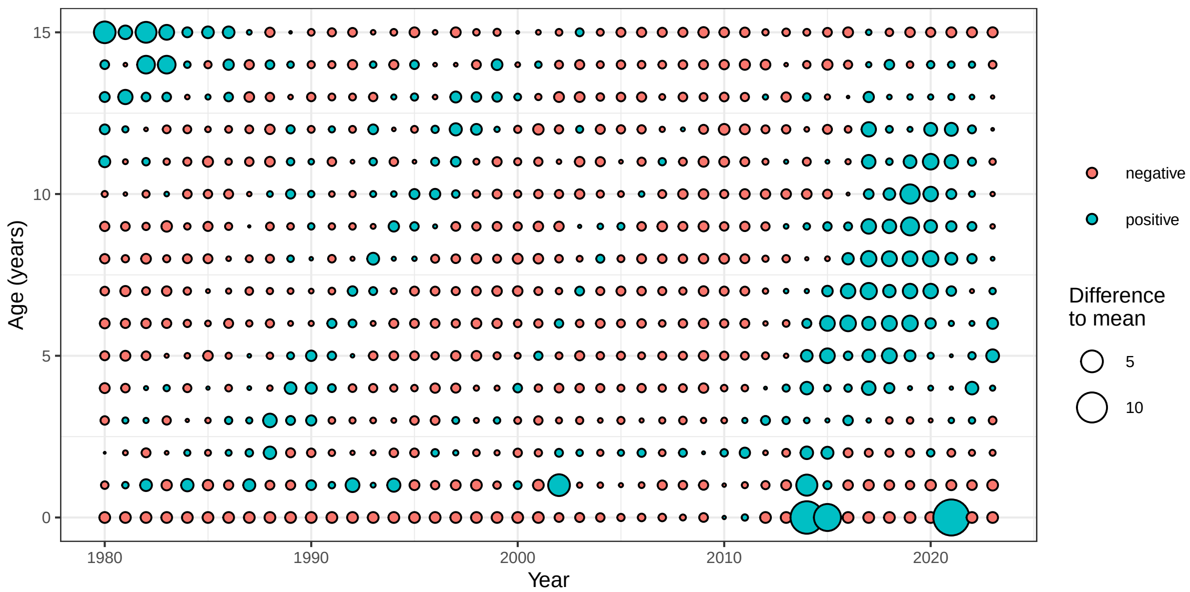


Figure 10: Catch numbers at age (bubble plot), standardised by age.

Consequently, discards of older fish had a negligible contribution to the total catch (biomass, numbers, weights) and SAM uses only total catch.

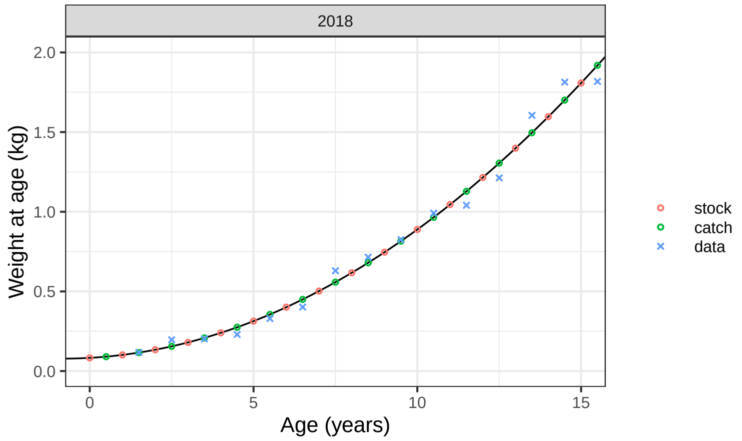


Figure 11: The traditional approach of smoothing catch weights at age by fitting a second-degree polynomial, illustrated for data from 2018.

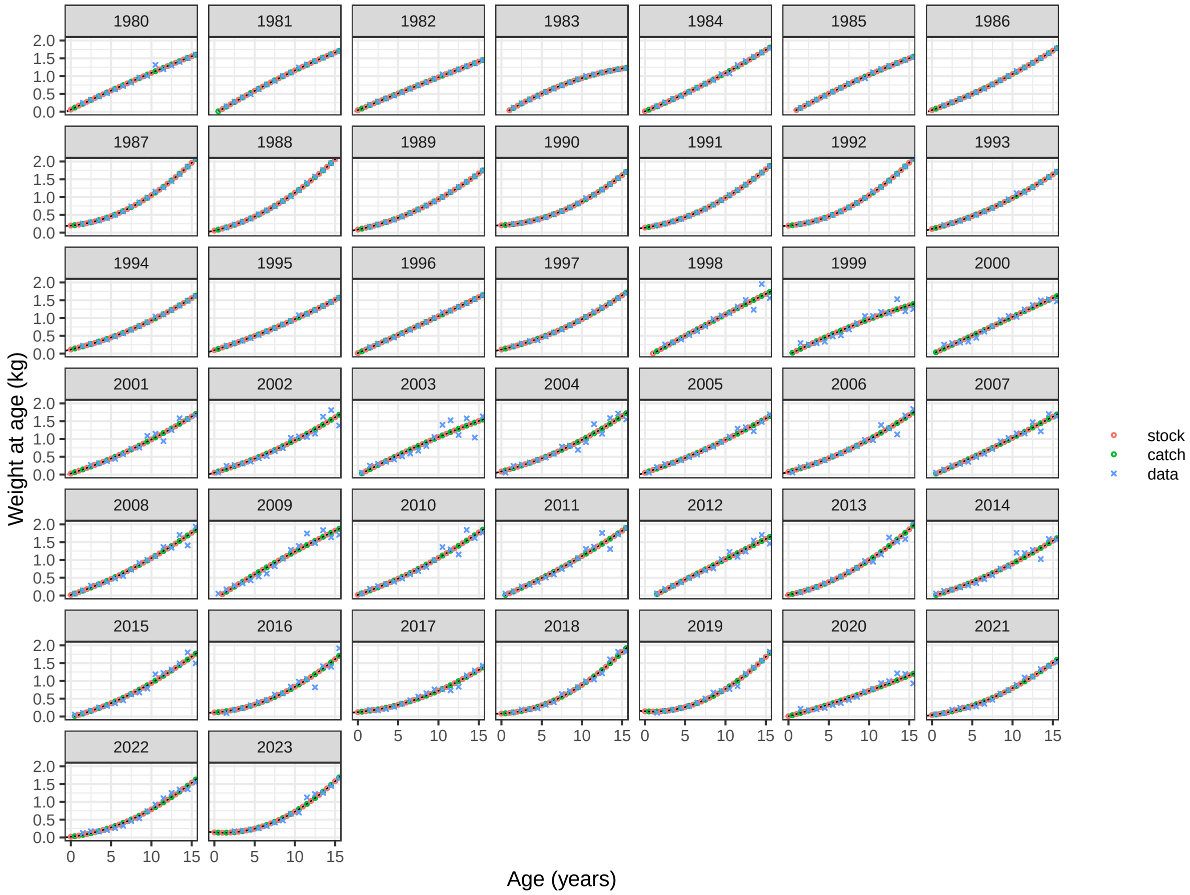


Figure 12: The traditional approach of smoothing catch weights at age by fitting a second-degree polynomial, illustrated for all years.

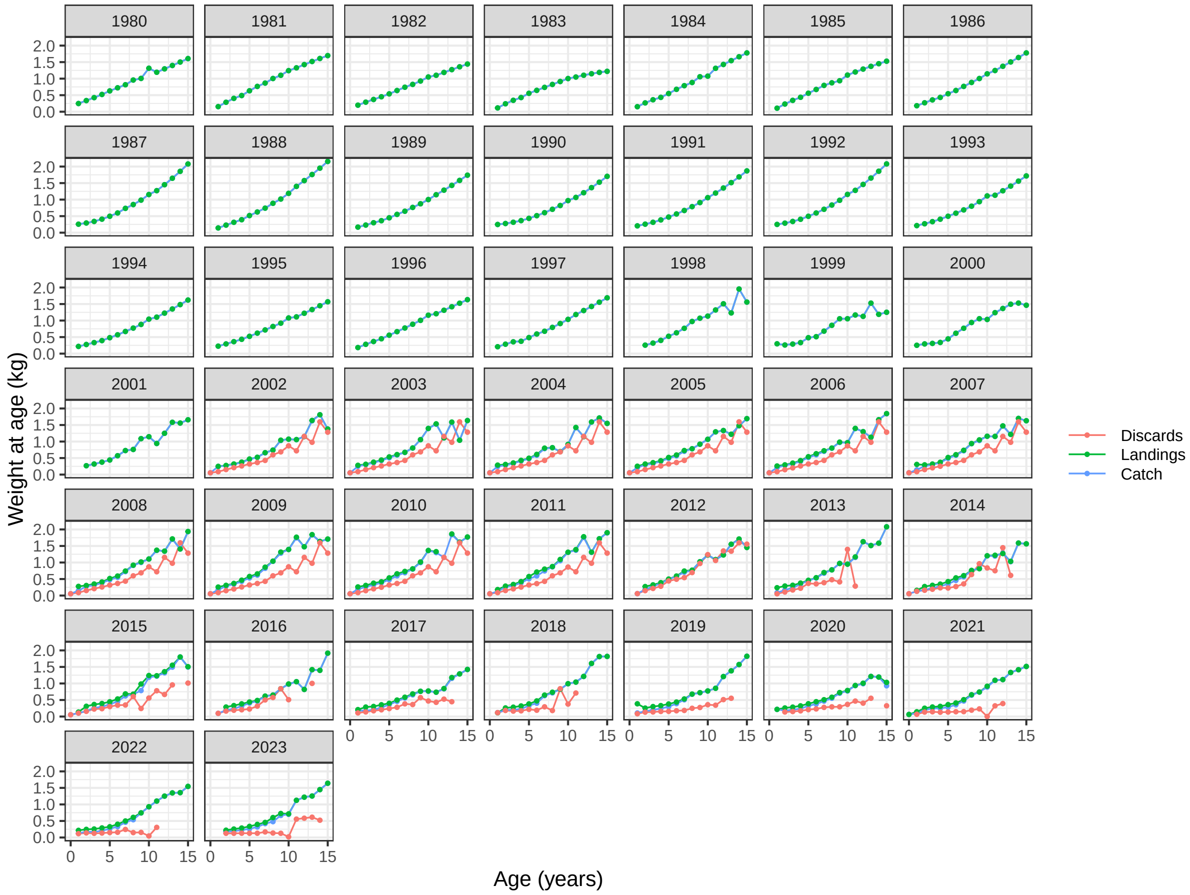


Figure 13: Raw catch weights at age, split by landings and discard, as available for the benchmark.

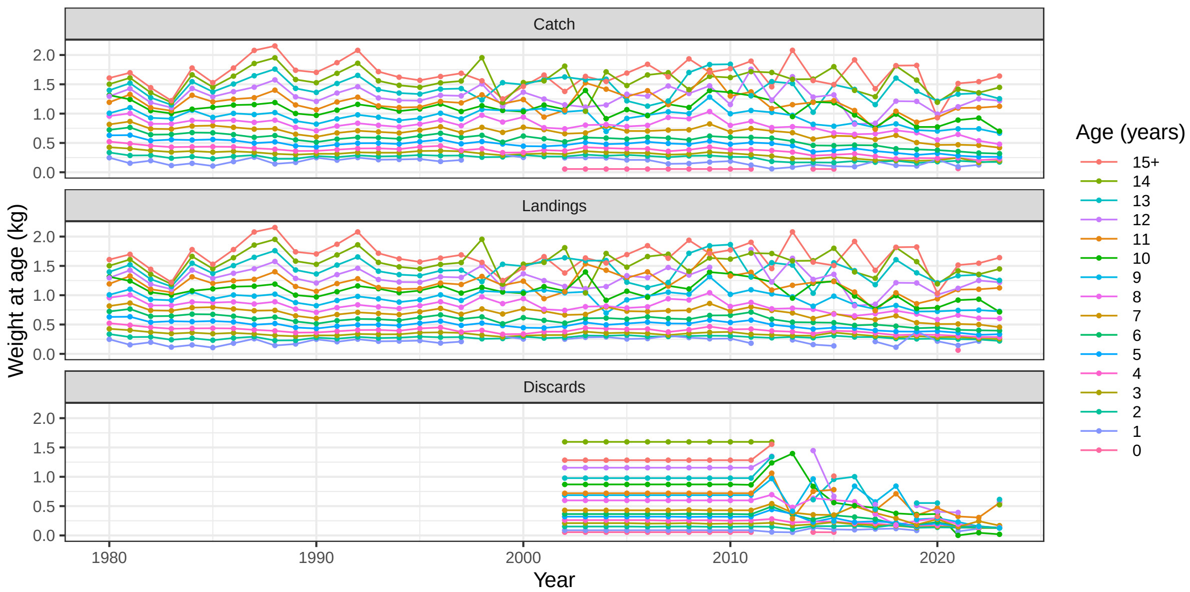


Figure 14: Raw catch weights at age, split by landings and discard, as available for the benchmark. Discard weights 2002–2011 are identical because they are based on a discard reconstruction and the average of 2012–2016.

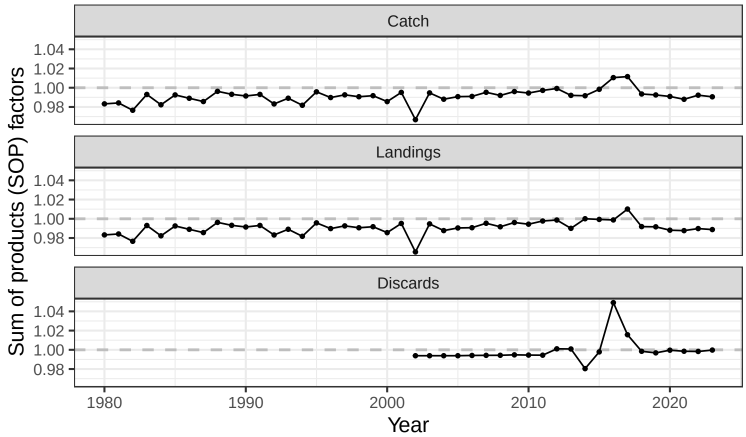


Figure 15: Sum of products (SOP) for the catch, landings, and discards. Please note that the y-axis does not start at 0.

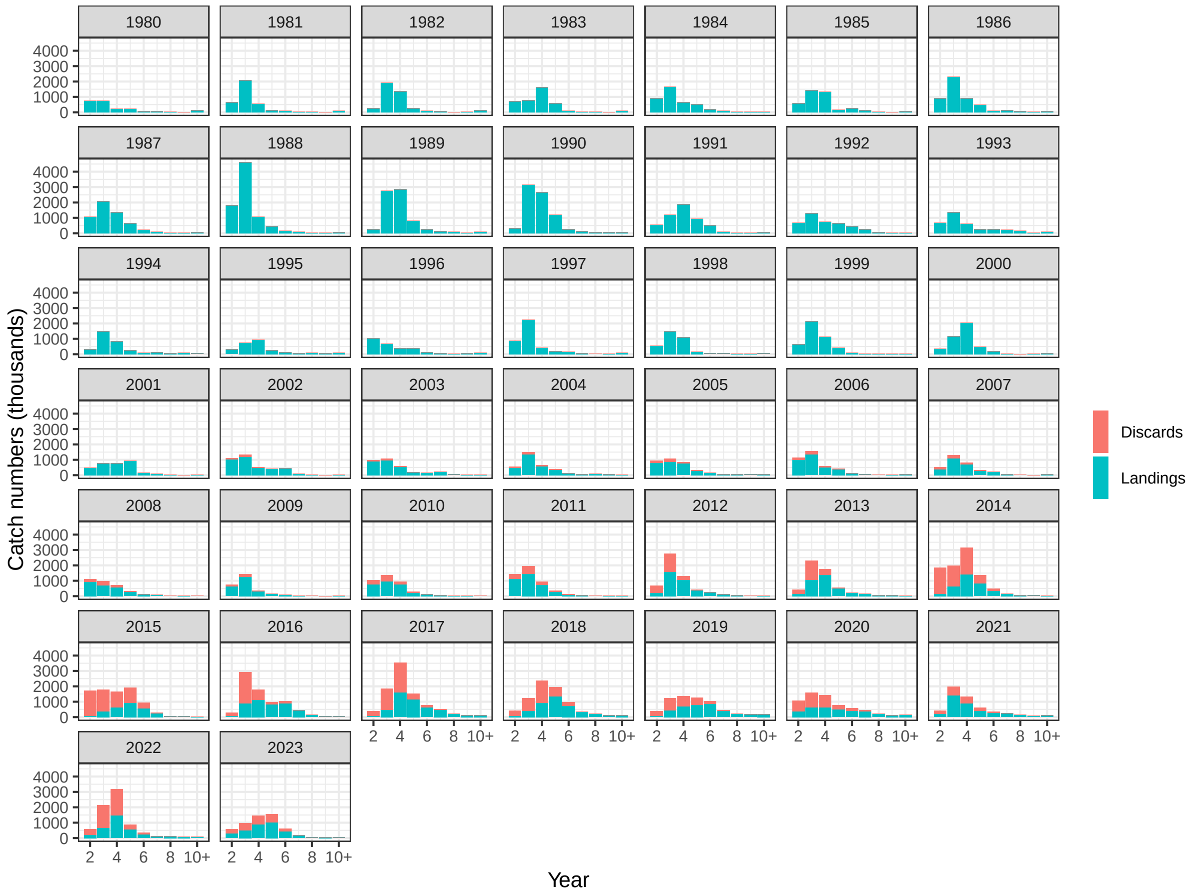


Figure 16: Final catch numbers at age.

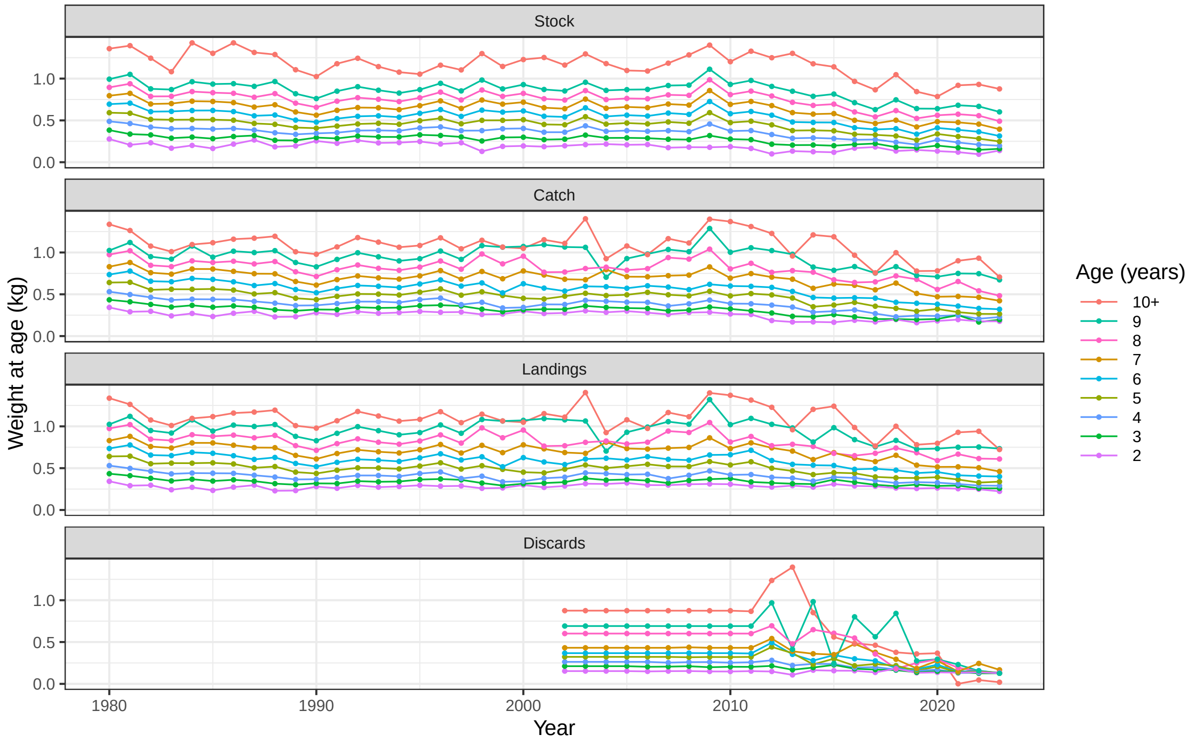


Figure 17: Final catch weights at age.

5.2 Discard survival

The recent discard rate for this plaice stock (approximately 19% in 2023, see Figure 3) is relatively low and much lower compared to other plaice stocks (ple.27.7d: 77%, ple.27.420: 63%, ple.27.7hjk: 36%, ple.27.7fg: 45%, ple.27.7a: 71%, approximate discard rates in 2023 from 2024 ICES advice sheets). However, discards are not negligible and should be included in any stock assessment.

There is a landing obligation for plaice in Division 7.e, which has been phased in by the EU 2019–2021 (EU, 2018, 2019) and is also applicable in the UK (MMO, 2022a,b). However, the landings obligations include a *de minimis* exemption that covers trammel nets, otter trawls, and beam trawls, essentially covering almost all catches of plaice.

ICES, assessment working groups, and stock assessors are repeatedly being asked to consider discard survival for species such as plaice. The ICES workshop on discard survival (WKSURVIVE; ICES, 2021b) commented that discard survival should be considered for plaice in Division 7.e. There are at least two scientific publications on plaice discard survival with relevance for this plaice stock.

Morfin et al. (2017) explored discard survival of plaice for otter trawls in the eastern English Channel (Division 7.d, not 7.e) and found that survivability was between 45% and 67% depending on season, vessel, handling duration, temperature, tow depth, and fish length. Survivability was 62.8% (54.9–70.7%) in January/February, 45.2% (32.7–55.3%) in July, and 66.6% (57.0–74.3%) in November. Averaging these values leads to a survivability of 58.2%, i.e. a discard mortality of 41.8%.

Revill et al. (2013) explored discard survival of plaice (and sole) for beam trawls in the western English Channel (Division 7.e). The study estimated and reported discard mortality, but these values can be converted to discard survival to make them comparable to Morfin et al. (2017). Revill et al. (2013) reported various different mortalities, including immediate mortality, short-term mortality, unadjusted total mortality and adjusted (modelled) total mortality. For example, short-term mortality was reported as 72.5% (57.2–83.9%) in February and March, and 42.5% (28.5–57.8%) in May. Averaged over the monthly values, this leads to a discard survivability of 37.5% (short term), 34.2% (total), and 54.7% (total, adjusted).

The discards of plaice in Division 7.e are mainly caught by beam trawls and otter trawls (Figure 3) but the proportion of the two gears changes from year to year. An exploration of discard survival was conducted by splitting discards into beam trawl catches and otter trawl catches and applying corresponding discard survival rates, i.e. 58.2% based on Morfin et al. (2017) for otter trawls and 37.5% based on the short-term survival estimated by Revill et al. (2013). Discard proportions by gear type were available for 2012–2023. Prior to that, the average proportion of available data was used. The results of this exploration are shown in Figure 18. The outcome was that there were only small fluctuations in discard survival between years, around the average of 48.1%. Using other discard survival estimates (e.g. total unadjusted vs. total adjusted) estimated by Revill et al. (2013) had only minor impacts on the total discard survival for the stock and values were always around 50%.

Based on the discard data for the stock and information on discard survival from Morfin et al. (2017) and Revill et al. (2013), the discard survival of the baseline model run was simplified

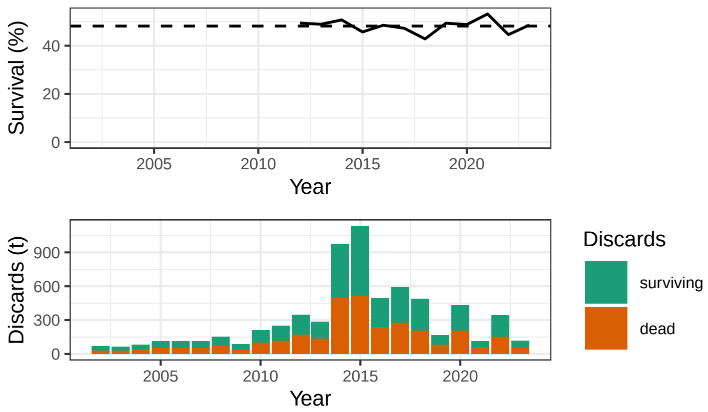


Figure 18: Exploration of discard survival by splitting discards into otter trawls and beam trawls and applying discard survival estimated by Morfin et al. (2017) and Revill et al. (2013).

by assuming a discard survival of 50%. However, there is a degree of uncertainty about this value. Consequently, additional alternative operating models will be developed which cover both extremes, i.e. assuming 0% and 100% discard survival.

5.3 Surveys

There are two scientific surveys in Division 7.e that target plaice; UK-FSP and Q1SWBeam. Both provide standardised (but not statistically modelled with e.g. a delta-GAM) catch numbers and biomass at age time series. Both surveys also target sole and are used in the category 1 data-rich assessment for sole in Division 7.e (with the same approach for calculating indices). There were no changes in the calculation of the indices at this benchmark but the following sections provide a summary of both surveys.

5.3.1 UK-FSP

The UK-FSP survey (previously called "Fisheries Science Partnership" survey, now "Western English Channel beam trawl survey", ICES code B4381) has been running continuously in quarter 3 since 2003. It deploys two 4m commercial bream trawls with an 80mm mesh. The survey is conducted on a commercial fishing vessel (FV Carhelmar, since 2023 FV Admiral Grenville) with observer(s) onboard to measure and record catches. It consists of 90 fixed stations (Figure 19) around the English coast and covers the main plaice habitat. The survey index is a simple standardised catch-per-unit-effort (CPUE) at age (i.e. the average of all valid stations), provided in numbers (Figure 20) and biomass (kg) per hour per metre of beam. Measurements for plaice are length, age (through otolith ageing, e.g. with 496 otoliths in 2023), and maturity. The biomass index is derived with a length-weight conversion.

Figure 21 shows the catch numbers at age for the UK-FSP index. Numbers are reported for ages 1–27, but numbers for age 1 and above 10 are sporadic, with no fish above age 20. Figure 22 presents the time series of catch numbers at age, biomass at age, and weight at age.

The correlations between ages (i.e. the numbers in the index at a age, compared to the numbers at the following age one year later) are good for ages above 1 (Figure 23).

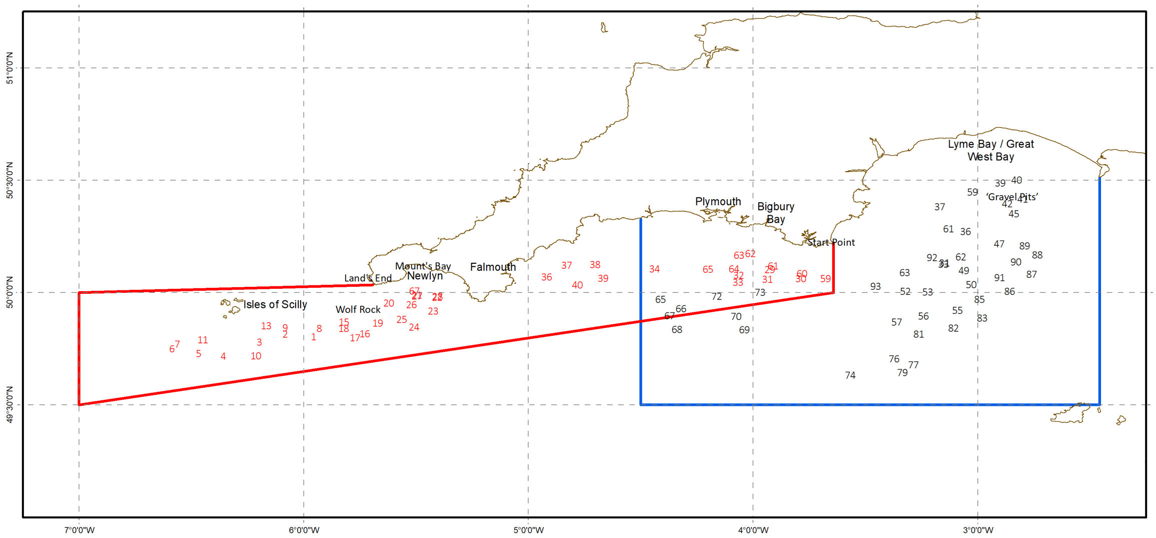


Figure 19: UK-FSP: survey stations. Source: Burt et al. (2024).

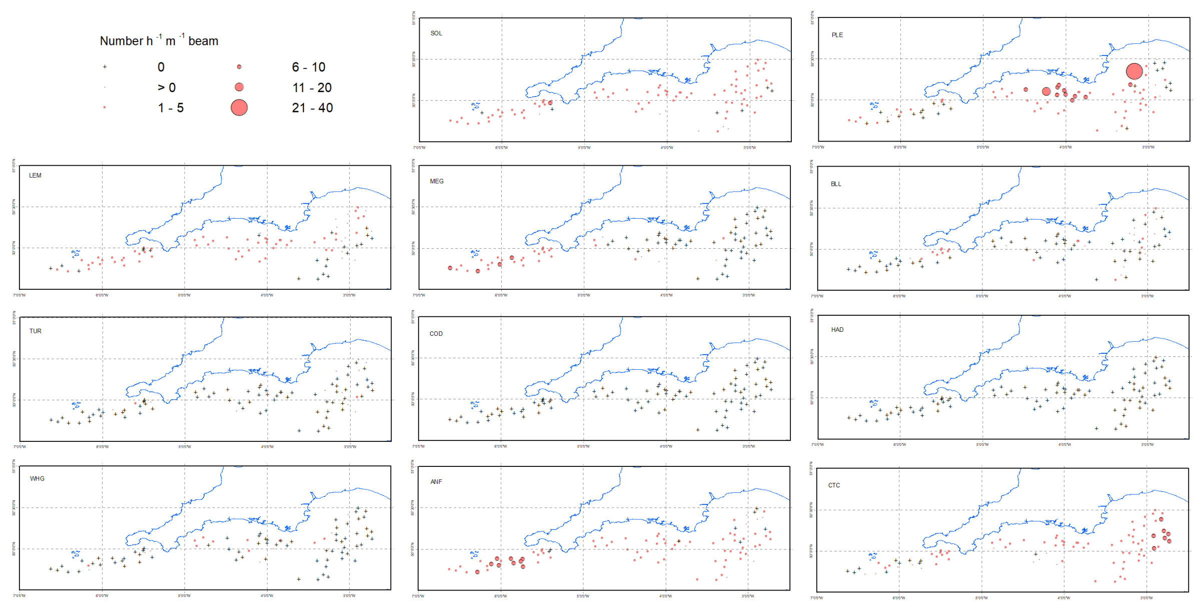


Figure 20: UK-FSP: catch by species, with plaice in the top right panel. Source: Burt et al. (2024).

The final proposed UK-FSP data to be used for fitting the baseline SAM model were the entire year range (2003–2023) and ages 2–8 because younger fish are not well retained in the survey, and fish above age 8 are also not well retained and show deteriorating consistency (Figure 23). This was the same age range as previously used by the former XSA assessment for plaice.

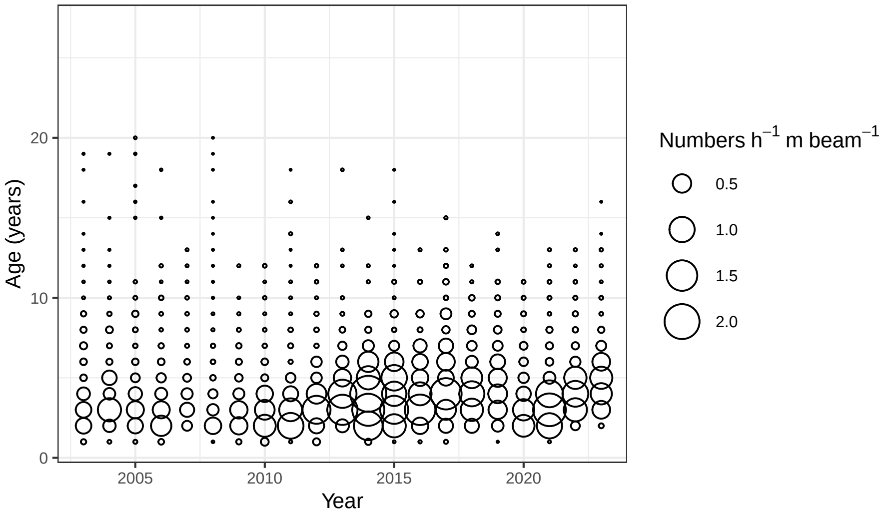


Figure 21: UK-FSP: Catch numbers at age (bubble plot).

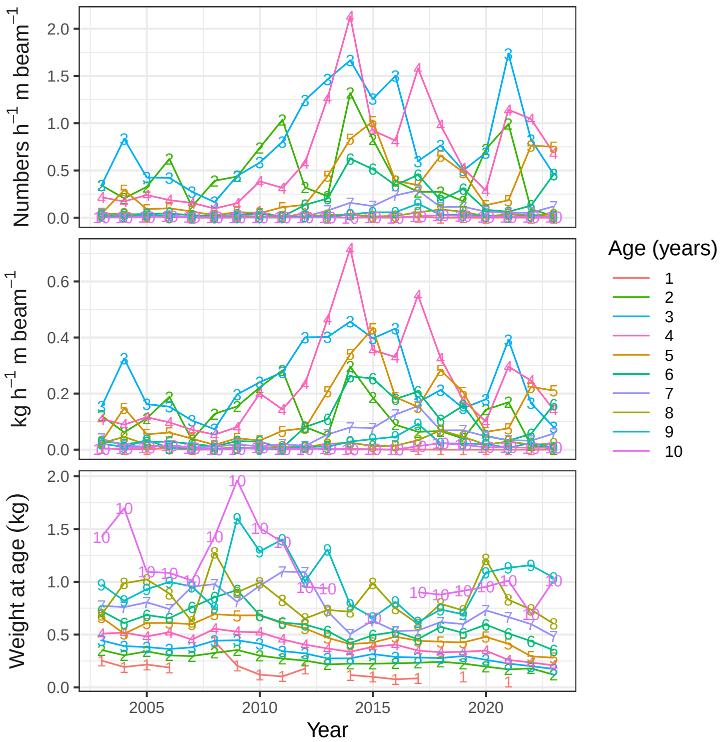


Figure 22: UK-FSP: Time series of catch numbers, biomass, and weight at age.

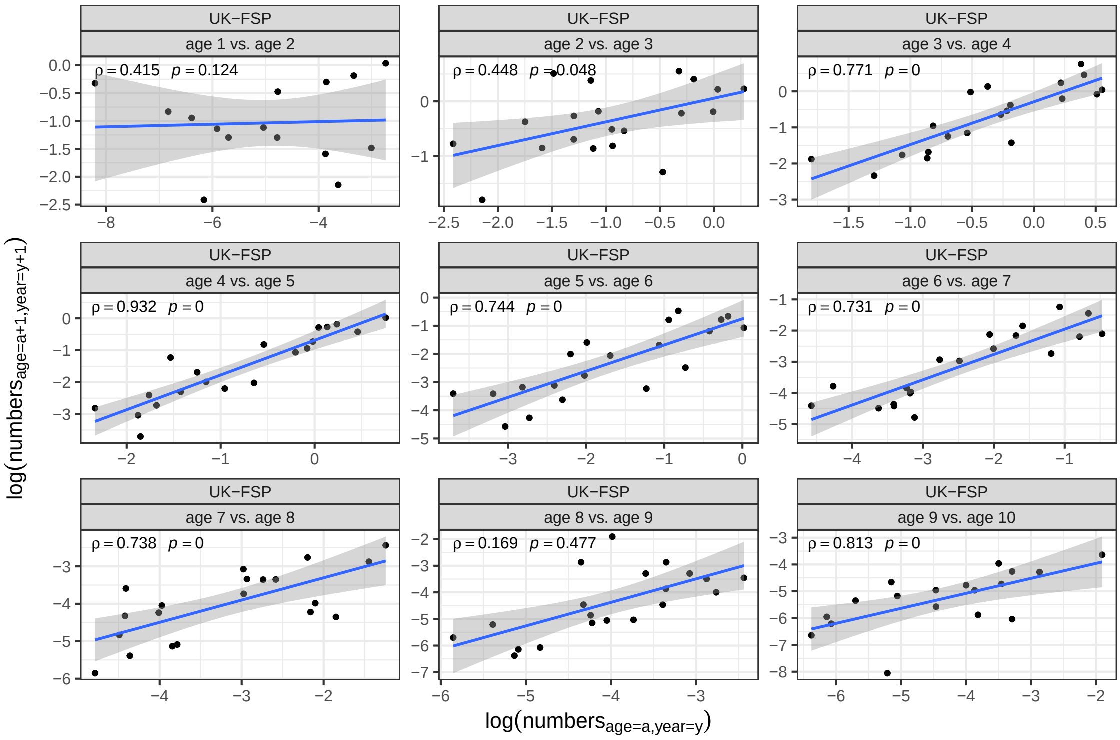


Figure 23: UK-FSP: Time series of catch numbers, biomass, and weight at age.

5.3.2 Q1SWBeam

The Q1SWBeam survey (quarter 1 south-west beam trawl, ICES code B2732) has been running continuously in quarter 1 since 2006. It deploys 2 4m commercial bream trawls with an 80mm mesh on Cefas' research vessel Cefas Endeavour. The survey area covers the entire Division 7.e. Furthermore, the survey extends into the Celtic Sea, if time and resources allow (usually called Q1SWEcos) but data from this extension are not included in the Division 7.e survey index. The survey was originally designed for sole and follows a "stratified random design" (Figure 24). The survey strata are based on fishers' knowledge and ecosystem/habitat information. This design was chosen because of assumed strong environmental gradients in Division 7.e, it being a biogeographic transition zone, and temporally variable environmental and ecological conditions. The survey consists of 81 stations in Division 7.e, which are selected following a two-stage selection process. First, random grids are selected within each stratum, proportional to the size of the stratum, and secondly, random microgrids are selected. This means that stations change from year to year. The survey index is a simple standardised CPUE (in numbers and kg per km^2) derived by applying an age-length key (ALK) to the numbers at length by sex, stratum, and year and then standardising these values. Measurements for plaice are length, weight, age (through otolith ageing, e.g. with 396 otoliths in 2023), and maturity.

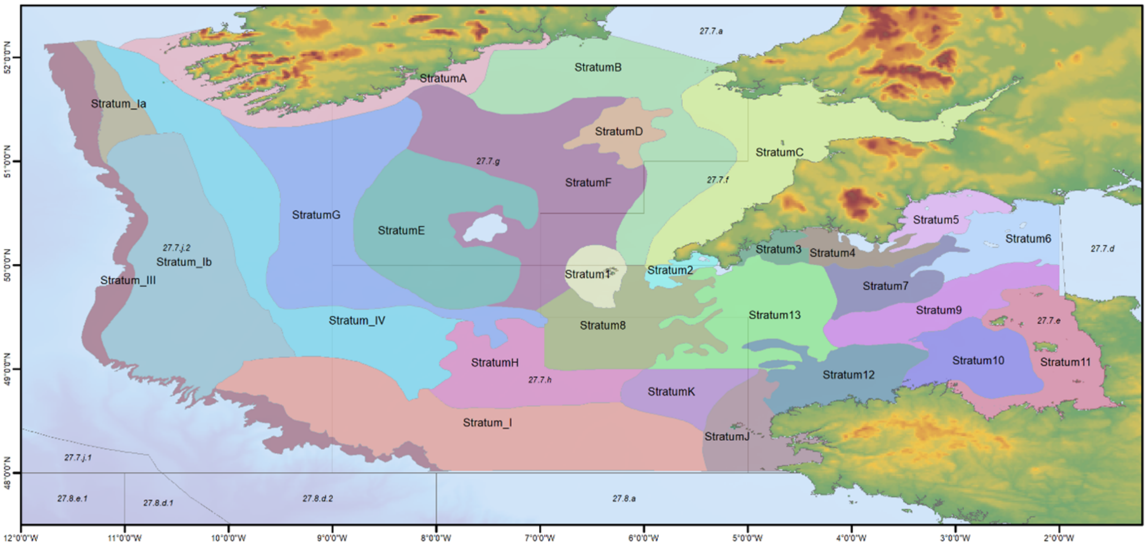


Figure 24: Q1SWBeam: Survey strata. Source: Readdy (2020).

Figures 25 and 26 show the distribution of plaice catches for the entire time series. Plaice are mainly caught along the English coast, with much fewer catches in the middle of the English Channel or along the French coast. However, there appears to be some spillover away from the English coast in years with a high plaice abundance. The survey was restricted in 2022 and did not fish any stations in French waters. This meant that 2022 data were not used in the stock assessment for sole. However, plaice are much more concentrated along the English coast, so there did not appear to be a need to remove 2022 Q1SWBeam data for plaice.

Figure 27 shows the catch numbers at age for the Q1SWBeam index. Numbers are reported

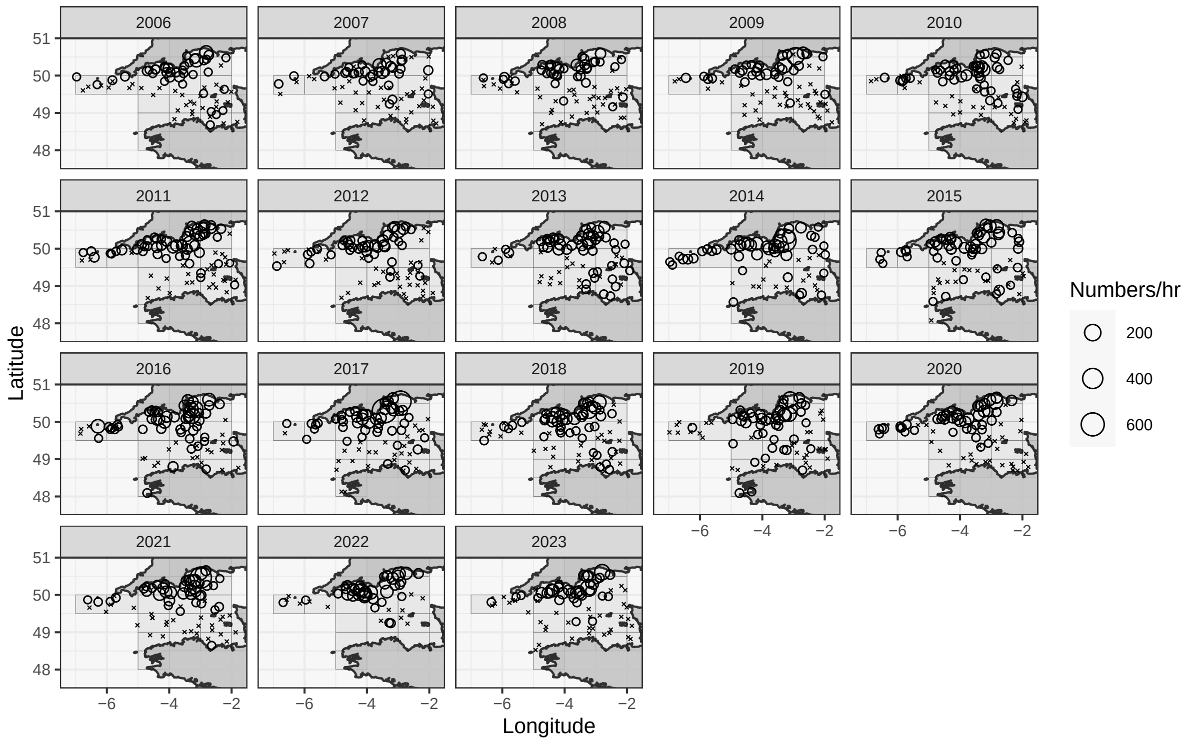


Figure 25: Q1SWBeam: Distribution of plaice numbers.

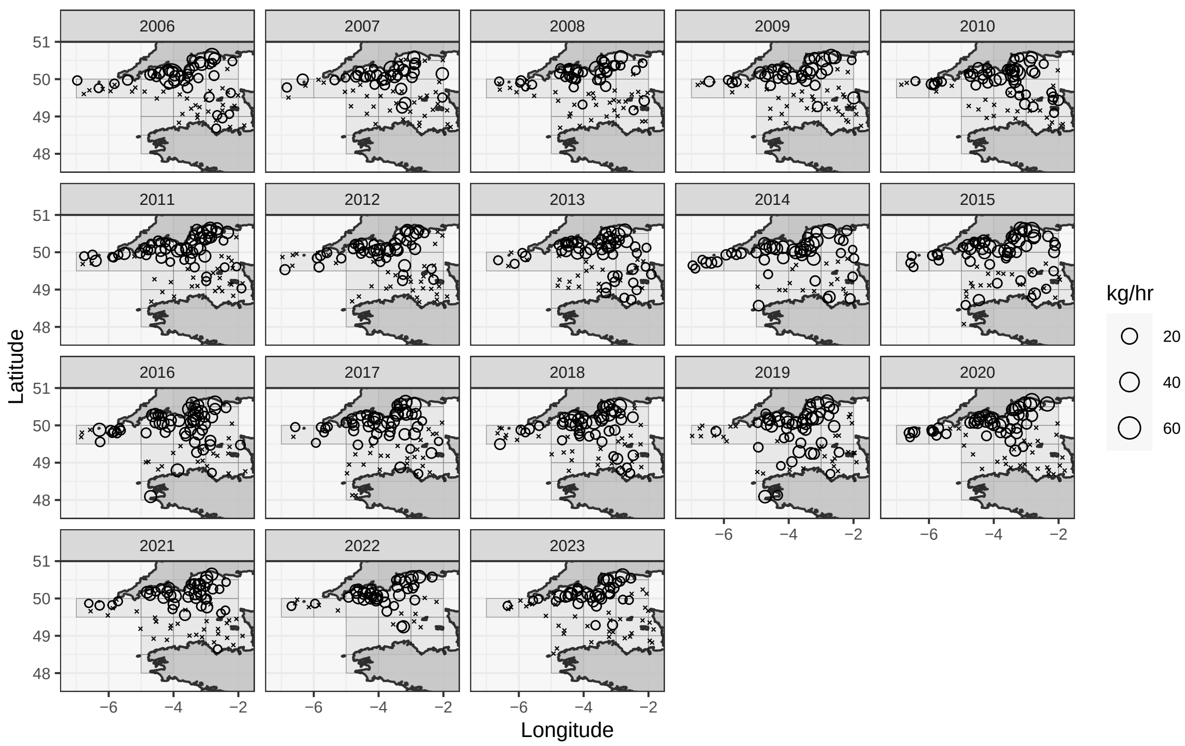


Figure 26: Q1SWBeam: Distribution of plaice biomass.

for ages 1–27, but numbers for age 1 and above 10 are sporadic. Figure 28 presents the time series of catch numbers at age, biomass at age, and weight at age.

The correlations between ages (i.e. the numbers in the index at a age, compared to the

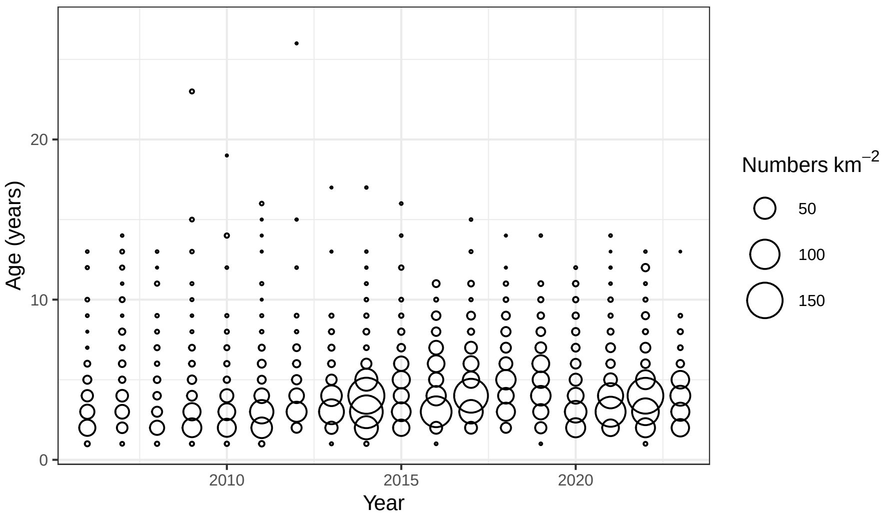


Figure 27: Q1SWBeam: Catch numbers at age (bubble plot).

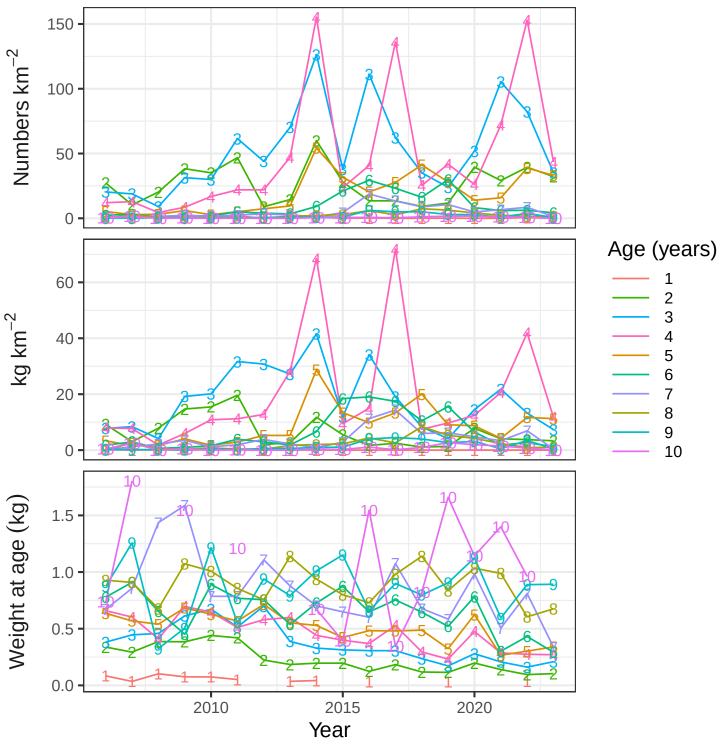


Figure 28: Q1SWBeam: Time series of catch numbers, biomass, and weight at age.

numbers at the following age one year later) are reasonable for ages above 2 (Figure 29).

The final proposed Q1SWBeam data to be used for fitting the baseline SAM model were the entire year range (2006–2023) and ages 2–9 because younger fish are not well retained in the survey, and fish above age 9 are also not well retained and show deteriorating consistency (Figure 29). This was the same age range as previously used by the former XSA assessment for plaice.

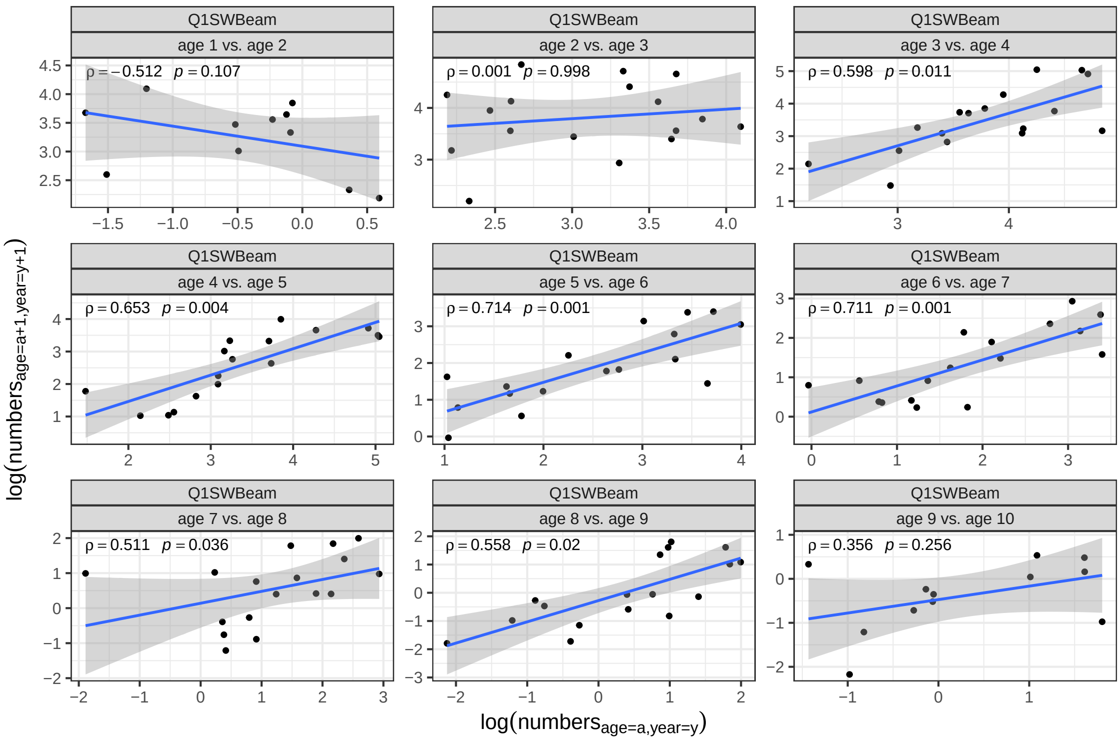


Figure 29: Q1SWBeam: Time series of catch numbers, biomass, and weight at age.

5.4 Biological data

5.4.1 Stock weights

The traditional approach for deriving stock weights at age was to smooth catch weights (with a second degree polynomial) and back calculate weights at the beginning of the year (see Section 5.1.3 and Figure 11).

An alternative approach to derive stock weights in ICES is to use quarter 1 catch weights. However, the quarter 1 weights were very similar to the annual values (Figure 30), so this would not make much difference. Furthermore, these data were only available since 2012 from InterCatch.

For some stocks in ICES, survey catch weights at age are used as stock weights. However, these data appeared not that reliable for this plaice stock, were fairly noisy, and did not cover the entire catch time series (Figures 22 and 28).

In conclusion, there did not appear a new source of data for stock weights appropriate for use in a stock assessment. Consequently, the previous approach of smoothing catch weights (total catch, including landings and discards) with a polynomial function and back-calculating the values at the beginning of the year was retained (Figure 17).

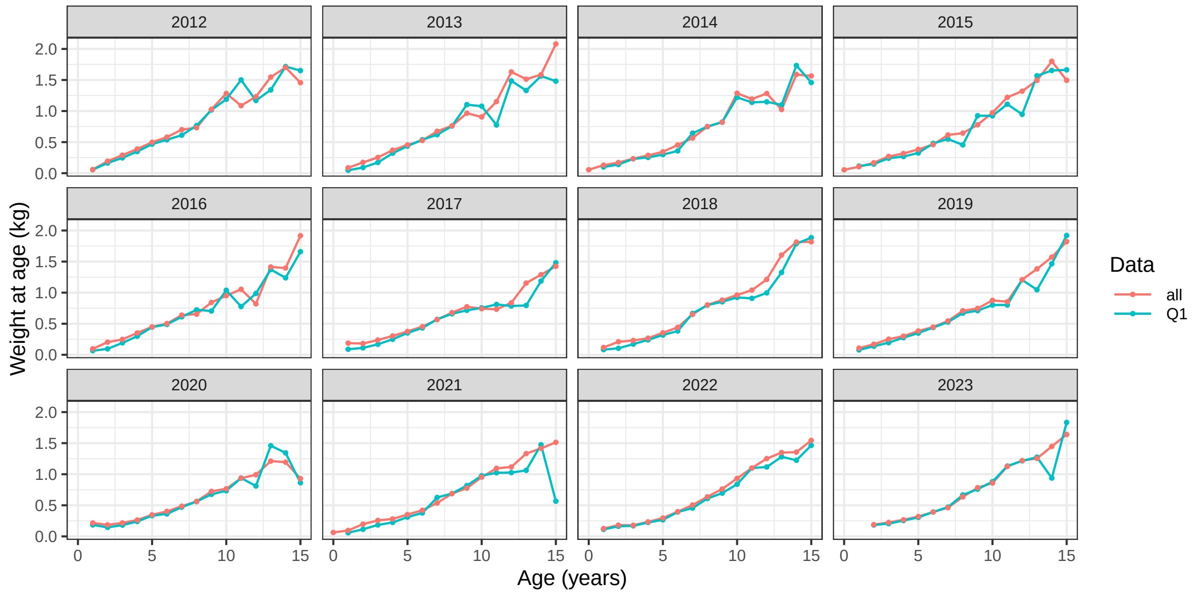


Figure 30: Catch weights from InterCatch. Comparison of quarter 1 values (Q1) and annual (all).

5.4.2 Growth

Age-length keys (ALKs) were available both from surveys and commercial catches (Figure 31). The commercial ALKs were available by quarter. Commercial ALKs had good coverage of older and larger fish but lacked younger and smaller fish. On the other hand, the ALK from the Q1SWBeam survey included smaller fish but lacked larger fish. For the purpose of fitting growth models, the two ALKs could be combined in this case to have a wider range of ages and lengths. This was appropriate for this stock because the majority of commercial catches come from beam trawls with 70-99mm, and the Q1SWBeam survey also uses commercial beam trawls with 80mm mesh size.

Table 2: Individual growth parameters of the von Bertalanffy model, as fitted in Figure 31.

Year	k **(year^{-1})**	L_∞ **(cm)**	t_0 **(years)**
2013	0.164	56.0	−0.9
2014	0.184	51.6	−0.5
2015	0.134	59.2	−1.1
2016	0.143	54.5	−1.4
2017	0.139	54.0	−1.1
2018	0.136	54.8	−1.1
2019	0.119	55.6	−1.5
2020	0.144	55.4	−1.5
2021	0.130	51.5	−1.7
2022	0.080	75.8	−1.7
2023	0.042	107.0	−3.1
2019–2023	0.092	64.5	−2.1

A von Bertalanffy model can be used to model individual growth:

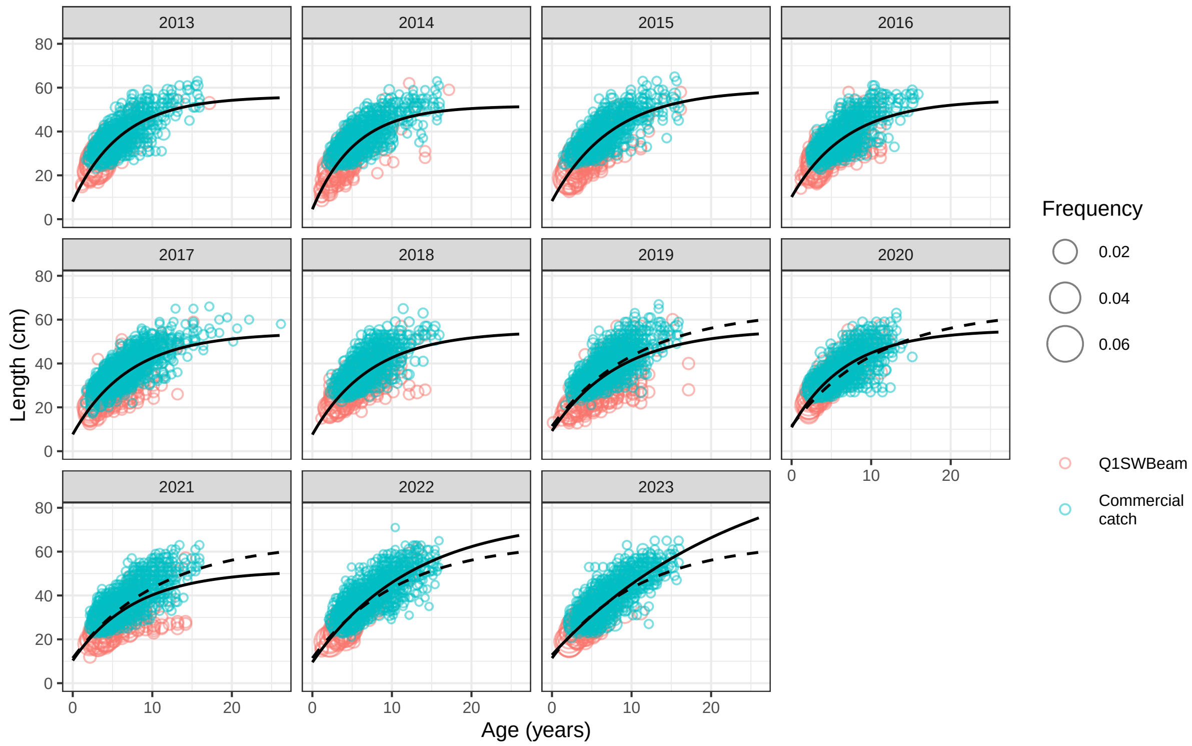


Figure 31: Age-length keys from commercial catches (catch) and the Q1SWBeam. The solid curves show a von Bertalanffy growth model fitted by year and the dashed curve shows a model fit to the pooled data of the last five years (2019–2023).

$$L_t = L_\infty \left(1 - \exp^{-k(t-t_0)}\right) \tag{2}$$

where L_t is the length at age t, L_∞ the asymptotic length, k the individual growth coefficient and t_0 the theoretical age at length 0. The von Bertalanffy model was fit to the combined ALK (Figure 31). The fitting was done by log-transforming lengths to account for higher variability at older ages. The ages from the commercial ALK were available by quarter and the ages were set to mid-quarter ages. The Q1SWBeam ages were set to the middle of the first quarter. The individual growth parameters varied from year to year (Table 2). In addition to the annual estimates, individual growth parameters were also estimated by pooling data from the last five years (2019–2023), which led to $k = 0.092$ year^{-1}, $L_\infty = 64.5$ cm, and $t_0 = -2.1$ years.

5.4.3 Natural mortality

Natural mortality (M) for this plaice stock is essentially unknown. The previously used value of $M = 0.12$ was borrowed from plaice in Division 7.a and based on a study from 1981 and is not used anymore for that stock.

There is a wide range of methods that promise to estimate M. Ideally, M is estimated from tagging studies, but such data do not exist for plaice in Division 7.e. Catch curve analysis can estimate total mortality ($Z = F + M$). However, to derive M, fishing mortality F is required, which is not known with confidence for this plaice stock. Some stock assessment models can estimate M internally or it is possible to determine M by testing different values and using the M that provides the best model fit. However, this approach is infeasible for this plaice stock because total catch levels are somewhat uncertain and migration is known to occur, so estimating M with a stock assessment model may lead to confounding results.

Alternatively, there are a range of predictors that estimate M based on life-history parameters and a few of them were trialled.

Gislason et al. (2010) provide an equation to estimate M at length:

$$\ln(M_L) = 0.55 - 1.61\ln(L) + 1.44\ln(L_\infty) + \ln(k) \tag{3}$$

where L_∞ and k are von Bertalanffy individual growth parameters (Equation 2).

Lorenzen et al. (2022) provide several equations to estimate M, e.g. at length:

$$\ln(M_L) = 0.28 - 1.30\ln(L/L_\infty) + 1.08\ln(k) \tag{4}$$

or at $L = L_\infty$:

$$\ln(M_{L=L_\infty}) = 0.65 + 0.87\ln(k) \tag{5}$$

Then et al. (2013) provide an equation to estimate a (constant) M:

$$M = 4.118\ k^{0.73}\ L_\infty^{-0.33} \tag{6}$$

M was calculated with Equations 3–6 and the von Bertalanffy individual growth parameters derived from the last five years of age-length data (Table 2) and is shown in Figure 32. Lengths were converted into ages with Equation 2 and ages were assumed to be mid-year values.

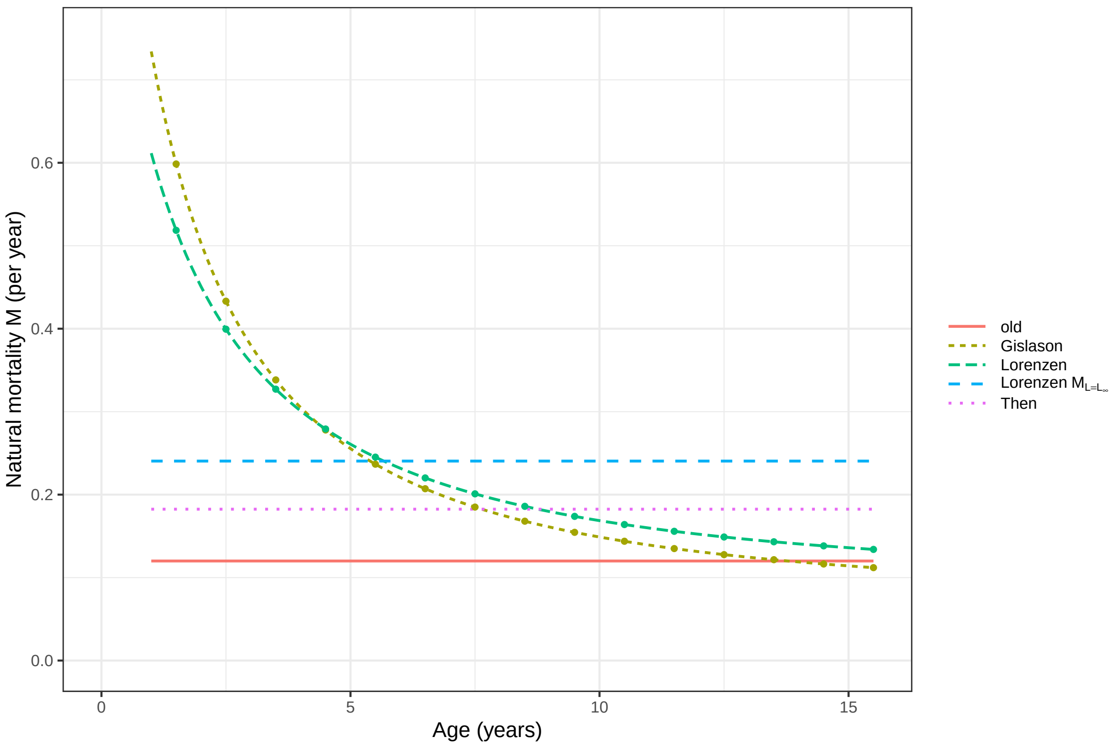


Figure 32: Various estimators of natural mortality M.

There was no clear "best" estimator for M for this stock. Consequently, several different assumptions about M will be included in the form of alternative operating models. The previously used value of $M = 0.12$ appeared too low compared to other plaice stocks. The estimators of M at length of Gislason et al. (2010) and Lorenzen et al. (2022) provided very similar results and so the decision was to only continue with one of them (Gislason et al., 2010) to avoid redundancy. The M estimated with the formulation of Then et al. (2013) appeared reasonable and in the middle of the other values. Furthermore, Lorenzen et al. (2022) noted that their predictors of adult M perform less well than Then et al. (2013). Consequently, the Then et al. (2013) estimator result of $M = 0.1825$ was used as the baseline. However, because there is a degree of uncertainty about M, alternative operating models that increase and decrease M by 50% will also be included, essentially covering a large range of possible M values.

5.4.4 Maturity

The previously used maturity ogive for plaice in Division 7.e (Table 3) was borrowed from plaice in divisions 7.fg and used for all years. These values were based on survey data from 1993/1994 and based on an analysis in 1997. Stock-specific maturity has never been used for this stock.

Table 3: Previously used maturity ogive for plaice in Division 7.e.

Age (years)	**1**	**2**	**3**	**4**	**5+**
Maturity (proportion)	0	0.26	0.52	0.86	1.00

Maturity data has been routinely collected on both current surveys (UK-FSP since 2003, Q1SWBeam since 2006) but has never been examined before. The data from the Q1SWBeam survey was selected for analysis because it consistently has a higher number of annual maturity measurements for plaice (between 203 and 1033, mean 562) compared to the UK-FSP survey.

Several approaches to modelling maturity were explored during the data evaluation workshop of WKBPLAICE. For brevity, only the final modelling approach is presented here.

Figure 33 shows the maturity data from Q1SWBeam. Maturity was modelled at length, by sex (females, males, and combined), and using year as a random effect with the R package `lme4`. The resulting maturity at length curves are shown in Figure 33, the R model summary for the model fit to females in Table 4, and the length at 50% maturity (L_{50}) in Figure 34. The benchmark decided to only use the fit to female fish, to be more precautionary.

The maturity at length then had to be converted into maturity at age. This was done by converting lengths to ages with the annual von Bertalanffy model fits described in Section 5.4.2 (Figure 35). The maturity at age time series showed fairly large fluctuation from year to year (Figure 36). Consequently, the annual values were smoothed with a 3-year moving average (average of the current year's value and the values from the two preceding years, Figure 36). Using a 5-year average was explored but rejected because the smoothing appeared too strong.

In conclusion, the final maturity suggested by WKBPLAICE was based on data from the Q1SWBeam survey for females, modelled by length with a logistic regression and using years as a random effect, these values were then converted into ages by using annual von Bertalanffy growth curves, and these values then smoothed with a 3-year average. For previous years, the average of the first three years of data was used.

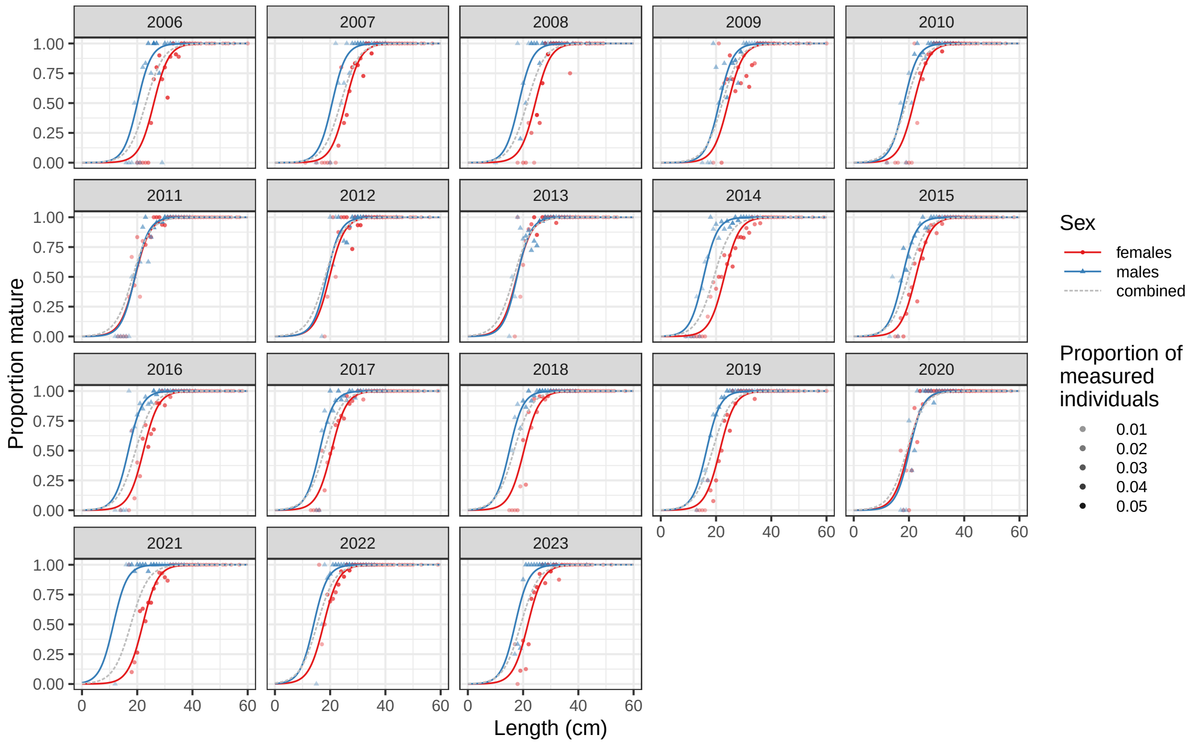


Figure 33: Maturity for plaice in Division 7.e from Q1SWBeam. Points represent data, the curves the model fit of a logistic regression, by sex, and year as a random effect.

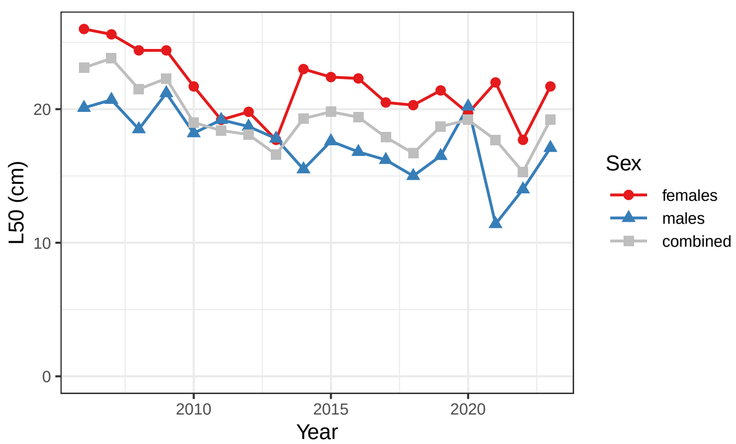


Figure 34: Length at 50% maturity (L_{50}) from the model fits shown in Figure 33.

Table 4: Summary of the maturity modelling (females only).

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) ['glmerMod']
 Family: binomial  ( logit )
Formula: prop_mature ~ length + (1 | year)
   Data: mat_smry_sex %>% filter(sex == "F") %>% mutate(length = length/10)
Weights: total

     AIC      BIC   logLik deviance df.resid
   972.7    986.3   -483.4    966.7      673

Scaled residuals:
    Min      1Q  Median      3Q     Max
-4.9450 -0.0491  0.0262  0.2684  3.2223

Random effects:
 Groups Name        Variance Std.Dev.
 year   (Intercept) 0.8104   0.9002
Number of obs: 676, groups:  year, 18

Fixed effects:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -7.97607    0.37854  -21.07   <2e-16 ***
length       0.36871    0.01267   29.10   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
       (Intr)
length -0.817
```

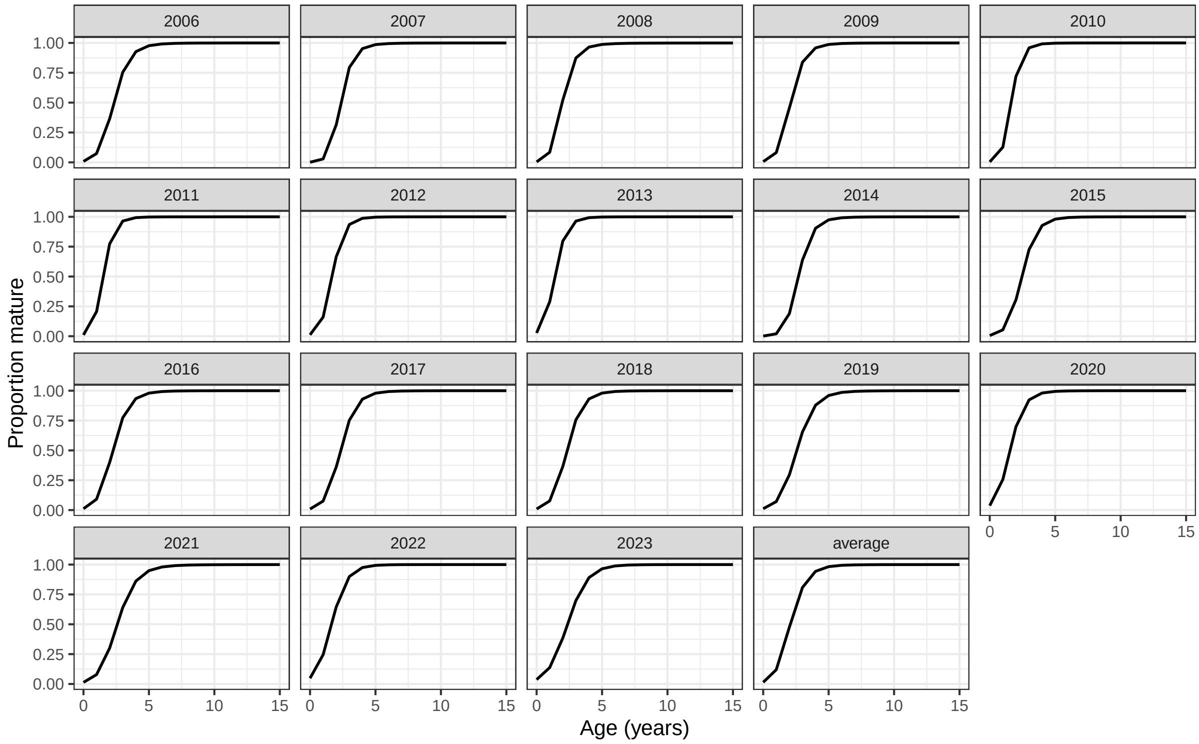


Figure 35: Maturity at age. The data shown here correspond to the model fit for female maturity in Figure 33, converted to ages with annual von Bertalanffy models.

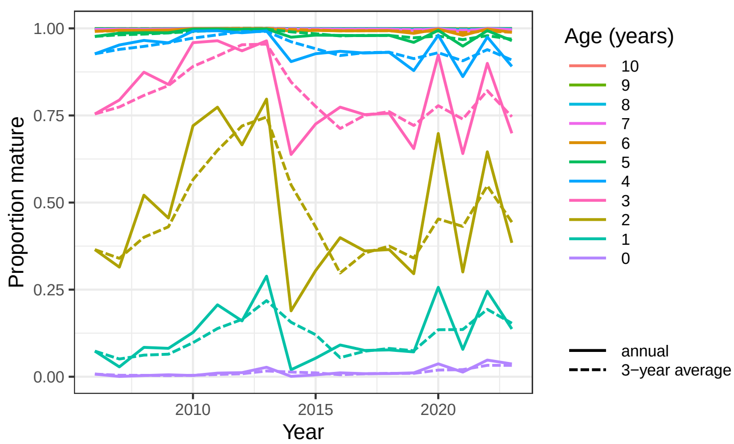


Figure 36: Maturity at age time series. The data shown here correspond to the data in Figure 35. The 3-year averages are the average of the current year's and the values from the two preceding years.

6 Exploratory SAM runs

This section describes the SAM model fits that will be used to condition the operating models in the MSE. As described in previous sections of this document, the baseline operating model will be based on the most plausible data configuration.

6.1 Baseline

The baseline SAM model (including input files, outputs, and diagnostics) is available on the online platform https://www.stockassessment.org with the link https://www.stockassessment.org/setStock.php?stock=ple.27.7e_WKBPLAICE_OM.

6.1.1 Data

Figure 37 illustrates the catch and survey data input. The input data and choices for the baseline SAM model are described in the previous sections of this document. The catch data includes only 50% of the total discards because the baseline model assumes 50% discard survival (see Section 5.2).

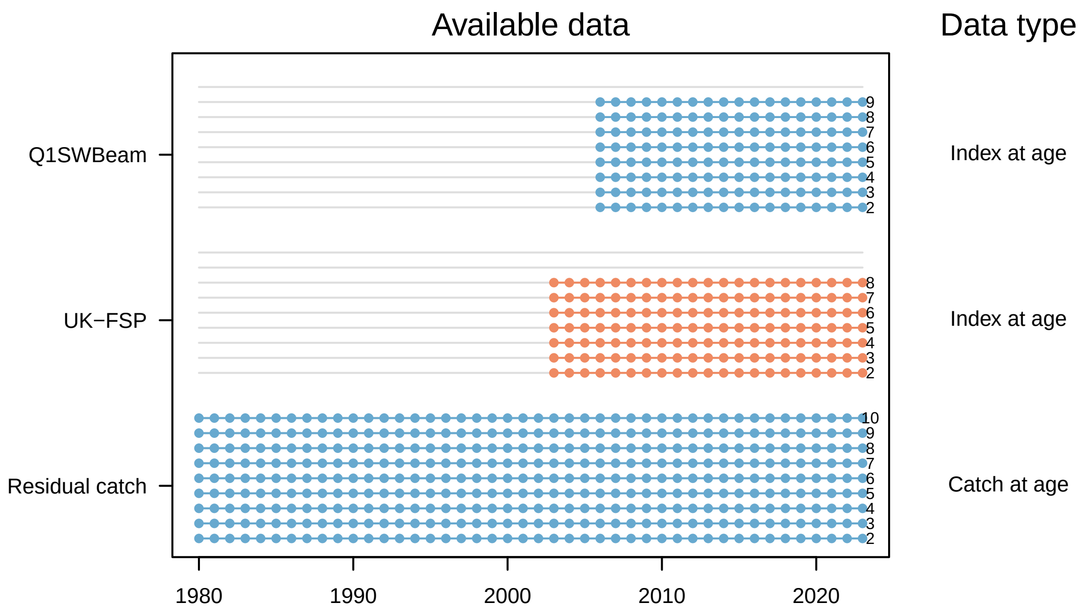


Figure 37: Baseline SAM: Catch and survey data input.

6.1.2 SAM configuration

The default SAM model configuration was used (Table 5). The fbar range (range of ages included for calculating mean F) was kept at ages 3–6, and confirmed to be the ages that include 90% of the catch numbers at age.

Table 5: Baseline SAM: Model configuration

```
# Configuration saved:  Thu Jun 6 11:27:46 2024
#
```

Table 5: (continued)

```
# Where a matrix is specified rows corresponds to fleets and columns to ages.
# Same number indicates same parameter used
# Numbers (integers) starts from zero and must be consecutive
# Negative numbers indicate that the parameter is not included in the model
#
$minAge
# The minimium age class in the assessment
2

$maxAge
# The maximum age class in the assessment
10

$maxAgePlusGroup
# Is last age group considered a plus group for each fleet (1 yes, or 0 no).
1 0 0

$keyLogFsta
# Coupling of the fishing mortality states processes for each age (normally only
# the first row (= fleet) is used).
# Sequential numbers indicate that the fishing mortality is estimated individually
# for those ages; if the same number is used for two or more ages, F is bound for
# those ages (assumed to be the same).  Binding fully selected ages will result in a
# flat selection pattern for those ages.
0 1 2 3 4 5 6 7 7
-1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1

$corFlag
# Correlation of fishing mortality across ages (0 independent, 1 compound symmetry,
# 2 AR(1), 3 separable AR(1).
# 0:  independent means there is no correlation between F across age
# 1:  compound symmetry means that all ages are equally correlated;
# 2:  AR(1) first order autoregressive - similar ages are more highly correlated than
# ages that are further apart, so similar ages have similar F patterns over time.
# if the estimated correlation is high, then the F pattern over time for each age
# varies in a similar way.  E.g if almost one, then they are parallel (like a
# separable model) and if almost zero then they are independent.
# 3:  Separable AR - Included for historic reasons .  .  .  more later
2

$keyLogFpar
# Coupling of the survey catchability parameters (nomally first row is
# not used, as that is covered by fishing mortality).
-1 -1 -1 -1 -1 -1 -1 -1 -1
0 1 2 3 4 5 5 -1 -1
```

Table 5: (continued)

```
6 7 8 9 10 11 12 12 -1

$keyQpow
# Density dependent catchability power parameters (if any).
-1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1

$keyVarF
# Coupling of process variance parameters for log(F)-process (Fishing mortality
# normally applies to the first (fishing) fleet; therefore only first row is used)

0 0 0 0 0 0 0 0 0
-1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1

$keyVarLogN
# Coupling of the recruitment and survival process variance parameters for the
# log(N)-process at the different ages.  It is advisable to have at least the first
age
# class (recruitment) separate, because recruitment is a different process than
# survival.
0 1 1 1 1 1 1 1 1

$keyVarLogP
#

$keyVarObs
# Coupling of the variance parameters for the observations.
# First row refers to the coupling of the variance parameters for the catch data
# observations by age
# Second and further rows refers to coupling of the variance parameters for the
# index data observations by age
0 0 0 0 0 0 0 0 0
1 1 1 1 1 1 1 -1 -1
2 2 2 2 2 2 2 2 -1

$obsCorStruct
# Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for
unstructured).  | Possible values are:  "ID" "AR" "US"
"ID" "ID" "ID"

$keyCorObs
# Coupling of correlation parameters can only be specified if the AR(1) structure is
chosen above.
# NA's indicate where correlation parameters can be specified (-1 where they cannot).
```

Table 5: (continued)

```
#2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10
NA NA NA NA NA NA NA NA
NA NA NA NA NA NA -1 -1
NA NA NA NA NA NA NA -1

$stockRecruitmentModelCode
# Stock recruitment code (0 for plain random walk, 1 for Ricker, 2 for Beverton-Holt,
3 piece-wise constant, 61 for segmented regression/hockey stick, 62 for AR(1), 63 for
bent hyperbola / smooth hockey stick, 64 for power function with degree < 1, 65 for
power function with degree > 1, 66 for Shepher, 67 for Deriso, 68 for Saila-Lorda, 69
for sigmoidal Beverton-Holt, 90 for CMP spline, 91 for more flexible spline, and 92
for most flexible spline).
0

$noScaledYears
# Number of years where catch scaling is applied.
0

$keyScaledYears
# A vector of the years where catch scaling is applied.


$keyParScaledYA
# A matrix specifying the couplings of scale parameters (nrow = no scaled years, ncols
= no ages).

$fbarRange
# lowest and higest age included in Fbar
3 6

$keyBiomassTreat
# To be defined only if a biomass survey is used (0 SSB index, 1 catch index, 2 FSB
index, 3 total catch, 4 total landings, 5 TSB index, 6 TSN index, and 10 Fbar idx).
-1 -1 -1

$obsLikelihoodFlag
# Option for observational likelihood | Possible values are:  "LN" "ALN"
"LN" "LN" "LN"

$fixVarToWeight
# If weight attribute is supplied for observations this option sets the treatment (0
relative weight, 1 fix variance to weight).  Can be specified fleetwise.
0 0 0

$fracMixF
# The fraction of t(3) distribution used in logF increment distribution
```

Table 5: (continued)

```
0

$fracMixN
# The fraction of t(3) distribution used in logN increment distribution (for each age
group)
0 0 0 0 0 0 0 0 0

$fracMixObs
# A vector with same length as number of fleets, where each element is the fraction of
t(3) distribution used in the distribution of that fleet
0 0 0

$constRecBreaks
# For stock-recruitment code 3:  Vector of break years between which recruitment is at
constant level.  The break year is included in the left interval.  For spline
stock-recruitment:  Vector of log-ssb knots.  (This option is only used in combination
with stock-recruitment code 3, 90-92, and 290)

$predVarObsLink
# Coupling of parameters used in a prediction-variance link for observations.
-1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 NA NA
-1 -1 -1 -1 -1 -1 -1 -1 NA

$stockWeightModel
# Integer code describing the treatment of stock weights in the model (0 use as known,
1 use as observations to inform stock weight process (GMRF with cohort and within year
correlations)), 2 to add extra correlation to plusgroup
0

$keyStockWeightMean
# Coupling of stock-weight process mean parameters (not used if stockWeightModel==0)
NA NA NA NA NA NA NA NA NA

$keyStockWeightObsVar
# Coupling of stock-weight observation variance parameters (not used if
stockWeightModel==0)
NA NA NA NA NA NA NA NA NA

$catchWeightModel
# Integer code describing the treatment of catch weights in the model (0 use as known,
1 use as observations to inform catch weight process (GMRF with cohort and within year
correlations)), 2 to add extra correlation to plusgroup
0

$keyCatchWeightMean
```

Table 5: (continued)

```
# Coupling of catch-weight process mean parameters (not used if catchWeightModel==0)
NA NA NA NA NA NA NA NA NA

$keyCatchWeightObsVar
# Coupling of catch-weight observation variance parameters (not used if
catchWeightModel==0)
NA NA NA NA NA NA NA NA NA

$matureModel
# Integer code describing the treatment of proportion mature in the model (0 use as
known, 1 use as observations to inform proportion mature process (GMRF with cohort and
within year correlations on logit(proportion mature))), 2 to add extra correlation to
plusgroup
0

$keyMatureMean
# Coupling of mature process mean parameters (not used if matureModel==0)
NA NA NA NA NA NA NA NA NA

$mortalityModel
# Integer code describing the treatment of natural mortality in the model (0 use as
known, 1 use as observations to inform natural mortality process (GMRF with cohort and
within year correlations)), 2 to add extra correlation to plusgroup
0

$keyMortalityMean
#
NA NA NA NA NA NA NA NA NA

$keyMortalityObsVar
# Coupling of natural mortality observation variance parameters (not used if
mortalityModel==0)
NA NA NA NA NA NA NA NA NA

$keyXtraSd
# An integer matrix with 4 columns (fleet year age coupling), which allows additional
uncertainty to be estimated for the specified observations

$logNMeanAssumption
#
0 0

$initState
#
0
```

6.1.3 SAM results

The results of the baseline SAM model are shown in Figure 38 and Table 6. Figure 39 shows a comparison of spawning stock biomass (SSB) and total stock biomass (TSB) and Figure 40 the stock-recruitment plot.

The results differ from those presented by Fischer et al. (2023, Figure 41). However, the new SAM assessment is based on updated data (e.g. a newly considered discard survival, other assumptions about maturity, natural mortality, etc.) and so differences are to be expected.

Figure 42 shows the selectivity in F, Figure 43 the contribution of the different ages to the stock biomass, and Figure 44 the estimated survey catchabilites for the two surveys.

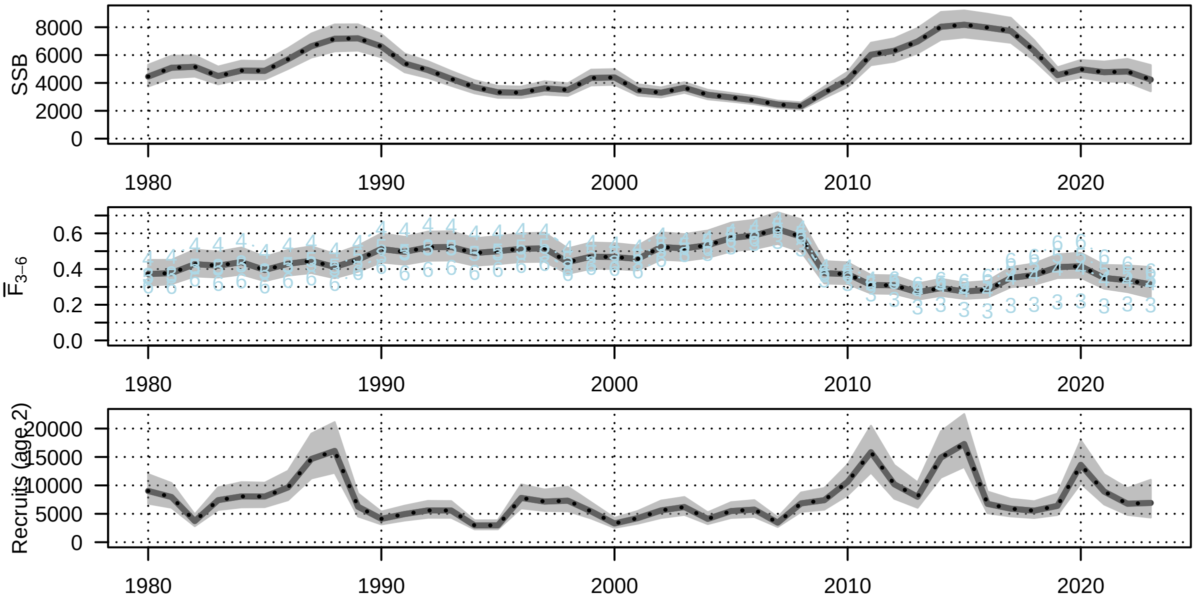


Figure 38: Baseline SAM: Summarised results for SSB, F, and recruits.

Table 6: Baseline SAM: Summarised results for recruitment (R, in thousands), spawning stock biomass (SSB, in tonnes), and mean fishing mortality (Fbar(3-6)). Low and high refer to 95% confidence intervals.

Year	R low	R	R high	SSB low	SSB	SSB high	Fbar(3-6) low	Fbar(3-6)	Fbar(3-6) high
1980	6804	9023	11966	3748	4456	5298	0.307	0.372	0.451
1981	6084	7955	10402	4352	5089	5950	0.316	0.377	0.451
1982	2831	3716	4877	4459	5160	5971	0.359	0.427	0.509
1983	5686	7401	9632	3903	4493	5170	0.353	0.419	0.498
1984	6152	8060	10559	4268	4887	5596	0.370	0.439	0.520
1985	6188	8045	10460	4255	4866	5564	0.333	0.395	0.468
1986	7412	9645	12550	5007	5700	6489	0.364	0.429	0.507
1987	11238	14651	19100	5826	6629	7542	0.378	0.446	0.527
1988	12230	16076	21131	6276	7171	8194	0.349	0.411	0.485
1989	4552	6249	8577	6324	7202	8203	0.385	0.452	0.531
1990	3148	4114	5375	5847	6623	7501	0.437	0.512	0.599
1991	3826	4955	6415	4773	5397	6101	0.425	0.497	0.580
1992	4315	5596	7256	4364	4921	5550	0.447	0.522	0.609
1993	4311	5579	7221	3798	4292	4850	0.448	0.524	0.611
1994	2281	2956	3829	3258	3695	4191	0.419	0.490	0.572
1995	2291	2970	3850	2939	3330	3774	0.428	0.500	0.584
1996	5977	7795	10167	2919	3301	3733	0.440	0.514	0.600
1997	5523	7149	9254	3167	3612	4120	0.441	0.516	0.603
1998	5469	7305	9756	3078	3496	3970	0.374	0.439	0.516
1999	4191	5424	7020	3828	4352	4947	0.402	0.470	0.549
2000	2547	3300	4275	3872	4393	4983	0.401	0.467	0.545
2001	3281	4242	5483	3093	3474	3902	0.393	0.457	0.531
2002	4277	5592	7312	2967	3302	3675	0.453	0.524	0.606
2003	4828	6192	7941	3295	3652	4048	0.446	0.516	0.596
2004	3202	4100	5249	2831	3149	3503	0.463	0.534	0.615
2005	4280	5484	7025	2664	2955	3278	0.499	0.574	0.660
2006	4455	5738	7391	2480	2751	3052	0.513	0.589	0.676
2007	2696	3438	4383	2209	2454	2725	0.541	0.623	0.718
2008	5351	6834	8729	2088	2333	2606	0.498	0.581	0.678
2009	5745	7394	9516	2919	3304	3740	0.32	0.377	0.444
2010	8264	10631	13675	3717	4220	4791	0.316	0.372	0.437
2011	12245	15841	20493	5278	6026	6880	0.263	0.311	0.366
2012	7665	10200	13574	5530	6309	7198	0.262	0.308	0.364
2013	6073	7993	10520	6127	6974	7939	0.229	0.270	0.319
2014	11378	14890	19487	7099	8033	9089	0.250	0.294	0.345
2015	13255	17288	22547	7271	8178	9198	0.233	0.274	0.323
2016	5115	6749	8906	7094	7972	8959	0.240	0.283	0.333
2017	4552	5893	7628	6887	7727	8670	0.298	0.350	0.411
2018	4272	5545	7197	5622	6303	7067	0.312	0.367	0.431
2019	4801	6400	8533	4062	4560	5118	0.35	0.411	0.482
2020	10351	13623	17930	4398	4982	5644	0.352	0.416	0.491
2021	6658	8916	11939	4116	4770	5527	0.29	0.350	0.422
2022	4822	6770	9505	4058	4817	5719	0.271	0.337	0.420
2023	4357	6915	10974	3403	4238	5278	0.239	0.314	0.411

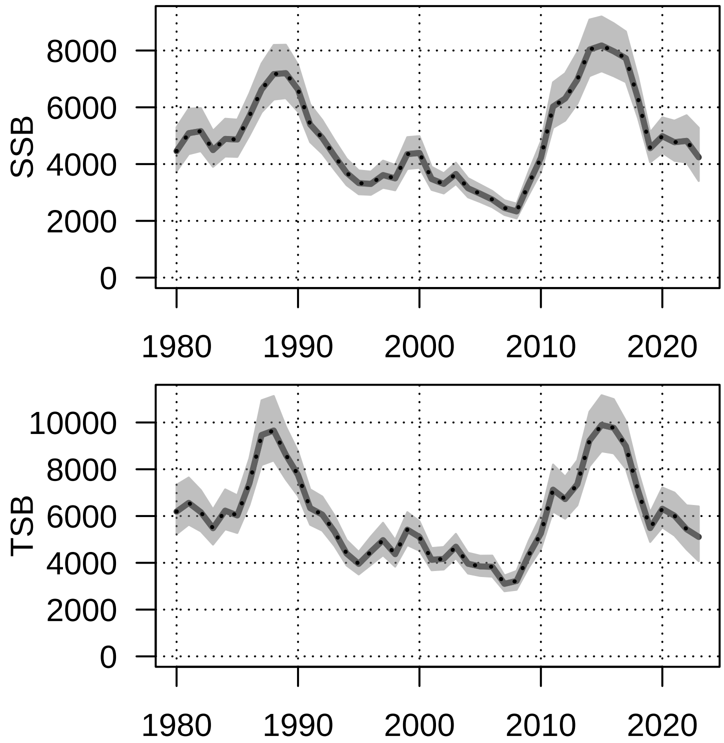


Figure 39: Baseline SAM: Spawning stock biomass (SSB) and total stock biomass (TSB).

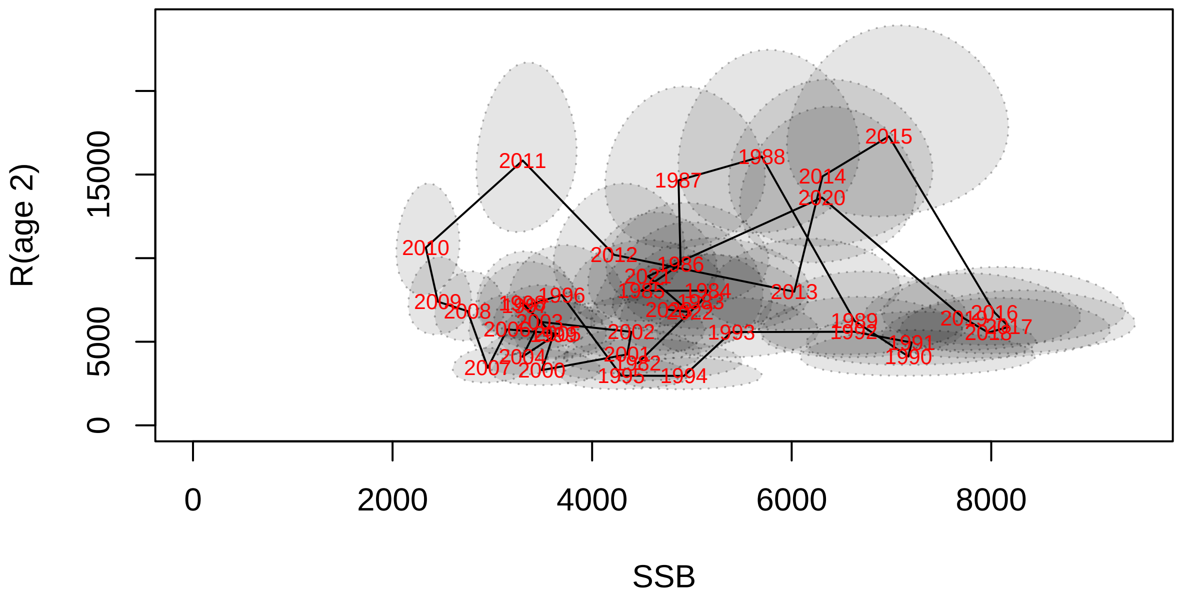


Figure 40: Baseline SAM: Stock-recruitment plot.

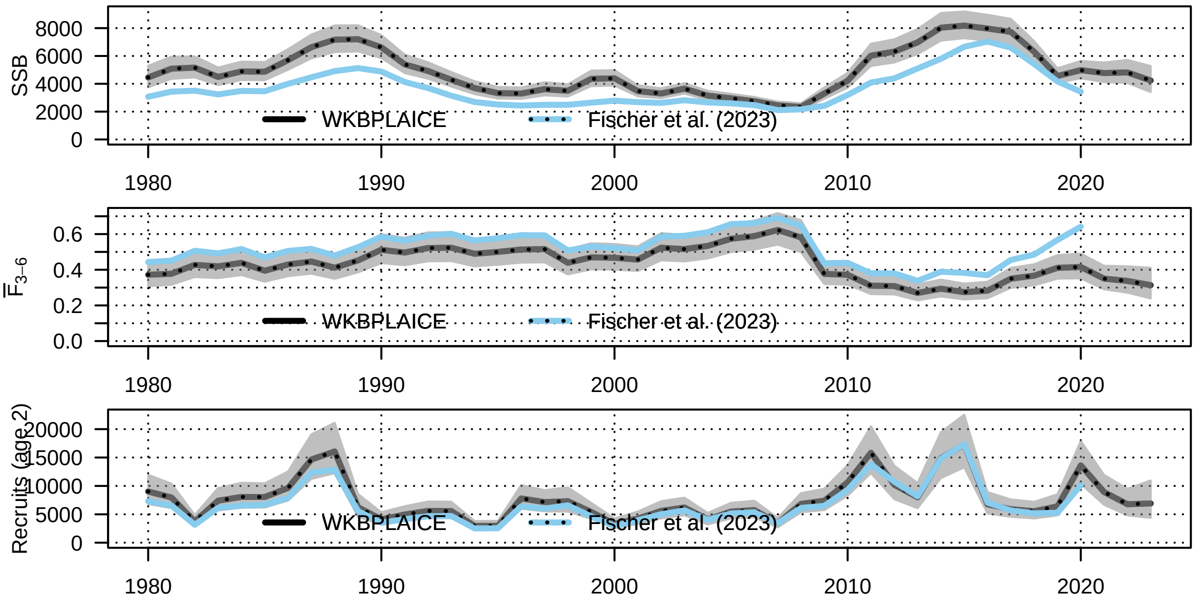


Figure 41: Baseline SAM: Summarised results and comparison to Fischer et al. (2023).

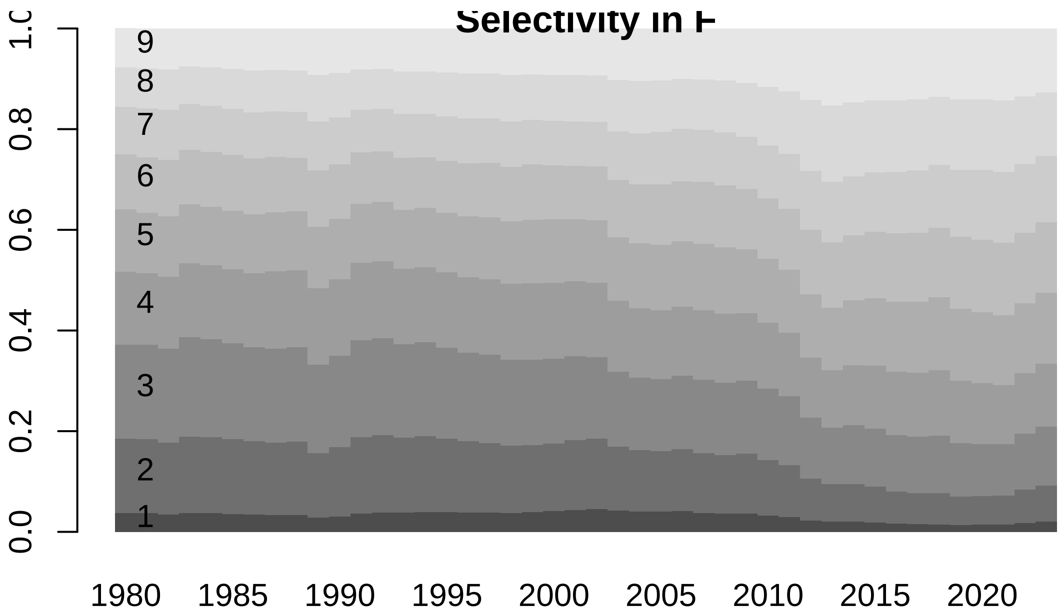


Figure 42: Baseline SAM: Selectivity in F.

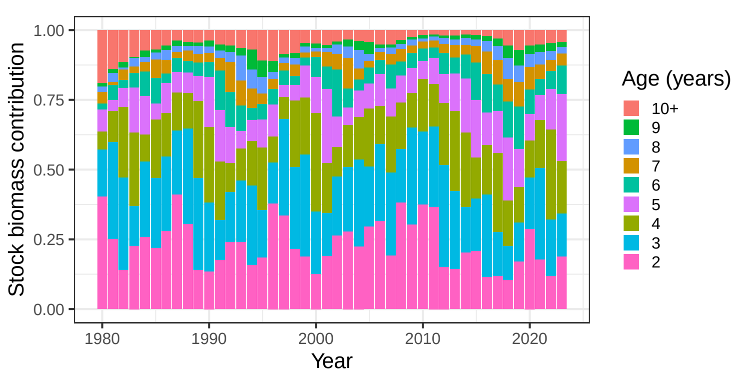


Figure 43: Baseline SAM: Contribution of ages to stock biomass.

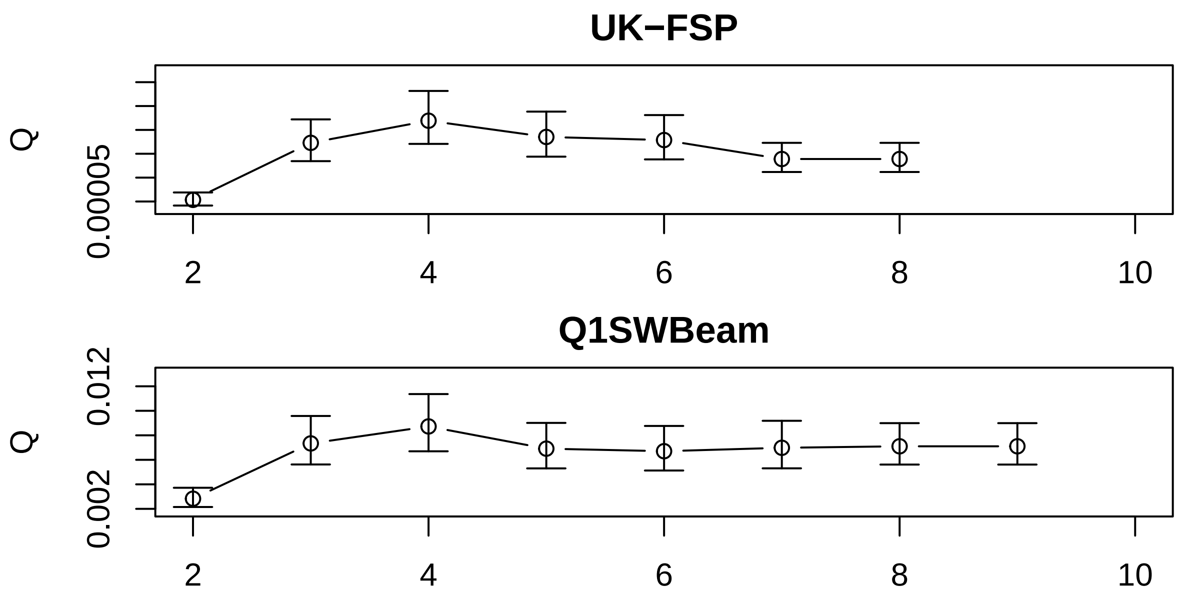


Figure 44: Baseline SAM: Estimated survey catchabilities.

6.1.4 Diagnostics

Figure 45 shows the fit to the data (catch numbers at age, survey indices at age), Figure 46 the residuals for catch and survey indices, and Figure 47 process residuals for stock numbers and fishing mortality.

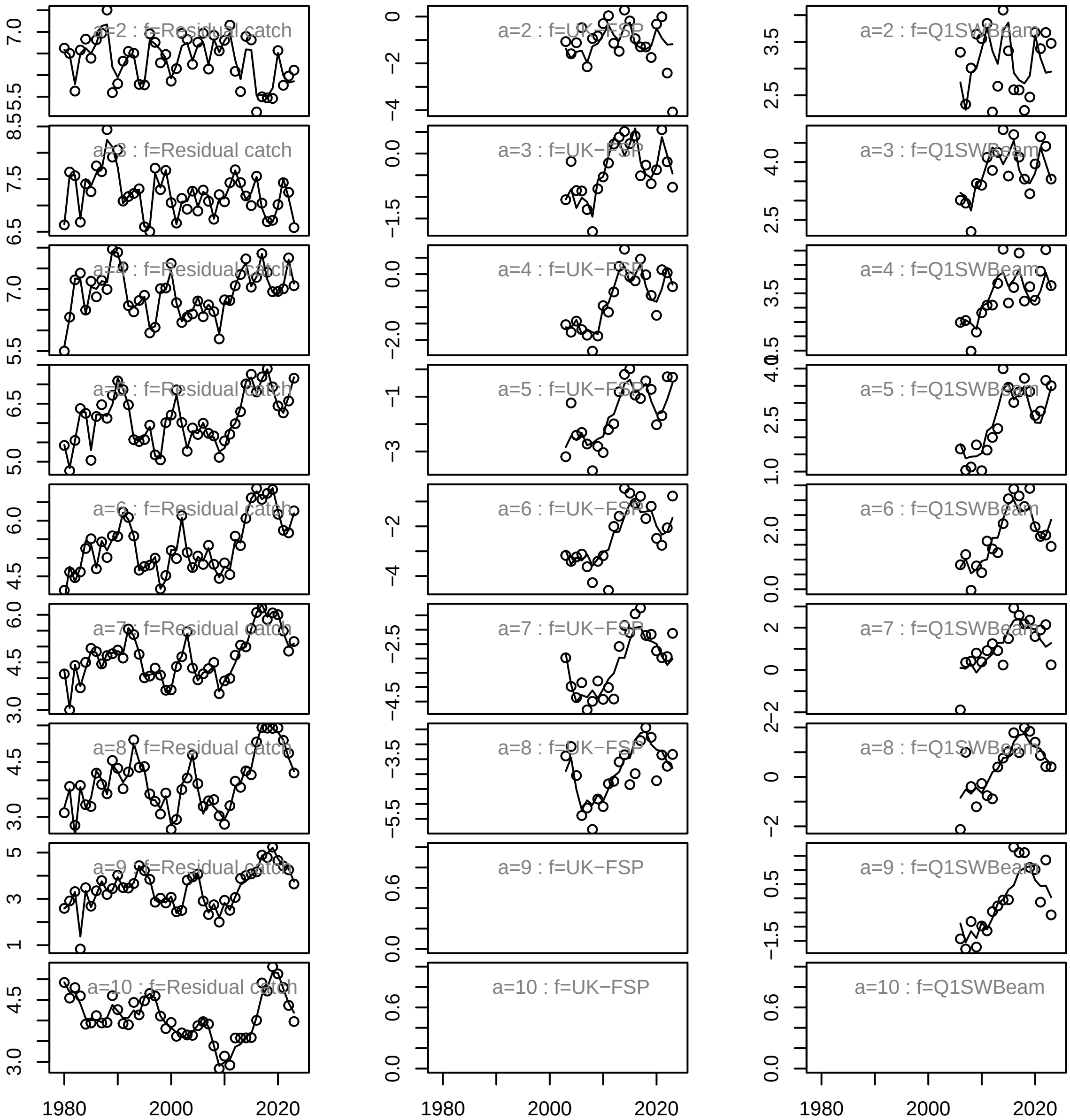


Figure 45: Baseline SAM: Fit to catch and survey indices.

Figure 48 presents the results of a five-year retrospective analysis (Mohn's rho values: +13.7% for the SSB, −9.3% for F, +0.4% for recruitment) and Figure 49 the survey leave-one-out analysis. Jittering of starting values for the model fitting process did not have any impact on the results (Figure 50). Simulating data from the model fit and then refitting SAM to the simulated data (Figure 51) did not show any issues, and the results were within the confidence bounds without any systematic bias.

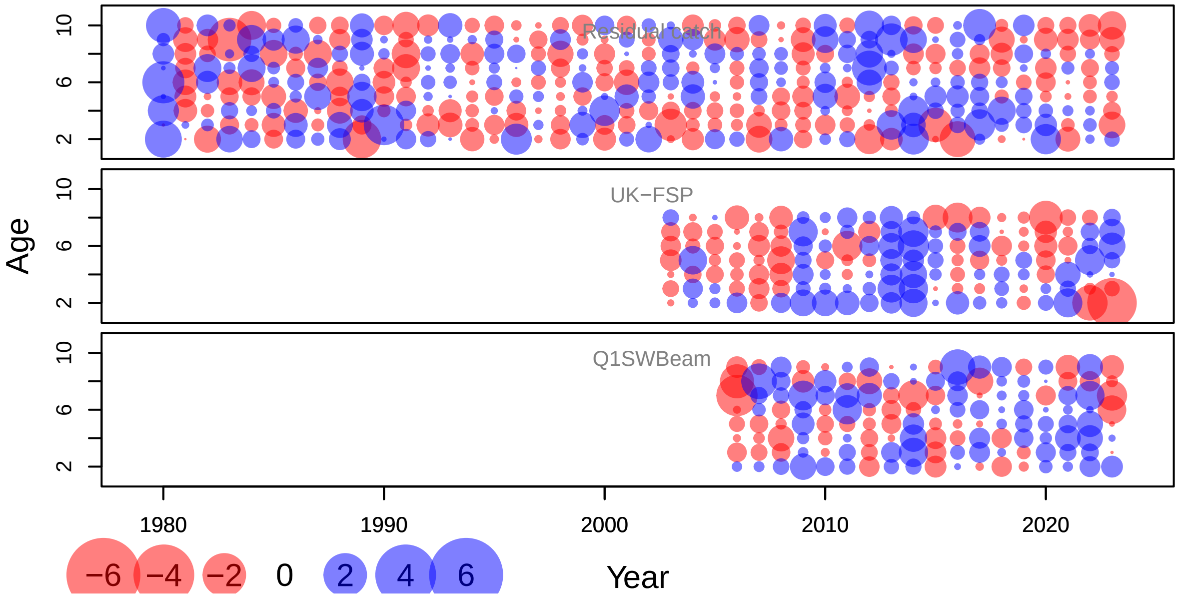


Figure 46: Baseline SAM: One-step ahead residuals for catch and survey indices.

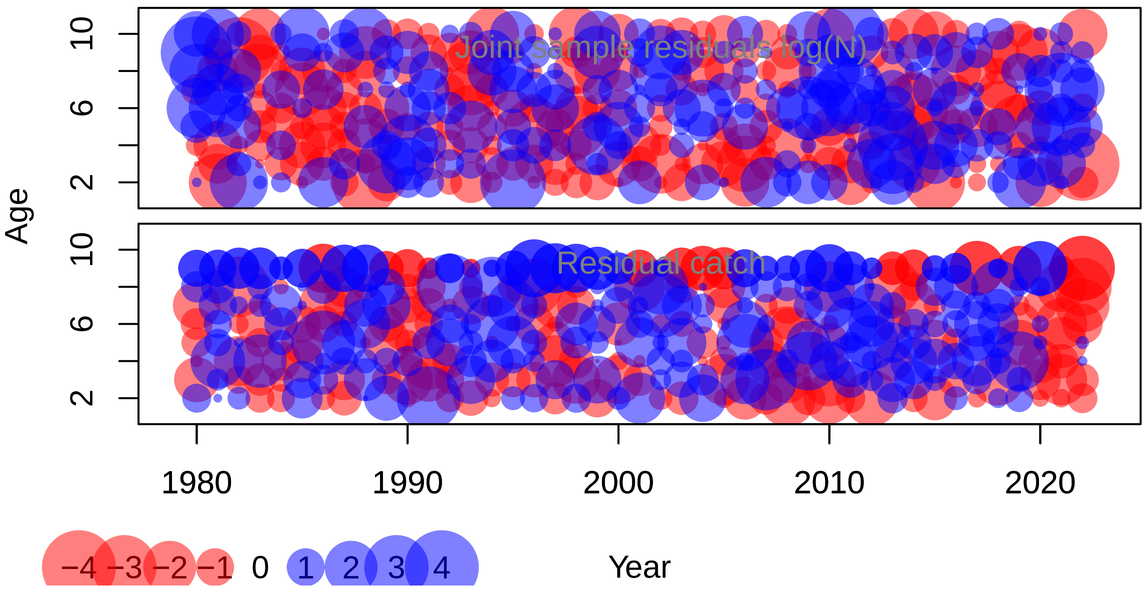


Figure 47: Baseline SAM: One-step ahead process residuals for stock numbers and fishing mortality.

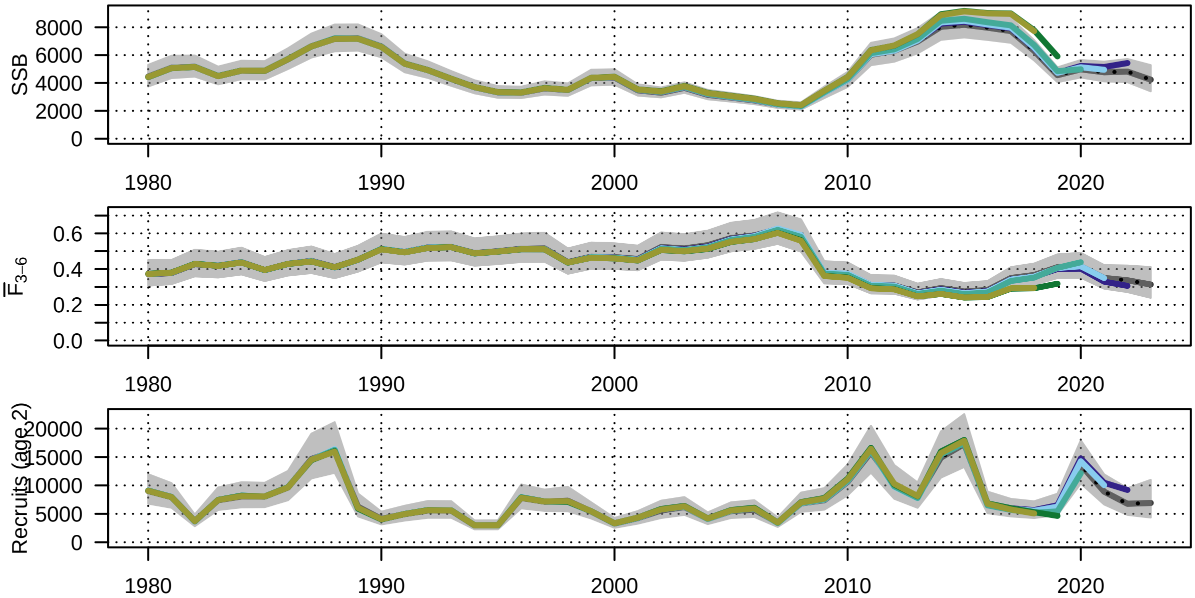


Figure 48: Baseline SAM: Five-year retrospective analysis.

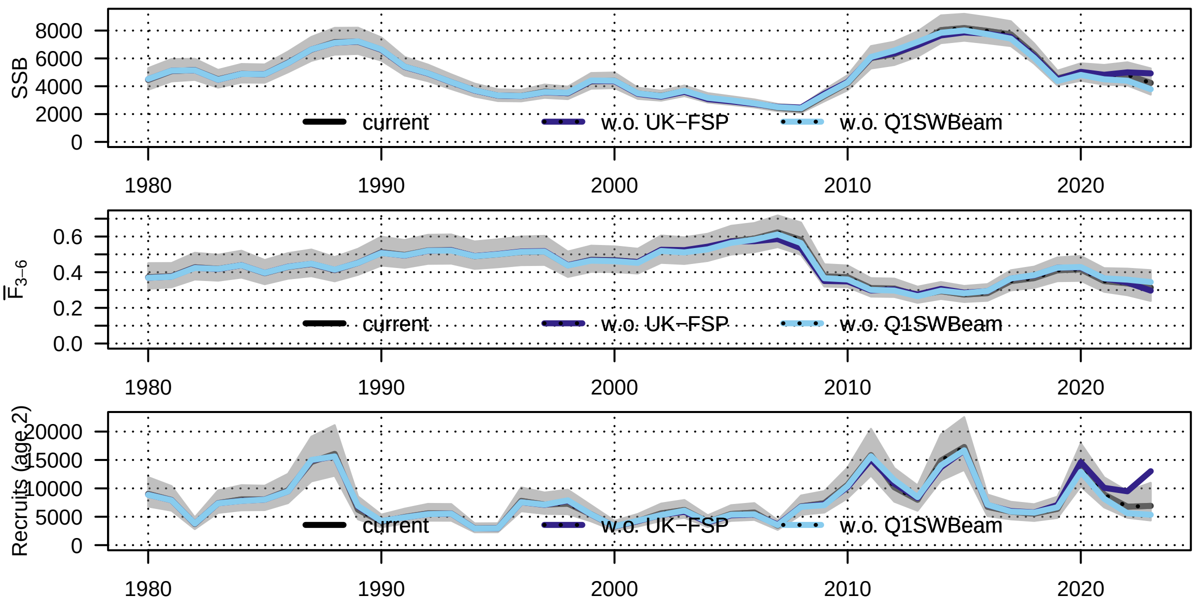


Figure 49: Baseline SAM: Survey leave-one-out analysis.

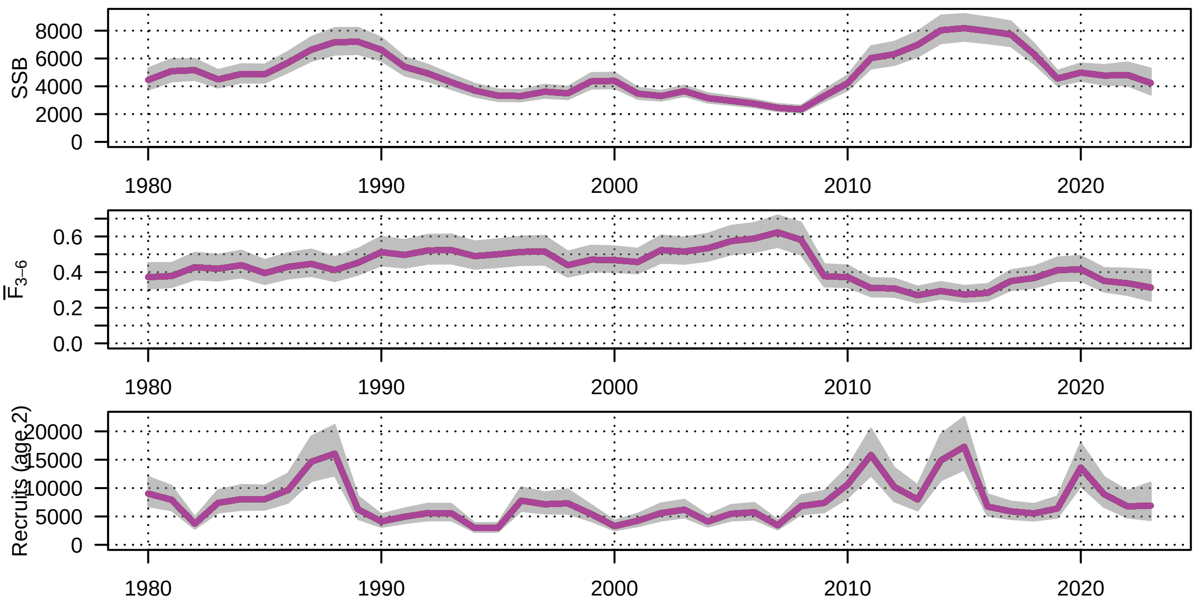


Figure 50: Baseline SAM: Jitter analysis (random starting values, 100 iterations).

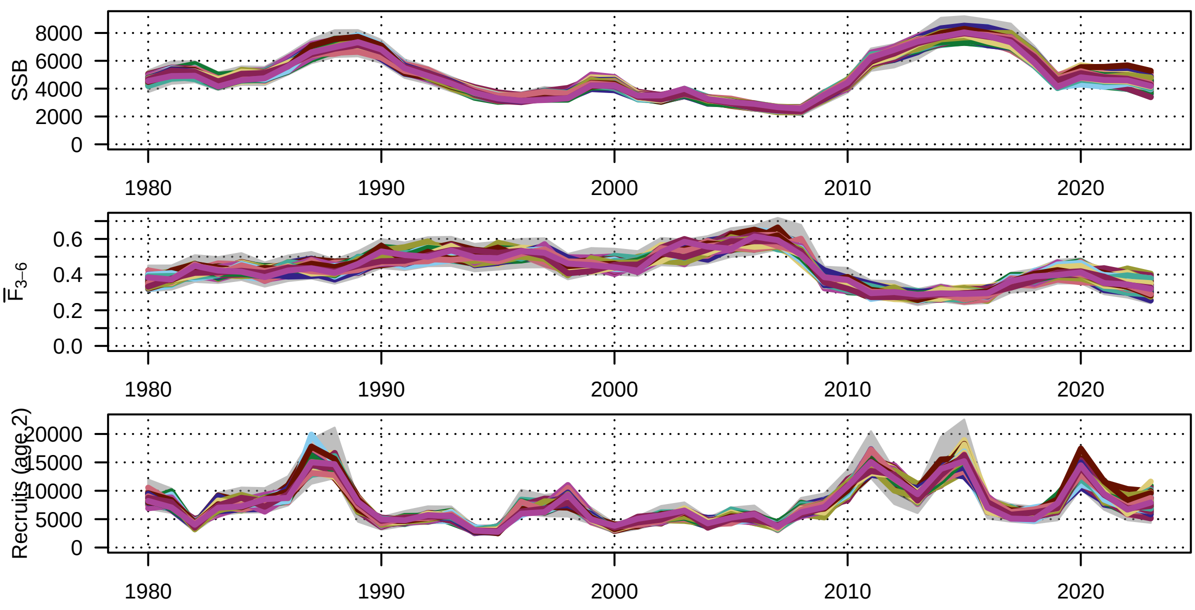


Figure 51: Baseline SAM: Simulation study (simulate data from the model fit, refit model to simulated data, 100 times).

6.2 Plusgroup

The baseline SAM model (Section 6.1) used a plusgroup of 10+ (years) for the catch. The impact of lower plusgroups was explored by setting the plusgroup to 9+ and 8+. For this exploration, the survey index age ranges were also reduced so that the oldest age in the survey index was always one age below the catch plusgroup (i.e. a maximum age of 8 for both surveys for the 9+ plusgroup and age 7 for the 8+ plusgroup). The impact on the results of SAM was minor (Figure 52), and model residuals did not show any substantial improvement (Figure 53) that would warrant reducing the plusgroup of the baseline SAM mode.

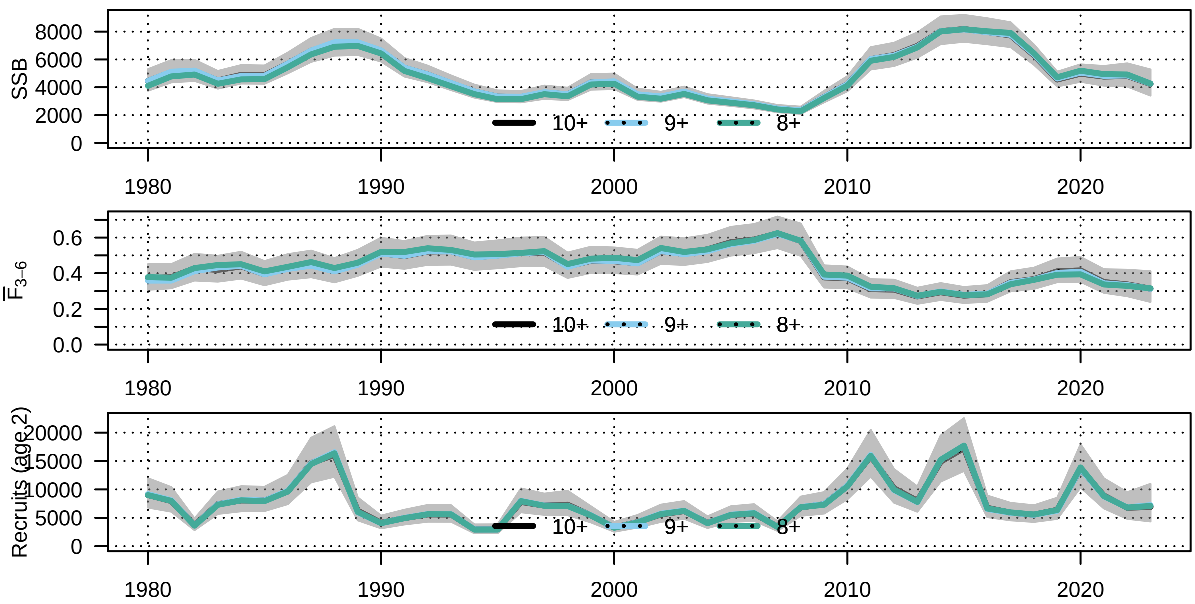
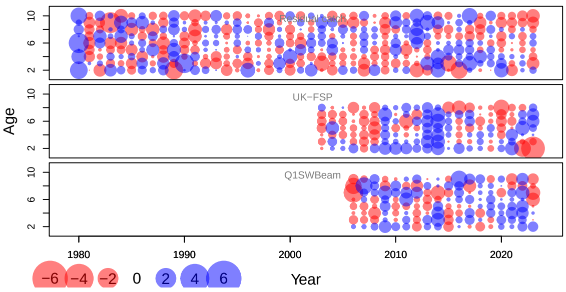
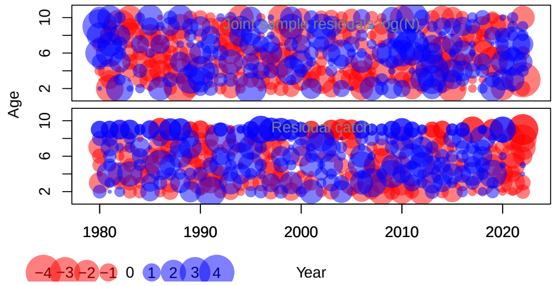


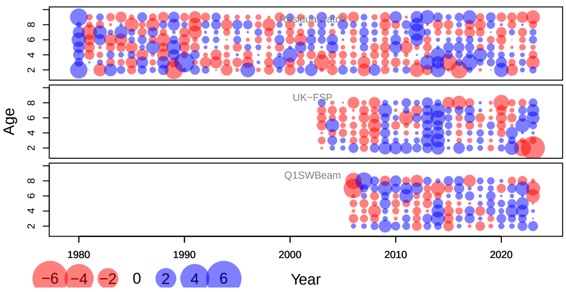
Figure 52: SAM: Comparison of different plusgroups, 10+ (baseline), 9+, and 8+.



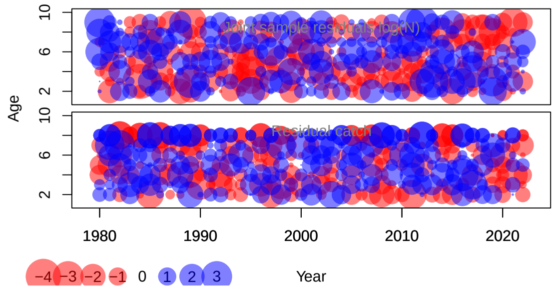
(a) 10+ residuals



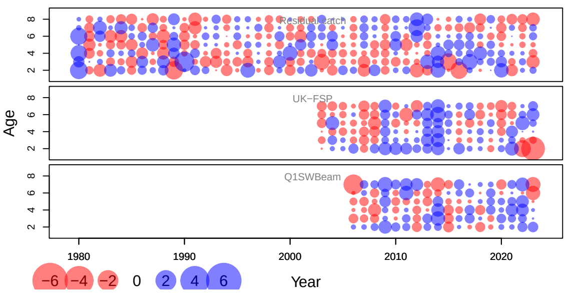
(b) 10+ process residuals



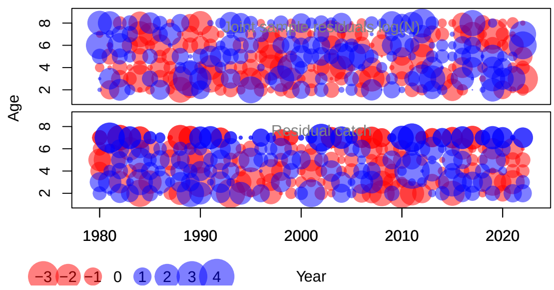
(c) 9+ residuals



(d) 9+ process residuals



(e) 8+ residuals



(f) 8+ process residuals

Figure 53: SAM: Comparison of SAM model residuals with different plusgroups, 10+ (baseline), 9+, and 8+.

6.3 Discard survival

The baseline SAM model assumed a discard survival of 50% (Section 5.2). Two alternatives were explored: 0% discard survival (all discards die) and 100% discard survival (no discards die). The fit to the catch closely followed the different discard scenarios, with a lower estimated total catch for the 100% discard survival scenario, and a higher estimated total catch for the 0% discard survival scenarios compared to the baseline assumption of 50% discard survival (Figure 54). The SSB also changed with the different assumptions, with a lower SSB for lower total catches and a higher SSB for higher total catches (Figure 55).

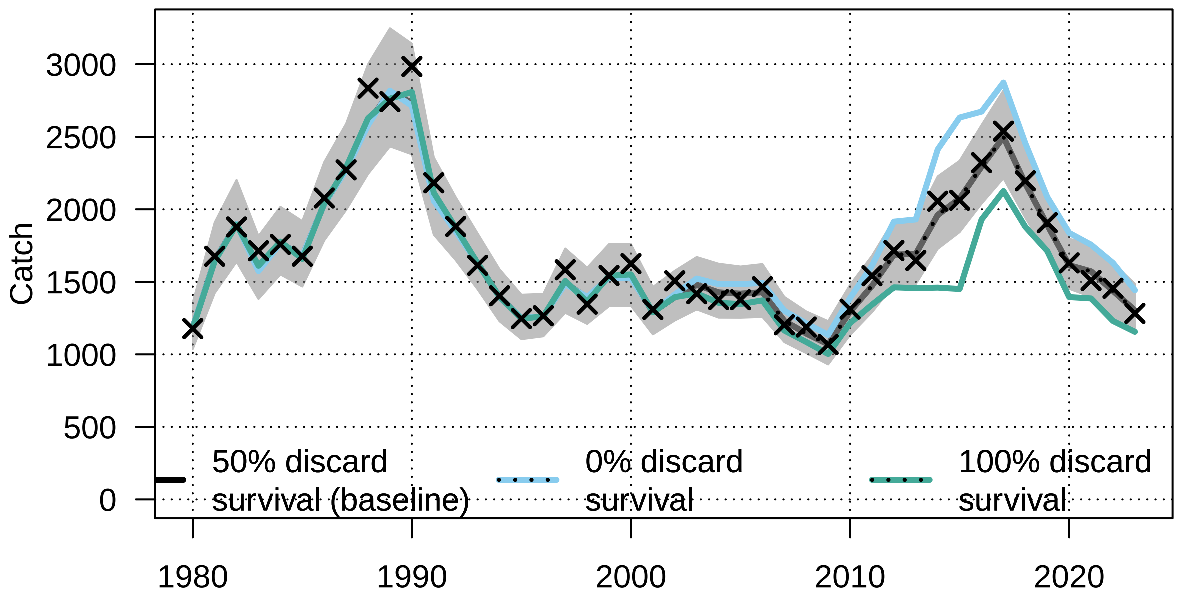


Figure 54: SAM: Comparison of different discard survival on catch estimation. Please note that the input data highlighted by "x" is only shown for the 50% discard survival scenario.

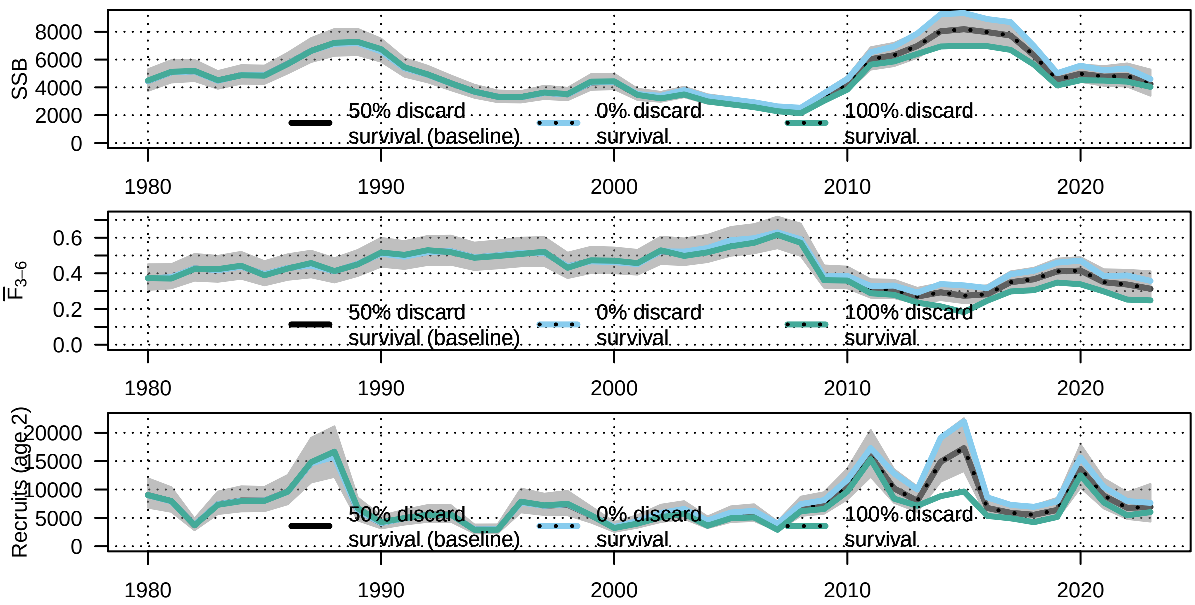


Figure 55: SAM: Comparison of different discard survival.

6.4 Migration

The catch input data for the baseline SAM model includes a migration component from Division 7.d (Section 4). An alternative scenario was explored where this migration component is removed from the catch, i.e. the total catch was lower. The difference is similar to the alternative discard survival exploration (Section 6.3), with a lower estimated catch by SAM (Figure 56) and a lower SSB (Figure 57).

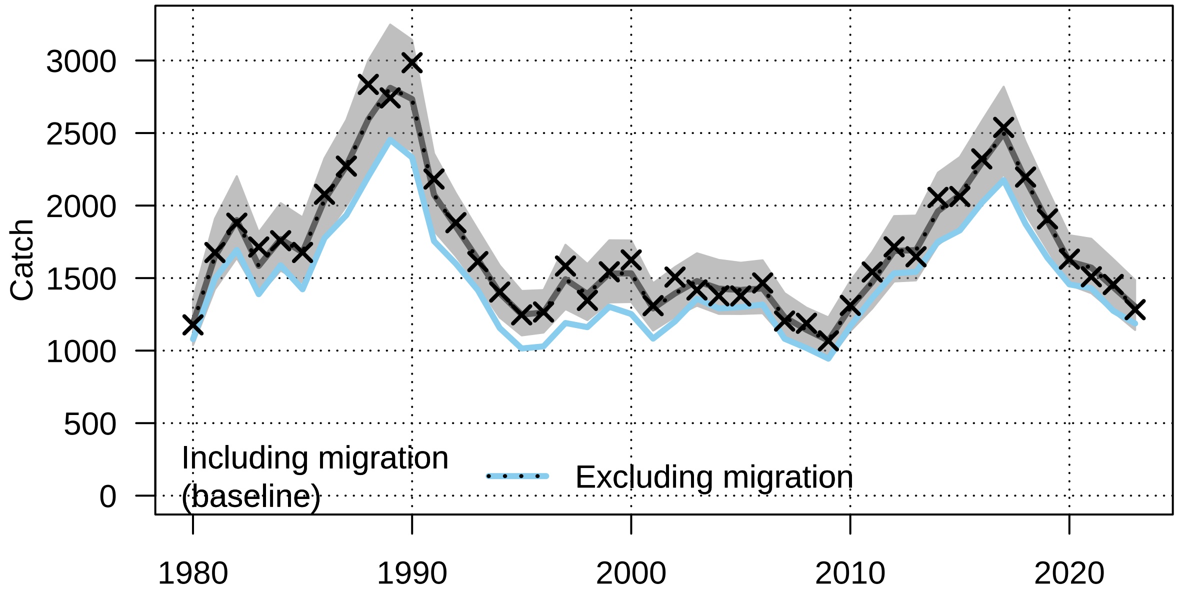


Figure 56: SAM: Comparison of different migration scenarios on catch estimation. Please note that the input data highlighted by “x” is only shown for the scenario including the migration component.

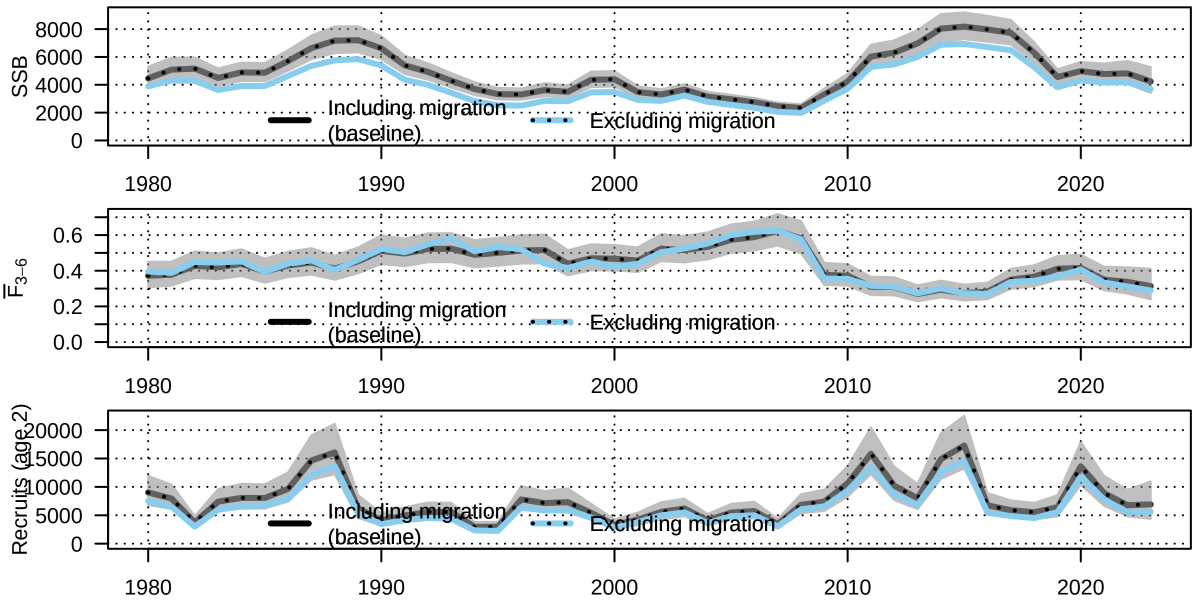


Figure 57: SAM: Comparison of different migration assumptions.

6.5 Natural mortality

The baseline SAM model used natural mortality following Then et al. (2013) with a value of $M = 0.1825$ (Section 5.4.3). Figure 58 shows a comparison to alternative assumptions about M. Increasing M by 50% shifted the entire SSB times series upwards while decreasing F but temporal trends were nearly identical. Decreasing M by 50% had the opposite effect. The two age-based M estimators (Gislason et al., 2010; Lorenzen et al., 2022) led to similar results and the SSB and F time series were within the range of the other M scenarios.

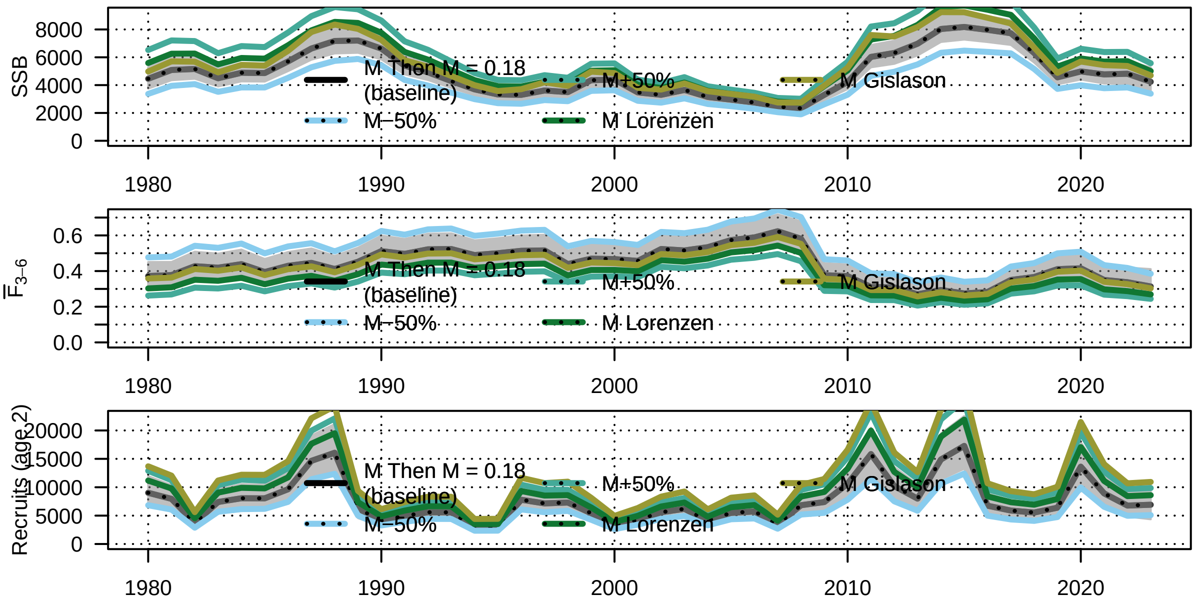


Figure 58: SAM: Comparison of different natural mortality M values.

6.6 Decoupling of ages in SAM configuration

In the default SAM model configuration, the fishing mortality states of the last two ages (age 9 and 10+) are coupled:

```
> conf$keyLogFsta
     [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9]
[1,]    0    1    2    3    4    5    6    7    7
[2,]   -1   -1   -1   -1   -1   -1   -1   -1   -1
[3,]   -1   -1   -1   -1   -1   -1   -1   -1   -1
```

An exploration of the SAM model was conducted where the last two ages were decoupled:

```
> conf$keyLogFsta
     [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9]
[1,]    0    1    2    3    4    5    6    7    8
[2,]   -1   -1   -1   -1   -1   -1   -1   -1   -1
[3,]   -1   -1   -1   -1   -1   -1   -1   -1   -1
```

However, this caused issues with the SAM model and the model did not converge and terminated without returning any results.

Furthermore, the survey catchability of the last two survey ages is also coupled with the default SAM model configuration:

```
> conf$keyLogFpar
     [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9]
[1,]   -1   -1   -1   -1   -1   -1   -1   -1   -1
[2,]    0    1    2    3    4    5    5   -1   -1
[3,]    6    7    8    9   10   11   12   12   -1
```

An exploration was conducted where these ages were decoupled (either survey at a time and for both surveys combined. The summarised results are nearly identical (Figure 59), and the log-likelihoods and AIC are very similar, not indicating any improvement:

```
           log(L) #par      AIC
baseline -369.4675   20 778.9351
UK-FSP   -368.2127   21 778.4253
Q1SWBeam -369.0968   21 780.1936
both     -367.8635   22 779.7270
```

However, freeing the catchabilities for the last survey ages led to some changes in the catchability estimates by SAM (Figure 60). Additionally, the uncertainty in the catchability for both ages increased substantially (Figure 60).

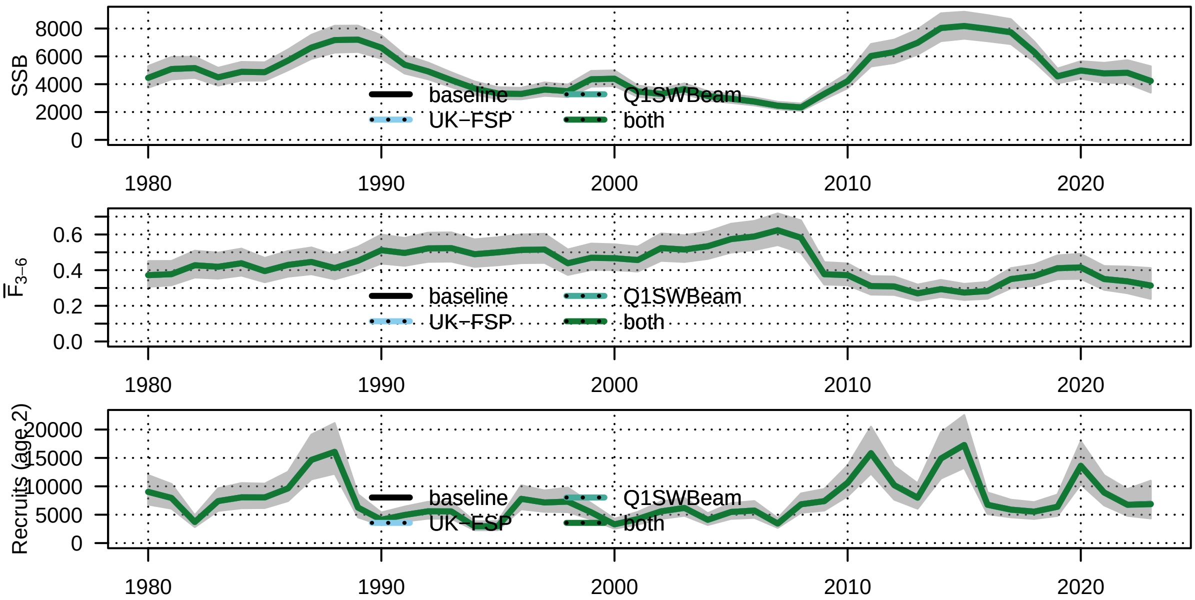


Figure 59: SAM: Comparison of models where survey catchabilities for the last two ages are coupled (baseline) or decoupled (UK-FSP, Q1SWBeam, both).

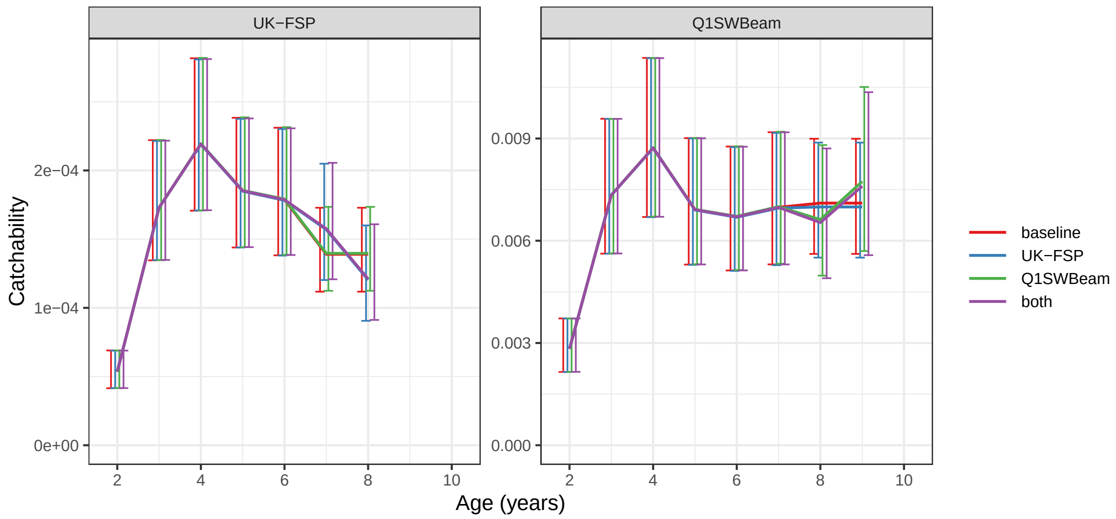


Figure 60: SAM: Survey catchability estimates (and 95% confidence intervals) of models where survey catchabilities for the last two ages are coupled (baseline) or decoupled (UK-FSP, Q1SWBeam, both).

7 References

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EU. (2023). Council Regulation (EU) 2023/194 of 30 January 2023 fixing for 2023 the fishing opportunities for certain fish stocks, applicable in Union waters and, for Union fishing vessels, in certain non-Union waters, as well as fixing for 2023 and 2024 such fishing opportunities for certain deep-sea fish stocks. ST/16233/2022/INIT. OJ L 28, 31.1.2023, p. 1–219. http://data.europa.eu/eli/reg/2023/194/oj

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